



PROCEEDING BOOK

Edited by
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Prof. Ercan Çelik

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FOREWORD

We are pleased to present the Proceedings of the 2nd International Congress on Science and Technology (ICSAT 2026), organized in collaboration between Atatürk University and Kyrgyz-Turkish Manas University.

ICSAT 2026 was established to provide an international and interdisciplinary platform where researchers, academics, and industry representatives can exchange ideas, present their latest scientific achievements, and foster collaborations that contribute to the advancement of science and technology. Bringing together participants from diverse disciplines, the congress reflects our shared commitment to scientific excellence, innovation, and sustainable development.

This year's congress attracted significant attention with 119 scientific papers from 21 countries, 14 keynote speeches, 44 on-site oral presentations, 56 online presentations, and 5 poster presentations. The broad international participation underscores ICSAT's growing scientific recognition and strengthens its role as a global forum for knowledge exchange and interdisciplinary collaboration.

The articles presented in this Proceedings Book offer valuable contributions across a wide range of scientific and technological fields. We hope that this compilation will be a useful scientific resource, inspire future research, and encourage new international collaborations.

On behalf of the Organizing Committee, we sincerely thank all keynote speakers, authors, reviewers, members of the Scientific and Organizing Committees, sponsors, and participants for their valuable contributions and support. Their dedication has been vital to the success of ICSAT 2026.

We hope you find this Proceedings Book both informative and inspiring, and we wish you success in your scientific work.

On behalf of the organizing committee

Prof. Dr. Hayrunnisa Nadaroğlu and Prof. Dr. Ercan Çelik
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Assoc. Prof. Arzu Kanca – Atatürk University, TÜRKİYE
Assoc. Prof. Ayse Merve Senol – University of Health Sciences, TÜRKİYE
Assoc. Prof. Betül Cicek – Erzincan Binali Yıldırım University, TÜRKİYE
Assoc. Prof. Caglar Ozer – Atatürk University, TÜRKİYE
Assoc. Prof. Deniz Dal – Atatürk University, TÜRKİYE
Assoc. Prof. Dilek Okuyucu – Erzurum Technical University, TÜRKİYE
Assoc. Prof. Elif Das – Atatürk University, TÜRKİYE
Assoc. Prof. Elmira Abdildayeva – Kyrgyz-Turkish Manas University, KYRGYZSTAN
Assoc. Prof. Gamze Bozkurt – Erzurum Technical University, TÜRKİYE
Assoc. Prof. Hasan Ilhan – Ankara University, TÜRKİYE
Assoc. Prof. Melike Sevim Bayrak – Atatürk University, TÜRKİYE
Assoc. Prof. Mesut Karabacak – Atatürk University, TÜRKİYE
Assoc. Prof. Muhammed Fatih Corapsız – Atatürk University, TÜRKİYE
Assoc. Prof. Pınar Karaman Baykan – Ağrı Ibrahim Cecen University, TÜRKİYE
Assoc. Prof. Sıdika Şule Şener – Atatürk University, TÜRKİYE
Assoc. Prof. Taha Cagrı Senocak – Atatürk University, TÜRKİYE
Assoc. Prof. Ulas Acaroz – Afyon Kocatepe University, TÜRKİYE
Assoc. Prof. Zeynep Karcioğlu Karakas – Atatürk University, TÜRKİYE
Asst. Prof. Bilal Usanmaz – Atatürk University, TÜRKİYE
Asst. Prof. Bilgehan Polatoglu – Atatürk University, TÜRKİYE
Asst. Prof. Buket Bakan – Atatürk University, TÜRKİYE
Asst. Prof. Cemalettin Alp – Erzincan Binali Yıldırım University, TÜRKİYE
Asst. Prof. Ekrem Sulukan – Atatürk University, TÜRKİYE
Asst.Prof. Elif Ercarikci – Atatürk University, TÜRKİYE
Asst. Prof. Ella Abilayeva – Kyrgyz-Turkish Manas University, KYRGYZSTAN
Asst. Prof. Ilker Acar – Atatürk University, TÜRKİYE
Asst. Prof. Muhammet Kaan Yesilyurt – Atatürk University, TÜRKİYE
Asst. Prof. Peyil Esengül Kızı – Kyrgyz-Turkish Manas University, KYRGYZSTAN
Asst. Prof. Semra Yurttancikmaz – Atatürk University, TÜRKİYE
Lect. Dr. Zeynep Orhan – Atatürk University, TÜRKİYE
Research Assistant Dr. Esra Celik – Atatürk University, TÜRKİYE
Dr. Mansur Mustafaoglu – Atatürk University, TÜRKİYE
Geo. Eng. Hüseyin Ilhan – Erzurum Cadastre Directorate, TÜRKİYE



2nd INTERNATIONAL CONGRESS ON SCIENCE AND TECHNOLOGY
07-09 MAY 2026, ERZURUM, TÜRKİYE

2nd INTERNATIONAL SCIENCE AND TECHNOLOGY CONGRESS (ICSAT 2026)

May 7-9, 2026 / ERZURUM

CONGRESS PROGRAM

Zoom Meeting Face to Face Sessions

<https://zoom.us/j/94410549149>

Zoom Meeting Online Sessions

<https://zoom.us/j/97426724756>



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Participation certificates will be sent to you via email in PDF format at the end of the congress.



MAY 7, THURSDAY

Atatürk University Nenehatun Congress Center

09:00-

11:30

REGISTRATION

09:30-

10:15

OPENING CEREMONY

10:15-

10:30

COFFEE BREAK

Turkish Time	MAIN HALL Session Chair: Prof. Abdulkadir Özer	HALL A Session Chair: Prof. Esen Taşgın	HALL B Session Chair: Assoc. Prof. Hatice Bayrakçeken	HALL C Session Chair: Prof. Sinan Taşpınar
	Invited Speaker Assoc. Prof. Hasan İlhan Nanostructured Platforms for Ultra-Sensitive Biosensing: Advances in SERS-Based Detection Systems			
10:30-10:50	Hayrunnisa Mazlumoğlu, Mehmet Yilmaz Design of Ti ₃ C ₂ MXene-Gold Nanoparticle Layered Films for Enhanced SERS Detection	Maryam Kakaey, Özlem Gülmez Aksak, Mesut Dönmez, Özlem Barış Hydrocarbon Biodegradation Potential of Indigenous Bacterial Isolates from the Kirkuk Oil Field	Merve Güven, Yasemin Aykut, Ayşe Bayrakçeken, Hatice Bayrakçeken Polypyrrole/g-C ₃ N ₄ Composite: Synthesis, Characterization, and Evaluation of Thermal Decomposition Kinetics	İlgın Asena Sibirlioğlu, Mahmut Sinan Taşpınar Investigation of the Effect of Selenium Nanoparticles on Chlorophyll Content Against Vanadium Stress in Common Bean (<i>Phaseolus vulgaris</i> L.)
10:50-11:05				
11:05-11:20	Hayrunnisa Mazlumoğlu, Şule Binici Role of Loading Ratio on Photocatalytic Efficiency in MXene-AuNP Hybrid Systems	Kübra Hanım Koçer, Esen Taşgın Nutritional Approaches in Polycystic Ovary Syndrome: The Role of the Mediterranean Diet	Özlem Karagöz, Serhat Demirci, Ashi Yilmaz, Mehmet Yilmaz Carbon Quantum Dots Derived from Methylene Blue and Disodium Phosphate:	Mahir Murat Cengiz, Aynur Babagil, Hayrunnisa Nadaroğlu, Özlem Barış The Effectiveness and Application Strategies of Organic Acids in the Control of



			Synthesis and Optimization	Varroa destructor in Honey Bee (<i>Apis mellifera</i> L.) Colonies
11:20-11:35	<u>Sümevra Okci,</u> <u>Hayrunnisa Nadaroğlu,</u> <u>Azize Alayli</u> Detection of Azodyes by Ultrasonic Spray Pyrolysis (USP) Using Metal Nanosensors	<u>Behina Asadoghli,</u> <u>Esen Taşgin</u> The Effects of DHA and EPA on Cognitive Function in Alzheimer's Disease	<u>Zeynep Orhan,</u> <u>Hülya Öztürk Doğan</u> Effect of NiS on hydrogen evolution reaction performance of CoCr ₂ O ₄ -graphene nanostructures	<u>Serpil Tıraşci,</u> <u>Haluk Çağlar Kaymak</u> The Use of Nano-Fertilizers in Improving Yield and Quality in Vegetables
11:35-11:50	<u>Bilgehan Polatoğlu,</u> <u>Hayrunnisa Nadaroğlu</u> One of the Innovative Nano Materials in Modern Material Science and Engineering: Polymeric Organic Frameworks	<u>Sibel Erkan,</u> <u>Güleray Agar</u> Protective Effect of Baicalin on Chlorophyll Content against Aluminum Toxicity in Wheat (<i>Triticum aestivum</i> L.)	<u>Tuba Çakici Can,</u> <u>Murat Özdal</u> Bacterial One-Step Synthesis and Electronic Application Potential of GO-Based Metal and Semiconductor Nanocomposites	<u>Haluk Çağlar Kaymak,</u> <u>Selim Daşci,</u> <u>Hayrunnisa Nadaroğlu,</u> <u>Serpil Tıraşci,</u> <u>Md. Mamunur Reza</u> Effect of Priming with ZnO Nanoparticles on Germination of Marigold Under Salinity Stress
11:50-12:05	<u>Azizeh Shadidizaji,</u> <u>Hadi Feizi</u> In Silico Prediction and Characterization of Antidiabetic Peptide Fragments Derived from Cineole Synthase of <i>Salvia mirzayanii</i>	<u>Kübra Solak</u> A Comparative Analysis of 2D and 3D Culture Models in Lung Carcinoma		

12:15-13:30

LUNCH (Guest House 2)

MAIN HALL
Session Chair:
Prof. Harun Güney

HALL A
Session Chair:
Prof. Aydın Gezer

HALL B
Session Chair:
Assist. Prof. Hilal Kübra Sağlam

HALL C
Session Chair:
Prof. Alper Nuhoglu



13:30- 13:50	Invited Speaker Prof. Dr. Murat Kurudirek Nanoscintillator Arrays for Advanced Radiation Detection			
13:50- 14:05	Melek Fidan, Enisa Yetimoğlu Effects of Nd_2O_3 addition on the structural properties of $\text{B}_2\text{O}_3\text{-ZnO-Li}_2\text{O-CuO}$ glasses	Ayşegül Kirmizigöz, Aydın Gezer, Erkan Karakaş Conformal Soliton Structures on Tangent Bundles with Semi-Symmetric Metric Connections	Onur Can Delice, Elif Erçarıkçı, Emir Çepni Production and Applications of Nickel Selenide Modified Graphene-Based Electrodes for Roll-Type Flexible Supercapacitor Device Design	Nuriye Kabakuş, Ahmet Kamil Kabakuş, Nathan Wankunda Mwasembe Evaluation of the Impacts of Autonomous Vehicle Technologies on Traffic Safety and Urban Transportation: An MCDM-Based Approach
14:05- 14:20	Furkan İbanoğlu, Kübra Çınar Demir, Emre Demir Investigation of the Electrochemical Supercapacitor Performance and Stability of Hematite (Fe_2O_3) Thin Films Grown on ITO Substrates	Özlem Kethuda, Aydın Gezer, Çağrı Karaman Symmetries of Almost Golden Lorentzian Walker Three-Manifold	Yaşar Mutaş, Kaan Can, Hilal Kübra Sağlam An Adaptive Control Approach for Robust Trajectory Tracking Against Wind Disturbances in Quadrotor UAVs	Burak Hülagü, Özay Öztürk Analysis of Impact Behavior of Composite Motorcycle Helmets with Auxetic Cell Structures by Finite Element Method
14:20- 14:35	Aynur Babagil, Hayrunnisa Nadaroğlu, Mahir Murat Cengiz, Özlem Barış Plant-Derived Essential Oils: Extraction Methods, Nanoemulsion Synthesis, and Applications	Rabia Kaya, Aydın Gezer, Nour Elhouda Djaa Harmonic and Biharmonic Mappings Induced by a Killing-Type Metric Deformation	Rabiye Kiliç, Hilal Kübra Sağlam Deep Learning for Robust Defect Detection in SEM Wafer Images under Imbalanced Data Distribution	Tarık Tortum, Mahir Gökdağ The Impact of Service Quality on Passenger Satisfaction in Urban Public Transport: The Case of Erzurum



14:35-14:50	<u>Aynur Babagil,</u> <u>Esra Turan,</u> <u>Hayrunnisa Nadaroğlu,</u> <u>Azize Alayli</u> Removal of Harmful Dyes from Water using Calcium-Containing Nanoflowers	<u>Murat Subaşı,</u> <u>Hanife Altun</u> A Multi-Criteria Optimal Control Framework for the Van der Pol Oscillator	<u>Elif Tekle, Tuana Akvazi,</u> <u>Başak Rana Şanda,</u> <u>Eslem Nur Alak,</u> <u>Dilruba Turhan,</u> <u>Beyza Karakoç,</u> <u>Mehmet Semih Kihtir,</u> <u>Samet Akkamış,</u> <u>Kaan Can</u> Performance Analysis of Distributed Formation Navigation and Optical Recognition (QR) Systems for Swarm UAVs in a Gazebo Environment	<u>Nuh Kaplan,</u> <u>Erdem Bayrak,</u> <u>Ömer Lütfi Aydın</u> Integrated Geophysical Characterization of an Active Landslide: A Case Study from İspir (Erzurum, Türkiye)
14:50-15:05	<u>Ülkü Altan Bayram,</u> <u>Abdulkadir Özer</u> Co-B/Co ₃ O ₄ catalyst for efficient H ₂ generation from methanolysis NaBH ₄	<u>Büşra Aktaş</u> Notes on the Ricci Curvature Tensor on an Almost Product Lorentzian Walker Three-Manifold	<u>Muhammed Berat Özgüngördü,</u> <u>Mete Yağanoğlu</u> Deep Learning-Based SNFH Segmentation in Post-Treatment Glioma MRI	

15:05-15:20

COFFEE BREAK

	MAIN HALL Session Chair: Prof. Murat Özdal	HALL A Session Chair: Prof. Handan Uysal	HALL B Session Chair:	HALL C Session Chair:
15:20-15:35	<u>Öznur Namal,</u> <u>Abdulkadir Özer</u> From GLP-1 to Dual Agonists: Evolution and Therapeutic Potential of Incretin-Based Strategies in Diabetes and Obesity	<u>Erdem Şimşek,</u> <u>Handan Uysal</u> Digitalized Law Enforcement: The Contribution of Social Media Integration to Security Policies		



- 15:35-15:50 **Torkan Haghi,** **Fatma Gecikli,**
Murat Özdal **Alaattin Inam**
Synergistic Antimicrobial Activity of Thymus vulgaris Essential Oil and Antibiotics Against Pathogenic Bacterial Strains
Immigrants' Fear of Being Victimized and Perceived Risk of Victimization: An Analysis in the Context of Demographic Variables
- 15:50-16:05 **Torkan Haghi,** **Kadir**
Özlem Gür Özdal **Kızılkaya,**
Mesut **Karabacak**
In Vitro Antioxidant Activities of Urtica dioica, Allium sativum, and Camellia sinensis Essential Oils: A Comparative Study
The Potential Impact of The Shor Algorithm on Modern Cryptographic Systems
- 16:05-16:20 **Hazal Özece,**
Güleray Agar
Determining the effect of zinc oxide nanoparticles on chlorophyll content in wheat (*Triticum aestivum* L.) against boric acid stress
- 17:00-17:20 **Invited Speaker**
Prof. Dr. Ramesh Agarwal
Fluidization Characteristics of Spherocylindrical Particles and Binary Mixtures: Experiment and CFD-DEM Simulations
- 17:20-17:40 **Invited Speaker**
Prof. Mehmet Yilmaz
Carbon Quantum Dots in Biomedicine: Emerging Platforms



for Imaging,
Sensing, and
Therapy

19:00-
22:00

GALA DINNER (Atatürk University Training Hotel Space Restaurant)

MAY 7, THURSDAY

**Atatürk University Nenehatun Congress Center
HALL B (POSTER SESSIONS) (<https://zoom.us/j/94410549149>)**

Session Chair:

Assist. Prof. Hayrunnisa Mazlumoglu

- 15:20- **Nazan Demir, Sıla Nezahat Daşdemir, Yaşar Demir**
15:30 Investigation of Controlled Release Mechanisms in Pectin and Starch-Based Biodegradable Polymer Matrices
- 15:30- **Nazan Demir, Yiğit Deveci, Yaşar Demir**
15:40 Biochemical Profile and Phytochemical Analysis of the White Water Lily (*Nymphaea alba*) Growing in Lake Köyceğiz
- 15:40- **Saba İzadi**
15:50 Feline Hyperthyroidism: Biochemical Mechanisms and Clinical Implications
- 15:50- **Ozan Özgen**
16:00 Ketosis in Dairy Cows: Causes, Effects, and Management
- 16:00- **Tarique Hussain, Ali Doğan Ömür**
16:10 Effect of resveratrol on post-thaw motility, kinematics, structural parameters and antioxidant/oxidant status of Kamori buck spermatozoa

MAY 8, FRIDAY ONLINE SESSIONS

(Zoom Link: <https://zoom.us/j/97426724756>)

	HALL 1	HALL 2	HALL 3
Turkish Time	Session Chair: Assoc. Prof. Melike Sevim Bayrak Invited Speaker Assoc. Prof. Amir Syahir Amir Hamzah	Session Chair: Assist. Prof. Kaan Yeşilyurt Invited Speaker Assoc. Prof. Ahmad Ali	Session Chair: Assist. Prof. Rabiye Kılıç Invited Speaker Prof. Norhasmah Sulaiman
09:00-09:20	High-Affinity Aptamers Generated from Post-SELEX Computational Fine Tuning	Suppression of Anti-inflammatory Cytokines in Rat Models by Polyherbal Formulation	The Impact and Effectiveness of Sugar-Sweetened Beverages Taxation in Malaysia: The Role of Sugar Tax in Tackling Obesity



09:20-09:35	<u>Kurmanzhan Abdykaparova,</u> <u>Askarbek Tulobaev,</u> <u>Nurbek Aldayarov</u> Micromorphological and Immunohistochemical Characterization of MALT in the Digestive Tract of Yaks (<i>Bos grunniens</i>) from Kyrgyzstan	<u>Ayshana Hamidova</u> Model for Improving Reliability Indicators of a 10 kV Radial Distribution Network Based on Intelligent Control of PV and Battery Energy Storage Systems	<u>Nurbek Ermatov, Emil Omurzak</u> Visible light photocatalytic activity of silver nanoparticles obtained by the pulsed plasma method
09:35-09:50	<u>Meerim Turgunova,</u> <u>Askar Davletbakov,</u> <u>Nurbek Aldayarov</u> Natural Death Associated with Senile Dementia in a Snow Leopard (<i>Panthera uncia</i>): A Case Report	<u>Asim Harunov,</u> <u>Orkhan Karimzada,</u> <u>Khayala Aliguliyeva</u> Innovative Renewable Energy Technologies as a Driver of Sustainable Economic Development: Opportunities for Solar Energy Integration in Azerbaijan	<u>Azem Dairbek Kizi, Kalipa Salieva, Emil Omurzak</u> Determination of Phenolic and Flavonoid Contents in Plant Extracts Enriched with Silver Nanoparticles
09:50-10:05	<u>Iyman Binti Fayaz, Mohammad Mateen Zehgeer</u> Molecular Detection and Virulence Profiling of <i>Bacillus cereus</i> in Raw Mutton and Slaughterhouse Environments of the North-West Himalayan Region, India	<u>Rizwan Ahamad, Nazreen Tabassum, Mohd Mujeeb, Mohd Aqil, Mohd Akhtar</u> Development and Evaluation of Bilosome-Based Nanocarriers for Dual Delivery of Ascorbic Acid and Polyphenolic Compound: An Integrated Computational and Experimental Studies	<u>Akmaral Ovezdurdyeva, Saikal Bobusheva, Emil Omurzak</u> Synthesis of Ag and Cu Nanoparticles and Their Biological Activity
10:05-10:15	<u>Tilek Chakiev, Kadyrbay Chekirov</u> The Strategic Importance of Kyrgyzstan's Genetic Resources: Biodiversity, Conservation, And Biotechnological Potential	<u>Nazreen Tabassum, Rizwan Ahamad, Mohd Aqil, Mohd Mujeeb</u> Development and Optimization of Linagliptin–Polyphenol Co-Loaded Bilosomes via Design of Experiments for Targeted Neuroprotection in	<u>Elena Zhyldyzbek Kyzy, Kalipa Salieva, Emil Omurzak</u> Synthesis and Physicochemical Characterization of Biodegradable Films Modified with Nanoparticles and Medicinal Plant Extracts



			Diabetes-Associated Alzheimer's Disease
	<u>Aziza Murzakamilova,</u> Özlem Bariş Valorization of Apricot Kernel Shell Waste: Biochar Application in <i>Pleurotus ostreatus</i> Cultivation		
10:15-10:30			
10:30-10:40		COFFEE BREAK	
	HALL 1 Session Chair: Assoc. Prof. Kaan Can	HALL 2 Session Chair: Assist. Prof. Cemil Bayram	HALL 3 Session Chair: Assoc. Prof. Tolga Yurtcan
	Turkish Time		
10:40-11:00	Invited Speaker Prof. Hirofumi Tanaka Physical Reservoir Computing Devices Using Random Network of Nanomaterials for Physical AI Applications	Invited Speaker Dr. Tapas Sen Design and Application of Magnetic Nanomaterials in Advanced Healthcare & Environmental Research	<u>Diana Zharkynbek,</u> Ömür Aras Continuous Visible- Light Photocatalytic Degradation of Methylene Blue in a thin Film Coated Reactor
11:00-11:20	Invited Speaker Md. Dr. Habibur Rahman Translational Pharmacology in Drug Discovery	<u>Sallahuddin Panhwar,</u> Hasan İlhan, Uğur Tamer Fabrication of an impedimetric biosensor based on co-polymer for the detection of <i>E. coli</i> K12 in water	<u>Nurlan Abdullazade</u> Investigation of paraffin deposition in Caspian Sea subsea oil pipelines
11:20-11:35	Ahmad Asadzadeh Gajouti, Ökkeş Atici, Özlem Gülmez Aksak, Hülya Türk Vanadium-Induced Alterations in Nitrogen Assimilation Pathway and Oxidative Status in Wheat (<i>Triticum aestivum L.</i>)	Meerim Saparbaeva, Aichurok Mazhitova Development and Nutritional Characterization of Functional Snack Bars Enriched with Bee Bread (Perga)	<u>Sultan Onur, Mustafa Çeşme, Ferhan Tümer</u> Synthesis, Characterization and Microbiological Evaluation of Novel Schiff Base Compounds Containing A Diarylmethylamine Skeleton
11:35-11:50	Azizeh Shadidizaji, Kagan Tolga Cinisli, Ahmet Hacimuftuoglu, Farideh Ghalamfarsa In Silico Enzyme Engineering: Enhancing	Nagima Saadaibek Kyzy, Mazhitova Development and Technological Optimization of	<u>Sultan Onur, Mustafa Çeşme, Ferhan Tümer</u> Design of Aryl α - Hydroxyphosphonate- Derived Hybrid



	Stability and Reusability for Industrial Biocatalysis	Functional Beverages with Natural Additives	Soy-Based Enriched Bioactive	Molecules: Enzyme Inhibition Potential
11:50-12:05	Assiya Mussayeva, Ainur Nurpeisova, Ainazik Sarygulova, Nurbek Aldayarov Histopathological Features of Necrotizing Hepatitis in Ducks Associated with Paratyphoid (Salmonellosis)	Aicholpon Koichubaeva, Nurzat Shaikieva, Mustafa Dolaz Production of aluminum compounds from food waste		Gizem Seyman Cytokines, Interleukins and Interleukin-41 (Metrnl): Immune Regulation and Cardiovascular Effects
12:05-12:20	Avşe Aygün, Meral Kekeçoğlu, Fatih Demir The Effects of Propolis Extracted with Different Solvents on Utero-Ovarian Histomorphology in Prepubertal Female Rats	Bahar Özyörük, Emine İkikat Tümer Bread Waste in Mersin Province		Nilofar Nadaf, Shivangi Kanase <i>Bacillus toyonensis</i> mediated synthesis of Zinc Oxide nanoparticles: Characterization and study of its antibacterial and anticancer activity
12:20-12:35	Bridget Goodwin Apitherapy and Sonodynamic Therapy for Brain tumours			
12:30-13:00		LUNCH		
	HALL 1 Session Chair: Assist. Prof. Emir Çepni Invited Speaker Prof. Jagpreet Singh Nanotechnology-Driven Pathways Toward Net-Zero Carbon and Sustainable Development	HALL 2 Session Chair: Dr. Mansur Mustafaoglu Invited Speaker Dr. Norafizah ABAS A Structured Mechatronics Design Framework for Industrial Automation with Application to Pail Filling Line Systems	HALL 3 Session Chair: Assist. Prof. Merve Acar Labiba Bulbul Rinti Nanotechnology in Pharmaceuticals: Revolutionizing Drug Delivery and Therapeutic Outcomes	
13:00-13:20				
13:20-13:35	Muhammad Abdul Rahim Liposomal Microencapsulation and Food Ingredients	Muhammad Shahzwan Mohamed Shahiful Hizan, Nur Al Aswad Zulkefli, Norafizah Abas Development of an IoT-Based Machine		Zainab Mantasha, Mohd Mujeeb Estimation of Coumarin from Optimised Extract of <i>Cinnamomum cassia</i> By HPTLC Method



13:35-13:50	Downtime Monitoring and Prediction System <u>Aswad Zulkefli,</u> <u>Norafizah Abas,</u> <u>Lee Leong Jin</u> Development of IoT-enabled Multimodal Myoelectric Sensing System for Hand Motion Analysis	<u>Achraf Benbella</u> Enhanced Detection of Lung Cancer Biomarkers using Al-Decorated B ₂ O ₃ Monolayers: A First-Principles Study
13:50-14:05	<u>Bahar Özyörük,</u> <u>Emine İkikat Tümer</u> Analysis of Sustainable Campus Performance of Public Universities in Türkiye Under the Transportation Criterion in The Context of Ui Greenmetric	<u>Ruslan Dadashov</u> SCADA Applications in Residential Fire Safety
14:05-14:20	<u>Mahammadali Aliyev</u> Development of A Comprehensive Quality Control Process Model Conforming to ISO 9001 And ISO 17025	
14:20-14:35 14:35-14:45	COFFEE BREAK	
Turkish Time	HALL 1 Session Chair: Assoc. Prof. Mete Yağanoğlu Invited Speaker Prof. Łukasz Tomczyk Education of Seniors in the Field of Artificial Intelligence	HALL 2 Session Chair: Assoc. Prof. Çağrı Karaman <u>Muhammed Emin Batuhan,</u> <u>Ercan Çelik</u> Solving of Fractal Complex Differential Equations with the Homotopy Analysis Method <u>Muhammet Kamali</u> On the upper bound of a special type of Hankel determinant for a subclass of analytic functions subordinated with the sine function
14:45-15:05	HALL 3 Session Chair: Prof. Özlem Barış <u>Umida Majnunlu</u> Biochemical Composition of Defatted Grape Seed Residue	
15:05-15:20	<u>Mahbuba Shirinova</u> The Potential for “Self-Improvement” of Artificial Intelligence in the Adaptability of Technical Systems	<u>Hamas Rahman</u> Sustainable Ruminant Farming Strategies under Hot-Humid Conditions: Insights from Cyprus
15:20-15:35	<u>Askat Rakhymbekov,</u> <u>Gulshat Muhametjanova</u>	<u>Hamas Rahman</u> Impact of Pre-Slaughter Transportation Stress on



	RowNet – A Multi-Layer Row Transformer for Tabular Regression <u>Ali Sartaj</u> Lipid Nanocarriers in Drug Delivery: Current Trends and AI Intergartion	Meat Quality in Livestock	
15:35-15:50		Mahir Murat Cengiz, <u>Özlem Barış</u>, Mehmet Bektaş, Aynur Babagil, Hayrunnisa Nadaroğlu Natural Compounds in Apiculture: Therapeutic Potential Against Bee Diseases and Residue Implications in Bee Products	
	<u>Roya Mammadli</u> Technological innovations and artificial intelligence as a development factor in the manufacturing industry enterprises of Azerbaijan		
15:50-16:05			
16:20-16:30			
	HALL 1 Session Chair: Dr. Azizeh Shadidizaji Invited Speaker Assoc. Prof. Fedor S. Fedorov From Synthesis to Printing: Engineering On-Chip Multisensor Systems with Tunable Selectivity <u>Folarin Owagboriaye, Abdulwahab Osibogun, Julius Bamidele, Marvellous Ariyibi, Opeyemi Ogunbiyi</u> Cumulative Risk Assessment of Combined Exposure to Glyphosate and Atrazine Mixtures in Drinking Water and Soil from Four Rural Farmlands in Southwest Nigeria	HALL 2 Session Chair: Prof. Mutlu Kundakçı Atilla <u>Karabacak</u>, Çağrı Karaman, Kürşat Akbulut, Ercan Çelik Golden Structure on Walker Manifolds <u>Timur Lale</u> Meteorological Variable-Based Solar Power Forecasting Using Machine Learning Regression Algorithms: A Comparative Study	HALL 3
16:30-16:50			
16:50-17:05			



17:05-17:20	<u>Shirin Sherimbekova,</u> <u>Nurbek Aldayarov,</u> <u>Marasulbek</u> <u>Amirakulov</u> Age- and Sex-Related Morphometric Development of the Thymus, Bursa of Fabricius, and Spleen in Indigenous Türkiyes (<i>Meleagris gallopavo</i>) in Kyrgyzstan	<u>Funda Turk, Berkant</u> <u>Bal, Ercan Çelik</u> Fractional Modeling of Chemical Reaction Dynamics with Memory Effects
17:20-17:35	<u>Aliia Toktosunova,</u> <u>Nurbek Aldayarov,</u> <u>Vladislava Suchshikh,</u> <u>Ainur Nurpeisova</u> Histopathological Characteristics of the Mammary Gland in Acute Suppurative Mastitis Caused by <i>Staphylococcus aureus</i>	<u>Sümeyye Palangi</u> Reconceptualizing Second Language Learning through Media Integration: Insights for ELT
17:35-17:50	<u>Bunyamin Ozgeris</u> Synthesis and Biological Properties of Novel Pyridine-Based Carbamate	



2nd INTERNATIONAL CONGRESS ON SCIENCE AND TECHNOLOGY
07-09 MAY 2026, ERZURUM, TÜRKİYE





**2nd INTERNATIONAL CONGRESS ON SCIENCE AND TECHNOLOGY
07-09 MAY 2026, ERZURUM, TÜRKİYE**





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Toplantı

Hirofumi Tanaka adlı kişinin

Rabiya KILIÇ
Rabiya KILIÇ

Kyutech
Hirofumi Tanaka

Ökkeş ATICI
Ökkeş ATICI

Aziza Murzak...
Aziza Murzakamilova

Dr. Fedor S. F...
Dr. Fedor S. Fedorov

Katılımcılar (14)

Rabiya KILIÇ (Ortak oturum sahibi, ben)

Hirofumi Tanaka

Ainazik Sarygulova

Aziza Murzakamilova

Dr. Md. Habibur Rahman

Hayrunnisa Nadaroğlu

Mariem ahmad

Tümünü sessize al

Daha fazla

Relationship noise against bias

Random Network of SWNT/POM complex

Au electrode

SWNT

POM

1mm

Model of sample and real electrodes

H. Tanaka et al., Nature Commun. 9, 2693 (2018)

Current / $\times 10^{-9}$ A

Time / s

Noise amplitude was gradually increased during V=6-125V.

Noise became unstable at V=150V.

Workplace

Muhammed Emin Batuhan adlı ki...

cemil

Muhammed Emin Batuhan

anila karabacak

Hulya Öztürk D...

ZEYNEP ORHAN

Çağrı Karaman

cemil

Muhammed Emin Batuhan

anila karabacak

Hulya Öztürk Doğan

ZEYNEP ORHAN

Katılımcılar (7)

Çağrı ... (Ortak oturum sahibi, ben)

Muhammed Emin Batuhan

anila karabacak

cemil

Hulya Öztürk Doğan

Necde Çağlar

ZEYNEP ORHAN

Tümünü Sessize Al

Solving of Fractal Complex Differential Equations with the Homotopy Analysis Method

Muhammed Emin BATUHAN, Ercan CELIK

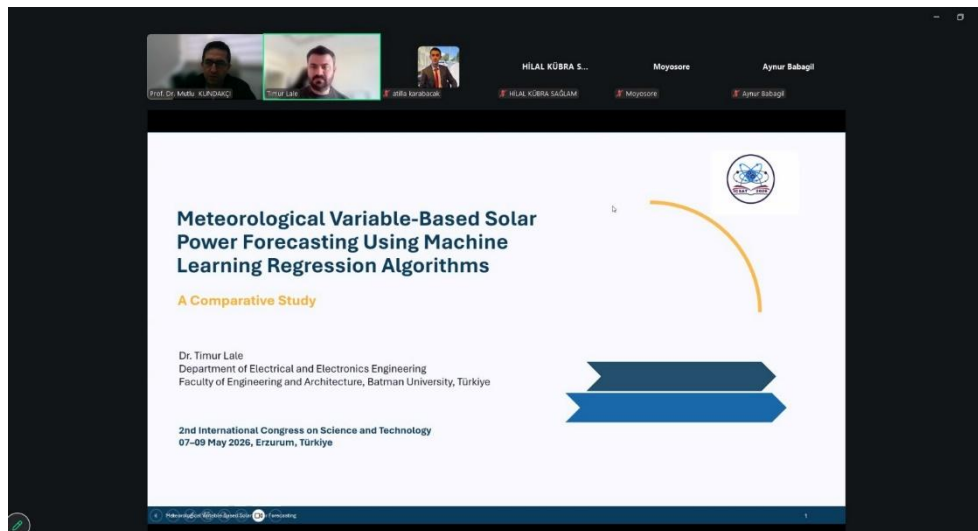
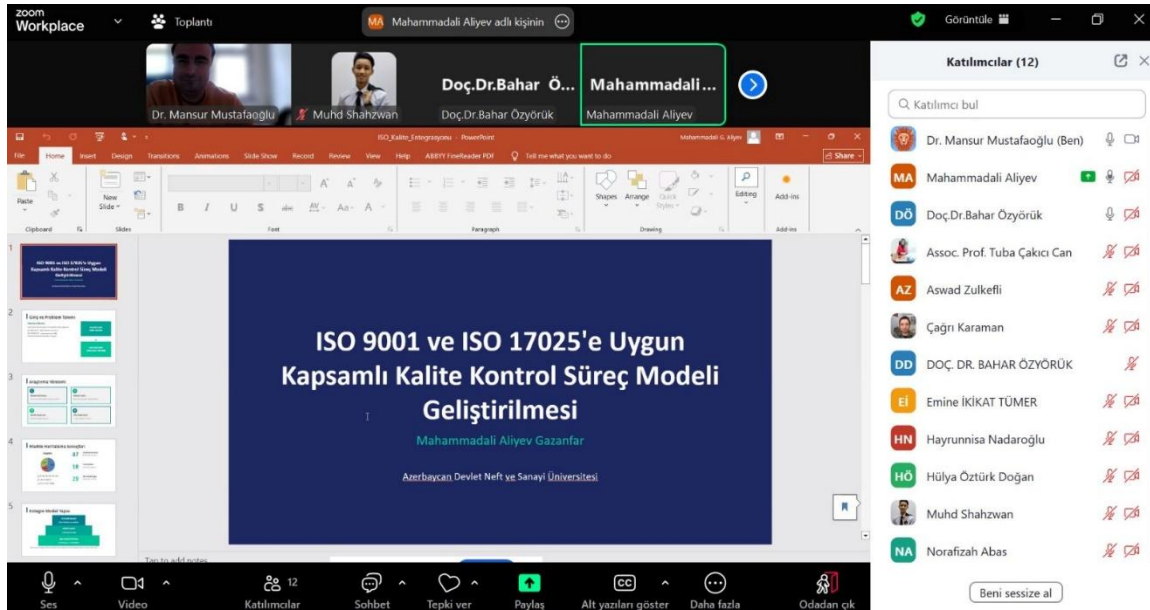
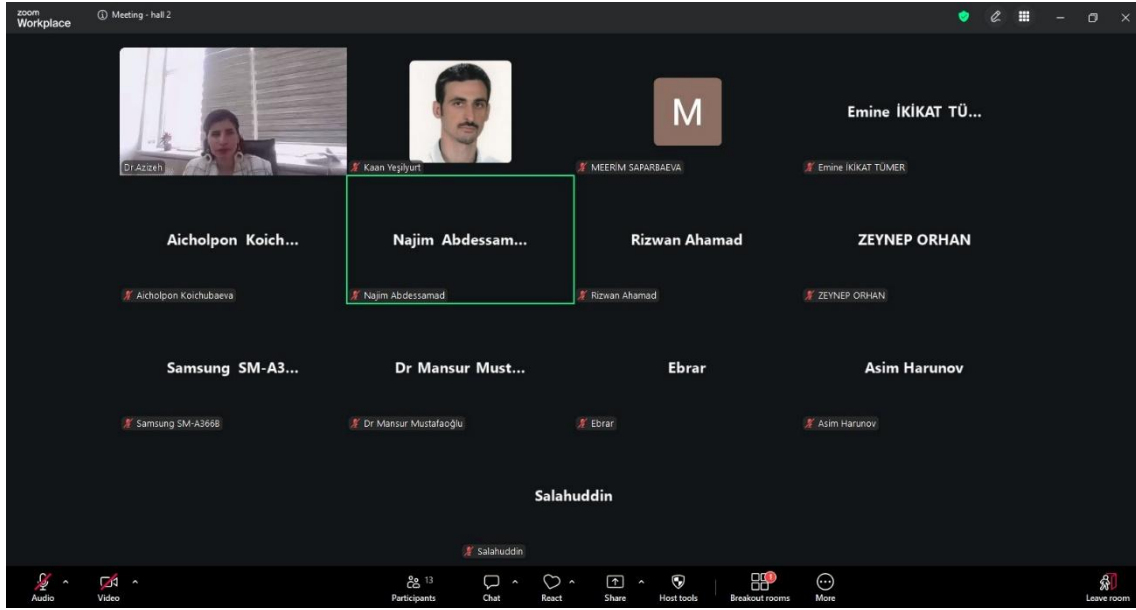
Department of Applied Mathematics and Informatics,
Faculty of Science, Kyrgyz-Turkish Manas University

May 7-9, 2026

Kyrgyz-Turkish Manas University



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Бактериалдык сыноу		
Түрү	Шар-ы	Өлчөмү
1	2.5	1.5
2	2.5	1.5
3	2.5	1.5

КЫРГЫЗ-ТҮРК МАНАС УНИВЕРСИТЕТИ
KIRGIZISTAN-TURKIYE MANAS UNIVERSITESI

2ND INTERNATIONAL SCIENCE AND TECHNOLOGY CONGRESS (ICSAT 2026)

İnce Film Kaplı bir Reaktörde Metilen Mavisinin Sürekli Görünür Işık Altında Fotokatalitik Degradasyonu

Diana ZHARKYNBEK
Doç. Dr. Ömür ARAS

7-9 May 2026
Erzurum, Türkiye



2nd INTERNATIONAL CONGRESS ON SCIENCE AND TECHNOLOGY
07-09 MAY 2026, ERZURUM, TÜRKİYE

KEYNOTE SPEECHES



Suppression of Anti-inflammatory Cytokines in Rat Models by Polyherbal Formulation

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<https://doi.org/10.5281/zenodo.21224955>

Cytokines are important physiological components for the suppression and induction of inflammatory responses in the body. Inflammation is a major factor in the onset of several diseases including arthritis which is a painful condition. Therefore, the major objective of this work was to evaluate the role of polyherbal formulation in the regulation of different cytokines. The toxicity analysis of formulation on the rats was analysed as per the guidelines of OECD. Different cytokines were measured from the serum samples using ELISA kits. Histopathological analyses of organs from the control and treated animals were also performed. The results were compared with the standard drug Indomethacin. The polyherbal formulation was found to be safe even at very high dose of 2000mg/kg. The formulation was very potent in suppressing the proinflammatory cytokines and increased the levels of anti-inflammatory cytokines. Histopathological analyses suggest that the formulation did not affect the major organs. These results indicate that the polyherbal formulation is very safe, possesses significant anti-inflammatory activity and more effective as compared to the standard drug.

Keywords: *Anti-inflammatory, arthritis, cytokines, polyherbal formulation, Unani medicine.*



High-Affinity Aptamers Generated from Post-SELEX Computational Fine Tuning

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Amir Syahir Amir Hamzah^{*1}**

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<https://doi.org/10.5281/zenodo.21225112>

Label-free biosensors are fundamentally constrained by the selectivity and affinity of surface-immobilized biorecognition elements, also known as capturing agent. Although antibodies provide excellent specificity, their large size imposes practical limitations especially for plasmonic biosensor. Aptamer offers a smaller and more versatile alternative, but conventional SELEX frequently yields sequences that are longer than necessary and not fully optimized for binding performance. Here, we propose a lightweight post-SELEX in-silico workflow to systematically convert parent aptamers into shorter, higher-affinity variants suitable for electrochemical biosensing. Aptamers selected against CD44, CD133, CD90, and EpCAM were iteratively truncated and refined. Candidate sequences were screened by secondary-structure prediction using mfold, modelled in three dimensions with RNAcomposer, docked to their protein targets using HDock, and further evaluated by molecular dynamics simulation in GROMACS followed by MMPBSA binding free-energy estimation. Top ranked variants were synthesized, immobilized on electrode surfaces, and experimentally assessed at room temperature by differential pulse voltammetry, with apparent surface dissociation constants ($K_{D,surf}$) derived from Langmuir isotherm fitting. Across all four targets, multiple truncated variants showed improved predicted binding free energies relative to their parent sequences, and these computational trends were supported by electrochemical measurements showing consistently stronger surface binding. For CD90, the best-performing truncated aptamer achieved up to a 10-fold improvement in $K_{D,surf}$ compared with its parent. Importantly, sequence shortening preserved functional structure while enabling denser surface packing and larger signal changes upon target binding. Overall, this integrated computational and experimental pipeline offers an efficient route to engineer compact, higher-affinity aptamers with materially improved performance in label-free electrochemical biosensors.

Keywords: Post-SELEX Process, Molecular Dynamics, Aptamer, Plasmonic Biosensor.

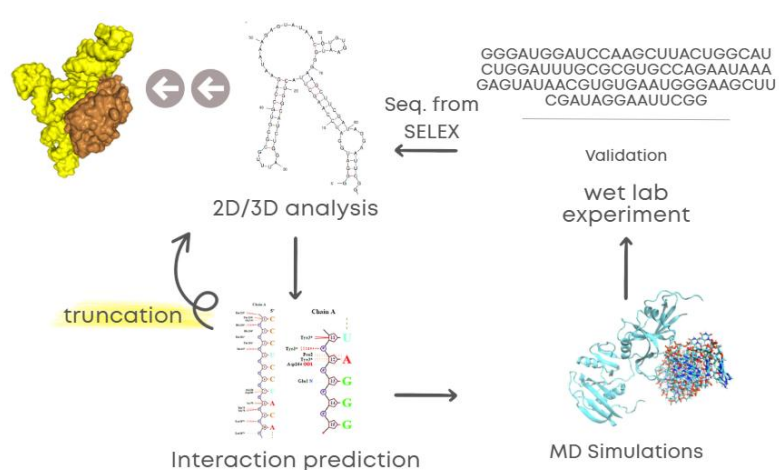


Figure shows the flow for generating shorter and higher affinity aptamer

Acknowledgments: This Project is supported by Putra Matching Grant IN-PUTRA/2024/9300500 from Universiti Putra Malaysia in collaboration with Kyushu Institute of Technology Japan.

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From Synthesis to Printing: Engineering On-Chip Multisensor Systems with Tunable Selectivity

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Additive technologies are transforming the development of advanced sensor and multisensor systems. Supported by high-precision synthesis, these technologies provide a solid foundation for tackling the selectivity challenge in multisensor arrays, particularly in on-chip implementations. By enabling accurate deposition of materials with tailored chemical composition, crystal structure, and morphology, state-of-the-art printing technologies make it possible to fine-tune the selectivity profile of sensor arrays under combinatorial approach. At the same time, the synthesis supports deliberate modification of material properties to enhance sensitivity and optimize overall sensing performance. Here we demonstrate how to enhance multisensor system selectivity toward specific analytes by plotting particular metal oxide material combinations on a single chip platform [1].

To quantify and exploit combinatorial selectivity, the multidimensional response space is analyzed using principal component transformation, distance-based metrics of class separability, and ensemble machine-learning classifiers. This framework identifies those subsets of about ten sensing elements show a maximized discrimination among target analytes (acetone, benzene, short-chain alcohols) while avoiding unnecessary redundancy, and it delivers near-perfect classification under these conditions. We demonstrate that specific combination, when found and printed, enable achieving greater selectivity to particular volatile compound. Operating at temperature of 300 °C, the chemiresistive arrays is shown to respond to the studied representative volatile organic compounds at concentrations around the *ppm* level and below, with individual elements reaching limits of detection on the order of 0.1 *ppm* and response amplitudes up to roughly 0.2 at 1 *ppm*.

The results demonstrate a general strategy that unites controlled material synthesis, printing-based integration, and data-driven evaluation to engineer application-tailored multisensor systems.

Keywords: Microplotter Printing, Metal Oxide, Combinatorial Library

Acknowledgments: This study is supported by Russian Scientific Foundation, grant № 26-19-00828, <https://rscf.ru/project/26-19-00828/>.

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Translational Pharmacology Drug Discovery

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Medicinal plants and other natural products remain central to modern drug development because they provide structurally diverse phytochemicals that serve as lead compounds and pharmacophores. Notable examples include paclitaxel, artemisinin, and penicillin, which have had major therapeutic impacts. The integration of ethnobotanical knowledge with bioassay-guided fractionation allows researchers to efficiently identify, isolate, and characterize biologically active compounds from complex natural sources. This targeted approach improves the likelihood of discovering clinically useful molecules. Promising drugs are rigorously evaluated within a translational pharmacology framework, starting with preclinical in vitro and in vivo investigations to evaluate safety and efficacy. To comprehend absorption, distribution, metabolism, excretion, and toxicity, ADME/Tox profiling comes next. Compounds go through stepwise clinical studies to determine their safety and efficacy in people if the outcomes are positive. Despite these benefits, there are a number of obstacles in the way of developing medications derived from plants. Consistency and reproducibility may be impacted by variations in the phytochemical content. Numerous natural substances also have complicated metabolic routes and poor bioavailability. Traditional knowledge usage and access-and-benefit-sharing agreements, like those found in international frameworks like the Nagoya Protocol, which govern the use of genetic resources, also give rise to ethical and legal concerns.

Keywords: *Medicinal plants, natural products, translational pharmacology*



From Synthesis to Printing: Engineering On-Chip Multisensor Systems with Tunable Selectivity

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<https://doi.org/10.5281/zenodo.21225456>

Surface-enhanced Raman scattering (SERS) has emerged as a powerful tool for ultra-sensitive detection of biological and chemical analytes. In this talk, we present our recent advances in SERS-based biosensing platforms by integrating nanostructured materials with antibody-based lateral flow assays, bacteriophage-enabled recognition systems, and passive microchip technologies.

We demonstrate that replacing antibodies with bacteriophages in lateral flow systems enables selective and robust detection of protein or bacteria, while immunomagnetic enrichment combined with paper-based platforms significantly enhances detection sensitivity. In addition, passive microfluidic SERS chips provide improved analyte–nanostructure interactions, leading to enhanced signal reproducibility and lower detection limits.

Beyond pathogen detection, our platforms are successfully applied to small-molecule analysis, including the quantification of heroin and its metabolites in biological samples. These findings highlight the potential of integrating nanotechnology with innovative recognition strategies to develop rapid, portable, and highly sensitive diagnostic systems.



Physical Reservoir Computing Devices Using Random Network of Nanomaterials for Physical AI Applications

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<https://doi.org/10.5281/zenodo.21225492>

In recent years, the remarkable computational capabilities of deep learning have driven rapid advances in artificial intelligence (AI) across a wide range of applications. However, the substantial memory and computational demands of deep learning have exposed critical limitations in conventional hardware, particularly silicon CMOS-based systems. As device miniaturization and energy efficiency approach their physical limits, further performance scaling is becoming increasingly challenging. To address these issues, growing attention has been directed toward alternative hardware paradigms, including physical implementations of artificial neural networks (ANNs) and neuromorphic computing systems that emulate brain-like information processing. A key feature of such systems is their reliance on intrinsic physical dynamics. By exploiting the nonlinear properties and complex network structures of nanomaterials, it is possible to develop devices capable of generating pulses, noise, and other rich physical phenomena utilized for AI computation. These approaches offer the potential for significantly reduced power consumption and higher integration density. In our research center, we investigate molecular and/or nanocarbon materials as building blocks for next-generation AI devices, with a particular focus on their integration into autonomous robotic systems. In this work, we introduce relevant nanomaterials and network architectures, outline key functionalization strategies, and present recent advances in their application to robotics. Notably, we demonstrate a carbon nanotube (CNT) sponge-based sensor integrated into a robot hand [1], which enables on-sensor computation while simultaneously functioning as a memory element. This multifunctional device highlights a promising pathway toward low-power, compact, and efficient AI hardware for portable and autonomous systems especially physical AI applications.

Keywords: *Physical Reservoir; Random Network; In-materio computing; Physical AI; Chemical dynamics*

ORCID iD  Hirofumi Tanaka: 0000-0002-4378-5747

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Nanotechnology-Driven Pathways Toward Net-Zero Carbon and Sustainable Development

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Achieving net-zero greenhouse gas (GHG) emissions has become a central objective of global climate policy under the Paris Agreement, which aims to limit global temperature rise to 1.5–2 °C above pre-industrial levels. The IPCC highlights the rapidly shrinking carbon budget and emphasizes the urgent need for deep emission reductions across energy, industry, and transportation sectors within this decade. Meeting these targets requires transformative technological innovations that enable efficient decarbonization while supporting sustainable development. Nanotechnology offers significant potential to accelerate the transition toward low-carbon energy and industrial systems. Nanostructured materials with high surface area, tunable chemistry, and enhanced catalytic activity are enabling improvements in solar photovoltaics, advanced energy storage systems, hydrogen production, and carbon capture, utilization, and storage (CCUS). Porous nanomaterials such as metal–organic frameworks, functional carbons, and nanocomposites show strong promise for efficient CO₂ capture and separation, while nanostructured catalysts and electrode materials enhance energy conversion and storage performance.

This talk highlights recent advances in nanomaterials for environmental applications and discusses their potential role in supporting global decarbonization pathways. It also addresses key challenges related to technology scaling, lifecycle sustainability, and policy integration required to translate nanoscale innovations into practical climate solutions.

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Education of Seniors in the Field of Artificial Intelligence

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<https://doi.org/10.5281/zenodo.21225593>

The rapid development of generative artificial intelligence creates new opportunities to improve the quality of life for older adults, but at the same time exacerbates the risks of digital exclusion, misinformation, and unequal access to the safe use of technology. The aim of this presentation is to outline the principles of digital education for seniors focused on developing competencies related to information retrieval, online communication, resilience to media manipulation, and the practical use of AI tools.

The starting point is a reflection on the diversity of the 50+ demographic, stereotypes regarding older adults' use of technology, and the limitations of traditional approaches to combating digital exclusion. Particular attention will be devoted to the relational dimension of digital competencies, encompassing not only technical skills but also safety, critical evaluation of content, mindful sharing of information, and the selection of appropriate communication tools.

The presentation also discusses the structure of the PRODIGI educational program, which comprises three modules: communication and information search, resilience to manipulation and information overload, and improving quality of life through the use of artificial intelligence. An innovative element of the program is the integration of generative AI into senior education through practical exercises, problem-based learning, and intergenerational activities involving students. Research tools for assessing basic digital competencies and knowledge regarding disinformation will also be presented.

The findings indicate that effective AI education for older adults should combine safety, critical thinking, practical applications of technology, and social support. Intergenerational learning models can provide an important response to the challenges of digital inclusion in aging societies.

Keywords: *older adults, digital literacy, generative AI, digital exclusion, intergenerational education, disinformation.*



Carbon Quantum Dots in Biomedicine: Emerging Platforms for Imaging, Sensing, and Therapy

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Carbon quantum dots (CQDs) are zero-dimensional nanoparticles with sizes smaller than 10 nm. Due to their unique features, including optical, chemical, and biological, CQDs have emerged as a versatile class of carbon-based nanomaterials with highly promising applications for biomedical purposes. The top-down and bottom-up approaches can be utilized for the fabrication of CQDs. While the top-down methods are arc discharge, laser ablation, electrochemical processes, and acid reflux, the bottom-up procedures include microwave, hydrothermal, and pyrolysis methods. These flexible fabrication procedures enable the synthesis of nanoparticles with easy-to-tune size, well-controlled surface chemistry, and extraordinary photoluminescence characteristics. Also, their high solubility in water, low toxicity, and tunable fluorescence nature provide unique performances in major biomedical applications such as bioimaging, biosensing, and drug administration applications. For the case of bioimaging, CQDs exhibit robust and sustained fluorescence, enabling high-resolution imaging of cells and tissues with improved photobleaching resistance. Furthermore, the proper attachment of targeting ligand molecules, including antibodies and aptamers, enhances their selectivity for different targets. As a biosensing system, CQDs exhibit high sensitivity for the efficient detection of various biomolecules, ions, and pathogens. The detection can be due to the fluorescence quenching or amplification mechanisms. CQDs provide considerable promise as drug delivery systems. The surface of CQDs can be functionalized to carry therapeutic agents and release them in a well-controlled manner.

Recently, it was shown that the heteroatom doping of CQDs with some elements such as nitrogen, sulfur, etc. remarkably improves some critical characteristics such as the electrical structure and biological activity. These modifications increase quantum yield, targeting performances, and multifunctionality.

In summary, CQDs prove to be a potent and versatile nanosystem in various biomedical applications. With their tunable nature and flexible functionality, they provide novel opportunities for various uses, such as precision medicine, diagnosis, and targeted therapy. This study provides a detailed examination of CQD synthesis, surface modification, and their incorporation into sophisticated bioanalytical and medicinal systems. In addition to various characteristics of CQDs, we discuss challenges and future directions in detail.

Keywords: Carbon quantum dots, Biomedicine, Imaging, Sensing, Therapy



Nanoscintillator Arrays for Advanced Radiation Detection

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<https://doi.org/10.5281/zenodo.21460190>

Radiation detection materials combining fast response, structural stability, and scalable fabrication are of significant interest for applications in nuclear security, radiation monitoring, and neutron-sensitive detector technologies. In this invited talk, recent progress on vertically self-oriented ZnO nanorod arrays will be presented, with particular emphasis on their scintillation properties and their potential for thermal neutron detection.

The presentation will focus on low-temperature hydrothermal growth of highly crystalline ZnO nanorods and on the role of lithium incorporation in neutron-sensitive scintillation behavior. Owing to their one-dimensional vertically aligned architecture, these nanorod arrays provide a large effective interaction surface together with reduced photon scattering and improved light-guiding compared with planar structures. Structural and morphological analyses confirm strong c-axis orientation and well-defined nanorod geometry, while optical studies reveal pronounced near-band-edge ultraviolet emission around 380 nm and a broader defect-related visible emission centered near 580 nm. Post-growth annealing strongly suppresses the defect-related visible emission and enhances the ultraviolet emission component.

The talk will also address the relationship between nanorod architecture, dopants, defect control, and scintillation response. Their sub-nanosecond scintillation dynamics, together with the favorable structural and optical properties of these ZnO-based nanoarrays, indicate that they are promising candidates for compact and efficient thermal neutron detection platforms. Future directions toward practical detector development and broader radiation detection applications will also be outlined.

Keywords: ZnO nanorods, Li doping, hydrothermal synthesis, scintillation, thermal neutrons

Acknowledgments: This work was supported by the European Research Commission under the program Horizon2020 with grant agreement number 101026555.



A Structured Mechatronics Design Framework for Industrial Automation with Application to Pail Filling Line Systems

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<https://doi.org/10.5281/zenodo.21228307>

Industrial automation systems often underperform not due to technological limitations, but because of weak integration between customer requirements, engineering specifications, and system validation. This keynote presents a structured mechatronics design framework that systematically translates industrial needs into robust, scalable, and deployable solutions aligned with smart manufacturing and Industry 4.0 principles. The framework integrates House of Quality, Product Design Specification, functional decomposition, morphological chart-based concept generation, and multi-criteria decision-making within a unified workflow. Its effectiveness is demonstrated through an industrial case study on the design and deployment of an automated lid denester system for a lubricant filling line. The system resolves key operational challenges including inconsistent lid separation, lid misalignment, and production inefficiencies caused by manual handling. The proposed solution integrates sensor-based automation, PLC-driven control architecture, and synchronized mechanical systems, validated in an operational environment. This work provides a transferable and industry-validated design framework that bridges theory and practice, enabling rapid development of intelligent automation systems for real-world industrial applications.

Keywords - *Mechatronics design framework, industrial automation, smart manufacturing, Industry 4.0, system integration and automated handling systems.*



The Impact and Effectiveness of Sugar-Sweetened Beverages Taxation in Malaysia: The Role of Sugar Tax in Tackling Obesity

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<https://doi.org/10.5281/zenodo.21228477>

The rising burden of obesity and diet-related non-communicable diseases (NCDs) in Malaysia is closely linked to increased consumption of sugar-sweetened beverages (SSBs), particularly among children and adolescents. In response, Malaysia implemented an excise tax of RM0.40 per litre on SSBs in July 2019 to reduce sugar intake and improve population health outcomes. This study evaluates the relevance, effectiveness, and impact of the SSB tax using a comprehensive mixed-methods approach.

A nationwide cross-sectional study was conducted between January and August 2022 involving 5,211 children and adolescents aged 7–17 years and 5,013 parents across 123 schools. Quantitative data on SSB consumption, behavioural and environmental factors, and tax awareness were collected, complemented by qualitative in-depth interviews with beverage producers and policymakers. Secondary data included retail price information and Healthier Choice Logo (HCL) certification trends.

Findings indicate that the SSB tax has produced modest but important outcomes. Retail prices increased by only 2.24%, below the expected threshold to significantly influence consumption behaviour. This limited price effect was largely due to producers absorbing the tax or only partially passing it on to consumers. Nonetheless, the policy stimulated reformulation efforts, with large manufacturers reformulating at least 50% of their products and a notable increase in HCL-certified beverages. Consumption patterns showed partial improvement, with reductions reported among 45.1% of adolescents and 53.8% of parents; however, overall intake remains high at approximately 758.79 mL per day. Awareness of the tax remains low, particularly among adolescents (26%), highlighting gaps in public communication strategies. Socioeconomic disparities persist, with higher consumption observed among rural populations and low-income (B40) groups, who also spend a greater proportion of income on SSBs.

In conclusion, while Malaysia's SSB tax has initiated positive shifts in industry practices and consumption, its current design limits its effectiveness. Strengthening the tax rate, enhancing enforcement, improving public awareness, and targeting vulnerable populations are critical to maximise its public health impact and equity outcomes.

Keywords: Sugar-sweetened beverages; taxation policy; obesity prevention; health equity; Malaysia



Fluidization Characteristics of Spherocylindrical Particles and Binary Mixtures: Experiment and CFD-DEM Simulations

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The study of the kinetic behavior of binary particles within a spouted bed as well as the heat transfer characteristics is important for the industrial optimization of the design of related fluidized bed reactors. In this presentation, the effect of different spherical particle diameters of spouted bed on the flow and heat transfer behavior of a binary particle system is discussed using the Computational Fluid Dynamics-Discrete Element Method (CFD-DEM). The process is that the same spherocylindrical particles are thoroughly mixed with spherical particles with diameters of 2.5 mm, 3.0 mm, and 3.5 mm, respectively. The results show that when the difference between the diameter of spherical particles and the equivalent diameter of spherocylindrical particles is larger, the difference between the average heights of the two types of particles in the spouted bed gradually increases, the average number of particle collisions of spherocylindrical particles with the spherocylindrical particles decreases, and the average number of collisions of spherical particles with the spherical particles increases. In binary particle systems where the diameter of the spherical particles is smaller, the aggregation of spherical particles at the bottom of the bed is more pronounced. Meanwhile, the diameter of spherical particles in the binary particle system influences the void fraction distribution pattern in the wall zone. In addition, the larger the diameter of the spherical particles in the binary particle system, the larger the drag force on the spherocylindrical particles, and the amount of convective heat transfer between the two particles increases. Furthermore, the rotational kinetic energy of both kinds of particles increases, but the translational moving energy of spherocylindrical particles decreases and the translational moving energy of spherical particles increases. It was also found that increasing air velocity helps the cooling of the particles, but the particle collision frequency does not necessarily increase. In addition, the cooling rate of spherocylindrical particles can be accelerated when the difference between the diameter of added spherical particles and the equivalent diameter of spherocylindrical particles is smaller; however, the cooling rate of the spherical particles is reduced. The CFD-DEM simulations are validated and compared with the experimental data as much as possible.



Design and Application of Magnetic Nanomaterials in Advanced Healthcare & Environmental Research

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Superparamagnetic iron oxide nanoparticles (SPIONs) have played a pivotal role in the development of nanomedicine, owing to their versatile nanoscale properties, which facilitate targeted delivery, high-contrast imaging, and on-demand therapy. Sen and co-workers [1] reviewed the importance of such nanoparticles in medical applications in 2011, and since then, the field has grown exponentially. Later, Sen and coworkers published several special issues [2-6] in *Nanomedicine* covering the latest developments of SPIONs and plasmonic nanoparticles [7]. Recently, Sen and coworkers developed novel magneto-optical nanocomposites involving SPIONs and a NIR sensitive dye, Indocyanine, for a multimodal therapeutics and diagnostics platform for cancer therapy [8-9]. Bacterial infections in the bloodstream have been recognised as a leading cause of mortality in the clinical field due to low detection of bacteria and their resistance to antibiotics by excessive misuse [10]. Therefore, a brand-new project in collaboration with Bruker, Germany, and Royal Preston Hospital, UK, has been initiated in 2024 to develop a fast diagnostic platform using a combination of magnetic porous nanocomposites and MALDI-TOF. Similarly, surface-engineered magnetic nanoparticles and porous magnetic nanocomposites, including hierarchically ordered porous silica composites, have been developed and applied for antimicrobial resistance in dental water lines and removal of toxic pollutants from environmental water ecosystems [11].

Keywords: *Magnetic nanoparticles, SPIONs, Nanomedicine, Nanowater technology, Commercialisation*

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Evaluation of the Impacts of Autonomous Vehicle Technologies on Traffic Safety and Urban Transportation: An MCDM-Based Approach

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Abstract

This study examines the impacts of autonomous vehicle technologies on urban transportation systems and traffic safety within a systematic and comprehensive multi-criteria decision-making framework. Six key criteria were defined as Traffic Safety, Reduction of Human Error, Infrastructure Compatibility, User Confidence, Cost, and Energy Consumption. In this context, the Analytic Hierarchy Process was applied to evaluate the relative importance of the determined criteria. The consistency analysis indicated that the Consistency Ratio ($CR = 0.0405 < 0.10$) falls within acceptable limits, confirming the reliability of the evaluations. The findings reveal that the most influential factors in the adoption of autonomous vehicles are Traffic Safety (weight = 0.441) and Reduction of Human Error (weight = 0.220), highlighting the central role of a human-centered safety perspective. Infrastructure Compatibility and User Confidence were found to have moderate importance, whereas Cost and Energy Consumption were identified as relatively less significant factors. The results provide practical insights for decision-makers, engineers, and urban planners, emphasizing the prioritization of safety-enhancing technologies and strategies to minimize human-induced errors. Overall, the study shows that AHP is an effective and robust method for analyzing complex decision problems, offering a reliable framework to support decision-making and strategic planning in autonomous vehicle deployment.

Keywords: *Autonomous Vehicles, Traffic Safety, Analytic Hierarchy Process, Urban Transportation, Sustainable Mobility*

1. INTRODUCTION

Autonomous vehicle (AV) technologies have emerged as a groundbreaking innovation with the potential to significantly transform traffic safety and urban transportation systems. AVs are expected to reduce the human factor in driving while improving the overall efficiency and safety of transportation systems through advancements in artificial intelligence, sensor technologies, and real-time data processing. As a result, AVs are widely recognized as key components of future intelligent transportation systems, with far-reaching implications for mobility, accessibility, and sustainability in urban environments.

There is a large amount of literature highlighting the potential of AVs to enhance traffic safety, with the reduction of human error being the most prominent aspect of road accidents. It has been shown that AV technologies can be used to reduce the risks of driver distraction, fatigue, and poor decision-making when they use advanced perception systems and automated control mechanisms (Chougule et al., 2024; Othman, 2022; Ferencz and Zoldy, 2023). Moreover, safety



technologies that are installed on vehicles, including automatic emergency braking (AEB), forward collision warning (FCW), blind spot warning (BSW), and rear cross-traffic braking (RCTB), are emphasized as effective interventions to mitigate certain kinds of accidents, namely rear-end and lane-change ones (Ferencz & Zoldy, 2023). Along with these encouraging results, there is also some contradictory evidence in the literature on the safety effects of AVs, which is subtle and sometimes contradictory. Certain empirical data indicate that initial AV implementations can have higher crash rates caused by the lack of operational experience, small samples, and non-representative conditions of the tests (Patel et al., 2023). Also, the period between the autonomous and the human-driven vehicles will have complex interaction dynamics that can affect safety outcomes. AVs have to be capable of decoding and reacting to human driver, pedestrian, and cyclist behavior in mixed traffic, which under some conditions cuts off the benefits to their safety (Chougule et al., 2024; Xu et al., 2022). The other noteworthy point that is raised in the literature is the correlation between the penetration of AVs and safety performance. Simulation-based research shows that the benefit of safety is more likely to increase with greater levels of AV penetration, and substantial gains have been made in the efficiency of the traffic flow and reduction of delays at penetration rates between 25 and 100 percent (Abdeen et al., 2022). In a similar fashion, extensive studies show that even the implementation of AVs in part will result in quantifiable safety and mobility gains, but the extent of the gains will depend on the interplay between AVs and traditional vehicles (Pauwels et al., 2022; Al-Malki et al., 2024; Tu and Xu, 2024). Besides the matter of safety, AVs are likely to have an important impact on the transportation infrastructure and mobility trends in cities. The literature identifies the option of AVs to enhance accessibility, especially to the elderly and disabled groups, and to facilitate the creation of more inclusive transportation systems (Dani et al., 2019; Tu and Xu, 2024). Furthermore, the development of shared systems of autonomous vehicles (SAVs) and Mobility-as-a-Service (MaaS) is anticipated to decrease the number of vehicles and parking spaces, which will make the city space more efficient and sustainable mobility (Luca et al., 2023; Guo et al., 2020).

Urban planning-wise, the use of AVs is expected to affect land use, infrastructure demands, and the design of transportation systems. Evidence highlights the necessity of the adaptive planning approach, such as the redesign of parking facilities, the combination with the public transit network, and the creation of special pick-up and drop-off areas (Razavi and Sierpiński, 2024; Hasan et al., 2019; Guo et al., 2020). Furthermore, the decreased parking need in the AV-dominated contexts might leave a chance to repurpose the urban space with the use of the public amenities and environmentally friendly purposes (Luca et al., 2023; Hosseini et al., 2024).

AVs, however, are an ongoing debate on their environmental effects. Whereas certain researchers believe that AVs can decrease emissions due to eco-driving, platooning, and optimized routing, others believe that higher travel demand and vehicle kilometers traveled (VKT) can cancel out the advantages (Massar et al., 2021; Ferencz and Zoldy, 2023). Consequently, the overall environmental effect of AVs is extremely sensitive to the sources of energy, electrification of vehicles, and travel patterns.

In addition to operational and environmental factors, the literature also indicates extremely significant challenges associated with cybersecurity, governance, and regulatory frameworks. AV systems are also susceptible to cyber-physical attacks, and such threats can jeopardize the safety unless they are adequately managed (Girdhar et al., 2022; Gohar and Nencioni, 2021). In addition, such concerns as liability, social acceptability, and the absence of unified regulations are also mentioned as the obstacles to the universal use of AV technologies (Othman, 2021; Ferencz and Zöldy, 2023).



Even though a significant amount of literature exists on the subject of autonomous vehicles, a gap in thorough research, which would also assess the multi-dimensional effects of AV technologies on traffic safety and transportation systems in cities in the context of a single decision-making framework, does exist. Current research is usually done on some of the isolated components including safety component, efficiency component or even environmental performance without being able to analyze the trade-offs and interdependence of these criteria.

In order to fill this gap, the proposed study is a systematic MCDM model using the AHP to assess the effects of AV technologies. The primary value of the study is that it combines several key aspects such as safety, minimization of human errors, compatibility of infrastructure, user confidence, affordability, and energy use into a single analysis framework.

The proposed method, including expert suggestions and systematically weighting these criteria, offers a powerful decision support tool to policy-makers and transportation planners and enables them to make more informed and balanced decisions in the shift to autonomous mobility.

2. MATERIALS AND METHODS

2.1. Study Framework

This study evaluates the impacts of autonomous vehicle (AV) technologies on traffic safety and urban transportation systems using a multi-criteria decision-making (MCDM) approach. Considering the complex and multidimensional nature of AV impacts, a structured and systematic framework was adopted to ensure both methodological rigor and clarity within the scope of the study.

Figure 1 illustrates the overall methodological framework of the study in a systematic and structured multi-stage process. The proposed framework begins with the problem definition phase, in which the research problem is clearly identified and the study objectives are established based on an extensive literature review and expert insights. This initial step ensures that the scope of the analysis is well-defined and aligned with the research context.

In the second phase, the evaluation criteria are determined by considering key dimensions relevant to autonomous vehicle (AV) adoption, including traffic safety, reduction of human error, infrastructure compatibility, user confidence and acceptance, cost, and energy consumption. These criteria represent the multidimensional nature of AV evaluation and reflect both technical and socio-economic factors.

The third phase involves data collection, where expert judgments are obtained through pairwise comparisons. This step is critical for capturing domain-specific knowledge and transforming qualitative judgments into quantitative inputs for analysis.

In the fourth phase, a multi-criteria decision-making (MCDM) approach is implemented using the Analytic Hierarchy Process (AHP), and a hierarchical decision model is constructed accordingly. In the fifth stage, AHP calculations are performed to derive the relative weights of each criterion, while the consistency ratio is evaluated to ensure the reliability of expert judgments.

Finally, in the last stage, the obtained results are interpreted within the context of AV adoption, and policy-relevant conclusions are drawn. This structured and sequential framework enhances

the methodological rigor of the study and ensures the transparency, reproducibility, and reliability of the analytic process.

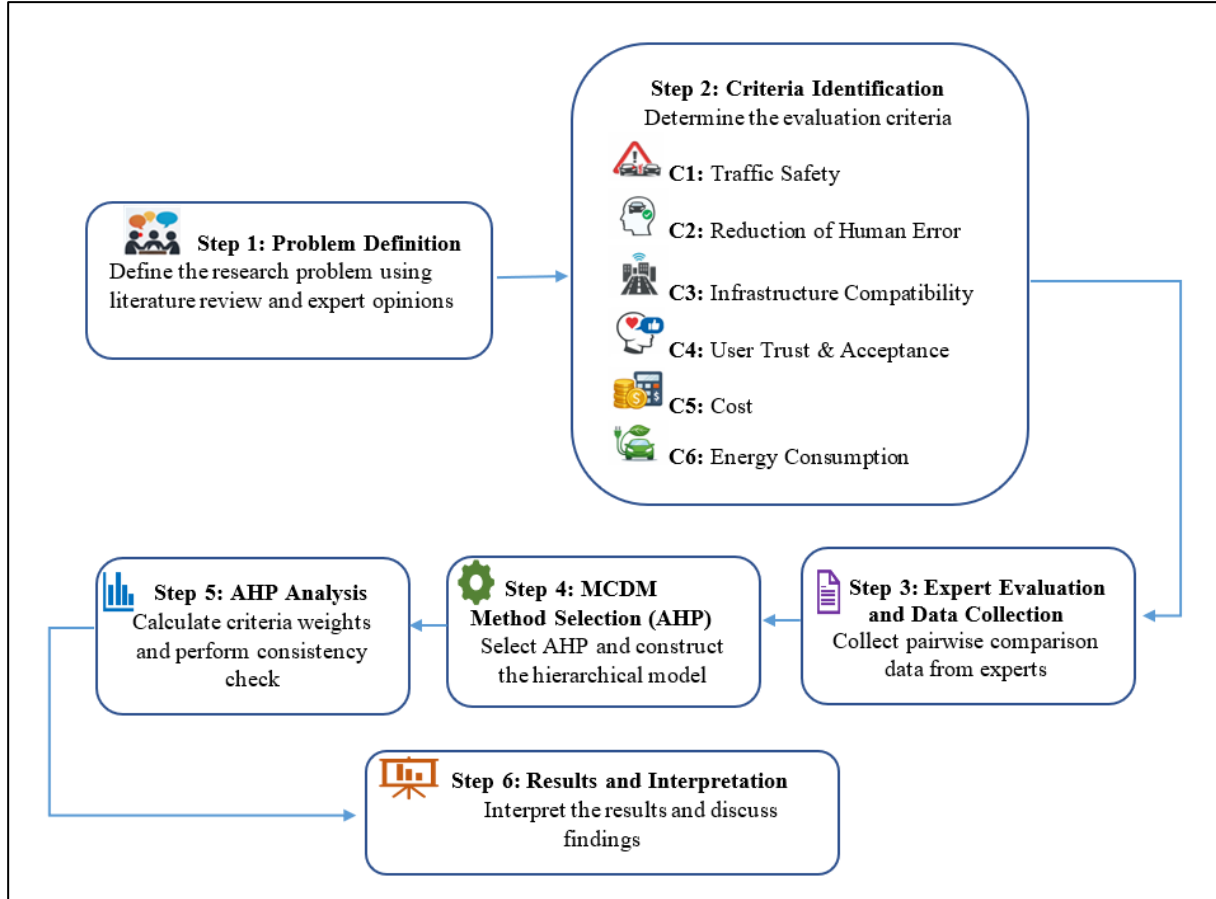


Figure 1. Framework of the study

2.2. Criteria Selection

In order to depict the most important dimensions of the autonomous vehicle (AV) impacts, six major criteria were formulated as a result of a detailed analysis of the existing literature and further narrowed down by the subject matter experts. This combined methodology ensures that the chosen criteria are informative and realistic at the same time.

To make it more understandable and prevent an undue complexity, a simplified hierarchical structure without sub-criteria was embraced.

The criteria chosen are as follows:

- **C1: Traffic Safety** – Overall impact on reducing accidents, injuries, and fatalities
- **C2: Reduction of Human Error** – Ability to minimize driver-related errors
- **C3:Infrastructure Compatibility** – **Compatibility with existing transportation infrastructure**
- **C4:User Trust and Acceptance** – Public confidence and willingness to adopt AV technologies
- **C5: Cost** – Implementation and operational costs



- **C6: Energy Consumption** – Energy efficiency and environmental impact

All these criteria are used to describe the most important safety, technical, economic and environmental factors of AV deployment. Moreover, the expert feedback made sure that the criteria are more realistic and based on the real-life situation and contemporary difficulties in transportation systems.

2.3. Data Collection

The analysis is founded on the expert evaluations acquired in the course of the structured process of assessment. Five experts took part in the study out of which three were academicians in transportation engineering and two were civil engineers (with a minimum of five years of professional experience in the field).

The rating experts were requested to use the basic scale of 1 to 9 created by Saaty to carry out pairwise comparisons of the criteria against which one criterion would outweigh the other. The individual comparison matrices derived out of every expert were pooled together using the geometric mean technique to create a consensus pairwise comparison matrix.

In order to make the evaluations reliable, a consistency analysis was carried out. Consistency Ratio (CR) was determined and compared to the acceptable threshold value ($CR < 0.10$). The findings proved that the professional judgments are consistent and can be discussed further.

2.4. Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a popular multi-criteria decision-making (MCDM) technique that has been implemented to solve complex problems in the social, technical, and economic fields (Saaty, 1980; Saaty, 2000; Özbek and Eren, 2013). AHP enables decision makers to rank alternatives based on specified criteria, including expert opinion, preferences and other qualitative aspects. The approach is also flexible, and one can add or remove criteria that can be evaluated by sensitivity analysis.

The overall procedures of AHP are as follows (Saaty, 1980):

1. Problem Definition and Criteria Selection: The decision problem is identified, the criteria are identified and their relative importance is first taken into consideration.
2. Hierarchy Construction: A hierarchical structure is established whose goal is at the top, criteria (and possibly sub-criteria) at lower levels, and options at the bottom.
3. Pairwise Comparisons: Pairs of criteria and alternatives are compared to see how important each one is, based on a 1–9 scale by Saaty. A comparison of n elements involves $n(n-1)/2$ comparisons.

$$\begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} = 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} = 1/a_{1n} & a_{n2} = 1/a_{2n} & \cdots & 1 \end{bmatrix}$$

4. Normalization: Pairwise comparison matrices are normalized by dividing every element by the sum of its column, and this normalization produces column sums of 1.

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad i, j = 1, 2, \dots, n \quad (1)$$

5. Priority Vector Calculation: The importance weight (priority vector) of the individual criterion is determined by averaging the rows of the normalized matrix.

$$w_i = \left(\frac{1}{n}\right) \sum_{j=1}^n a'_{ij} \quad i, j = 1, 2, \dots, n \quad (2)$$

6. Consistency Check: Consistency of the comparisons is measured using Consistency Index (CI) and Consistency Ratio (CR). The CR below 0.10 represents a reasonable consistency, and the comparisons are revised and corrected (Saaty, 1980; Özbek and Eren, 2013).

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \left(\frac{\sum_{j=1}^n a_{ij} w_j}{w_i} \right) \quad (3)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

$$CR = \frac{CI}{RI} \quad (5)$$

In order to measure consistency, the value of the dimension of the comparison matrix will be required to determine the Random Index (RI) value. Table 1 has the RI values that are set to N-dimensional matrices of comparison. The Consistency Ratio (CR) is derived after the calculation of the CI and RI values.

Table 1. RI values defined for comparison matrix (Saaty 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,53	1,56	1,57	1,59

The Analytic Hierarchy Process (AHP) offers a clear and methodical method of dealing with complicated decision-making scenarios. Its ability to combine various criteria and professional opinions makes it especially appropriate in assessing the effects of autonomous vehicle technologies on the traffic safety and the transport systems in the urban areas.

3. RESULTS

The Analytic Hierarchy Process (AHP) was applied to evaluate six key criteria influencing the adoption of autonomous vehicles (AVs): Safety, Human Error, Infrastructure, User Confidence, Cost, and Energy Consumption. The pairwise comparison matrix was constructed based on

expert opinions, and the relative importance levels of the criteria were obtained through normalization and the calculation of priority weights.

To enhance the transparency of the analysis, the key steps of the AHP calculation process are briefly described. Table 2 presents the pairwise comparison matrix constructed based on expert judgments. Each element in the matrix represents the relative importance of the criterion in the corresponding row compared to the criterion in the corresponding column, forming the basis for subsequent normalization and weight derivation within the AHP framework.

Table 2. Pairwise Comparison Matrix of AV Evaluation Criteria

Criteria	Safety	Human Error	Infrastructure	User Trust	Cost	Energy
Safety	1	3	4	5	7	6
Human Error	0.3333	1	2	3	5	4
Infrastructure	0.25	0.5	1	2	4	3
User Trust	0.2	0.3333	0.5	1	3	2
Cost	0.1429	0.2	0.25	0.3333	1	0.5
Energy Consumption	0.1667	0.25	0.3333	0.5	2	1

The pairwise comparison matrix was subsequently normalized by dividing each element by the sum of its corresponding column. The priority weights were then derived by calculating the arithmetic mean of the normalized values in each row. Table 3 presents both the normalized matrix and the resulting priority weights obtained from this procedure.

Table 3. Normalized Matrix and Priority Weights

Criteria	Safety	Human Error	Infrastructure	User Trust	Cost	Energy	Priority Weight
Safety	0.478	0.568	0.495	0.423	0.318	0.364	0.441
Human Error	0.159	0.189	0.247	0.254	0.227	0.242	0.220
Infrastructure	0.119	0.095	0.124	0.169	0.182	0.182	0.145
User Trust	0.096	0.063	0.062	0.085	0.136	0.121	0.094
Cost	0.068	0.038	0.031	0.028	0.045	0.030	0.040
Energy Consumption	0.080	0.047	0.041	0.042	0.091	0.061	0.060

As shown in Table 3, Safety (0.441) and Human Error (0.220) exhibit the highest priority weights, indicating that these criteria play a more dominant role in the evaluation of autonomous vehicle (AV) adoption compared to the remaining criteria. Infrastructure (0.145) and User Trust (0.094) follow in importance, whereas Cost (0.040) and Energy Consumption (0.060) are relatively less influential in the decision-making process.

To provide further transparency in the AHP computation process, intermediate calculation results, including the weighted sum values (T/C) and the average values (AVG), are presented in Table 4. These values form the basis for the consistency evaluation and the subsequent derivation of reliability measures within the AHP framework.

Table 4. Consistency Metrics

Criteria	Sum (T/C)	Average
Safety	2.793	0.441
Human Error	1.380	0.220
Infrastructure	0.894	0.145
User Trust	0.569	0.094
Cost	0.245	0.040
Energy Consumption	0.364	0.060

The consistency of the pairwise comparisons was evaluated through a step-by-step procedure using the maximum eigenvalue ($\lambda_{\max}$), Consistency Index (CI), and Consistency Ratio (CR), as defined in Equations (3,4,5). First, the maximum eigenvalue ($\lambda_{\max}=6.163$) was calculated using Equation (3), which is derived from the weighted sum vector and priority weights obtained from the AHP process. Then, the Consistency Index (CI=0.0327) was computed using Equation (4) to measure the degree of deviation from perfect consistency in the pairwise comparison matrix. Finally, the Consistency Ratio (CR) was determined using Equation (5) by comparing the CI value with the Random Index (RI). The RI value (1.24) was obtained from Table 1 based on the dimension of the comparison matrix. The calculated consistency ratio was found to be CR = 0.0405, which is below the acceptable threshold value of 0.10. This indicates that the expert judgments are consistent and the results are reliable.

Figure 2 presents the resulting priority weights of the criteria obtained from the AHP analysis. The findings clearly indicate that Safety and Reduction of Human Error are the most influential criteria in the adoption of autonomous vehicles. This result highlights the dominant role of human-centered considerations in the evaluation of emerging autonomous vehicle technologies. It suggests that, despite advancements in automation and intelligent transportation systems, safety remains the primary concern for decision-makers and stakeholders. In particular, the high importance assigned to human error reduction reflects the well-established understanding in the literature that human factors are the leading cause of traffic accidents. Although these findings may appear expected, the study contributes by providing a structured quantitative prioritization of multiple evaluation criteria within a unified decision-making framework. This allows for a more systematic understanding of trade-offs between safety, infrastructure, cost, and environmental considerations. Furthermore, the results provide practical implications for policy-makers and engineers, indicating that strategies aimed at enhancing traffic safety and minimizing human error should be prioritized in the development and deployment of autonomous vehicle systems. At the same time, lower-weighted criteria such as cost and energy consumption suggest that these factors may become more influential in later stages of AV adoption as the technology matures and becomes more widely implemented.

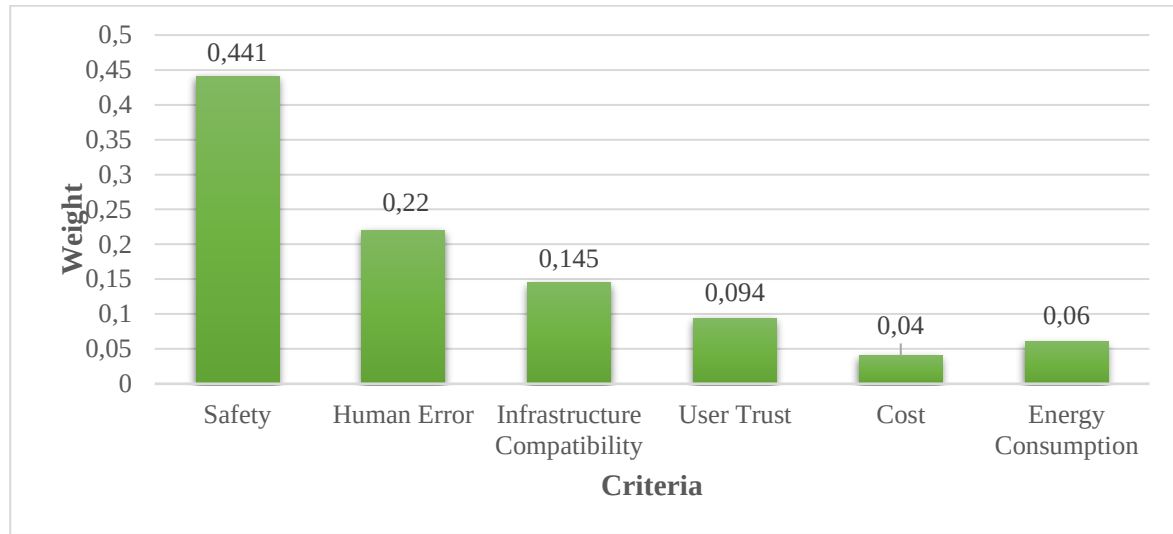


Figure 2. Criterion Weights

4. DISCUSSION

The results of this study provide important findings regarding the prioritization of key factors influencing the adoption of autonomous vehicles (AVs) in urban transportation systems. The findings indicate that the criteria of Safety and Reduction of Human Error are the most dominant factors, a finding consistent with studies in the literature that emphasize the central role of the human factor in traffic safety and autonomous vehicle performance (Othman, 2022; Chougule et al., 2024). This finding indicates that, despite technological advancements, the transition to autonomous mobility is still being shaped by a safety-focused approach rather than economic or environmental factors. In particular, the high priority placed on reducing human error supports the widely held view that a significant portion of traffic accidents are caused by human factors and highlights the potential of AV technologies to mitigate these risks.

The relatively low priority given to cost and energy consumption indicates that, at the current stage of AV technology development, stakeholders prioritize safety and system reliability over economic efficiency and environmental sustainability. This aligns with studies in the literature suggesting that early-stage AV adoption is typically safety-focused, while cost and sustainability factors may become more significant in the long term (Massar et al., 2021; Luca et al., 2023). In addition, the fact that the criteria of infrastructure compatibility and user trust are of moderate importance indicates that technological readiness and social acceptance are significant facilitating factors in the adoption of AVs. These findings demonstrate that the adoption of AVs depends not only on technical advancements but also on building social trust and ensuring infrastructure compatibility.

Overall, the findings support the need for a holistic approach in AV applications; they indicate that while safety remains the top priority, economic, social, and environmental considerations must be increasingly integrated into policy-making processes.

5. CONCLUSION AND RECOMMENDATIONS

The present study employed a multi-criteria decision-making (MCDM) framework, specifically the Analytic Hierarchy Process (AHP), to evaluate the key factors influencing the



adoption of autonomous vehicles (AVs) in urban transportation systems. The analysis integrated both a comprehensive literature review and expert judgments across six criteria: traffic safety, reduction of human error, infrastructure compatibility, user trust and acceptance, cost, and energy consumption, ensuring a robust and structured decision-making framework.

The consistency of the expert evaluations was assessed using the Consistency Ratio (CR), which was calculated as 0.0405. Since this value is well below the acceptable threshold of 0.10, the pairwise comparisons are considered consistent and reliable.

The results indicate that Safety (0.441) and Reduction of Human Error (0.220) are the most influential criteria in the adoption of AVs. This finding highlights the dominant role of human-centered safety considerations in autonomous vehicle deployment. Infrastructure compatibility and user trust also contribute to the decision-making process, while cost and energy consumption are comparatively less influential at the current stage of technological development.

Overall, the study emphasizes that the successful implementation of autonomous vehicles requires a strong focus on human-centered safety and the mitigation of human error, alongside technical, social, and economic considerations within a holistic decision-making framework. The proposed AHP-based approach provides a structured and transparent decision-support tool for policymakers, engineers, and urban planners.

Based on the findings, the following recommendations are proposed:

- Policymakers should prioritize safety-oriented regulations and standards to ensure secure and human-centered deployment of autonomous vehicles.
- Engineers and developers should integrate advanced driver assistance and monitoring systems to minimize human error and enhance operational safety.
- Public awareness strategies should be developed to improve trust and acceptance of autonomous vehicle technologies.
- Although cost and energy consumption are less dominant in the current analysis, long-term strategies should still address efficiency and sustainability goals.
- Future research should incorporate dynamic traffic conditions, infrastructure variability, and behavioral factors to develop more comprehensive decision-making models.
- The integration of AHP-based results into policy and planning processes can support more evidence-based and balanced transportation strategies.

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Vanadium-Induced Alterations in Nitrogen Assimilation Pathway and Oxidative Status in Wheat (*Triticum aestivum* L.)

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Abstract

Vanadium (V) contamination of agricultural soils is increasing due to industrial activities, fossil fuel combustion, and phosphate fertilizer use. This study investigated the effects of V stress (NaVO_3) on vanadium accumulation, N-metabolizing enzymes, photosynthetic pigments, protein content, and lipid peroxidation in two wheat (*Triticum aestivum* L.) cultivars (Altındane and Doğu-88) within the first 24 hours of exposure. The V application increased endogenous V content (by ICP-MS) in a concentration-dependent manner, with roots accumulating 4-45 times more V than shoots. It increased malondialdehyde levels in the roots by 46-77%, indicating severe oxidative stress, and reduced chlorophyll a and b contents in the leaves, while carotenoid levels increased. Notably, chlorophyll a was more adversely affected by the V stress than chlorophyll b. Soluble protein content decreased at 0.1 mM V but recovered or increased at 1 mM V. In addition, the V stress significantly inhibited nitrate reductase (NR), nitrite reductase (NiR), and glutamine synthetase (GS) activities, with stronger inhibition at 1 mM V and in roots compared to shoots. In contrast, glutamate synthase (GOGAT) activity showed differential responses: decreased in shoots but increased in roots at 0.1 mM V. These findings demonstrate that V stress rapidly disrupts N assimilation primarily by inhibiting NR, NiR, and GS activities within 24 hours, with root tissues being more vulnerable due to higher V accumulation. The Doğu-88 cultivar exhibited relatively higher tolerance to V stress than the Altındane.

Keywords: Nitrogen metabolism, Wheat, Vanadium, MDA, Chlorophyll

1. INTRODUCTION

Heavy metal contamination of agricultural ecosystems has become a global environmental concern due to rapid industrialization, mining activities, wastewater irrigation, and excessive use of synthetic fertilizers and pesticides [1,2]. Among potentially toxic elements, vanadium (V) has received increasing attention as an emerging contaminant, particularly in regions with petroleum refining, steel manufacturing, and phosphate fertilizer application [3,4]. Vanadium is a transition metal (atomic number 23) that exists in multiple oxidation states (+2 to +5), with pentavalent vanadate (VO_4^{3-}) and tetravalent vanadyl (VO^{2+}) being the most common forms in natural environments [5]. While V is essential for some lower organisms such as green algae and nitrogen-fixing bacteria, its essentiality for higher plants remains controversial [6,7].

Anthropogenic activities have substantially elevated V concentrations in soils, often exceeding the natural background level of 10-200 mg kg⁻¹. Phosphate fertilizers contain 0.05-2 g V kg⁻¹, and their repeated application has led to significant V accumulation in agricultural soils [8]. Atmospheric V deposition from burning of fossil fuels, particularly heavy crude oil and coal,



further contributes to soil contamination [9]. In contaminated areas, soil V concentrations can reach 300-1000 mg kg⁻¹, posing potential risks to crop productivity and food safety [4,10]. Vanadium toxicity in plants manifests as growth inhibition, chlorosis, root deformation, nutrient imbalance, and reduced yield [11,12,13]. At the cellular level, V induces oxidative stress by generating reactive oxygen species (ROS), leading to lipid peroxidation (LPO), membrane damage, and disruption of metabolic processes [14,15].

Nitrogen (N) is an essential macronutrient required for the synthesis of amino acids, proteins, nucleic acids, and chlorophyll. Plants primarily absorb N as nitrate (NO₃⁻) or ammonium (NH₄⁺) from the soil solution. The assimilation of NO₃⁻ into organic compounds involves a series of enzymatic reactions: nitrate reductase (NR) catalyzes the reduction of NO₃⁻ to nitrite (NO₂⁻) in the cytosol; nitrite reductase (NiR) reduces NO₂⁻ to NH₄⁺ in plastids (chloroplasts in leaves, leucoplasts in roots); and the GS-GOGAT cycle (glutamine synthetase [GS] and glutamate synthase [GOGAT]) assimilates NH₄⁺ into glutamine and glutamate, which serve as nitrogen donors for all other nitrogenous compounds [16]. These enzymes are highly sensitive to environmental stresses, including heavy metal exposure. For instance, cadmium (Cd), chromium (Cr), and nickel (Ni) have been shown to inhibit NR, NiR, and GS activities in various plant species [17,18,19]. However, the specific effects of V on the entire N assimilation pathway-particularly during the early stress response-remain largely unexplored.

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide, providing approximately 20% of global caloric intake. Türkiye ranks among the top ten wheat-producing countries, with annual production exceeding 20 million tons [20]. Wheat is known to be relatively sensitive to V compared to other crops such as rice and soybean [21]. Understanding how V stress affects N metabolism in wheat is therefore critical for predicting and mitigating potential yield losses in V-contaminated agricultural regions.

The first hours of stress exposure represent a critical window during which plants initiate adaptive responses. Early changes in enzyme activities and metabolic fluxes often determine the eventual outcome of stress acclimation. Therefore, this study aimed to: (i) determine the short-term (24 h) effects of V stress on the activities of key N-assimilating enzymes (NR, NiR, GS, and GOGAT) in wheat; (ii) evaluate tissue-specific responses (roots vs. shoots) and cultivar-dependent differences using two wheat cultivars with contrasting stress tolerance (Altındane, relatively sensitive; Doğu-88, relatively tolerant); (iii) assess V accumulation, protein content, photosynthetic pigments, and lipid peroxidation to provide a comprehensive understanding of V-induced metabolic disruption. We hypothesized that V stress would rapidly inhibit N assimilation enzymes, with roots being more severely affected due to higher V accumulation, and that the tolerant cultivar would exhibit less pronounced inhibition of these enzymes.

2. MATERIALS AND METHODS

2.1. Plant Material and Growth Conditions

Seeds of two bread wheat (*Triticum aestivum* L.) cultivars-Altındane (relatively stress-sensitive) and Doğu-88 (relatively stress-tolerant)-were obtained from The East Anatolian Agricultural Research Institute (Erzurum, Türkiye). The seeds were surface-sterilized with 10% (v/v) sodium hypochlorite for 10 min followed by 70% (v/v) ethanol for 5 min, then rinsed thoroughly with distilled water. We planted approximately 10 wheat seeds in each plastic basket pot (5 cm in diameter) in a hydroponic system. Seed germination and seedling growth were



carried out in a climate-controlled growth chamber (JenoTech, South Korea) under the following conditions: 24/20°C day/night temperature, 65% relative humidity, 16/8 h light/dark photoperiod with photosynthetically active radiation of 250 $\mu\text{mol m}^{-2} \text{s}^{-1}$ provided by cool-white fluorescent lamps. Seedlings were grown hydroponically using a modified Arnon and Hoagland (%50) nutrient solution for 14 days, with the solution renewed every 3 days.

The primary objective of this study was to evaluate the effects of vanadium on nitrogen metabolism enzymes. The presence of NH_4^+ in the plant growth medium would bypass the activities of nitrate reductase (NR) and nitrite reductase (NiR), thereby promoting the activity of the downstream enzymes glutamine synthetase (GS) and glutamate synthase (GOGAT). Consequently, the effect of vanadium on NR and NiR activities could not be accurately determined under such conditions. For this reason, NH_4^+ was omitted from the Hoagland nutrient solution used in this study, and nitrate (NO_3^-) was provided as the sole nitrogen source in the hydroponic growth medium. Under these conditions, plants assimilate nitrogen exclusively in the form of NO_3^- , which is sequentially reduced to NO_2^- by NR, then to NH_4^+ by NiR, and finally incorporated into amino acids through the GS-GOGAT pathway. The NH_4^+ free macronutrient solution (per liter) contained: 2.3 mM KH_2PO_4 , 6.0 mM KNO_3 , 4.9 mM $\text{Ca}(\text{NO}_3)_2$, and 4.9 mM MgSO_4 . Micronutrients (per liter) were: 0.286 mM H_3BO_3 , 0.181 mM $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$, 0.022 mM $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, 0.008 mM $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, and 0.009 mM $\text{H}_2\text{MoO}_4 \cdot \text{H}_2\text{O}$. Iron was supplied as 0.01 mM Fe-EDTA. The final pH was adjusted to 6.0 ± 0.5 .

2.2. Vanadium Treatment and Experimental Design

On day 14 after germination, seedlings were exposed to vanadium (as sodium metavanadate, $\text{NaVO}_3 \cdot 2\text{H}_2\text{O}$, Sigma-Aldrich, purity $\geq 99\%$) at concentrations of 0 (control), 0.1 mM, and 1.0 mM. These concentrations were selected based on preliminary experiments evaluating root and shoot length, dry weight, and malondialdehyde (MDA) content. The V-containing solutions were prepared in the modified nutrient solution (pH adjusted to 6.0). After 24 hours of V treatment, the plants were harvested and separated into roots and shoots. Tissues were immediately frozen in liquid nitrogen and stored at -80°C until analysis. Each treatment consisted of three biological replicates (pots), with each replicate containing 8-10 seedlings.

2.3. Determination of Endogenous Vanadium Content

Vanadium content was determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS; Perkin-Elmer, USA) following the method of [22]. Dried tissue samples (0.2 g) were digested with 7 mL of 65% HNO_3 in a microwave digestion system (800 W, 180°C , 15 s). After cooling, 2 mL of 30% H_2O_2 was added, and the mixture was evaporated to approximately 1 mL on a hot plate. The residue was dissolved in 5 mL of 1.5 M HNO_3 , boiled for 2 min, cooled, filtered, and diluted to 25 mL with deionized water. V concentrations were quantified against standard solutions prepared from 1000 mg L^{-1} V stock solution in 1.0 M HNO_3 . Results were expressed as ppm ($\mu\text{g g}^{-1}$ dry weight).

2.4. Photosynthetic Pigment Analysis

Chlorophyll a, chlorophyll b, and total carotenoid contents were determined according to [23]. Fresh leaf tissue (0.2 g) was homogenized in 10 mL of 80% (v/v) cold acetone. The homogenate was filtered and centrifuged at 5,000 x g for 10 min. Absorbance of the supernatant was measured at 450, 645, and 663 nm using a UV-visible spectrophotometer (Shimadzu UVmini-1240, Japan). Pigment concentrations were calculated using the following equations:



Chlorophyll a (mg g⁻¹ FW) = [(12.7 x A₆₆₃) - (2.69 x A₆₄₅)] x (V / (1000 x FW))

Chlorophyll b (mg g⁻¹ FW) = [(22.9 x A₆₄₅) - (4.68 x A₆₆₃)] x (V / (1000 x FW))

Total chlorophyll (mg g⁻¹ FW) = [(20.2 x A₆₄₅) + (8.02 x A₆₆₃)] x (V / (1000 x FW))

Total carotenoids (mg g⁻¹ FW) = (4.07 x A₄₅₀) - (0.0435 x Chl a + 0.367 x Chl b)

where V = volume of extract (mL) and FW = fresh weight (g).

2.5. Malondialdehyde (MDA) Assay

Lipid peroxidation was assessed by measuring MDA content using the thiobarbituric acid (TBA) method [24]. Fresh tissue (0.5 g) was homogenized in 5 mL of 5% (w/v) trichloroacetic acid (TCA). The homogenate was centrifuged at 13,000 x g for 15 min. Then, 1.5 mL of supernatant was mixed with 1.5 mL of 0.5% (w/v) TBA prepared in 20% TCA. The mixture was heated at 95°C for 30 min, cooled on ice, and centrifuged at 12,000 x g for 5 min. Absorbance was measured at 532, 600, and 440 nm. MDA concentration was calculated using the formula: MDA (nmol mL⁻¹) = {(A₅₃₂-A₆₀₀) - (A₄₄₀-A₆₀₀) x 0.0571} / 157,000} x 10⁶

2.6. Soluble Protein Content Determination

Soluble protein content was quantified using the bicinchoninic acid (BCA) method [25]. Tissue (0.5 g) was homogenized in 5 mL of 100 mM KH₂PO₄ buffer (pH 7.0). The homogenate was centrifuged at 12,000 x g for 15 min at 4°C. The supernatant (20 µL) was mixed with 200 µL of BCA reagent (bicinchoninic acid + CuSO₄) in a microplate and incubated at 60°C for 15 min. Absorbance was read at 562 nm using a microplate reader (Multiscan Go, Thermo Scientific). Bovine serum albumin (BSA) was used as standard. Results were expressed as µg protein g⁻¹ fresh weight.

2.7. Enzyme Extraction

All extraction procedures were performed at 4°C. For NR, NiR, and GOGAT assays, tissue (0.25 g) was homogenized in 2.5 mL of 50 mM phosphate buffer (pH 7.0) containing 0.2 mM EDTA, 0.1% (w/v) polyvinylpyrrolidone (PVP), and 1 mM dithiothreitol (DTT). For GS assay, the extraction buffer was 0.1 M HEPES (pH 7.6) containing 5 mM DTT, 0.2 mM EDTA, and 10 mM MgCl₂. Homogenates were centrifuged at 12,000 x g for 15 min at 4°C, and the clear supernatant was used as crude enzyme source.

2.8. Nitrate Reductase (NR) Activity Assay

NR (EC 1.7.1.1) activity was measured using the method of [26]. The reaction mixture (2 mL) contained 25 mM phosphate buffer (pH 7.5), 10 mM NaNO₃, 0.05 mM EDTA, 2 mM NADH, and 0.2 mL enzyme extract. The reaction was initiated by adding NADH and incubated at 30°C for 30 min. To stop the reaction and develop color, 1 mL of 58 mM sulfanilamide (in 3 M HCl) and 1 mL of 0.77 mM N-(1-naphthyl)ethylenediamine dihydrochloride (NED) were added. After 30 min, absorbance was measured at 540 nm. Nitrite (NO₂⁻) concentration was determined using a standard curve prepared with NaNO₂ (0-3 µM). One unit (U) of NR activity was defined as the amount of enzyme producing 1 µmol NO₂⁻ per minute. Activity was expressed as µmol NO₂⁻ g⁻¹ FW.

2.9. Nitrite Reductase (NiR) Activity Assay

NiR (EC 1.7.7.1) activity was assayed following [27]. The reaction mixture (2 mL) contained 0.5 M phosphate buffer (pH 7.4), 15 mM NaNO₂, 5 mM methyl viologen, 86 mM sodium



dithionite in 190 mM sodium bicarbonate, and 0.1 mL enzyme extract. After incubation at 35°C for 30 min, the reaction was stopped by vigorous shaking until the dark blue color disappeared, followed by heating in boiling water for 1 min. After centrifugation (10,000 × g, 5 min, 4°C), the supernatant was mixed with 1 mL of 1% sulfanilamide (in 1.5 M HCl) and 1 mL of 0.02% NED. Absorbance was measured at 540 nm after 30 min. Residual NO₂⁻ was quantified using a NaNO₂ standard curve. One unit of NiR activity was defined as the amount of enzyme consuming 1 μmol NO₂⁻ per minute at 30°C.

2.10. Glutamine Synthetase (GS) Activity Assay

GS (EC 6.3.1.2) activity was determined using the hydroxamate method [28]. The reaction mixture (1.3 mL) contained 0.25 M Tris-HCl buffer (pH 7.0), 0.03 M ATP (pH 7.0), 0.5 M MgSO₄, 1 M hydroxylamine hydrochloride (pH 7.0), and 0.1 mL enzyme extract. After incubation at 30°C for 30 min, the reaction was terminated by adding 0.75 mL of FeCl₃ reagent (0.37 M FeCl₃, 0.2 M TCA, 0.67 M HCl). The absorbance of the γ-glutamyl hydroxamate (GGH)-Fe complex was measured at 540 nm. One unit of GS activity was defined as the amount of enzyme producing 1 μmol GGH per minute. Activity was expressed as U g⁻¹ FW.

2.11. Glutamate Synthase (GOGAT) Activity Assay

NADH-dependent GOGAT (EC 1.4.1.14) activity was assayed according to [29]. The reaction mixture (1.8 mL) contained 25 mM HEPES buffer (pH 7.5), 10 mM 2-oxoglutarate (α-ketoglutarate), 10 mM glutamine, 0.14 mM NADH, 10 mM KCl, 1 mM Na-EDTA, and 0.5% (v/v) β-mercaptoethanol. The reaction was initiated by adding 0.2 mL enzyme extract, and the decrease in absorbance at 340 nm (NADH oxidation) was monitored for 3 min. One unit of GOGAT activity was defined as the amount of enzyme oxidizing 1 μmol NADH per minute, using the extinction coefficient $\epsilon = 6.22 \times 10^3 \text{ L mol}^{-1} \text{ cm}^{-1}$.

2.12. Statistical Analysis

All experiments were conducted with three independent biological replicates, each measured in duplicate (n = 6). Data are presented as mean ± standard error (SE). Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test (p < 0.05) using SPSS software (version 15.0, SPSS). Different letters within each parameter indicate statistically significant differences (p < 0.05).

3. RESULTS AND DISCUSSION

3.1. Vanadium Accumulation in Tissues

The endogenous V content in roots and shoots of both wheat cultivars increased significantly (p < 0.05) with V application in a concentration-dependent manner (Table 1). In control plants, baseline V levels were low (4.18-5.11 ppm in roots; 1.47-1.73 ppm in shoots). After 0.1 mM V treatment, the root V content increased 23.6-fold in Altındane (to 98.75 ppm) and 15.2-fold in Doğu-88 (to 77.46 ppm). At 1 mM V, root V reached 188.86 ppm (45.1-fold increase) in Altındane and 138.46 ppm (27.1-fold increase) in Doğu-88. The shoot V content also increased but to a much lesser extent (2-15-fold), indicating that the V was predominantly retained in roots. The Altındane cultivar accumulated significantly more V than Doğu-88 in both roots and shoots at both concentrations (p < 0.05).



Table 1. Endogenous vanadium content (ppm, $\mu\text{g g}^{-1}$ DW) in roots and shoots of wheat cultivars after 24 h of V treatment.

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
Control	4.18 $\pm$ 0.13e	1.47 $\pm$ 0.07e	5.11 $\pm$ 0.12e	1.73 $\pm$ 0.19e
0.1 mM V	98.75 $\pm$ 3.04c	2.94 $\pm$ 0.21f	77.46 $\pm$ 3.98c	3.01 $\pm$ 0.76f
1 mM V	188.86 $\pm$ 7.18a	21.51 $\pm$ 1.98d	138.46 $\pm$ 6.24b	17.55 $\pm$ 2.56d

Values are mean $\pm$ SE (n = 6). Different letters within each column indicate significant differences (p < 0.05, Duncan's test). DR: Dry weight.

Our results are consistent with previous reports showing that V accumulates preferentially in roots of various plant species, including chickpea [7], sweet basil [30], and *Brassica* species [31]. This root-localized accumulation likely reflects limited translocation to shoots, possibly due to V binding to cell wall components or sequestration in vacuoles [13]. The higher V accumulation in Altındane compared to Doğu-88 suggests that the latter may possess more efficient V exclusion or detoxification mechanisms, which could contribute to its relatively higher stress tolerance.

3.2. Soluble Protein Content

The V treatment at 0.1 mM significantly decreased soluble protein content in both roots and shoots of both cultivars (Table 2). In Altındane, protein decreased by 18.4% in roots (from 733 to 598 $\mu\text{g g}^{-1}$ FW) and 7.5% in shoots (from 1421 to 1314 $\mu\text{g g}^{-1}$ FW). Similar reductions (13.3% in roots, 8.8% in shoots) were observed in Doğu-88. However, at 1 mM V, protein content was not significantly different from controls in most cases, except for a slight increase (7%) in Doğu-88 shoots. This biphasic response-decrease at low V, recovery or increase at high V-is intriguing and may reflect stress-induced synthesis of protective proteins (e.g., heat shock proteins, antioxidant enzymes) at higher V concentrations, or possibly reduced tissue water content causing apparent concentration effects.

Table 2. Soluble protein content ($\mu\text{g g}^{-1}$ FW) in roots and shoots of wheat cultivars.

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
Control	733 $\pm$ 13ef	1421 $\pm$ 18c	676 $\pm$ 21f	1581 $\pm$ 27b
0.1 mM V	598 $\pm$ 10g	1314 $\pm$ 40d	586 $\pm$ 18g	1442 $\pm$ 46d
1 mM V	808 $\pm$ 28e	1418 $\pm$ 34bc	689 $\pm$ 12f	1693 $\pm$ 39a

Values are mean $\pm$ SE (n = 6). Different letters indicate significant differences (p < 0.05).

Similar V-induced protein reduction has been reported in chickpea [7] and rice [32]. The decrease in protein content at 0.1 mM V likely results from inhibition of protein synthesis (due to impaired N assimilation, as discussed below) and/or enhanced proteolysis under oxidative stress conditions. The lack of protein decrease at 1 mM V may be explained by the activation of stress-responsive protein synthesis, a phenomenon commonly observed under severe stress where cells produce chaperones and antioxidant enzymes to mitigate damage [33].



3.3. Lipid Peroxidation (as MDA) Content

The V treatment significantly increased MDA content, an indicator of lipid peroxidation (LPO) and oxidative membrane damage, in both cultivars (Table 3). At 0.1 mM V, MDA increased by 45.8% in Altındane roots (from 4.02 to 5.86 nmol mL⁻¹) and 36.8% in Doğu-88 roots (from 3.75 to 5.13 nmol mL⁻¹). At 1 mM V, the increases were even more pronounced: 77.1% in Altındane roots and 57.9% in Doğu-88 roots. Shoot MDA levels also increased but to a lesser extent (6-12% increases), reflecting the lower V accumulation in shoots. The Altındane cultivar consistently showed higher MDA levels than Doğu-88 under V stress, indicating greater oxidative damage.

Table 3. MDA content (nmol mL⁻¹) in roots and shoots of wheat cultivars.

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
Control	4.02 ± 0.21f	5.65 ± 0.43d	3.75 ± 0.42f	6.74 ± 0.37bc
0.1 mM V	5.86 ± 0.62d	6.32 ± 0.50cd	5.13 ± 0.65e	7.15 ± 0.56a
1 mM V	7.12 ± 0.45ab	5.21 ± 0.49e	5.92 ± 0.89d	7.46 ± 0.67a

Values are mean ± SE (n = 6). Different letters indicate significant differences (p < 0.05).

Elevated MDA levels indicate that the V exposure induces ROS production and subsequent lipid peroxidation, consistent with previous studies in *Brassica napus* [14], chickpea [7], and melon [15]. The positive correlation between V accumulation (Table 1) and MDA increase (Table 3) across tissues and cultivars strongly suggests that V-induced oxidative stress is directly related to tissue V concentration. The greater oxidative damage in Altındane roots correlates with its higher V accumulation, supporting the conclusion that Doğu-88's relative tolerance involves more efficient ROS scavenging or V chelation mechanisms.

3.4. Photosynthetic Pigment Content

V treatment significantly reduced chlorophyll a and b contents in both cultivars, with the effect being more pronounced at 1 mM V (Tables 4 and 5). In Altındane, chlorophyll a decreased by 9.3% at 0.1 mM V and 15.1% at 1 mM V; chlorophyll b decreased by 7.7% and 11.3%, respectively. In Doğu-88, the reductions were somewhat smaller: chlorophyll a decreased by 3.3% and 13.8%, chlorophyll b by 6.7% and 8.6% at 0.1 and 1 mM V, respectively. Chlorophyll a was more sensitive to V stress than chlorophyll b in both cultivars. Total chlorophyll content declined by 16.4% (Altındane) and 9.0% (Doğu-88) at 0.1 mM V, and by 19.5% and 21.9% at 1 mM V, respectively.

In striking contrast, carotenoid content increased significantly under V stress. In Altındane, carotenoids rose by 14.0% and 19.5% at 0.1 and 1 mM V, respectively; in Doğu-88, increases were 6.9% and 13.9%, respectively (Tables 4 and 5).

Table 4. Photosynthetic pigment content (mg g⁻¹ fresh weight) in Altındane shoots.

Treatment	Chl a	Chl b	Total Chl	Carotenoids
Control	1.72 ± 0.08c	1.42 ± 0.06e	2.92 ± 0.06a	0.215 ± 0.02b
0.1 mM V	1.56 ± 0.06d	1.31 ± 0.08f	2.44 ± 0.06a	0.245 ± 0.01a



Treatment	Chl a	Chl b	Total Chl	Carotenoids
1 mM V	1.46 ± 0.05de	1.26 ± 0.09f	2.35 ± 0.07b	0.257 ± 0.03a

Values are mean ± SE (n = 6). Different letters within each column indicate significant differences (p < 0.05).

Table 5. Photosynthetic pigment content (mg g⁻¹ fresh weight) in Doğu-88 shoots.

Treatment	Chl a	Chl b	Total Chl	Carotenoids
Control	1.81 ± 0.07a	1.62 ± 0.15de	3.11 ± 0.21a	0.274 ± 0.02b
0.1 mM V	1.75 ± 0.08d	1.51 ± 0.11ef	2.83 ± 0.09b	0.293 ± 0.01ba
1 mM V	1.56 ± 0.04e	1.48 ± 0.07f	2.43 ± 0.12c	0.312 ± 0.04a

Values are mean ± SE (n = 6). Different letters within each column indicate significant differences (p < 0.05).

The V-induced decline in chlorophyll content is consistent with previous observations in rice [32], pepper [34], and *Brassica napus* [14]. Several mechanisms may explain this decline: (i) V interferes with Mg and Fe uptake and utilization, both essential for chlorophyll biosynthesis [35]; (ii) V-induced oxidative stress damages chloroplast membranes and pigment-protein complexes; (iii) inhibition of N assimilation (discussed below) reduces the availability of nitrogenous precursors for chlorophyll synthesis (e.g., glutamate, which is the precursor for δ-aminolevulinic acid). The greater sensitivity of chlorophyll a compared to chlorophyll b has been reported for other heavy metals and may reflect differential susceptibility of photosystem II (enriched in Chl a) versus light-harvesting complexes (enriched in Chl b).

The increase in carotenoid content under the V stress is a notable finding. Carotenoids serve as non-enzymatic antioxidants, scavenging singlet oxygen and triplet chlorophyll, and dissipating excess excitation energy through the xanthophyll cycle [36]. The upregulation of carotenoids likely represents an adaptive response to V-induced oxidative stress, protecting photosynthetic apparatus from photo-oxidative damage. Similar carotenoid increases have been reported under various abiotic stresses, including heavy metal exposure [37,38]. The higher carotenoid increase in Altındane (19.5% at 1 mM V) compared to Doğu-88 (13.9%) may indicate a stronger stress response rather than higher tolerance, as this cultivar also showed greater chlorophyll loss and MDA accumulation.

3.5. Nitrate Reductase (NR) Activity

NR activity was significantly inhibited by the V treatment in both roots and shoots of both cultivars, with inhibition being more pronounced at 1 mM V and in roots (Table 6). In Altındane roots, NR activity decreased by 16.7% at 0.1 mM V and 32.3% at 1 mM V; in shoots, decreases were 9.2% and 18.4%, respectively. In Doğu-88, the decreases were slightly smaller: roots 13.7% and 31.7%; shoots 7.2% and 17.4% at 0.1 and 1 mM V, respectively. Control NR activity was higher in shoots than roots for both cultivars, consistent with the general pattern that leaves are the primary site of NO₃⁻ reduction in most herbaceous plants [16].

Table 6. Nitrate reductase (NR) activity (μmol NO₂⁻ g⁻¹ FW) in wheat cultivars.

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
Control	6.88 ± 0.51ef	7.50 ± 0.34e	10.78 ± 0.71bc	12.74 ± 0.23a
0.1 mM V	5.73 ± 0.33g	6.81 ± 0.16f	8.52 ± 0.41d	11.82 ± 0.12b

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
1 mM V	4.66 ± 0.14g	6.12 ± 0.29f	7.36 ± 0.24e	10.52 ± 0.14c

Values are mean ± SE (n = 6). Different letters indicate significant differences (p < 0.05).

NR is the first and rate-limiting enzyme in the NO₃⁻ assimilation pathway, and its activity is highly sensitive to environmental stresses. The inhibition of NR by V observed in this study is consistent with reports on other heavy metals: Cd inhibits NR in *Solanum nigrum* [39] and bean [17]; Zn inhibits NR in rice [40]; Cr inhibits NR in clusterbean [19]. Several mechanisms may account for V-induced NR inhibition: (i) direct interaction of vanadate with the enzyme, as vanadate is a known phosphate analog and can bind to the molybdenum cofactor of NR; (ii) V-induced ROS production leading to oxidative modification of the enzyme; (iii) reduced availability of NADH (the electron donor for NR) due to impaired photosynthesis and/or mitochondrial electron transport; (iv) downregulation of NR gene expression in response to stress. [32] suggested that V-induced NR inhibition in rice was not due to substrate limitation (NO₃⁻) but rather to reduced supply of reducing equivalents (NAD(P)H) from photosynthetic processes. Our observation that NR inhibition was more severe in roots than shoots, despite lower V accumulation in shoots (Table 1), suggests that additional factors such as the direct toxic effect of V translocated to shoots may also contribute.

3.6. Nitrite Reductase (NiR) Activity

NiR activity was also significantly inhibited by V treatment, with a pattern similar to NR but with some differences (Table 7). Control NiR activity was substantially higher than NR activity (e.g., 16.5 vs. 6.9 μmol NO₂⁻ g⁻¹ FW in Altındane roots; 19.8 vs. 7.5 in shoots), reflecting the need to rapidly metabolize the toxic NO₂⁻ produced by NR. V treatment at 0.1 mM reduced NiR activity by 12.9% in Altındane roots and 9.9% in shoots; at 1 mM V, reductions were 26.5% and 18.1%, respectively. In Doğu-88, the reductions were 9.3% (roots) and 3.0% (shoots) at 0.1 mM V, and 24.6% (roots) and 11.0% (shoots) at 1 mM V. As with NR, root NiR was more severely inhibited than shoot NiR, particularly at 1 mM V.

Table 7. Nitrite reductase (NiR) activity (μmol NO₂⁻ g⁻¹ FW) in wheat cultivars.

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
Control	16.51 ± 0.42de	19.83 ± 0.41c	20.13 ± 0.31bc	24.45 ± 0.97a
0.1 mM V	14.38 ± 0.51g	17.86 ± 0.61d	18.26 ± 0.64cd	23.71 ± 0.13a
1 mM V	12.14 ± 0.43h	16.25 ± 0.24ef	15.17 ± 0.18fg	21.76 ± 0.75b

Values are mean ± SE (n = 6). Different letters indicate significant differences (p < 0.05).

The inhibition of NiR by V is consistent with reports on other heavy metals. In peanut (*Arachis hypogaea*), 0.1 mM Cd inhibited NiR by >50% [41]. In wheat, 100 mM Ni caused nearly 80% reduction in NiR activity after 7 days [18]. NiR is a plastid-localized enzyme containing an Fe-S cluster and siroheme prosthetic groups, both of which are potential targets for metal toxicity. The more severe inhibition of NiR in roots compared to shoots correlates with higher V accumulation in roots, suggesting a direct toxic effect. The fact that Doğu-88 maintained higher NiR activity under V stress (e.g., 23.71 vs. 17.86 μmol NO₂⁻ g⁻¹ FW at 0.1 mM V in shoots)

indicates better preservation of NO_2^- reduction capacity, which is critical for preventing NO_2^- accumulation and its associated toxicity.

3.7. Glutamine Synthetase (GS) Activity

GS activity was the most severely affected among the four enzymes studied, showing substantial inhibition even at 0.1 mM V (Table 8). In Altındane roots, GS activity decreased by 26.3% at 0.1 mM V (from 3.69 to 2.72 U g^{-1} FW) and 39.8% at 1 mM V (to 2.43 U g^{-1} FW). Shoot GS was also significantly inhibited (17.0% at 0.1 mM V; 39.2% at 1 mM V). In Doğu-88, root GS decreased by 22.6% at 0.1 mM V (from 5.71 to 4.42 U g^{-1} FW) and 37.7% at 1 mM V (to 3.56 U g^{-1} FW). Interestingly, shoot GS in Doğu-88 was not significantly affected at 0.1 mM V (10.16 vs. 9.18 U g^{-1} FW, $p > 0.05$) but decreased by 20.6% at 1 mM V.

Table 8. Glutamine synthetase (GS) activity (U g^{-1} FW) in wheat cultivars.

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
Control	3.69 $\pm$ 0.14e	4.24 $\pm$ 0.25ed	5.71 $\pm$ 0.29c	9.18 $\pm$ 1.14a
0.1 mM V	2.72 $\pm$ 0.21f	3.52 $\pm$ 0.31e	4.42 $\pm$ 0.24cd	10.16 $\pm$ 1.23a
1 mM V	2.43 $\pm$ 0.13f	2.58 $\pm$ 0.09f	3.56 $\pm$ 0.19e	7.29 $\pm$ 0.19b

Values are mean $\pm$ SE ($n = 6$). Different letters indicate significant differences ($p < 0.05$).

GS catalyzes the ATP-dependent condensation of NH_4^+ with glutamate to form glutamine, representing the primary pathway for NH_4^+ assimilation in plants. The high sensitivity of GS to the V stress is alarming because GS inhibition leads to NH_4^+ accumulation, which is phytotoxic even at low concentrations. Similar heavy metal inhibition of GS has been reported: Cd inhibited GS by ~50% in lupine [42] and maize [43]; Ni caused significant GS inhibition in wheat [18]. Vanadate is a well-known inhibitor of P-type ATPases, including plasma membrane H^+ -ATPases, and can also interfere with ATP metabolism [44]. The severe GS inhibition observed may result from V-induced ATP depletion (GS requires ATP) and/or direct interaction of vanadate with the enzyme's active site. The relative tolerance of Doğu-88 shoot GS to 0.1 mM V may contribute to this cultivar's overall better performance under V stress.

3.8. Glutamate Synthase (GOGAT) Activity

GOGAT activity showed a unique response pattern distinct from the other three enzymes (Table 9). In control plants, GOGAT activity was substantially higher in shoots than in roots (e.g., 60.0 vs. 6.4 U g^{-1} FW in Altındane; 47.2 vs. 8.2 U g^{-1} FW in Doğu-88), reflecting the predominant role of leaf chloroplasts in N assimilation. The V treatment at 0.1 mM increased root GOGAT activity by 26.8% in Altındane (from 6.43 to 8.15 U g^{-1} FW) and 21.0% in Doğu-88 (from 8.15 to 9.86 U g^{-1} FW). At 1 mM V, root GOGAT remained elevated in Altındane (+33.3%) but decreased in Doğu-88 (-19.9% compared to control). In contrast, shoot GOGAT activity was significantly decreased by the V treatment: in Altındane, by 21.4% at 0.1 mM V and 54.5% at 1 mM V; in Doğu-88, by 12.1% at 0.1 mM V and 23.4% at 1 mM V.

Table 9. Glutamate synthase (GOGAT) activity (U g⁻¹ FW) in wheat cultivars.

Treatment	Altındane		Doğu-88	
	Root	Shoot	Root	Shoot
Control	6.43 ± 0.35b	60.02 ± 1.26a	8.15 ± 0.33g	47.16 ± 0.94b
0.1 mM V	8.15 ± 1.04g	47.16 ± 0.96b	9.86 ± 0.46f	41.44 ± 0.93c
1 mM V	8.57 ± 0.47fg	27.29 ± 0.21e	6.53 ± 0.32h	36.15 ± 0.78d

Values are mean ± SE (n = 6). Different letters indicate significant differences (p < 0.05).

The differential response of GOGAT-activation in roots but inhibition in shoots-is intriguing and may reflect tissue-specific differences in V toxicity mechanisms or in the regulation of GOGAT isoforms. Plants contain two major GOGAT isoforms: ferredoxin-dependent GOGAT (Fd-GOGAT), which is predominantly expressed in leaf chloroplasts and accounts for most GOGAT activity in photosynthetic tissues; and NADH-dependent GOGAT (NADH-GOGAT), which is more abundant in non-photosynthetic tissues (roots) and is involved in primary N assimilation and N remobilization [16]. The NADH-GOGAT isoform may be less sensitive to V or even activated under mild stress conditions as a compensatory mechanism. The activation of root GOGAT at 0.1 mM V suggests that plants attempt to maintain NH₄⁺ assimilation capacity despite the severe inhibition of GS (which supplies the glutamine substrate for GOGAT). However, at 1 mM V, even root GOGAT was inhibited in Doğu-88, indicating that the compensatory capacity is overwhelmed at higher V concentrations. The dramatic inhibition of shoot GOGAT (particularly in Altındane at 1 mM V, >50% reduction) likely contributes to the observed decline in chlorophyll and protein content, as GOGAT is essential for providing glutamate for chlorophyll and amino acid biosynthesis.

4. CONCLUSIONS

This study provides a comprehensive analysis of the short-term (24 h) effects of vanadium stress on the entire nitrogen assimilation pathway in wheat. The results of this study collectively demonstrate that the V stress rapidly (within 24 h) disrupts N assimilation in wheat through a cascade of inhibitory effects. The primary site of V accumulation is the root system, where V concentrations reach levels 4-45 times higher than in shoots. This root-localized V accumulation leads to: (i) severe oxidative stress, as evidenced by 46-77% increases in MDA content; (ii) inhibition of NR, NiR, and GS activities, with roots showing greater inhibition than shoots; (iii) disruption of protein metabolism, with decreased soluble protein at 0.1 mM V.

The inhibition of NR and NiR impairs the reduction of NO₃⁻ to NH₄⁺, while inhibition of GS prevents the assimilation of NH₄⁺ into glutamine. The net effect is a bottleneck in N flow from inorganic to organic forms, leading to reduced synthesis of amino acids, proteins, and chlorophyll. The differential response of GOGAT-activation in roots but inhibition in shoots-suggests that roots attempt to compensate for GS inhibition by upregulating NADH-GOGAT, but this compensatory mechanism is insufficient to maintain overall N assimilation capacity.

The Doğu-88 cultivar exhibited relatively higher tolerance to the V stress compared to Altındane. These situation may be attributed to genetic variation in V uptake, translocation, chelation (e.g., by phytochelatins or organic acids), and/or antioxidant capacity. The rapid inhibition of N assimilation enzymes by the V levels suggests that even short-term exposure to V-contaminated soils or irrigation water could impair crop N use efficiency and reduce protein



and chlorophyll content. This is particularly concerning for wheat, a V-sensitive crop that is a major global food source.

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Effect of NiS on Hydrogen Evolution Reaction Performance of CoCr₂O₄-Graphene Nanostructures

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Abstract

In this study, cobalt chromite-graphene nanostructures (CCO-G) were prepared on the surface of nickel foam electrodes using electrochemical techniques. Subsequently, CCO-G surfaces were electrochemically coated with NiS. The HER performance of NiS-coated and uncoated electrodes was compared in an acidic environment. It was determined that the HER current density increased approximately two-fold with the addition of NiS. In this respect, NiS made a positive contribution to CCO-G.

Keywords: Electrochemical synthesis, graphene, hydrogen evolution reaction, cobalt chromide.

1. INTRODUCTION

With the development of renewable energy sources, electrolytic hydrogen production is attracting attention as an alternative method for producing hydrogen for fuel cells. The hydrogen evolution reaction (HER) is one of the most frequently studied and simplest electrocatalytic processes. HER occurs as a cathodic reaction in electrochemical water splitting. HER involves hydrogen adsorption on the electrode surface, and the adsorption energy depends on the nature of the electrode materials used. Accordingly, the kinetics of HER can also vary. Strong hydrogen adsorption occurs in noble metals such as Pt, Rh, Ru, Ir, and Pd [1]. However, the scarcity and high cost of these noble metals limit their use. Nickel and nickel-based catalysts have been frequently used in HER applications due to their low cost, platinum-like hydrogen adsorption properties, and environmental friendliness [2].

Spinel oxides, belonging to the mineral class with the general formula AB₂O₄, are materials with significant properties not found in binary oxides. Spinel oxides have rapidly become a research focus in the fields of nanoscience and engineering. Cobalt chromite (CoCr₂O₄; CCO), a member of the spinel oxides, has emerged as an interesting class of materials due to its absorption in the visible region, high resistance to corrosion and oxidation, high thermal stability, and mechanical strength. CCO nanoparticles are used in various applications, including catalysts, industrial inorganic pigments, gas sensors, and electrode materials for solid oxide fuel cells. To date, several synthesis methods have been reported for the synthesis of CCO nanostructures, including hydrothermal, solvothermal, sol-gel, co-precipitation, microwave-assisted synthesis, and spray pyrolysis. However, most of these methods involve high temperatures, high energy, and harmful chemicals. Therefore, new, rapid, and low-cost methods

that do not create harmful byproducts that seriously affect the environment and human health are being investigated.

Nickel sulfide (NiS) is a promising material for a wide range of applications, including electrochemical energy conversion and storage, due to its high conductivity, chemical stability, and cost-effectiveness. However, obtaining high-quality, phase-pure, and homogeneous NiS thin films remains challenging. In this study, the surfaces of CoCr₂O₄-graphene nanostructures were coated with NiS using an electrochemical technique. The HER performance of the fabricated NiS/CoCr₂O₄-graphene electrodes was investigated. Electrochemical measurements showed that the NiS coating exhibited high catalytic activity for HER under acidic conditions.

2. MATERIALS AND METHODS

All electrochemical studies were performed in a three-electrode cell. Nickel foam was used as the working electrode, Pt wire as the counter electrode, and Ag/AgCl as the reference electrode. Electrochemical synthesis of cobalt chromide nanostructures was carried out in electrolytes containing 5 mM Cr(NO₃)₃ and 10 mM Co(NO₃)₂. Graphene oxide was chosen as the graphene source. For the NiS coating, cyclic voltammetry was performed in a mixture of 2 mM NiCl₂ and 0.5 M thiourea.

3. RESULTS AND DISCUSSION

CCO-G nanostructures were produced in a one-pot, constant-potential environment on the surface of nickel foam electrodes using electrochemical techniques. For this purpose, 5 mM Cr(NO₃)₃, 10 mM Co(NO₃)₂, and graphene oxide solutions were mixed and deposited at a constant potential of -1.3 V for 30 minutes. Heat treatment at 500 °C for 1 hour was applied to form the CCO-G structure. Cyclic voltammetry was used to coat the surfaces of the produced CCO-G electrodes with NiS. The cyclic voltamogram recorded with the CCO-G electrode in a solution containing Ni²⁺ and thiourea is shown in Figure 1.

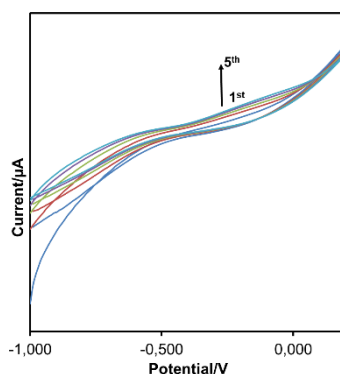


Figure 1. Coating of CCO-G electrode surfaces with NiS.

The HER performance of the prepared NiS/CCO-G electrodes was investigated in a 0.5 M H₂SO₄ solution. To compare their performance, linear sweep voltamograms (LSVs) of the CCO, CCO-G, and NiS/CCO-G electrodes are shown in Figure 2. When the HER performance was compared, the NiS/CCO-G electrode exhibited a lower HER overvoltage and higher current.

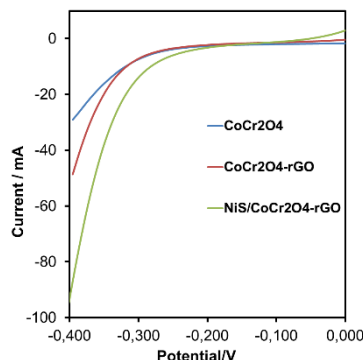


Figure 2. HER performances of CCO, CCO-G, and NiS/CCO-G electrodes.

4. CONCLUSIONS

In summary, CCO, CCO-G, and NiS/CCO-G electrodes were successfully produced using an electrochemical technique. The electrodes synthesized using various techniques were characterized. HER performance was studied in a 0.5 M H₂SO₄ electrolyte. The NiS coating provided approximately a 2-fold increase in current.

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Bacterial One-Step Synthesis and Electronic Application Potential of GO-Based Metal and Semiconductor Nanocomposites

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Abstract

The development of environmentally friendly and scalable synthesis routes for functional nanomaterials has become a key challenge in advanced electronic material research. In this study, graphene oxide (GO)-based metal and semiconductor nanocomposites, including GO:Se, GO:Cu, and GO:Cu:In, were successfully synthesized via a one-step bacterial reduction method and deposited as thin films on p-Si substrates.

The structural, morphological, and compositional properties of the synthesized nanocomposites were systematically investigated using X-ray diffraction (XRD), field-emission scanning electron microscopy (FE-SEM), and energy dispersive X-ray spectroscopy (EDX). XRD analysis revealed that all samples exhibit polycrystalline behavior, with characteristic diffraction peaks corresponding to GO, CuO, and In₂O₃ phases. The calculated crystallite sizes ranged between approximately 2 nm and 49 nm, indicating nanocrystalline structure formation with composition-dependent variations.

FE-SEM analysis demonstrated distinct morphological differences among the samples, where GO:Se exhibited a layered sheet-like structure, GO:Cu showed a more compact and continuous film morphology, and GO:Cu:In presented a nanoparticle-rich granular surface due to enhanced nucleation effects. EDX results confirmed the successful incorporation of Se, Cu, and In elements into the GO matrix, validating the formation of multi-component nanocomposite systems.

The results indicate that the bacterial synthesis approach enables tunable structural and morphological properties through controlled incorporation of metal and semiconductor components. These findings highlight the potential of GO-based nanocomposites as promising materials for electronic, optoelectronic, and sensing device applications.

Keywords: Graphene Oxide, Bacterial Synthesis, Nanocomposites, Semiconductor Nanoparticles, Electronic Devices

1. INTRODUCTION

Graphene-based nanomaterials have attracted significant attention in recent years due to their exceptional electrical, mechanical, and surface properties, making them promising candidates for advanced electronic and optoelectronic applications. Among these materials, graphene oxide (GO) stands out as a versatile platform due to its oxygen-containing functional groups, large surface area, and tunable electronic structure. These properties enable the effective



incorporation of metal and semiconductor nanoparticles, leading to hybrid nanocomposites with enhanced interfacial and electrical characteristics [1].

The synthesis of metal and semiconductor nanoparticles has traditionally relied on chemical and physical methods, which often involve high energy consumption, toxic chemicals, and complex processing steps. In contrast, green synthesis approaches have emerged as sustainable alternatives, offering environmentally friendly, low-cost, and scalable production routes. Biological systems such as plants, fungi, and bacteria have been widely used for nanoparticle synthesis due to their ability to reduce metal ions under mild conditions [2,3].

Bacterial-mediated synthesis, in particular, has gained considerable attention because of its enzymatic reduction mechanisms and its ability to produce stable nanoparticles with controlled morphology. Various studies have reported the biosynthesis of metallic nanoparticles such as Ag, Cu, and Au using microorganisms and their applications in catalysis, sensing, and electronic devices [2,3]. In addition, graphene oxide-based nanostructures have been successfully applied in sensing, electrode fabrication, and biomedical applications due to their high surface reactivity and conductivity [1,4].

Furthermore, GO-based metal nanocomposites such as GO:Cu have demonstrated polycrystalline structures and improved electrical characteristics when fabricated on semiconductor substrates, particularly in metal–semiconductor device configurations [4]. Recent studies have also shown that complex multi-component nanostructures such as GO:Cu:In can be synthesized via bacterial reduction, resulting in nanocrystalline thin films with promising optical and electronic properties [5].

Although significant progress has been made in the synthesis of single and binary nanocomposite systems, the simultaneous biosynthesis of multi-element GO-based nanocomposites remains limited in the literature. The development of such multifunctional materials is essential for tuning electrical, structural, and interfacial properties for advanced electronic applications.

In this study, GO-based metal and semiconductor nanocomposites (GO:Cu, GO:Cu:In, GO:Ag, GO:Se, and GO:Se:In) were synthesized via a one-step bacterial reduction method. The novelty of this work lies in the simultaneous incorporation of multiple metal and semiconductor elements into the GO matrix using a single-step biological approach. The structural, morphological, and compositional properties of the synthesized nanocomposites were systematically investigated, and their potential for electronic device applications was evaluated.

2. MATERIALS AND METHODS

Graphene oxide (GO) was used as the base material for the synthesis of metal and semiconductor nanocomposites. Metal precursor salts including copper sulfate (CuSO_4), indium chloride (InCl_3), and selenium dioxide (SeO_2) were prepared in aqueous solutions at appropriate molar concentrations. All chemicals were of analytical grade and used without further purification.

The bacterial strain *Pseudomonas aeruginosa* OG1 was employed as the biological reducing agent. The bacterial culture was prepared following previously reported procedures, where the strain was grown in Tryptic Soy Broth at 30 °C under shaking conditions (150 rpm) for 24 h to reach the exponential growth phase [2,6]. The prepared bacterial suspension ($\text{OD}_{600} \approx 1$) was



then inoculated into Luria–Bertani (LB) medium containing GO dispersion and metal precursor ions [6].

The biosynthesis process was carried out under dark conditions at 30 °C for approximately 72–96 h with continuous agitation. During this process, bacterial enzymatic activity enabled the simultaneous reduction of metal ions (Cu^{2+} , In^{3+} , SeO_3^{2-}) and their nucleation on the GO surface, leading to the formation of multi-component GO-based nanocomposites. This one-step synthesis approach allows homogeneous nanoparticle distribution and strong interfacial interaction between GO sheets and embedded nanoparticles, consistent with previous microbial synthesis studies [2,3,6].

After completion of the synthesis, the nanoparticles were separated from the bacterial medium by centrifugation and purified through repeated washing with deionized water [6]. The resulting colloidal solution was used for thin film fabrication. The nanocomposite solutions were deposited onto glass and p-type silicon (p-Si) substrates using a drop-casting technique [5,6]. Prior to deposition, the p-Si substrates were chemically cleaned using standard cleaning procedures to remove surface contaminants and native oxide layers [5].

The deposited films were dried and subsequently thermally treated at approximately 300 °C to improve adhesion and crystallinity of the nanocomposite layer [4,5]. For electronic device fabrication, aluminum (Al) was thermally evaporated onto the backside of the p-Si substrate to form an ohmic contact, followed by annealing at approximately 550 °C in a nitrogen atmosphere [5]. Gold (Au) was deposited onto the nanocomposite layer as a rectifying contact using a shadow mask technique, resulting in metal–semiconductor device structures [5].

Structural characterization of the synthesized nanocomposites and thin films was performed using X-ray diffraction (XRD) to determine crystalline phases and nanocrystalline nature [4]. Surface morphology and nanoparticle distribution were analyzed using field-emission scanning electron microscopy (FE-SEM), while elemental composition was determined by energy dispersive X-ray spectroscopy (EDX) [4,5]. Raman spectroscopy was used to evaluate structural disorder and defect density in the GO matrix. In addition, optical properties were analyzed using UV–Vis spectroscopy when required [4].

3. RESULTS AND DISCUSSION

The structural, morphological, and compositional properties of the synthesized GO-based nanocomposites were comprehensively investigated using XRD, FE-SEM, and EDX analyses.

Fig. 1 presents the comparative XRD patterns of GO:Se/p-Si, GO:Cu/p-Si, and GO:Cu:In/p-Si thin film structures. All samples exhibit distinct diffraction peaks corresponding to the p-Si substrate at approximately $2\theta \approx 33^\circ$, 61.5° , and 69° , confirming the successful deposition of nanocomposite thin films on the silicon substrate. In addition to substrate-related peaks, characteristic diffraction peaks associated with graphene oxide and metal/metal oxide phases are also observed.

For the GO:Se structure, two characteristic peaks located at $2\theta \approx 9.36^\circ$ and 23.11° correspond to the (002) plane of graphene oxide. The calculated interlayer spacing values of 0.94 nm and 0.38 nm indicate expanded GO layers due to the presence of oxygen-containing functional groups and structural defects, which is consistent with the literature [11,12]. The broad nature of these peaks suggests a partially amorphous structure.

In the GO:Cu sample, additional diffraction peaks observed at $2\theta \approx 28.27^\circ$ and 31.31° correspond to graphite (101) and CuO (110) phases, respectively. The presence of CuO confirms the successful incorporation of copper species into the GO matrix via the bacterial synthesis process. Similarly, the GO:Cu:In structure exhibits multiple diffraction peaks corresponding to graphite, CuO, and In_2O_3 phases. The appearance of the (111) peak of In_2O_3 at $2\theta \approx 35.34^\circ$ confirms the successful formation of a multi-component nanocomposite system.

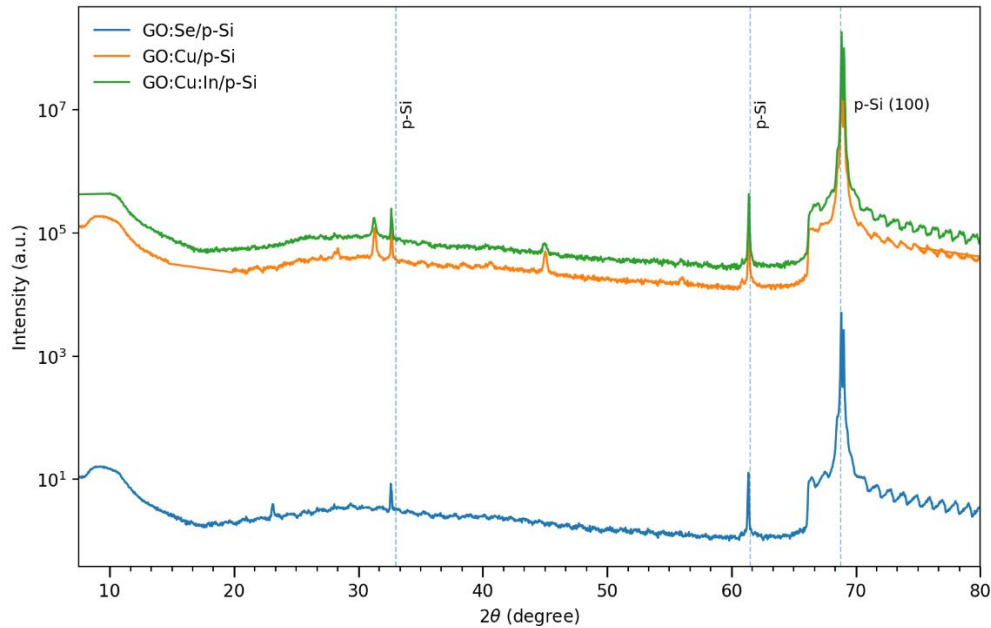


Fig. 1. Log-scaled XRD patterns of GO:Se/p-Si, GO:Cu/p-Si, and GO:Cu:In/p-Si nanocomposite thin films. The diffraction peaks observed at approximately $2\theta \approx 33^\circ$, 61.5° , and 69° correspond to the p-Si (100) substrate

The detailed structural parameters obtained from XRD analysis are summarized in Table 1. The crystallite size values calculated using the Debye–Scherrer equation indicate that the nanocomposites exhibit nanocrystalline behavior, with crystallite sizes ranging from approximately 2 nm to 49 nm. The variation in crystallite size depending on the incorporated metal species suggests that the bacterial synthesis process enables tunable structural properties.

Table 1. Structural parameters of GO-based nanocomposite thin films obtained from XRD analysis, including peak positions, FWHM values, interplanar spacing (d), crystallite size (D), and corresponding phases.

Sample	(hkl)	FWHM (°)	FWHM (rad)	Intensity (a.u.)	2θ (°)	d (nm)	Crystallite Size D (nm)	Phase
GO:Se/p-Si	(002)	3.58	0.062	4745.10	9.36	0.94	2.23	GO
	(002)	0.165	0.003	559.12	23.11	0.38	49.15	GO
	(002)	3.58	0.062	4745.10	9.36	0.94	2.23	GO
GO:Cu/p-Si	(101)	0.38	0.006	383.16	28.27	0.35	21.60	Graphite
	(110)	0.20	0.004	2467.33	31.31	0.29	41.51	CuO
GO:Cu:In/p-Si	(200)	0.255	0.004	790.87	45.02	0.20	33.73	GO
	(002)	0.52	0.009	2784.18	10.46	0.85	35.23	GO



(101)	0.45	0.008	66.42	28.21	0.32	25.60	Graphite
(110)	0.19	0.003	1164.59	31.25	0.29	45.51	CuO
(111)	0.37	0.007	78.40	35.34	0.25	22.03	In ₂ O ₃
(200)	0.26	0.005	252.13	44.96	0.20	33.73	GO

Fig. 2 shows the FE-SEM images of the synthesized nanocomposites. The cross-sectional image of GO:Se (Fig. 2a) reveals a layered thin film structure with good adhesion to the substrate. The surface morphology of GO:Se (Fig. 2b) exhibits typical sheet-like graphene oxide structures with wrinkled morphology. In contrast, the GO:Cu structure (Fig. 2c) shows a more compact and continuous film surface, indicating improved film formation due to copper incorporation. The GO:Cu:In sample (Fig. 2d) presents a granular and nanoparticle-rich morphology, suggesting increased nucleation and particle growth resulting from the presence of multiple metal components.

The elemental composition of the samples was analyzed using EDX spectroscopy, as shown in Fig. 3. The GO:Se spectrum confirms the presence of C, O, Se, and Si elements, where Si originates from the substrate. The GO:Cu sample shows dominant peaks of C, O, Si, and Cu, with quantitative analysis indicating 75.75 wt% Si, 19.12 wt% O, and 5.13 wt% Cu, confirming the successful incorporation of copper into the GO structure. Similarly, the GO:Cu:In spectrum reveals the presence of Cu and In along with C, O, and Si, validating the formation of a multi-component nanocomposite.

Overall, the combined XRD, SEM, and EDX results demonstrate that the bacterial synthesis approach enables the successful formation of GO-based metal and semiconductor nanocomposites with tunable structural and morphological properties. The incorporation of different metal species significantly influences crystallinity, morphology, and elemental composition, which are critical parameters for electronic device applications.

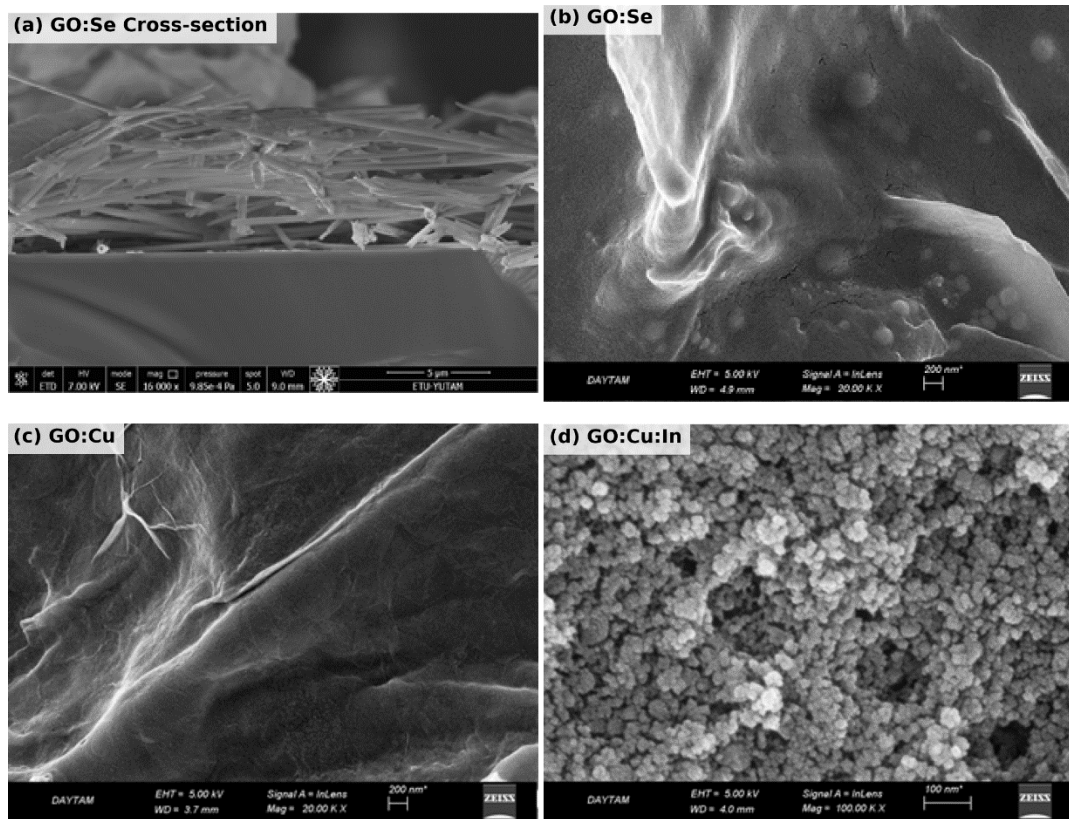


Fig.2. FE-SEM images of GO-based nanocomposites: (a) cross-sectional image of GO:Se thin film, (b) surface morphology of GO:Se, (c) GO:Cu thin film, and (d) GO:Cu:In nanocomposite structure.

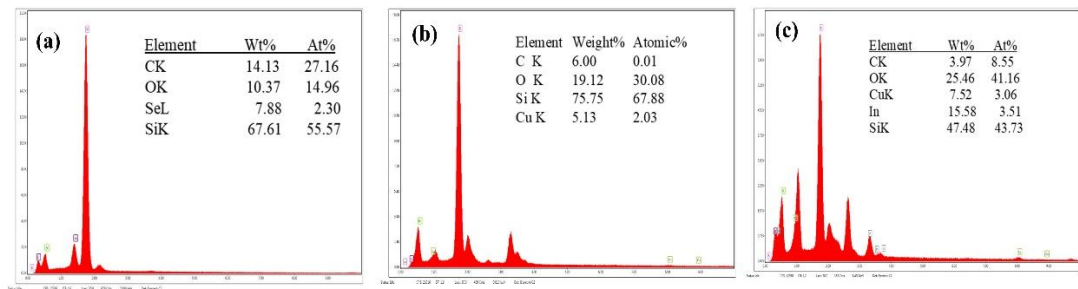


Fig. 3. EDX spectra and corresponding elemental compositions of GO-based nanocomposites: (a) GO:Se, (b) GO:Cu, and (c) GO:Cu:In thin films deposited on p-Si substrate.

4. CONCLUSIONS

In this study, GO-based metal and semiconductor nanocomposites (GO:Se, GO:Cu, and GO:Cu:In) were successfully synthesized using an environmentally friendly bacterial reduction method and deposited as thin films on p-Si substrates. XRD analysis confirmed that all samples exhibit polycrystalline structures, with characteristic GO and metal oxide diffraction peaks. The presence of CuO and In₂O₃ phases demonstrated the successful incorporation of metal and semiconductor elements into the GO matrix. The calculated crystallite sizes indicated nanocrystalline structures with tunable properties depending on the composition. FE-SEM analysis revealed distinct morphological differences among the samples. GO:Se exhibited a typical layered sheet structure, while GO:Cu showed a more uniform film morphology. The



GO:Cu:In sample presented a nanoparticle-rich and granular surface, indicating enhanced nucleation behavior in multi-component systems. EDX results verified the elemental composition of the synthesized nanocomposites, confirming the presence of expected elements such as C, O, Se, Cu, and In. The strong Si signal in all samples originated from the p-Si substrate, further confirming successful film deposition.

The results demonstrate that bacterial synthesis provides a simple, cost-effective, and scalable method for producing multifunctional GO-based nanocomposites. The tunable structural and morphological properties of these materials make them promising candidates for future electronic, optoelectronic, and sensing applications.

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Production and Applications of Nickel Selenide Modified Graphene-Based Electrodes for Roll-Type Flexible Supercapacitor Device Design

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Abstract

In today's rapidly evolving technological landscape, advances in information technologies have accelerated the demand for portable and wearable flexible electronic devices. This trend has consequently increased the need for environmentally friendly, compact, lightweight, and mechanically flexible energy storage systems. In addition, the integration of such devices into next-generation electronics requires energy storage units with high reliability, long cycle life, and stable electrochemical performance under demanding mechanical conditions. Flexible supercapacitors, also known as electrochemical capacitors, have emerged as promising candidates to meet these requirements due to their high power density compared to batteries, fast charge-discharge capability, and superior cycling stability. Moreover, their relatively higher energy density compared to conventional capacitors makes them highly attractive for flexible and wearable applications. In this study, a nickel selenide-based reduced graphene oxide composite paper is proposed as an alternative positive electrode material for flexible supercapacitors with an asymmetric device configuration. The synthesized composite paper was structurally characterized by X-ray powder diffraction and morphologically analyzed using field emission scanning electron microscopy. Furthermore, the capacitive performance of the composite electrode was evaluated through cyclic voltammetry and galvanostatic charge-discharge measurements. The obtained results demonstrate that the nickel selenide-based reduced graphene oxide composite paper is a promising candidate as a positive electrode material for flexible asymmetric supercapacitor applications.

Keywords: Flexible supercapacitors, Nickel selenide, Reduced graphene oxide, Asymmetric supercapacitor, Electrochemical performance

1. INTRODUCTION

In recent years, with the rapid advancement of the digital world, the integration of portable and wearable flexible electronic devices into numerous fields such as medicine, communication, and information technologies has been extensively investigated. In this context, there is a growing interest in developing environmentally friendly, lightweight, compact, and mechanically flexible energy storage systems for flexible electronic devices [1]. Supercapacitors (SCs), also known as electrochemical capacitors, have emerged as promising candidates for such systems due to their high reliability, long cycle life, and stable electrochemical performance. SCs can be fabricated in flexible configurations and exhibit



higher power density than batteries as well as higher energy density than conventional capacitors [2].

In addition to performance parameters such as energy and power density of flexible SCs, the electrode material plays a critical role in determining properties such as specific capacitance (C_s), cycle life, and flexibility. Owing to its exceptional characteristics, particularly its large surface area and high electrical conductivity, graphene (G) has become one of the most widely utilized materials for the fabrication of flexible electrodes [3]. For this purpose, graphene-based papers (GPs), which are rollable, free-standing, cuttable, mechanically robust, electroactive, and readily functionalizable, have attracted considerable attention in flexible SC applications [4, 5]. However, owing to strong van der Waals interactions, GPs tend to agglomerate and restack, leading to a densely packed structure. Consequently, ion diffusion within the electrode during charge–discharge processes becomes hindered in GP-based SC applications, resulting in deteriorated energy storage performance. To overcome this limitation, various electroactive spacer materials, including metal selenides, have been incorporated into the paper structure [6].

Herein, we present a nickel selenide-based reduced graphene oxide composite paper (NiSe/GP) as an alternative positive electrode material for flexible SCs with an asymmetric device configuration. The structural and morphological characteristics of NiSe/GP were investigated, and its electrochemical behavior was analyzed to evaluate its capacitive performance.

2. MATERIALS AND METHODS

The surface morphology of NiSe/GP was examined using field-emission scanning electron microscopy (FESEM). The crystal structure of NiSe/GP was analyzed by X-ray diffraction (XRD) using Cu-K α radiation ($\lambda=1.5405$ Å). The capacitive behavior of NiSe/GP was evaluated through cyclic voltammetry (CV) and galvanostatic charge-discharge (GCD) measurements.

For the hydrothermal synthesis of NiSe structures, predetermined amounts of nickel(II) chloride and selenium powder were dissolved in 50 mL of distilled water. Subsequently, 10 mL of hydrazine hydrate was added to the mixture, which was then transferred into a stainless-steel autoclave and maintained at 120 °C for 12 h to allow the hydrothermal reaction to proceed. The resulting product was separated from the solvent by centrifugation and dried at 50 °C for 12 h, yielding NiSe structures. A mold casting method was employed for the fabrication of flexible, durable, and electrochemically active NiSe/GP. For this purpose, 100 mg of NiSe powder was added to 100 mL of an aqueous GO dispersion and stirred for 30 min. The obtained mixture was then poured into an appropriate mold and dried. Finally, the peeled NiSe/GO film was subjected to a chemical reduction process to obtain flexible NiSe/GP. The production route of NiSe/GP was schematically illustrated in Figure 1.



Figure 1. The schematized production route of NiSe/GP.

3. RESULTS AND DISCUSSION

The surface morphology of NiSe/GP was investigated by FESEM, and the corresponding micrographs are presented in Figure 2. The FESEM images obtained from surface analysis reveal both the characteristic wrinkled sheet-like layered structure of G and the sea urchin-like morphology of NiSe composed of nanorods. The observed morphological architecture of NiSe/GP indicates a large surface area, which is associated with enhanced electrochemical performance.

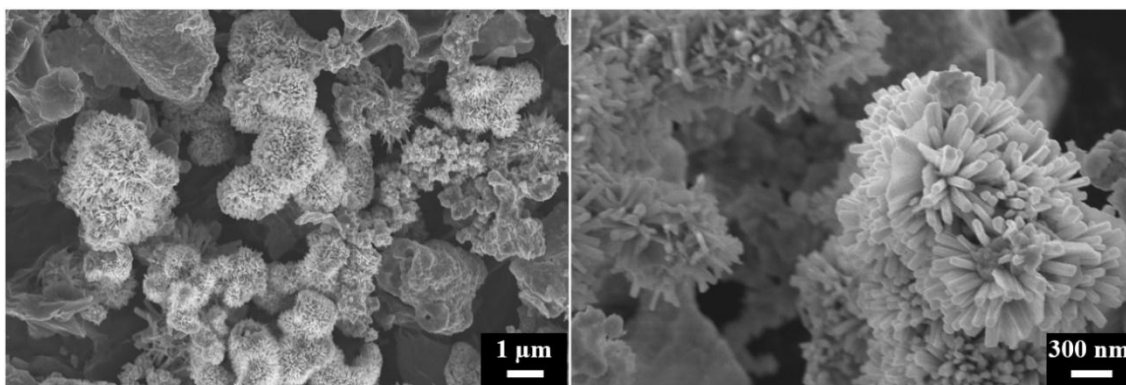


Figure 2. FESEM micrographs of NiSe/GP.

XRD analysis was carried out to investigate the crystal structure of NiSe/GP, and the corresponding diffraction pattern is presented in Figure 3. The characteristic diffraction peaks confirm the crystalline nature of both NiSe and reduced graphene oxide, thereby verifying the successful formation of the NiSe/GP composite structure.

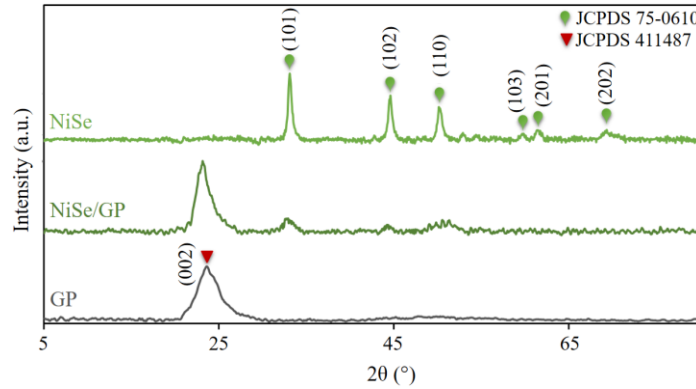


Figure 3. X-ray diffraction pattern of NiSe/GP.

The capacitive performance of NiSe/GP was investigated by CV and GCD measurements in 1.0 M KOH electrolyte (Figure 4). As can be observed from the CVs presented for GP and NiSe/GP in Figure 4a, NiSe/GP exhibited a considerably higher capacitive current response in the positive potential region compared to GP. The synergistic interaction between NiSe and G in the composite paper prepared by incorporating NiSe structures into GP led to a noticeable enhancement in the capacitive current. In addition, NiSe acted as a spacer material within the NiSe/GP structure, thereby suppressing the aggregation of G sheets. The CV results clearly demonstrate that NiSe/GP possesses significantly improved capacitive properties compared to GP. Figure 4b presents the GCD curves of GP and NiSe/GP recorded at the same current density. While GP exhibited a typical electric double-layer capacitive (EDLC) behavior, the discharge profile of NiSe/GP showed a non-linear characteristic with distinct plateau regions, indicating the contribution of faradaic reactions. Furthermore, the longer duration discharge of NiSe/GP at the same current density suggests its higher C_s compared to GP.

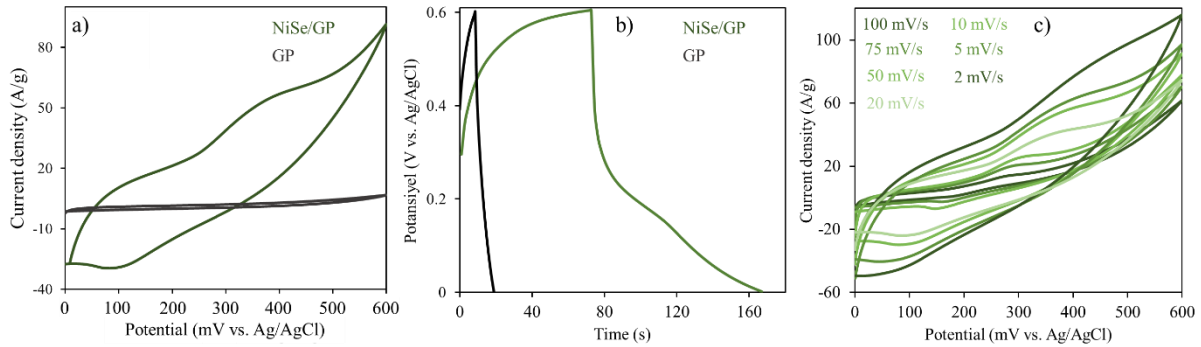


Figure 4. CVs (a) and GCD curves (b) of GP and NiSe/GP. CV curves of NiSe/GP measured at different scan rates ranging from 2 to 100 mV/s (c).

Figure 4c displays the CV curves of NiSe/GP recorded at different scan rates ranging from 2 to 100 mV/s. The specific capacitance (F/g) values were calculated from the CV curves using:

$$C_{s,cv} = \frac{\int I(V) * \Delta V}{m * \Delta V * v} \quad (\text{Eq. (1)})$$

In the equation, $\int I(V) * \Delta V$ represents the integrated area enclosed by the CV curve, while I , m , ΔV , Δt , and v correspond to the capacitive current, mass of the active material, potential



window, discharge time, and scan rate, respectively. The C_s values calculated for NiSe/GP based on Eq. (1) are summarized in Table 1.

Table 1. C_s values of NiSe/GP calculated from CV measurements at different scan rates

	Scan Rate (mV/s)						
	2	5	10	20	50	75	100
C_s (F/g)	1205	915	614	579	333	274	263

4. CONCLUSIONS

In this study, NiSe/GP was successfully fabricated and evaluated as a flexible electrode material for SC applications. FESEM and XRD analyses confirmed the successful formation of the composite structure and revealed the coexistence of the characteristic G sheet morphology and crystalline NiSe structures. Electrochemical measurements demonstrated that the incorporation of NiSe into GP significantly enhanced the capacitive behavior owing to the synergistic interaction between NiSe and G, as well as the spacer effect of NiSe that suppresses graphene restacking. Compared to GP, NiSe/GP exhibited improved capacitive current response and higher specific capacitance values. These findings suggest that NiSe/GP is a promising candidate as a high-performance positive electrode material for flexible asymmetric SC applications.

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From GLP-1 to Dual Agonists: Evolution and Therapeutic Potential of Incretin-Based Strategies in Diabetes and Obesity

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Abstract

Type 2 diabetes mellitus (T2DM) and obesity are interrelated metabolic disorders that are increasing worldwide and represent major global health concerns. In recent years, incretin-based therapies have become important in the management of both T2DM and obesity because of their multifaceted metabolic effects. The main incretin hormones, glucagon-like peptide-1 (GLP-1) and glucose-dependent insulintropic polypeptide (GIP), contribute to glucose regulation by enhancing glucose-dependent insulin secretion, suppressing glucagon release, and delaying gastric emptying. They also act on central appetite pathways, thereby supporting weight loss. In addition, these agents may reduce hepatic steatosis, improve insulin resistance, and provide hepatoprotective and multi-organ protective effects. Clinical studies and real-world evidence suggest that the evolution of GLP-1 receptor agonists into dual agonists offers superior efficacy, particularly in obesity management. This review aims to examine the progression from GLP-1 receptor agonists to dual agonists by synthesizing findings from the literature and real-world data, and to highlight their therapeutic potential in diabetes and obesity. Current evidence indicates that monotherapy may be insufficient, whereas GLP-1/GIP dual agonism, represented by tirzepatide, provides enhanced benefits in glycemic control, weight management, and cardiometabolic risk reduction. These developments may support more individualized, mechanism-based treatment strategies for patients with complex metabolic disease profiles.

Keywords: Dual agonist, GLP-1 receptor agonists, Incretin-based therapy, Obesity, Type 2 diabetes mellitus (T2DM)

1. INTRODUCTION

Type 2 diabetes mellitus (T2DM) and obesity are among the most challenging metabolic disorders of the twenty first century. According to the International Diabetes Federation, approximately 537 million adults were living with diabetes in 2021, with projections reaching 783 million by 2045 [1]. Obesity affects roughly 13% of the global adult population and increases the risk of developing T2DM by up to sevenfold, while simultaneously amplifying the risk of cardiovascular, renal, and hepatic complications [2]. Both conditions share a common pathophysiological core: insulin resistance, chronic low-grade inflammation emanating from dysfunctional adipose tissue, impaired beta cell function, and progressive glucotoxicity leading to beta cell apoptosis.

Conventional pharmacological strategies such as metformin, sulfonylureas, and insulin have demonstrated limited efficacy in addressing weight management and cardiometabolic risk reduction simultaneously. This therapeutic gap prompted the exploration of the incretin system



as a novel target. The incretin effects the amplification of glucose stimulated insulin secretion following oral nutrient intake relative to an equivalent intravenous glucose load was first conceptualized by La Barre in 1932 and later attributed primarily to two gut derived hormones: glucagon like peptide-1 (GLP-1) and glucose dependent insulinotropic polypeptide (GIP) [1]. Crucially, this incretin response is substantially attenuated in individuals with T2DM and obesity, making pharmacological restoration or amplification of incretin signaling a compelling therapeutic approach.

Over the past two decades, incretin-based therapies have evolved remarkably. The first approved GLP-1 receptor agonist (GLP-1 RA), exenatide, reached the market in 2005. Since then, the field has progressed through successive generations of increasingly potent agents, culminating in the dual GLP-1/GIP agonist tirzepatide (approved by the FDA in 2022 for T2DM and in 2023 for obesity) and the investigational triple agonist retatrutide, which additionally targets the glucagon receptor. This review synthesizes the mechanistic rationale and clinical evidence for this therapeutic evolution, with emphasis on tirzepatide and retatrutide as paradigm shifting agents in diabetes and obesity management.

2. MATERIALS AND METHODS

This work was conducted as a narrative review of the published scientific literature. A comprehensive search was performed in PubMed, Web of Science, Scopus, and Google Scholar databases using the following terms: “GLP-1 receptor agonists”, “GIP receptor”, “incretin-based therapy”, “dual agonist”, “tirzepatide”, “retatrutide”, “triple agonist”, “type 2 diabetes mellitus”, and “obesity”. Articles published in English from 2000 to 2025 were considered. Priority was given to randomized controlled trials, systematic reviews, and meta-analyses. Pivotal clinical programs reviewed include SURPASS-1 through SURPASS-5, SURMOUNT-1 and SURMOUNT-2, LEADER, SUSTAIN-6, PIONEER-6, REWIND, STEP-1, and the retatrutide Phase 2 obesity trial. Mechanistic and pharmacological characterization studies were also included to contextualize receptor biology and downstream signaling.

3. RESULTS AND DISCUSSION

3.1. Incretin Physiology and the GLP-1/GIP Axis

GLP-1 is a 7–37 amino acid peptide derived from proglucagon cleavage in intestinal L cells (ileum and colon), released in response to carbohydrate and fat ingestion. It is rapidly inactivated by dipeptidyl peptidase-4 (DPP-4) with a plasma half-life of approximately 2 minutes under physiological conditions. GLP-1 exerts its primary pancreatic effects by binding to the GLP-1 receptor (GLP-1R) on beta cells, triggering a cyclic AMP (cAMP) mediated cascade that potentiates glucose-stimulated insulin secretion. Simultaneously, it suppresses alpha cell glucagon secretion in a glucose dependent manner, reduces hepatic glucose output, slows gastric emptying, and acts centrally at the arcuate nucleus and nucleus tractus solitarius to suppress appetite and enhance satiety [1]. GIP is a 42 amino acid peptide secreted by duodenal and jejunal K cells, with a half-life of approximately 7 minutes. While GIP also stimulates insulin secretion, its additional role in adipose tissue lipolysis, bone metabolism, and hypothalamic energy regulation distinguishes it as a complementary target alongside GLP-1 [4].

In T2DM and obesity, GLP-1 secretion is attenuated and its insulinotropic effect is blunted, while GIP’s insulinotropic capacity is specifically impaired (though its adipose effects remain



intact). Pharmacological GLP-1 RAs overcome this impairment through DPP-4-resistant analogs, enabling sustained receptor activation. The hepatoprotective effects of GLP-1 RAs reducing hepatic steatosis and improving insulin resistance add further metabolic benefit beyond glycemic control.

3.2. Evolution of GLP-1 Receptor Agonists

The first-generation GLP-1 Ras exenatide (twice-daily) and liraglutide (once-daily) demonstrated HbA1c reductions of approximately 1.0–1.3% and modest weight loss of 2–3 kg [2]. Second-generation once weekly formulations, including semaglutide subcutaneous and dulaglutide, substantially improved these outcomes with HbA1c reductions up to 1.8% and weight loss of 4–6 kg. The LEADER trial (liraglutide), SUSTAIN-6 (semaglutide SC), PIONEER-6 (oral semaglutide), and REWIND (dulaglutide) collectively established that GLP-1 RAs significantly reduce major adverse cardiovascular events (MACE) in high-risk patients with T2DM, cementing their position as first line agents in current guidelines. The development of semaglutide 2.4 mg (STEP program) further demonstrated an average body weight reduction of 14.9% over 68 weeks in patients with obesity without T2DM, marking the entry of GLP-1 RAs into chronic weight management.

3.3. Tirzepatide: The GLP-1/GIP Dual Agonist

Tirzepatide is a once-weekly injectable 39-amino acid synthetic peptide that acts as a balanced dual agonist at both GLP-1R and GIPR, achieving co-activation through a single cAMP-mediated mechanism. By combining GLP-1R-driven insulin secretion, glucagon suppression, and appetite reduction with GIPR-mediated enhancement of adipose tissue metabolism and reinforcement of hypothalamic satiety signaling, tirzepatide produces a synergistic metabolic effect that exceeds what either receptor pathway can achieve alone [3]. Tirzepatide was approved by the FDA in May 2022 for the treatment of T2DM and in November 2023 for chronic weight management in adults with obesity or overweight with at least one weight-related comorbidity [6,7].

The SURPASS clinical program evaluated tirzepatide at doses of 5, 10, and 15 mg across a broad T2DM population. In SURPASS-2, the pivotal head-to-head trial against semaglutide 1 mg, tirzepatide produced significantly greater reductions in HbA1c and body weight at the highest dose [3]. Across the SURPASS program, HbA1c reductions ranged from –1.87 to –2.59%, and weight reductions ranged from –5.4 to –11.7 kg depending on background therapy and dose. Importantly, tirzepatide demonstrated a low risk of hypoglycemia due to its glucose-dependent mechanism of action, while gastrointestinal adverse effects such as nausea, vomiting, and diarrhea were manageable with gradual dose titration and decreased in frequency over time.

In the SURMOUNT program, which focused on obesity, SURMOUNT-1 enrolled adults without T2DM and demonstrated a mean weight loss of 20.9% with the 15 mg dose over 72 weeks, with 57% of participants achieving at least 20% weight reduction [8]. SURMOUNT-2, which enrolled participants with T2DM and obesity, confirmed a mean weight loss of 15.7% with the 15 mg dose over 72 weeks [9]. These findings collectively position tirzepatide as a highly effective pharmacological option for weight reduction while simultaneously providing superior glycemic control. Emerging data also suggest potential benefits in non-alcoholic steatohepatitis (NASH), with significant reductions in hepatic fat content observed across the clinical program [10,11].



3.4. Retatrutide: The GLP-1/GIP/Glucagon Triple Agonist

Retatrutide (LY3437943) represents the next frontier in incretin-based pharmacotherapy: a once-weekly injectable tri agonist that simultaneously activates GLP-1R, GIPR, and the glucagon receptor (GCGR). The addition of glucagon receptor agonism confers unique advantages not achievable with dual agonism alone: GCGR activation markedly increases energy expenditure through thermogenesis, accelerates hepatic fatty acid oxidation and lipolysis, reduces intrahepatic fat content (a property with strong implications for NASH/MAFLD), and independently promotes weight loss through catabolic metabolic reprogramming [5]. This tri receptor approach preserves glucose safety because GLP-1R co-activation counterbalances the hyperglycemic potential of GCGR stimulation.

The Phase 2 retatrutide obesity trial (NCT04881760) enrolled 338 adults with obesity or overweight. At 24 weeks, the 12 mg dose group achieved a mean weight loss of 17.5% from baseline the most substantial weight reduction observed for any pharmacological agent in a trial of this duration at the time of publication [5]. Notably, weight loss appeared to have not yet plateaued at 24 weeks, suggesting further reduction with longer treatment. The 4 mg and 8 mg doses produced mean reductions of 8.7% and 13.9%, respectively, demonstrating a clear dose-response relationship. In the T2DM Phase 2 trial (26 weeks), retatrutide at 12 mg produced a mean HbA1c reduction of 2.02% alongside a 16.9% reduction in body weight, with 26% of participants achieving HbA1c below 5.7% effectively normoglycemia [5]. The safety profile was consistent with the incretin drug class: nausea, vomiting, and diarrhea were the most common adverse events, with a modest increase in resting heart rate attributable to the glucagon component. Phase 3 trials are currently underway.

3.5. Multi-Organ Effects and Cardiometabolic Benefits

Beyond their glycemic and weight effects, incretin-based agents and dual/triple agonists in particular exert broad cardiometabolic benefits. GLP-1 RAs established in CVOTs reduce systolic blood pressure (2–5 mmHg), improve lipid profiles, reduce C-reactive protein, and decrease albuminuria. For tirzepatide, post hoc analyses from the SURPASS program demonstrated significant reductions in triglycerides, LDL cholesterol, and high-sensitivity CRP, alongside improvements in systolic blood pressure and hepatic fat. The SURPASS-CVOT trial (NCT04255433) is ongoing and will definitively establish tirzepatide's cardiovascular outcome profile. Emerging evidence also supports neuroprotective properties of GLP-1R activation, with ongoing clinical research into its potential role in neurodegenerative diseases including Alzheimer's and Parkinson's disease. Renal protective effects, mediated partly through blood pressure reduction and anti-inflammatory mechanisms, have been demonstrated for liraglutide and semaglutide; analogous trials for tirzepatide and retatrutide are anticipated.

The anti-inflammatory dimension of these therapies is particularly relevant in the context of T2DM pathophysiology. GLP-1 RAs reduce circulating levels of interleukin-6 (IL-6), tumor necrosis factor alpha (TNF- α), and monocyte chemoattractant protein-1 (MCP-1), markers that directly link adipose dysfunction to systemic cardiometabolic risk. Dual and triple agonists amplify these effects through complementary receptor pathways. In the liver, reductions in hepatic triglyceride content mediated by both GLP-1R and GCGR activation offer a mechanistically plausible basis for therapeutic efficacy in metabolic associated fatty liver disease (MAFLD), with retatrutide showing particularly pronounced hepatic fat reductions in Phase 2 data.



4. CONCLUSIONS

The incretin based therapeutic landscape has undergone a paradigm shift in the past decade, progressing from single-receptor GLP-1 agonists to dual and now triple receptor agonists with progressively broader and more powerful metabolic effects. The clinical evidence is compelling: GLP-1 receptor monotherapy established cardiovascular safety and superiority over traditional agents; dual GLP-1/GIP agonism with tirzepatide has surpassed all prior pharmacological benchmarks for glycemic control and weight reduction, producing outcomes comparable to bariatric surgery in dedicated obesity trials; and the investigational triple agonist retatrutide has demonstrated historically unprecedented weight loss in Phase 2, with a unique hepatic lipolytic mechanism through glucagon receptor co-activation.

The multi organ benefits of these agents encompassing cardiovascular protection, hepatic fat reduction, anti-inflammatory effects, and emerging neuroprotective properties position them as disease-modifying rather than merely symptom controlling therapies. The individualization of treatment based on patient phenotype, comorbidity burden, tolerability, and cost-effectiveness will be essential for translating these advances into optimized clinical practice. Long term cardiovascular outcome data for tirzepatide (SURPASS-CVOT) and Phase 3 trials for retatrutide are eagerly awaited. Future research directions should address durability of effect, impact on hard renal and hepatic endpoints, and the potential for combination with complementary mechanisms such as amylin analogs or sodium-glucose cotransporter 2 inhibitors.

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Digitalized Law Enforcement: The Contribution of Social Media Integration to Security Policies

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Abstract

Digitalization is profoundly transforming not only forms of communication but also the ways in which crime is committed, organized, and disseminated. This transformation compels law enforcement agencies to move beyond traditional methods and to adopt a data-driven, proactive, and multi-layered understanding of security. In this study, the role of social media platforms in digital policing practices is examined not merely as a technical tool but also as an element of sociological, administrative, and strategic transformation. Social media is emphasized as a multi-dimensional actor: a ground for the formation of crime, a means of communication and organization for offenders, and both an intelligence source and a platform for public engagement for law enforcement agencies.

The research is based on an analytical and comparative review of national and international literature. In this context, digital policing practices in different countries, social media-supported crime prevention strategies, and data analytics-based approaches have been examined. The findings indicate that the integration of social media provides significant advantages in combating crime. In particular, rapid response to incidents through real-time data flow, the ability to anticipate crime trends via big data analysis, and the strengthening of community-oriented policing in the digital environment stand out among these advantages. However, the study also shows that social media-based digital policing practices involve serious risks and challenges. Privacy violations, protection of personal data, ambiguity of ethical boundaries, and algorithmic biases constitute the most critical issues in this process.

In conclusion, this study demonstrates that digital policing is not merely a technological transformation but a multi-layered paradigm shift with governance, ethical, and social dimensions. In this context, it is emphasized that for the sustainability of digital policing, a comprehensive governance model based on transparency, accountability, data security, and human rights should be developed. At the same time, enhancing the digital competencies of law enforcement agencies, strengthening interdisciplinary cooperation, and raising public awareness are of critical importance for ensuring that this transformation progresses in a healthy and balanced manner.

Keywords: Digital policing, Social media analytics, Crime prevention, Data-driven law enforcement, Cybersecurity governance



1. INTRODUCTION

In today's world, digitalization is a multidimensional process that is not limited to technological advancements but also fundamentally transforms economic, political, and social structures. This transformation has led to a paradigmatic shift, particularly in the field of security. While the traditional understanding of security focused on threats bound by physical space and time, digitalization has transformed crime into a phenomenon that transcends spatial boundaries, evolves rapidly, and often occurs within a framework of anonymity. The widespread use of the internet and social media platforms has reshaped the ways in which crime is committed, organized, and disseminated, giving it a more flexible, network-based, and global character.

As a result, law enforcement agencies have also been compelled to transform. They have evolved from reactive structures that merely respond to incidents into proactive institutions that generate, process, and analyze data. The development of tools such as big data, artificial intelligence, and social media analytics has enabled security policies to be grounded in data-driven approaches. Social media lies at the center of this transformation, functioning both as an environment where crime occurs and as a tool for communication and organization among offenders. At the same time, it has become a strategic resource for law enforcement in terms of open-source intelligence (OSINT), early warning systems, and public engagement [1]. Parallel to the pace of digitalization, the diversification and increasing complexity of crime types have made it progressively more difficult for law enforcement agencies to combat crime effectively using traditional methods. Cybercrime, digitally organized networks, disinformation campaigns, and anonymity-based criminal structures compel security institutions to adopt more sophisticated, technology-driven tools. In this context, social media analysis plays a critical role in predicting crime trends, identifying risk areas, and developing preventive security strategies. Therefore, the integration of data-driven approaches into security policies provides a more effective and proactive means of addressing contemporary crime dynamics.

This study aims to examine, from a multidimensional perspective, the contributions of social media integration to security policies within the framework of digital policing. In this context, the role of social media in crime dynamics, its function in law enforcement practices, and the ethical and legal challenges it presents are analyzed from an analytical perspective. Accordingly, the study seeks to contribute to the literature by offering a balanced evaluation of both the opportunities and risks associated with digital policing practices.

1.1. The Rise of Digital Policing

The concept of digital policing represents a new understanding of security, referring to the holistic and systematic integration of information and communication technologies into security processes. In this approach, data is no longer merely a supportive element but becomes central to decision-making processes. Consequently, security management is restructured around the production, analysis, and interpretation of data.

While traditional policing practices were predominantly reactive, focusing on intervention after a crime had occurred, digital policing adopts a proactive model that emphasizes the identification of potential risks and the prevention of crime before it emerges. This transformation is closely linked to the increasing use of big data and artificial intelligence technologies in the field of security. Indeed, the literature highlights that data analytics and AI-supported applications accelerate and enhance the accuracy of law enforcement decision-making processes [2].



1.2. The Data Ecosystem of Social Media

Social media platforms can be considered large-scale digital data ecosystems in which user interactions are continuously generated and recorded. Activities such as posts, likes, comments, and interaction networks not only reflect communication practices but also make visible individuals' thought patterns, social relationships, and behavioral tendencies. In this respect, social media constitutes a dynamic domain where meaningful data production is concentrated at both individual and societal levels.

In the literature, social media is regarded as an important data source for both sociological analysis and security studies due to the high volume of user-generated content [3]. This indicates that social media has evolved beyond a mere communication medium into a comprehensive data environment where behavioral data is continuously produced and made analyzable. The digital traces left by user interactions allow for the indirect interpretation of social and psychological tendencies, making social media a strategic data source for both academic research and security-oriented analysis.

Research demonstrates that social media data is not limited to communication purposes but can also be used to analyze social trends, crisis dynamics, and potential security risks [4]. Therefore, for security institutions, social media is no longer a passive communication channel but an active data production field. Furthermore, it is emphasized that social media data can serve as an early warning mechanism in security and intelligence activities, although its use must be carefully evaluated in terms of data privacy and ethical boundaries [5]. This highlights that social media analysis is not merely a technical process but a multidisciplinary field encompassing legal and ethical dimensions.

1.3. Digital Surveillance and Societal Impacts

Digital policing practices in contemporary societies should be understood not merely as technical instruments aimed at crime prevention and the maintenance of public security, but also as constitutive elements of the surveillance society. The continuous collection, analysis, and interpretation of digital traces left by individuals in online environments give rise to a new form of governmentality mediated by state institutions, private corporations, and algorithmic systems. This transformation renders the balance between freedom and security increasingly complex [6,7].

In this context, digital policing emerges not only as a technical security mechanism oriented toward crime prevention, but also as a structural component contributing to the institutionalization of data-driven surveillance regimes in contemporary societies. Throughout this process, the data produced by individuals in digital environments are persistently processed and interpreted by various actors, thereby fostering an algorithmic mode of governance that extends beyond classical forms of control based on direct supervision. This shift situates the relationship between individual liberties and public security on a more complex and tension-laden ground.

1.4. Data-Driven Intervention Capacity

Data obtained through social media platforms provide contemporary law enforcement and emergency management practices with the ability to respond to incidents more rapidly and with enhanced situational awareness. Particularly during crises, disasters, and social unrest, content



generated by digital media users offers a real-time flow of information regarding developments on the ground, thereby significantly supporting decision-making processes [8, 9].

Social media platforms have evolved beyond being merely communicative channels in modern policing and emergency management, becoming dynamic sources of real-time data production related to ongoing events. Especially in times of crisis, disaster, and societal incidents, user-generated content enables the continuous monitoring of on-the-ground developments, contributing to increased situational awareness. This transformation indicates that decision-making processes are being restructured to rely not only on official information channels but also on digitally produced, citizen-generated data. In this context, as emphasized in the crisis informatics literature, social media is no longer a supplementary tool but is increasingly becoming a central source of data in disaster and emergency management. User-generated content that includes geolocation data, visual records, and direct observations from the scene reduces information asymmetry in the field and enables public authorities to develop faster and more flexible response capacities

1.5. Analysis of Crime Patterns

According to Perry *et al.* [10], this approach not only enables the identification of crime hot spots, but also contributes to a more efficient allocation of limited law enforcement resources. Through geographic information systems (GIS) and advanced statistical models, both the spatial and temporal patterns of crime can be analyzed, allowing for a more comprehensive assessment.

The central argument of this section is that crime does not occur randomly across space but emerges in measurable patterns, and that these patterns can be identified in advance through data analytics. In particular, predictive policing approaches provide a strategic advantage to security agencies in both analytical and operational planning by enabling the identification of high-risk areas based on historical crime data.

Moreover, such models do not merely highlight areas of concentrated criminal activity; they also facilitate a more targeted and systematic distribution of resources. The combined use of geographic information systems and statistical modeling techniques further allows for a more integrated evaluation of crime, taking into account not only its spatial but also its temporal dimensions.

1.6. Participatory Security Model

The participatory security model refers to a transformation in which the production of security is no longer a unilateral process conducted solely by state institutions, but rather a multidimensional structure in which different segments of society are also involved. In particular, the widespread adoption of social media platforms has enabled individuals to share information, observations, and experiences related to criminal incidents in real time, thereby significantly enhancing the data-gathering capacity of law enforcement agencies. Çelik [11] conceptualizes this transformation as a process in which citizens, alongside digitalization, evolve into active actors who indirectly contribute to the production of security.

In the literature, this approach is associated with community policing and network-based security models. Goldsmith [12] argues that user-generated data obtained through social media enables rapid response to incidents and functions as an early warning system for law



enforcement agencies. Similarly, Schneider [13] notes that visual, geolocation, and text-based content shared by citizens can be utilized as a complementary data source in crime analysis processes.

1.7. The Impact of Disinformation

The rapid spread of misinformation and intentionally produced disinformation content on social media platforms can significantly affect the accuracy and effectiveness of security processes. In particular, in high-uncertainty contexts such as crises, disasters, or major social events, the dissemination of unverified information not only shapes public perception but also complicates the decision-making processes of public authorities. Wardle [14].conceptualizes disinformation not merely as the spread of false information, but as part of an information ecosystem in which content is manipulated, decontextualized, or deliberately distorted.

In the literature on crisis communication, it is emphasized that social media–driven misinformation can generate an “information disorder,” thereby having a direct impact on public order. Especially during disasters, unverified reports, inaccurate location data, or fabricated images and visuals may lead to the misdirection of individuals and cause delays or errors in the operational decision-making processes of law enforcement agencies [15]. This situation makes the balance between speed and accuracy in security management increasingly critical.

1.8. International Practices and Comparison

Social media analytics and big data–driven security applications have become an important component of law enforcement activities in many countries today. In particular, in the United States, approaches such as crime prediction and hotspot analysis are actively used through their integration into data-driven policing models. Within this framework, institutions such as the New York Police Department (NYPD) and the Los Angeles Police Department (LAPD) utilize advanced algorithmic systems to identify high-risk areas by jointly analyzing historical crime data and social media interactions [16]. Similarly, in Europe, countries such as the United Kingdom, the Netherlands, and Germany integrate social media data into crime forecasting and public safety management processes within the scope of “smart policing” applications [17].

In conclusion, international examples demonstrate that social media analytics and big data applications are playing an increasingly central role in law enforcement activities. In Türkiye, in order to effectively utilize the potential in this field, both technological capacity needs to be enhanced and legal and ethical standards must be strengthened.

2. MATERIALS AND METHODS

This study was conducted using a qualitative research approach. Literature review and comparative analysis techniques were employed. The collected data were thematically categorized and analyzed. In addition, the study adopts an interdisciplinary perspective by jointly evaluating the literature in the fields of sociology, public administration, and information technologies.

3. RESULTS AND DISCUSSION

The findings of this study indicate that the integration of social media into law enforcement activities does not merely enhance technical capacity, but also generates a structural



transformation in the security paradigm. The traditional security approach, which is based on reactive, post-incident intervention, is increasingly being replaced by a data-driven, predictive, and network-based security model. However, this transformation brings not only improvements in operational efficiency but also significant ethical, legal, and societal debates.

First, the incorporation of social media data into security processes poses serious risks in terms of individual privacy. The analysis of data obtained from social media platforms is often conducted in a decontextualized manner, which may result in individuals' digital traces becoming objects of continuous surveillance. This situation demonstrates that privacy is no longer understood solely as an individual right in its classical sense, but is being redefined within data-driven governance structures [18, 19].

In conclusion, social media-based digital policing practices produce a dual effect: while they enhance security capacity on the one hand, they simultaneously create new areas of risk in terms of privacy, equality, and democratic oversight on the other. Therefore, the primary objective of future security policies should be to develop a transparent, accountable, and human rights-sensitive governance model capable of balancing this dual structure.

4. CONCLUSION

This study examined the impact of social media integration on digital policing activities from a multidimensional perspective. The findings and analyses demonstrate that social media is not merely a communication platform, but has also evolved into a strategic data environment at the core of modern security systems.

One of the principal findings of the study is that the understanding of security is shifting from a reactive structure toward a proactive and predictive one. This transformation enables law enforcement agencies to move beyond their traditional role as passive responders to incidents and instead become active entities that anticipate risks through data-driven analysis.

Finally, this study reveals that the future of digital policing practices depends not only on technological advancements, but also on social acceptance, institutional transparency, and democratic oversight mechanisms. The digital transformation in the field of security represents not only a change in tools, but also a redefinition of the relationship between the state, individuals, and technology.

Future research should particularly focus on the ethical boundaries of artificial intelligence-supported policing applications, data security policies, and comparative international security models, as these areas would make a significant contribution to the development of the field.

Digitalization has fundamentally transformed the nature of security policies. Social media integration provides significant advantages to law enforcement agencies; however, the sustainability of these advantages requires the preservation of ethical and legal balances.

Policy Recommendations:

- Clear legal regulations regarding data usage should be established
- Algorithmic systems should be made auditable and transparent
- Digital ethics training should be provided to law enforcement personnel
- International data-sharing mechanisms should be developed



In conclusion, the success of digital policing practices depends on the capacity to maintain a delicate balance between technology and civil liberties.

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Meteorological Variable-Based Solar Power Forecasting Using Machine Learning Regression Algorithms: A Comparative Study

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Abstract

This work proposes a comparative evaluation of four supervised machine learning regression models, Support Vector Regression (SVR), Extreme Gradient Boosting (XGBoost), Multilayer Perceptron (MLP), and K-Nearest Neighbors (KNN) for hourly photovoltaic (PV) power estimation using meteorological variables. The dataset was constructed by integrating operational power measurements from a JAM66S30-500/MR 500 W monocrystalline PV panel installed in Lahore, Pakistan, with atmospheric parameters sourced from the NASA MERRA-2 global reanalysis database. Following the removal of nighttime records, 846 usable hourly observations spanning 70 consecutive days were retained. Six meteorological features — ambient temperature, precipitation, air density, plane-of-array irradiance, global horizontal irradiance, and cloud cover fraction — were used as model inputs. A preliminary correlation analysis confirmed that solar irradiance variables exhibited the strongest associations with power output ($r = 0.94$ and $r = 0.93$). All models were trained on 70% of the data and evaluated on the remaining 30% using MAE, RMSE, R^2 , and RSE metrics. XGBoost achieved the best performance with MAE = 22.51 W, RMSE = 34.69 W, and $R^2 = 0.9299$, followed closely by SVR, MLP, and KNN. The results demonstrate that all four algorithms are viable tools for PV power forecasting, with XGBoost offering the best balance of accuracy and generalization.

Keywords: *XGBoost, machine learning, solar power forecasting, photovoltaic estimation, support vector regression*

1. INTRODUCTION

Over the past few decades, there has been a notable acceleration in the worldwide adoption of renewable energy, largely driven by concerns about climate change, diminishing fossil fuel resources, and the pursuit of sustainable energy systems. Solar photovoltaic (PV) systems have become one of the fastest-growing renewable energy technologies, driven by decreasing installation costs, high scalability, and notable environmental advantages [1]. Despite its advantages, solar power production is highly variable and intermittent, largely influenced by meteorological factors such as irradiance, cloud dynamics, temperature, and atmospheric conditions, which complicates grid integration, dispatch operations, and demand–supply coordination [2], [3].

Precise estimation of solar power output plays a pivotal role in ensuring the stable and efficient functioning of contemporary energy systems. Precise predictions allow grid operators to



optimize spinning reserves, reduce curtailment, and improve the economic viability of solar investments [4]. The forecasting problem is further complicated by the nonlinear and spatially variable nature of the relationships between meteorological inputs and PV output, necessitating the use of advanced data-driven modeling approaches [5].

Recently, deep learning (DL) and machine learning (ML) methods have demonstrated considerable potential in solar energy forecasting, consistently outperforming traditional statistical and physical models across a range of temporal horizons and geographic settings [6]. Support Vector Regression (SVR), a kernel-based method capable of capturing nonlinear input-output mappings, has been widely applied to solar power prediction tasks and shown competitive accuracy relative to more complex architectures [7]. Similarly, ensemble methods such as Gradient Boosting and Random Forest have proven effective by utilizing the collective predictive strength of multiple decision trees, with XGBoost in particular gaining recognition for its regularization capabilities and computational efficiency [8], [9]. Artificial neural network approaches, including Multilayer Perceptron (MLP) architectures, have also been extensively evaluated for photovoltaic power estimation, benefiting from their ability to learn hierarchical feature representations from meteorological data [1], [10].

More recently, deep learning architectures — specifically Gated Recurrent Units (GRU), Long Short-Term Memory (LSTM) networks, and hybrid models combining convolutional and recurrent layers — have achieved advanced performance in short- and long-term solar estimation by exploiting temporal dependencies in historical generation sequences [11], [12], [13], [14]. Transformer-based models have further extended forecasting capabilities to hybrid solar-wind systems and national-level energy production estimation, demonstrating superior accuracy at extended forecast horizons [15], [16]. Despite these advances, comparative evaluations of classical ML algorithms remain practically relevant, as they offer interpretable, computationally lightweight alternatives that are well-suited to deployment in resource-constrained environments or applications where training data is limited [6].

A critical observation across the literature is that the choice of input features — particularly the inclusion of irradiance-related variables — plays a decisive role in model performance [7, 16]. Studies have consistently identified global horizontal irradiance and plane-of-array irradiance as the strongest predictors of PV output, while secondary variables such as ambient temperature, cloud cover, and air density contribute additional explanatory power [2], [8]. The NASA MERRA-2 reanalysis database has emerged as a widely adopted source of high-quality meteorological data for solar forecasting research, providing spatially consistent and temporally continuous records suitable for model training and validation [8].

Despite the extensive body of literature on solar energy forecasting, comparative studies that systematically evaluate multiple classical ML algorithms — including SVR, KNN, MLP, and XGBoost — under identical experimental conditions on panel-level PV data from South Asian climatic contexts remain limited. The majority of existing benchmarks focus on large-scale solar farms in Europe or North America, leaving a gap in the understanding of model behavior under the distinct meteorological patterns characteristic of subtropical urban environments such as Lahore, Pakistan [1], [16].

This study addresses this gap by constructing a dataset combining operational power measurements from a 500 W monocrystalline PV panel in Lahore with corresponding MERRA-

2 meteorological variables, and by carrying out a rigorous performance comparison of four supervised ML regression approaches— SVR, KNN, MLP, and XGBoost — for hourly solar power estimation. The models are assessed using four performance metrics (MAE, RMSE, R^2 , and RSE), and their predictive behaviors are analyzed through time-series, scatter, and residual plots to provide a comprehensive characterization of each algorithm's strengths and limitations in this application context.

2. MATERIALS AND METHODS

2.1. Dataset and Preprocessing

This work utilized a dataset integrating operational and meteorological measurements from a photovoltaic solar energy system installed in Lahore, Pakistan (31.5204° N, 74.3587° E). The operational data were collected from a JAM66S30-500/MR 500 W monocrystalline photovoltaic panel, providing time-stamped power generation values recorded at hourly intervals [17]. The meteorological variables were sourced from the NASA MERRA-2 global reanalysis database, encompassing key atmospheric parameters known to influence photovoltaic performance [8].

The raw dataset covered a continuous 70-day observation period spanning from October 20 to December 31, 2014. During preprocessing, records corresponding to periods of no solar activity — primarily nighttime hours with zero power output — were removed to ensure the dataset reflected only effective generation periods. Following this filtering step, a total of 846 usable records were retained. The dataset contained no missing values, providing a clean and reliable foundation for model development.

The input feature set comprised six meteorological variables, while the electrical power output of the panel served as the prediction target. A detailed description of all variables is provided in Table I.

Table I. Description of Dataset Variables

Variable	Description	Unit
Temperature	Ambient air temperature	$^\circ\text{C}$
Prectotland	Total land precipitation	mm
Rhoa	Air density	kg/m^3
Irradiance (G)	Global horizontal solar irradiance	W/m^2
Irradiance (A)	Plane-of-array irradiance on panel surface	W/m^2
Cloud	Cloud cover fraction	0–1
Power (<i>target</i>)	Electrical power output of PV panel	W

The dataset was partitioned into training and test subsets using a random split strategy with a fixed random seed (`random_state = 42`). Specifically, 70% of the records were allocated for training and the remaining 30% for testing. For models sensitive to feature scale — namely SVR, KNN, and MLP — input features were standardized using zero-mean unit-variance normalization (`StandardScaler`) prior to training.

2.2. Preliminary Analysis: Correlation Matrix

Prior to model training, the linear relationships among all variables were examined using the Pearson correlation coefficient. The resulting correlation matrix is illustrated in Figure 1. The analysis revealed that Irradiance (G) ($r = 0.94$) and Irradiance (A) ($r = 0.93$) exhibited the strongest positive correlations with power output, confirming solar irradiance as the dominant driver of photovoltaic generation. Temperature also showed a moderate positive association ($r = 0.65$), while air density (Rhoa) displayed a negative correlation ($r = -0.37$), consistent with its inverse relationship with ambient temperature. Cloud cover and precipitation (Precip) demonstrated relatively weak direct correlations with power output ($r = -0.08$ and $r = -0.07$, respectively). Notably, a strong negative correlation was observed between Temperature and Rhoa ($r = -0.92$), reflecting the physical inverse relationship between air temperature and density.

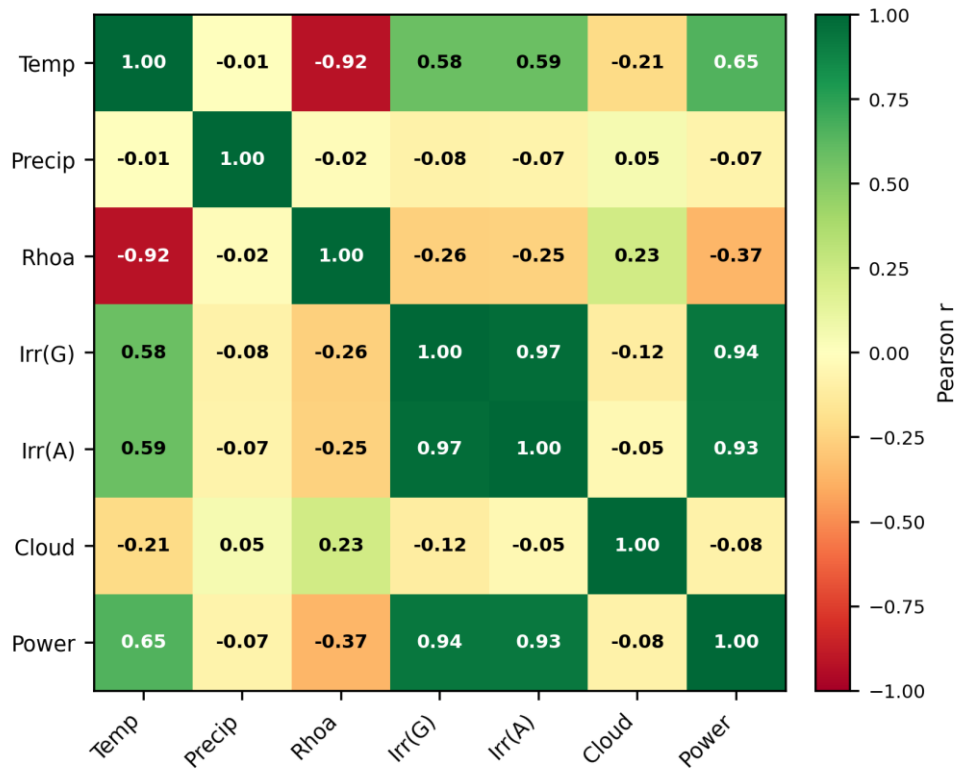


Figure 1. Correlaton of solar power and meteorological parameters

2.3. Machine Learning Methods

This work employs four supervised ML regression methods and evaluates their performance comparatively. To ensure fairness, all methods were trained and tested using the same data partitions. A brief description of each method and its hyperparameter configuration is provided below.

1) Support Vector Regression (SVR)

SVR adapts the fundamental concepts of Support Vector Machines to regression problems by identifying a function that restricts deviations from the observed target values within a predefined tolerance level ϵ , while preserving model smoothness [18]. An RBF kernel was selected to model complex nonlinear interactions between meteorological variables and power generation. The hyperparameter settings employed in this work are summarized in Table II.

Table II. Hyperparameter Configuration of SVR

Parameter	Value
Regularization parameter (C)	50
Epsilon tube width (ϵ)	0.05
Kernel function	RBF
Gamma	scale

2) K-Nearest Neighbors Regression (KNN)

KNN is a non-parametric, instance-based learning algorithm that estimates the output of a new sample by aggregating the target values of its k nearest neighbors in the feature space. Distance-based weighting was applied so that closer neighbors contribute more to the prediction [19]. The configuration is presented in Table III.

Table III. Hyperparameter Configuration of KNN

Parameter	Value
Number of neighbors (k)	5
Weighting scheme	Distance-based
Search algorithm	Auto
Distance metric	Minkowski

3) Multilayer Perceptron Regression (MLP)

The MLP represents a class of feedforward artificial neural networks structured with an input layer, multiple hidden layers, and a final output layer. Nonlinear activation functions allow the model to approximate intricate input–output mappings [20]. Model training was performed using backpropagation with the Adam optimization algorithm. The architecture and training parameters are given in Table IV.

Table IV. Hyperparameter Configuration of MLP

Parameter	Value
Hidden layer sizes	(64, 32)
Activation function	ReLU

Parameter	Value
Optimizer	Adam
Maximum iterations	1500

4) XGBoost Regression

XGBoost represents an efficient gradient boosting approach that constructs decision tree ensembles in a sequential manner, with successive trees focusing on minimizing residuals from preceding iterations [21]. Built-in regularization mechanisms (subsampling and column subsampling) help Prevent overfitting. The hyperparameters employed are detailed in Table V.

TABLE V. Hyperparameter Configuration of XGBoost

Parameter	Value
Number of estimators	200
Learning rate	0.05
Maximum tree depth	5
Subsample ratio	0.8
Column subsample ratio	0.8

2.4. Performance Metrics

The predictive performance of each model was quantified using four evaluation metrics. Lower MAE and RMSE values indicate smaller prediction errors, while an R^2 value closer to unity reflects a stronger explanatory power of the model [22].

Mean Absolute Error (MAE) measures the average magnitude of prediction errors:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad (1)$$

Root Mean Square Error (RMSE) penalizes larger errors more heavily due to the squared term:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (2)$$

Coefficient of Determination (R^2) quantifies the proportion of variance in the target variable explained by the model:

$$R^2 = 1 - \left[\sum_{i=1}^n (y_i - \hat{y}_i)^2 / \sum_{i=1}^n (y_i - \bar{y})^2 \right] \quad (3)$$



Relative Squared Error (RSE) represents the complement of R^2 and indicates the relative unexplained variance:

$$RSE = 1 - R^2 \quad (4)$$

where y_i denotes the actual value, $\hat{y}_i$ the predicted value, $\bar{y}$ the mean of actual values, and n the total number of test samples.

3. RESULTS AND DISCUSSION

The predictive performance of the four machine learning models — XGBoost, MLP, SVR, and KNN — was evaluated on the test set comprising 30% of the total dataset (240 samples). The quantitative results are summarized in Table VI, and the corresponding visual analyses are presented in Figures 2 through 5.

Table VI. Performance Comparison of Machine Learning Models on the Test Set

Model	MAE (W)	RMSE (W)	R^2	RSE
XGBoost	22.5080	34.6931	0.9299	0.0701
MLP	23.5516	35.3600	0.9272	0.0728
SVR	23.1133	35.3881	0.9271	0.0729
KNN	23.8893	36.9861	0.9204	0.0796

All four models demonstrated strong predictive capability, with R^2 values exceeding 0.92 across the board, indicating that each algorithm successfully captured the dominant patterns governing photovoltaic power generation from the meteorological input variables. The performance differences among the models were relatively modest, yet consistent across all four metrics.

XGBoost achieved the best overall performance with the lowest MAE (22.51 W), the lowest RMSE (34.69 W), the highest R^2 (0.9299), and the lowest RSE (0.0701). Its gradient boosting mechanism — which iteratively corrects residual errors through an ensemble of shallow decision trees — proved particularly well-suited to the nonlinear and moderately noisy relationships present in the solar power dataset. The regularization mechanisms inherent to XGBoost (subsampling and column subsampling) further contributed to its generalization ability on unseen test data.

SVR ranked second in terms of R^2 (0.9271) and achieved a slightly lower MAE (23.11 W) compared to MLP (23.55 W), though their RMSE values were nearly identical (35.39 W vs. 35.36 W). The RBF kernel enabled SVR to model the nonlinear irradiance–power relationship effectively, while the ϵ -insensitive loss function provided robustness against minor noise in the meteorological measurements. MLP delivered comparable results to SVR, with its two-layer architecture (64–32 neurons) and ReLU activations capturing the complex interactions among the input features. The marginal performance gap between SVR and MLP suggests that both models converged to similar solution spaces for this dataset.

KNN yielded the weakest performance among the four models, with the highest MAE (23.89 W), RMSE (36.99 W), and RSE (0.0796), and the lowest R^2 (0.9204). Despite distance-

weighted aggregation, the instance-based nature of KNN makes it sensitive to the local density and distribution of training samples, which may introduce inconsistencies in regions of the feature space with sparse coverage — particularly at low irradiance levels near sunrise and sunset.

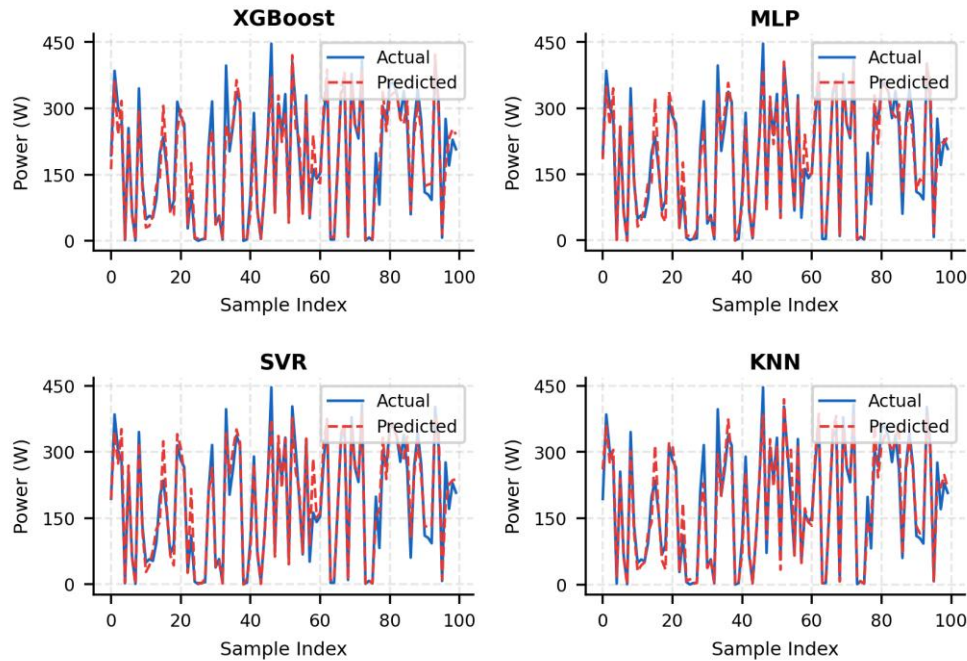


Figure 2. Actual vs. predicted power output for the first 100 test samples across all four models.

The actual versus predicted time-series plots for the first 100 test samples are shown in Figure 2. All models tracked the general shape of the power output curve, including the characteristic diurnal rise-and-fall pattern and the sharp drops associated with high cloud cover events. XGBoost and SVR exhibited the closest alignment with the actual values, particularly at peak power levels (250–450 W), where MLP and KNN showed slightly larger deviations. At near-zero power values — corresponding to early morning or heavily overcast conditions — all models performed comparably well.

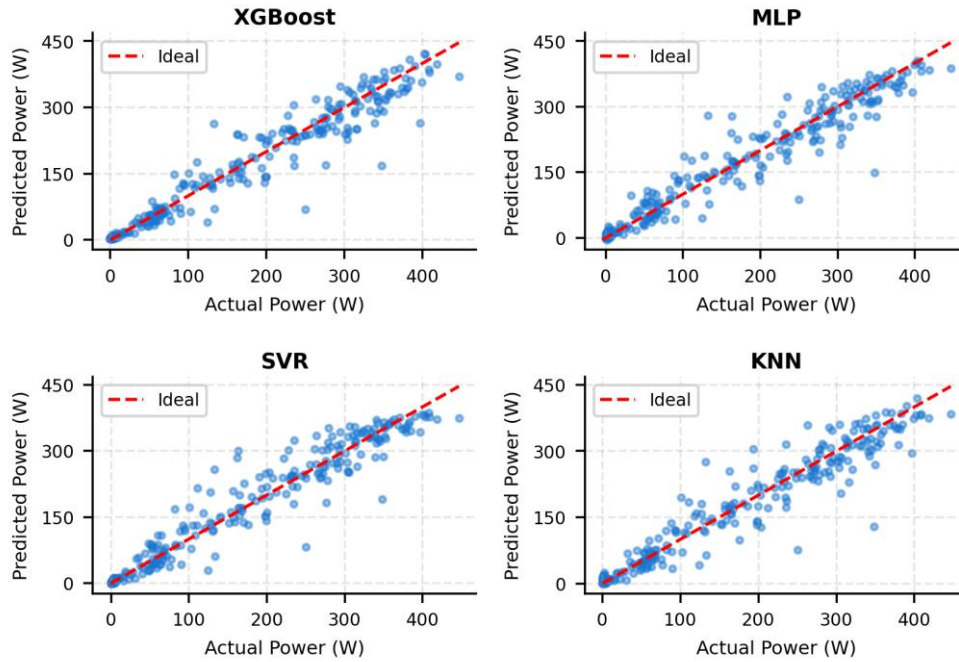


Figure 3. Scatter plots of actual versus predicted power output for all four models. The red dashed line represents the ideal 1:1 prediction line.

The scatter plots in Figure 3 further confirm the strong linear agreement between predicted and actual values for all models. The data points cluster tightly around the ideal 1:1 diagonal line across the full power range (0–450 W), with no systematic over- or under-prediction bias evident at the global level. XGBoost and SVR display the tightest point clouds, consistent with their superior R^2 values. A slight widening of the scatter is observable in the mid-range (100–250 W) for KNN, reflecting its comparatively higher prediction variance in this region.

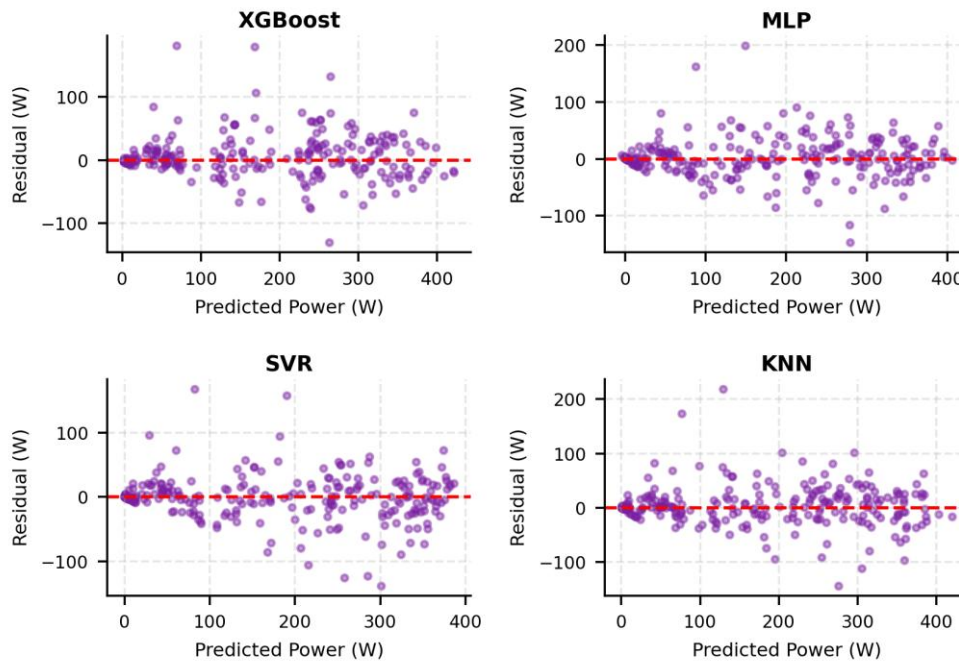


Figure 4. Residual plots (actual minus predicted) as a function of predicted power output for all four models. The red dashed line indicates zero residual.

The residual plots in Figure 4 provide insight into the error structure of each model. For all four algorithms, the residuals are distributed symmetrically around zero across the full range of predicted values, indicating the absence of systematic bias. XGBoost exhibits the most compact residual spread, with the majority of errors confined within ± 75 W. MLP and KNN show slightly larger residual magnitudes, with occasional outliers reaching ± 150 – 200 W, particularly in the low-to-mid power range. SVR demonstrates a well-balanced residual distribution with no pronounced heteroscedasticity, suggesting stable predictive variance across different operating conditions.

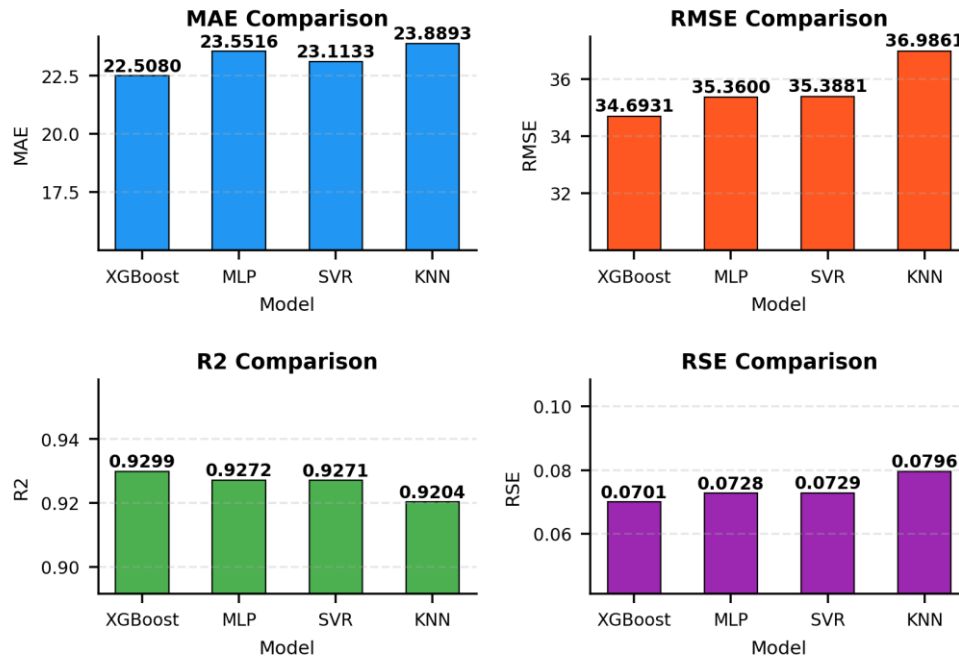


Figure 5. Comparison of model performance metrics (MAE, RMSE, R², and RSE) across all four machine learning models.

The bar chart in Figure 5 provides a consolidated visual comparison of all four-performance metrics. The ranking is consistent across metrics: XGBoost > SVR $\approx$ MLP > KNN. The narrow performance band across all models — with R² values spanning only 0.0095 (from 0.9204 to 0.9299) — suggests that the meteorological feature set is highly informative and that the primary performance driver is the quality of the input data rather than the choice of algorithm. Nevertheless, XGBoost's advantage is statistically meaningful in the context of real-time power forecasting, where even small reductions in MAE and RMSE translate to more reliable energy management decisions.

Overall, the results demonstrate that all four machine learning approaches are viable tools for photovoltaic power estimation using meteorological variables. XGBoost is identified as the most suitable model for this application, offering the best balance of accuracy, robustness, and computational efficiency.



4. CONCLUSIONS

This study conducted a systematic comparative evaluation of four machine learning regression algorithms — XGBoost, MLP, SVR, and KNN — for hourly solar power estimation from a single monocrystalline PV panel located in Lahore, Pakistan. The models were trained and tested on a preprocessed dataset of 846 effective generation records, incorporating six meteorological variables derived from the NASA MERRA-2 reanalysis database.

All four models demonstrated strong predictive performance, with R^2 values consistently exceeding 0.92, confirming that the selected meteorological feature set provides a highly informative basis for data-driven PV power forecasting. The preliminary correlation analysis further validated this finding, revealing that global horizontal irradiance and plane-of-array irradiance are the dominant predictors of power output, with correlation coefficients of 0.94 and 0.93, respectively.

Among the evaluated models, XGBoost achieved the highest accuracy across all four metrics (MAE = 22.51 W, RMSE = 34.69 W, R^2 = 0.9299, RSE = 0.0701), demonstrating superior generalization capability attributable to its gradient boosting mechanism and built-in regularization. SVR and MLP delivered nearly equivalent performance, with R^2 values of 0.9271 and 0.9272, respectively, suggesting that both kernel-based and neural network approaches converge to comparable solution spaces for this dataset. KNN, while still achieving an R^2 of 0.9204, exhibited the highest error magnitudes, reflecting its sensitivity to feature space density in low-irradiance boundary regions.

The residual and scatter plot analyses confirmed that all models produced unbiased predictions with no systematic over- or under-estimation across the full power range (0–450 W). The narrow performance band separating the four algorithms underscores that the quality and informativeness of the input feature set is the primary determinant of forecasting accuracy, rather than the algorithmic complexity of the model.

The findings of this study contribute to the growing body of evidence supporting the applicability of classical machine learning methods for panel-level PV power forecasting in subtropical urban environments. Future work will explore the integration of temporal sequence modeling — including LSTM and hybrid deep learning architectures — to capture the time-dependent dynamics of solar generation, as well as the incorporation of additional meteorological variables such as wind speed and relative humidity to further enhance predictive accuracy.

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The Effects of Propolis Extracted with Different Solvents on Utero-Ovarian Histomorphology in Prepubertal Female Rats

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Abstract

Aim: This study aimed to evaluate and compare the effects of propolis obtained using two different solvents (ethanol (EEP) and propylene glycol (PGE)) ovarian and uterine histomorphology and histopathological parameters of prepubertal female rats.

Method: Twenty-four female *Sprague dawley* rats (PND 27) were randomly assigned to three groups: Control, EEP (100 mg/kg), and PGE (100 mg/kg). The extracts were administered via oral gavage for 35 consecutive days until PND 60. Following the administration period, uterus and ovary tissues were fixed and embedded in paraffin blocks. Longitudinal and transverse sections (sagittal for ovaries; transverse for uterus) cut at a thickness of 4 µm were stained with Hematoxylin and Eosin (H&E). Detailed histomorphometric and histopathological analyses were performed by an expert pathologist, blinded to the experimental groups, using QuPath v0.5.0 digital pathology software.

Findings: Qualitative histopathological examination of the ovary and uterus tissues revealed that the general tissue architecture was well-preserved across all groups, with no evidence of extract-induced toxicity. Histomorphometric evaluations showed that EEP significantly increased the number of primordial follicles compared to the control ($p = 0.0241$). In the uterine tissue, PGE administration led to a significant decrease in endometrial gland density compared to both the control ($p = 0.0233$) and EEP ($p = 0.0035$) groups. No significant differences were observed in endometrial or myometrial thicknesses.

Results: Both EEP and PGE demonstrate a reliable safety profile regarding the structural integrity of reproductive tissues during the critical pubertal transition. While EEP appears to enhance the primordial follicle reserve, PGE displays a distinct impact on uterine glandular structures. These findings suggest that the choice of solvent significantly modulates the biological efficacy of propolis on reproductive organs. Due to its biocompatible profile in ovarian and uterine tissues, the PGE form stands out as a potent non-alcoholic alternative for pediatric and long-term applications.

Keywords: Propolis, Ethanol, Propylene Glycol, Ovary, Uterus, Histomorphometry, QuPath



1. INTRODUCTION

Propolis is a complex natural product collected by bees from botanical sources, characterized by its high biological activity [1]. The phenolic compounds, flavonoids, and aromatic acids in its composition are responsible for its anti-inflammatory, antioxidant, and immunomodulatory effects [2]. However, the therapeutic potential of propolis is directly dependent on the type and polarity of the solvent used during the extraction process [3]. Literature indicates that the choice of solvent plays a decisive role in the bioavailability of bioactive components in target tissues by altering their qualitative and quantitative profiles [4]. Ethanol is traditionally the most widely used solvent due to its high efficacy in dissolving the hydrophobic components of propolis [5]. Nevertheless, the pungent odor and alcohol content of ethanolic extracts (EEP) can be limiting factors in pediatric applications and specific histomorphological studies [6]. Propylene glycol (PG), an alternative solvent, attracts attention due to its low toxicity, high stability-providing capacity, and ability to increase water solubility [7]. It is emphasized that propylene glycol-based extracts (PGE) exhibit a different pharmacokinetic release compared to ethanolic extracts and that their effects, particularly on tissue integrity and cellular populations, should be evaluated through detailed histopathological analyses [8,9].

When examined from a histomorphological perspective, it has been reported that EEP can influence follicular development in the ovaries and exert trophic effects on uterine structures due to its bioactive components [2]. Furthermore, studies demonstrate that propolis extracts support cellular proliferation and tissue integrity in reproductive organs [10]. However, despite this potential efficacy of EEP, the alcohol content of ethanolic solvents may present limitations for delicate tissues during the prepubertal period, necessitating a comparison with alternative solvents such as propylene glycol. Although the success of EEP is frequently emphasized in the literature through 'damage models' (toxicity, diabetes, etc.), there is a notable lack of comparative studies evaluating tissue-level development and histomorphometric parameters in healthy subjects using digital pathology techniques.

Propylene glycol is a polar solvent with low toxicity that is widely used in the pharmaceutical and food industries [11]. In rat models, PG is generally characterized as a biologically neutral carrier that does not interfere with baseline physiological parameters [12]. Studies on PGE indicate that this solvent is successful in stabilizing hydrophilic and certain amphipathic phenolic compounds (e.g., p-coumaric acid and ferulic acid) within propolis [3]. Regarding the reproductive system, it has been reported that PGE presents a more 'biocompatible' profile in ovarian and uterine tissues by avoiding the potential irritant effects of ethanol. As a non-alcoholic alternative in apitherapy applications, PGE supports the maintenance of tissue architecture and cellular integrity in sensitive reproductive organs [7].

From a histopathological perspective, it is discussed in the literature that high doses of EEP may cause mild vascular congestion in uterine and ovarian tissues due to its alcohol content, whereas PGE exhibits a safer profile in preserving tissue architecture thanks to its mucosa-friendly structure [6]. In light of literature data, it is predicted that EEP exerts a more potent trophic effect on reproductive tissues in terms of bioactive component density, while PGE supports tissue development and cellular integrity through a more sustainable mechanism in terms of bioavailability stability and tissue compatibility [3, 8].

The primary aim of this study is to compare the effects of ethanolic and propylene glycol propolis extracts administered at a dose of 100 mg/kg on reproductive organ histomorphology and cellular integrity using a detailed histomorphometric approach. It is intended that the



findings obtained will contribute to determining the most suitable solvent choice for optimizing the biological efficacy of propolis on target tissues and filling this significant gap in the literature regarding structural development. In this study, ethanolic propolis extract (EEP) and propylene glycol extract (PGE) of Anatolian origin, which are standardized in terms of bioactive component content and represent the rich flora of Türkiye, were utilized.

2. MATERIALS AND METHODS

2.1. Experimental Animals and Ethical Approval

The experimental protocol of this study was reviewed and approved by the Duzce University Animal Experiments Local Ethics Committee (Approval No: 2024-05-01). A total of 24 female *Sprague dawley* rats were utilized, starting from the post-weaning period (postnatal day 27). The sample size was determined based on literature data for pubertal growth studies, where a group size of $n=8$ per group. The animals were housed under standardized laboratory conditions ($23 \pm 1^\circ\text{C}$, $60 \pm 5\%$ humidity, and a 12-hour light/dark cycle) with ad libitum access to water and a standard pellet diet.

2.2. Experimental Design and Grouping

The rats were randomly assigned to three experimental groups: a Control group, an EEP 100 group receiving 100 mg/kg/day of ethanolic extract of propolis, and a PGE 100 group receiving 100 mg/kg/day of propylene glycol extract of propolis. These dosages were determined based on traditional propolis consumption levels in pediatric populations and the toxicological safety thresholds established by Burdock [13]. The administration, conducted via oral gavage, commenced on postnatal day 27 (PND 27) and continued for 35 consecutive days until PND 60, effectively encompassing the entire pubertal transition period.

2.3. Euthanasia and Tissue Sampling

At the end of the experimental period (PND 60), all rats were placed under deep anesthesia via an intraperitoneal injection of a combination of xylazine (10 mg/kg) and ketamine hydrochloride (90 mg/kg). After confirming the depth of anesthesia by loss of reflexes, the rats were euthanized, and the reproductive organs (uterus and ovaries) were rapidly and carefully dissected. The tissues were immediately cleared of surrounding adipose and connective tissue, weighed using a precision balance, and transferred into a 10% neutral buffered formalin solution for histopathological fixation.

2.4. Histopathological and Histomorphometric Analyses

Following the fixation process, the uterus and ovary tissues underwent routine histological processing and were embedded in paraffin blocks. Longitudinal and transverse sections (sagittal for ovaries; transverse for uterus) were cut at a thickness of 4 μm and stained with Hematoxylin and Eosin (H&E). The prepared slides were digitized using a high-resolution slide scanner to create high-definition whole-slide images (WSI). All histological evaluations and morphometric measurements were performed by an expert pathologist, blinded to the experimental groups, using automated cell detection and manual annotation tools within QuPath v0.5.0 digital pathology software [9].

Ovarian Analysis: For each ovarian section, the numbers of primordial, primary, secondary, and antral follicles, as well as corpora lutea, were determined. Additionally, total ovarian area and the ratio of follicle types per unit area were calculated to assess follicle density.

Uterine Analysis: Endometrial and myometrial thicknesses, along with the surface area and numerical density of endometrial glands, were measured on transverse sections to evaluate the trophic impact of the extracts.

2.5. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics v27 (IBM Corp., Armonk, NY, USA). The normality of data distribution was evaluated using the Shapiro–Wilk test, while the homogeneity of variances was assessed with Levene’s test. All quantitative data are expressed as Mean $\pm$ Standard Error of the Mean (SEM). Quantitative histomorphometric parameters (follicle counts, tissue thicknesses, and glandular densities) were analyzed independently for groups. For data meeting parametric assumptions, One-Way Analysis of Variance (ANOVA) was applied, followed by Tukey’s post-hoc test to identify significant differences. In cases where parametric assumptions were not met, the Kruskal–Wallis test was employed, followed by Dunn’s post-hoc test. All graphical illustrations and visualizations were prepared using GraphPad Prism v8.0 (GraphPad Software, San Diego, CA, USA). Statistical significance was set at $p < 0.05$ for all analyses.

3. RESULTS AND DISCUSSION

One-way analysis of variance (ANOVA) results for primordial follicle measurements in female rats revealed a statistically significant difference among the groups (Figure 1A). According to the multiple comparison test, the mean value of the EEP 100 group was significantly higher than that of the control group ($p = 0.0241$). On the other hand, although the mean value observed in the PGE 100 group was numerically higher than the control, this difference did not reach statistical significance ($p = 0.0837$). Furthermore, a comparison between the two extract groups (EEP 100 and PGE 100) showed that the values were similar, with no statistically significant difference between them ($p = 0.9768$). The number of primary follicles in the ovarian tissues of female rats was analyzed using the Kruskal–Walli’s test, and no statistically significant difference was detected among the groups ($p > 0.05$; Figure 1A). According to the multiple comparison test results, no statistical significance was identified between the control group and the EEP 100 or PGE 100 groups in terms of primary follicle counts ($p = 0.4014$ and $p = 0.5586$, respectively). Similarly, when the EEP 100 and PGE 100 groups were compared with each other, no significant difference was observed in primary follicle counts ($p > 0.9999$).

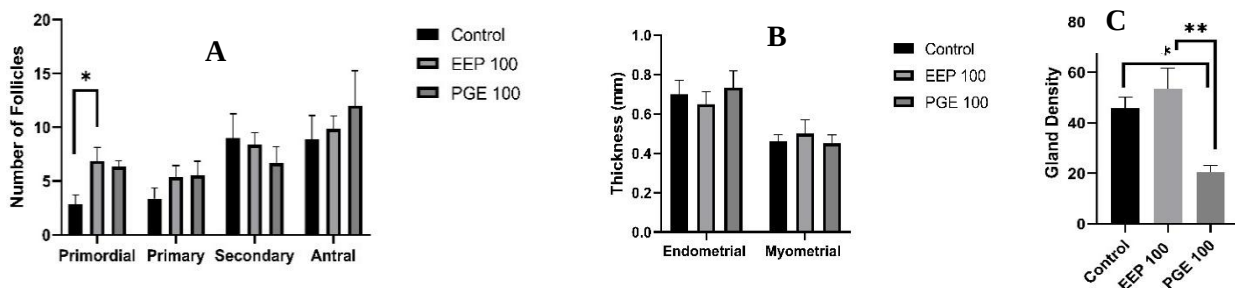


Figure 1. Histomorphometric analysis of ovary and uterus sections across experimental groups. (A) Distribution of primordial, primary, secondary, and antral follicle counts. (B) Endometrial and myometrial layer thicknesses (mm). (C) Comparison of uterine gland density. Data are presented as Mean $\pm$ Standard Error of the Mean (SEM). Significant differences are indicated as * $p < 0.05$ compared to the control, and ** $p < 0.01$ for comparisons between treatment groups.

According to the results of the one-way analysis of variance (ANOVA) performed on secondary follicle counts in the ovarian tissues of female rats, no statistically significant difference was detected among the groups ($p > 0.05$; Figure 1A). Examination of the Tukey multiple comparison test data revealed that neither EEP 100 nor PGE 100 administration resulted in a statistically significant change in secondary follicle counts compared to the control group ($p = 0.9623$ and $p = 0.6387$, respectively). Furthermore, pairwise comparisons between the EEP 100 and PGE 100 groups yielded similar results, showing that the difference between these groups was not significant ($p = 0.7842$). Regarding the antral follicle counts in female rats, no statistically significant difference was found among the groups ($p > 0.05$; Figure 1A). According to the results of the Tukey multiple comparison test, no statistical significance was identified between the mean antral follicle count of the control group and the EEP 100 or PGE 100 treatment groups ($p = 0.9403$ and $p = 0.6048$, respectively). Similarly, the comparison between the EEP 100 and PGE 100 groups themselves showed no significant difference in terms of antral follicle counts ($p = 0.7897$).

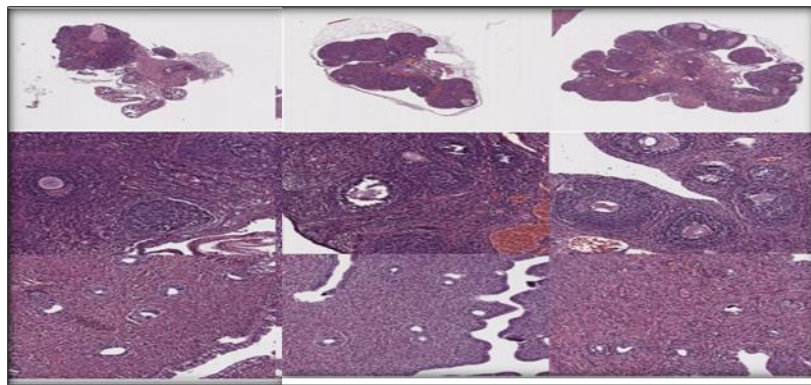


Figure 2. Representative digital histopathology images of ovarian and uterine sections from female rats in the Control, EEP 100, and PGE 100 groups. **(Top row)** Low-magnification overview of the entire ovarian architecture (all panels captured at the same field size). **(Middle row)** High-magnification images obtained from selected 0.5 mm² areas, showing various stages of follicular development across all groups. **(Bottom row)** Transverse sections of the endometrium, demonstrating comparative glandular density. A decrease in the density of endometrial glands is observed in the PGE 100 group compared to the other groups. (H&E staining).

Statistical analyses performed on endometrial thickness in the uterine tissues of female rats revealed no significant differences among the groups ($p > 0.05$; Figure 1B, Figure 2). According to the results of the Tukey multiple comparison test, no statistically significant changes were detected when comparing the endometrial thickness of the control group with the EEP 100 and PGE 100 treatment groups ($p = 0.8645$ and $p = 0.9458$, respectively). Furthermore, a comparison between the EEP 100 and PGE 100 groups showed that they exhibited similar values in terms of endometrial thickness, with no statistically significant difference ($p = 0.7097$). Data regarding myometrial thickness in female rats were analyzed using the Kruskal-Wallis test, as they did not meet parametric assumptions, and no statistically significant difference was found among the groups ($p > 0.05$; Figure 1B). According to the multiple comparison test results, no statistical significance was identified between the control group and the EEP 100 or PGE 100 groups in terms of myometrial thickness ($p > 0.9999$). Similarly, the pairwise comparison of both propolis extract groups (EEP 100 vs. PGE 100) yielded statistically similar results regarding the thickness of the myometrial layer ($p > 0.9999$). Analyses of gland density in the uterine tissues of female rats revealed statistically significant differences among the groups ($p < 0.05$; Figure 1C). According to the Tukey multiple comparison test results, while



the difference between the control group and the EEP 100 group was not significant ($p = 0.6233$), it was found that the gland density in the PGE 100 group significantly decreased compared to the control group ($p = 0.0233$). Additionally, when the two extract groups were compared with each other, it was determined that the gland density in the PGE 100 group was much lower than in the EEP 100 group, and this difference was highly significant ($p = 0.0035$).

The biological activity of propolis is directly correlated with its phytochemical richness, which is primarily determined by the extraction solvent. In the present study, the effects of ethanolic (EEP) and propylene glycol (PGE) extracts of Anatolian propolis on ovarian folliculogenesis and uterine histomorphology were compared histomorphometrically.

The observation that follicular development and uterine histomorphology remained stable and structurally sound across all groups is a critical finding regarding the safety profile of Anatolian propolis. Many natural products are under scrutiny due to their potential as endocrine disruptors during sensitive developmental windows, such as the pubertal period. Our results demonstrate that neither EEP nor PGE induces pathological alterations in the ovarian microenvironment or uterine architecture at the tested dosages. This finding suggests that while propolis exerts trophic effects on reproductive tissues (particularly on the primordial follicle pool) these do not lead to adverse structural fluctuations, consistent with literature indicating that propolis supports reproductive health without causing systemic imbalance [14].

4. CONCLUSIONS

This study provides a comparative investigation into the effects of ethanolic (EEP) and propylene glycol (PGE) extracts of Anatolian propolis on ovarian and uterine histomorphology during the prepubertal period. Although ethanol-based extraction (EEP) provides higher yields in the recovery of phenolic and flavonoid components (specifically Pinocembrin, Galangin, and CAPE) and exhibits superior antioxidant capacity, the PGE form represents a significant non-alcoholic alternative that preserves bioactive compound integrity.

It was demonstrated that propolis administration at a dose of 100 mg/kg (for both solvents) did not lead to pathological alterations in reproductive tissue architecture or follicular development. This finding confirms that Anatolian propolis does not exert a structural endocrine-disrupting effect during this critical developmental window, supporting its potential for safe application. Notably, the preservation of the primordial follicle pool and the stable endometrial thickness across groups underline the biocompatibility of both extracts.

Our study indicates that the biological effects of propolis depend not only on dosage and composition but also on the solvent utilized. It is concluded that PGE-based extracts may serve as a potent and safe alternative to ethanolic forms, particularly for pediatric and long-term metabolic applications where alcohol-free formulations are preferred. Future studies are recommended to investigate the underlying molecular signaling pathways responsible for the distinct effects observed in gland density and follicular dynamics.

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An Adaptive Control Approach for Robust Trajectory Tracking Against Wind Disturbances in Quadrotor UAVs

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Abstract

This study addresses the trajectory tracking problem of Quadrotor Unmanned Aerial Vehicles (UAVs) with non-linear dynamics and underactuated structures under external disturbances. UAVs are highly sensitive to factors such as wind gusts and model uncertainties. Although classical Sliding Mode Control (SMC) methods provide robustness, they require knowledge of the upper bound of the disturbances and can lead to high-frequency oscillations (chattering). To overcome these issues, this study proposes the Sigma-Modified Adaptive Sliding Mode Control (ASMC) method. The proposed method dynamically adjusts the control gain by instantaneously estimating the disturbance effect and prevents the "parameter drift" problem. Simulations performed in the MATLAB environment demonstrate that the proposed method minimizes the trajectory error even under variable wind gusts and optimizes the control gain when the wind stops, thereby ensuring energy efficiency.

Keywords: Quadrotor UAV, Adaptive Sliding Mode Control, Trajectory Tracking, Wind Disturbances, Sigma-Modification

1. INTRODUCTION

Quadrotor Unmanned Aerial Vehicles (UAVs) are "underactuated" systems because they attempt to control six degrees of freedom with only four motors. These vehicles are inherently unstable; their axes of motion interact with each other, and their dynamics are quite complex [1-4]. In addition to structural challenges, UAVs are lightweight and therefore easily affected by external influences such as wind and turbulence. This can cause the vehicle to lose its balance and deviate from its trajectory [5-7]. Furthermore, uncertainties such as payload changes or unforeseen friction forces during flight make the control task even more difficult [8-11].

PID controllers are generally utilized to solve these problems. However, the fixed nature of PID may be insufficient during sharp maneuvers or in windy conditions. Studies in the literature demonstrate that PID is weak against disturbances, whereas methods such as Sliding Mode Control (SMC) are considerably more robust [12]. SMC provides simple but effective resistance to external disturbances [13, 14]. Its low susceptibility to parameter changes and robust resistance to noise have made it a popular choice [15-18]. Experimental tests have also proven that SMC tracks the trajectory more effectively than PID and keeps errors to a minimum [19, 20]. Adaptive SMC versions have proven to be far superior, especially under challenging conditions [21-23].

However, classic SMC also exhibits a significant disadvantage: for stable flight, the control gain must be selected to be greater than even the strongest anticipated wind. In practical applications, it is difficult to determine how strong the wind will be beforehand. Therefore, engineers maintain the gain excessively (conservatively) high to ensure robustness. This leads to high-frequency vibrations in the system, which we refer to as "chattering" [20]. These vibrations heat the motors, cause them to wear out rapidly, and consume a significant amount of energy.

To overcome this problem, Adaptive Sliding Mode Control (ASMC) methods have been developed that automatically adjust the gain according to the instantaneous situation. ASMC applies the gain required at that specific moment without needing to know the upper limit of the wind, thereby reducing vibration [21-23]. Nevertheless, there is another risk inherent in standard ASMC algorithms: even if the wind subsides, the gain sometimes fails to decrease and remains at a high level. This is known as "parameter drift" in the literature. Ioannou and Kokotovic mathematically proved that this drift is inevitable under non-vanishing disturbances [24].

In this study, we utilized the Sigma-Modification (leakage term) technique, detailed by Ioannou and Sun, to prevent this drift [25]. This method, whose effectiveness was also validated by Plestan and his research team [26], increases the control effort when wind is present and, thanks to the leakage term, reduces the gain when the wind stops, thus preventing the "chattering" effect.

2. MATERIALS AND METHODS (SYSTEM MODELING AND DESIGN)

This section presents the dynamic model of the Quadrotor UAV and the proposed Sigma-Modified Adaptive Sliding Mode Controller (ASMC) design.

2.1. Quadrotor Dynamic Model

The quadrotor UAV is a system with 6 degrees of freedom and incomplete propulsion. In this study, since the focus is on the trajectory tracking problem, the translational (position) dynamics of the system are modeled using the Newton-Euler approach. When external disturbances and model uncertainties are included, the equations of motion for the $i \in \{x, y, z\}$ axes are expressed as follows:

$$\ddot{x} = \frac{1}{m}(u_x - d_x(t)) \quad (1)$$

$$\ddot{y} = \frac{1}{m}(u_y - d_y(t)) \quad (2)$$

$$\ddot{z} = \frac{1}{m}u_z - g - \frac{1}{m}d_z(t) \quad (3)$$

Here, m represents the total mass of the UAV, g the gravitational acceleration, u_i the virtual control inputs, and $d_i(t)$ the time-varying unknown external disturbances such as wind gusts. The aim of the controller is to asymptotically approximate the system positions (x, y, z) to the reference trajectory (x_d, y_d, z_d) .

2.2. Adaptive Sliding Mode Controller Design

The first step in controller design is defining the tracking error: $e_i(t) = x_{d_i}(t) - x_i(t)$

To stabilize the system in the error space, the following sliding surface function has been chosen:

$$s_i(t) = \dot{e}_i(t) + \lambda e_i(t) \quad (4)$$

Here, $\lambda > 0$ is the design parameter that determines the fault damping rate. The equivalent control and switching control law that will ensure the system reaches and remains on the sliding surface ($s_i = \dot{s}_i = 0$) is derived as follows:

$$u_i(t) = m(\ddot{x}_{d_i} + \lambda \dot{e}_i + K_i(t) \text{sgn}(s_i) + g\delta_{iz}) \quad (5)$$

Here, δ_{iz} is the Kronecker delta function that activates gravity compensation for the z-axis only. $K_i(t)$ is the adaptive switching gain.

2.3. The Sigma-Modified Adaptation Law

The law $\dot{K} = \gamma|s|$ used in classical ASMC methods tends to stabilize the gain at $s \rightarrow 0$ or in the absence of disturbances. However, in the case of measurement noise or momentary interruption of external disturbances, "drift" occurs in the gain due to the integral effect.

In this study, the Sigma-Modification technique is used to prevent parameter drift and keep the gain bounded. The proposed adaptation rule is as follows:

$$\dot{K}_i(t) = \gamma|s_i(t)| - \sigma(K_i(t) - K_{min}) \quad (6)$$

In this equation:

$\gamma > 0$: This is the adaptation speed. Choosing a large value ensures a quick response to sudden wind gusts.

$\sigma > 0$: This is the leakage coefficient. When the error decreases ($|s| \rightarrow 0$), the $-\sigma(K - K_{min})$ term becomes negatively dominant, bringing the gain to the safe lower limit of K_{min} .

K_{min} : This is the minimum gain value required for the nominal stability of the system.

Stability Sketch: When the Lyapunov function $V = \frac{1}{2}s^2 + \frac{1}{2\gamma}\widetilde{K}^2$ is chosen, the proposed sigma-modification term guarantees that the derivative of V is $\dot{V} < 0$, outside the error limits. This theoretically proves that the system has Uniformly Ultimately Bounded (UUB) stability and that the gains will not go to infinity.

3. RESULTS

The performance of the proposed Sigma-Modified ASMC method was tested on a nonlinear Quadrotor model created in MATLAB. For simulation studies, the sampling time was set as $dt = 0.001$ seconds and the total duration as $T = 20$ seconds. Controller parameters were

selected as error damping coefficient $\lambda = 2.0$, adaptation speed $\gamma = 10.0$, leakage coefficient $\sigma = 0.5$, and minimum gain $K_{min} = 0.1$.

3.1. Disruptive Scenario

A challenging scenario was designed to test the robustness of the system and the ability of the proposed method to prevent "parameter drift". The UAV follows a helix trajectory starting from the point (0,0,0). Between $t = 5$ and $t = 15$ seconds of the simulation, time-varying sinusoidal wind disturbances (d_x, d_y) were applied to the system as follows.

$$d_x(t) = 3 \sin(4t) + 2, \quad d_y(t) = 2 \cos(3t) \quad (7)$$

This scenario consists of three phases: an initial phase with no wind, a middle phase with strong winds, and a final phase where the wind subsides.

3.2. Trajectory Tracking and Error Analysis

Figures 1 and 2 present the trajectory tracking performance of the proposed controller in 3D space and the variations in errors along the axes.

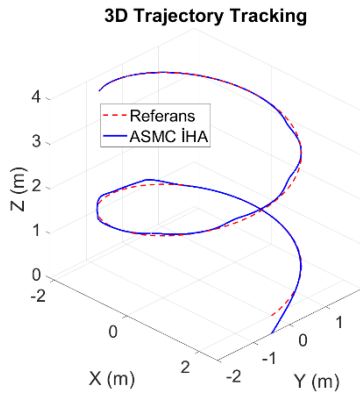


Figure 1. 3D trajectory tracking of the UAV controlled by ASCM

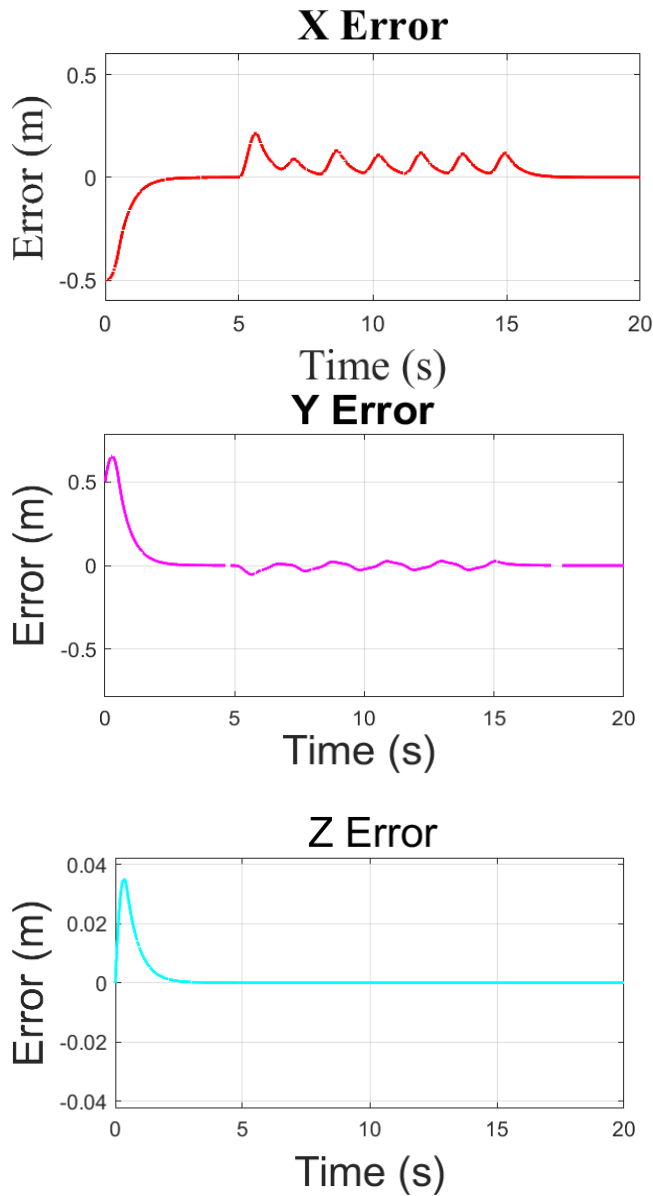


Figure 2. Schematic of error variations along the X, Y, and Z axes

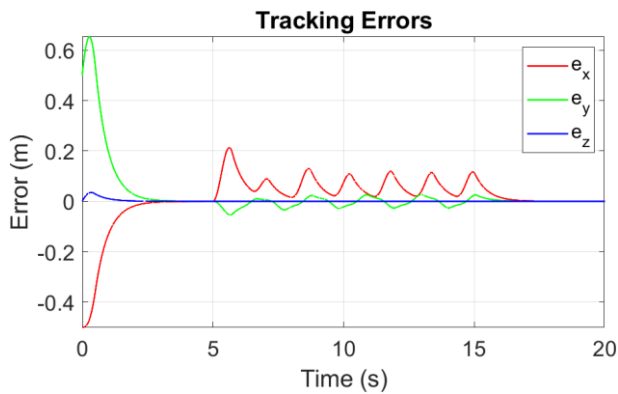


Figure 3. Overlapping representation of error variations along the X, Y, and Z axes

As seen in the graphs, transient response errors that occurred at the beginning of the simulation were damped within the first 2 seconds. Although the strong wind disturbance affecting the

system at $t = 5$ seconds caused momentary deviations in the x and y axes, the adaptive controller quickly eliminated these deviations and managed to keep the error around zero. This demonstrates that the controller has a high disturbance rejection capacity.

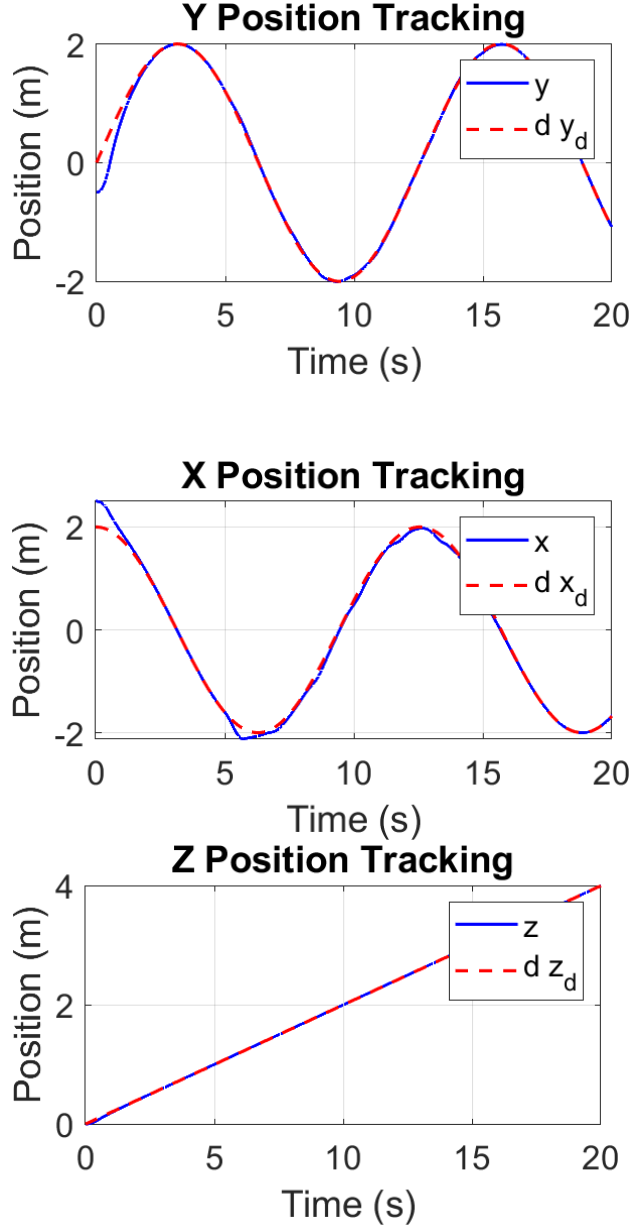
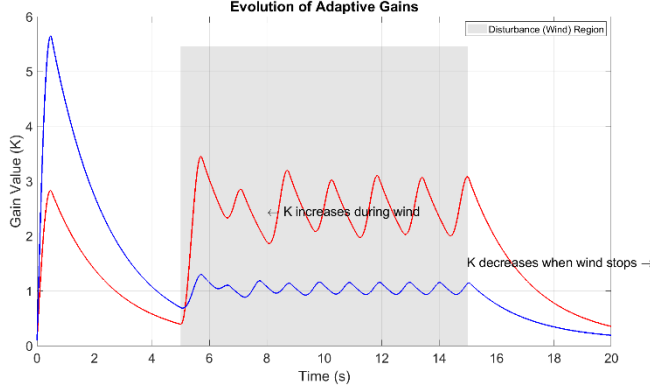


Figure 4. Evolution of Position Tracking Along the X, Y, and Z Axes Over Time

3.3. Adaptive Gain Dynamics (Critical Results)

The most important contribution of this study to the literature is the time-dependent variation of control gains. Figure 5 shows the variation of adaptive gains K_x , K_y for the x and y axes.

Figure 5. Variation of Sigma-modified adaptive control gains over time



The results obtained are fully consistent with theoretical expectations:

0 < t < 5 (Quiet State): Since there are no external disturbances, the gains remain at the $K_{min} = 0.1$ level, preventing unnecessary energy consumption.

5 < t < 15 (Adaptation Under Disturbance): When the wind effect begins, the $\dot{K} = \gamma|s|$ term becomes dominant, and the gains automatically increase to a level that suppresses the disturbance (approximately $K \approx 5-6$ band). In this way, system stability is maintained.

15 < t < 20 (Sigma-Modification Effect): When the wind stops, while the gain remains at a high level (parameter drift) in standard adaptive methods, the leakage term ($-\sigma K$) comes into play in the proposed method. As clearly seen in the graph, after $t = 15$ seconds, the gains automatically decrease back to the K_{min} level. This feature is the most critical factor minimizing the chattering effect and the risk of overheating in the motors.

4. CONCLUSIONS

In this study, we designed a wind-resistant controller for Quadrotor UAVs flying in challenging weather conditions. Our aim was to both solve the vibration (chattering) problem in classical SMCs and eliminate the "gain hanging" (parameter drift) problem seen in adaptive systems. For this purpose, we developed the Sigma-Modified Adaptive Sliding Mode Control method. The results we obtained from the simulations are as follows:

Durability: The developed controller maintained the balance of the UAV and prevented it from deviating from its trajectory even under strong wind gusts.

Intelligent Response: The system detected the increase in wind intensity and automatically increased the control gain (to approximately 5-6 levels) to suppress the disturbance.

Drift Prevention: This is the most critical output of the study; as soon as the wind subsided, the leakage term was activated and the gains were automatically reduced to a safe lower limit (K_{min}). In this way, unnecessary high gains were prevented from heating the motors and causing the system to vibrate. In summary, the proposed method provides a reliable solution for UAVs operating in uncertain outdoor environments, offering both precise flight capabilities and energy savings. Further validation of this algorithm through real-world flight tests is planned for later stages.



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Deep Learning-Based Defect Detection with SEM Images of Wafer: A Comparative Evaluation of DenseNet Architectures

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Abstract

Rapid and reliable detection of wafer defects in semiconductor manufacturing is critical for product quality and yield. This study systematically compares three variants of the DenseNet family (DenseNet121, DenseNet169, and DenseNet201) for the Normal–Abnormal binary classification of SEM-based wafer images. Models were initialized with ImageNet pre-trained weights, class-weighted Focal Loss was applied to address class imbalance, and 5-fold cross-validation was performed on a holdout test set to ensure the reliability of the results. Performance was evaluated using accuracy, balanced accuracy, F1, and AUC. The DenseNet169 model exhibited the best performance with 99.46 ± 0.72 F1 and 100.00 AUC. DenseNet201 produced zero false positives (100% accuracy/specificity); however, its sensitivity was slightly lower. The results reveal that DenseNet169 provides the best balance between parameter efficiency and success.

Keywords: SEM imaging, Wafer Defect Detection, DenseNet, Deep Learning, Transfer Learning

1. INTRODUCTION

In the semiconductor industry, wafer defects are a major problem that can affect productivity and production processes. Currently, defect inspection in silicon wafer production relies primarily on manual visual inspection or traditional machine vision techniques. Manual inspection of these defects is time-consuming because manual inspection is limited by factors such as operator fatigue, controller training, and skill differences. Therefore, many industries are adopting an automated defect detection system using machine vision. In addition, sophisticated defect detection and faster decision-making machines are becoming the most sought-after technology within the industry. With advancements in evolving technologies, Convolutional Neural Networks (CNNs) have improved performance in terms of faster image processing times and feature extraction from images. Transfer learning is a part of machine learning algorithms where algorithms are pre-trained with images from a database and use the acquired information to predict image classification. Further optimization can be performed to increase accuracy. However, the more image samples obtained for training and testing, the higher the accuracy. With advancements in sensor technology and artificial intelligence systems, defect detection based on deep learning has shown great potential in industrial automation inspection. These algorithms offer significant advantages over traditional machine vision approaches. By reducing missed errors and false positive rates, they provide a reliable solution for high-precision defect detection in semiconductor manufacturing lines [1,2].

Silicon integrated circuits are formed by the diffusion of dopants onto the surface of silicon wafers. A silicon wafer is a thin disc made of semiconductor material. Since silicon chip manufacturing is an industrial process, defects occur due to machine errors and a dirty factory environment. Accurate classification of wafer defects provides engineers with information through regular patterns in the processes. Wafer maps are used to examine defects. The patterns found in wafer map visualization are important for classification. Patterns detected by artificial intelligence can also help to correlate defects with the nuances of the production process. This provides an increase in the accuracy performance of the developed neural network. Therefore, it is expected to reduce waste in the semiconductor manufacturing process [3]. By determining the specific parameters of these defects, new strategies can be developed. Currently, it is difficult to distinguish between single-level and two-level defects and to extract the parameters of a two-level defect. It proposes an ML-based approach to distinguish between defects [4].

Scanning electron microscope (SEM) images are used in the classification of defects in semiconductor wafers. However, some disadvantages are that they require a large number of samples in the training phase and are generally computationally expensive. In addition, it is common to supplement with detailed imaging of defects by scanning electron microscopy (SEM) to perform offline classification later [5].

The first methods relied on rule-based algorithms with handcrafted features such as thresholding, edge detection and morphological processing and classical machine learning (ML) [7], [10]. The emergence of deep learning, especially Convolutional Neural Networks (CNNs), has presented a new research area in defect detection. DenseNet shows significant gains in AUC-ROC, macro F1-score and overall robustness compared to traditional CNN models. Convolutional networks have been used in research for many years. Research on convolutional neural networks has led to outstanding algorithms such as AlexNet, VGGNet, GoogLeNet, U-Net, EfficientNet, and ResNet. DenseNet leverages ResNet hopping connections by linking each layer in the convolutional neural network to all previous layers, thus achieving the highest accuracy rate. Each layer in DenseNet receives input from all preceding layers and transmits its output to all subsequent layers in a block. DenseNet also combines feature maps to provide diversity in the inputs of subsequent layers, unlike aggregation in residual networks. This feature reuse process creates many paths, leading to an exponential increase in memory requirements and computational complexity. It is well known that deeper networks are more efficient and easier to train than shallow or wider networks. Despite the high performance of very deep networks, they are limited in terms of vanishing gradient, decreasing forward stream, and slower training time [6,7].

2. MATERIALS AND METHODS

2.1. Data Set and Preprocessing

A SEM-based wafer defect dataset was used in the study [8]. The data consists of a "normal" class of defect samples and a "anomaly" main class containing multiple subcategories (block_etch, bridge, etc.). All sub-defect types were combined under a single Abnormal class in the binary classification problem; the data was naturally left unbalanced to represent a realistic industrial scenario. Images were converted to RGB format and rescaled to 224×224 pixels. To prevent overfitting in training, horizontal flipping, $\pm 30^\circ$ random rotation, and slight brightness and contrast changes were applied.

2.2. Cross-Validation Protocol and Architectures

Before cross-validation, the dataset was stratified to create a 15% holdout test set. The remaining 85% was divided into five subsets using a stratified 5-fold CV. In each fold, the models were restarted from scratch and evaluated on both the respective validation set and the fixed holdout test set. This protocol allows the reported metrics to be presented along with the standard deviation. General characteristics of the three DenseNet variants compared are given in Table 1. The final fully coupled layer of all models was restructured to conform to two-class output and a 0.5 probability Dropout layer was added before it.

2.3. Training Settings and Evaluation Metrics

All models were initialized with ImageNet pre-trained weights. The AdamW algorithm was used for optimization; the learning rate was set to 1×10^{-4} , the weight decay coefficient to 5×10^{-4} , and Cosine Annealing planning was applied. A maximum of 5 epochs of training was performed for each fold, and early stopping was applied to models that remained stable for 7 epochs via F1. Focal Loss with a class weight of $\gamma = 1$ was preferred for class imbalance; automatic mixed sensitivity (AMP) and gradient clipping were applied during training, and the batch size was set to 32. Performance; Accuracy, balanced accuracy, precision, sensitivity, specificity, F1, and AUC were evaluated together.

3. RESULTS AND DISCUSSION

The 5-fold cross-validation results of the three DenseNet variants on the holdout test set are presented in Table 1 in mean $\pm$ standard deviation format. The fact that all three models performed above 98% demonstrates the effectiveness of the DenseNet family in SEM-based defect detection. DenseNet169 outperformed the other two models in F1 and AUC metrics. The DenseNet201 model achieved 100% accuracy and 100% specificity, producing no false positives; however, its sensitivity remained relatively lower.

Table 1. DenseNet Model 5-Fold CV Test Results (mean $\pm$ standard)

Metrics (%)	DenseNet121	DenseNet169	DenseNet201
Accuracy	98,70 $\pm$ 0,81	99,35 $\pm$ 0,87	98,91 $\pm$ 0,97
Balanced Accuracy	98,73 $\pm$ 0,78	99,37 $\pm$ 0,79	99,11 $\pm$ 0,80
Precision	99,29 $\pm$ 0,87	99,65 $\pm$ 0,70	100,00 $\pm$ 0,00
Sensitivity	98,57 $\pm$ 1,34	99,29 $\pm$ 1,43	98,21 $\pm$ 1,60
Specificity	98,89 $\pm$ 1,36	99,44 $\pm$ 1,11	100,00 $\pm$ 0,00
F1-Score	98,92 $\pm$ 0,68	99,46 $\pm$ 0,72	99,09 $\pm$ 0,81

Figure 1 shows the average confusion matrices calculated over 5 folds for three models. In all matrices, the density on the diagonal is high, indicating that DenseNet201 does not produce any erroneous predictions in the Normal class.

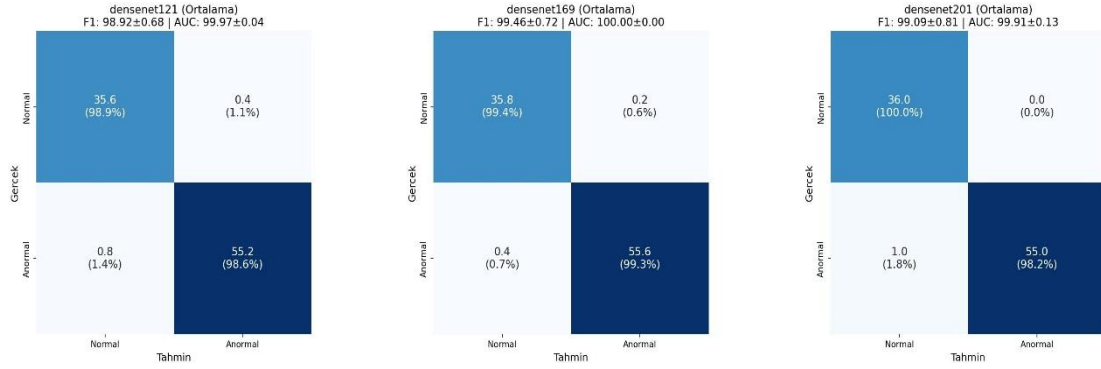


Figure 1. Average Confusion Matrices of Models (5-Fold CV)

The average ROC curves in Figure 2 are very close to the upper left corner, indicating that the models have high discriminatory power. DenseNet169 exhibited the most stable performance, achieving an AUC of %100.00 across five folds; the other two models also produced values above

%99.9.

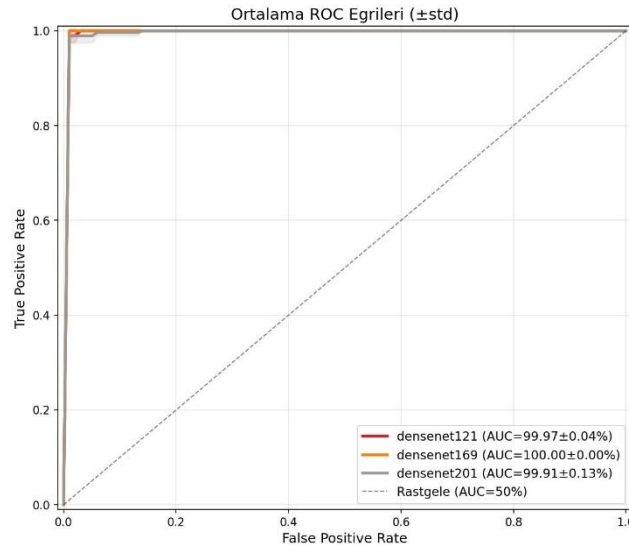


Figure 2. Mean ROC Curves of the Models (±std band)

When the results are evaluated, DenseNet169 provides the most optimal balance between the number of parameters and accuracy. This result can be explained by the fact that DenseNet169 achieves a deeper feature representation compared to DenseNet121 and is less prone to overfitting due to its fewer parameters compared to DenseNet201. DenseNet201 did not provide a significant increase in accuracy despite the increase in the number of parameters; this indicates that the model has reached sufficient capacity in the current dataset. DenseNet201 achieved excellent accuracy and specificity (%100.00); however, its sensitivity (98.21%) remained slightly lower than the other two models. In industrial quality control applications, missing a real defect (false negative) is generally much more costly than a false alarm (false positive). In this respect, DenseNet169, with its %99.29 sensitivity, stands out as a more suitable choice for practical use. Standard deviations remaining in the 0.7–2.0 range indicate that the models produced consistent results under different data distributions and that the high scores obtained were not due to data leakage or randomness.



4. CONCLUSIONS

In this study, DenseNet121, DenseNet169, and DenseNet201 architectures were compared for binary defect classification of SEM wafer images under a stratified 5-fold cross-validation protocol. The DenseNet169 model produced the best results with 99.46 ± 0.72 F1 and 100.00 AUC values; the low standard deviation values confirmed the methodological reliability of the results. Such automated systems, which support human inspection in industrial quality control, will both increase processing speed and reduce operator-induced errors. Future studies could address multi-defect type-based multi-class classification, comparison with Vision Transformer and hybrid CNN-Transformer architectures, integration of explainable artificial intelligence techniques such as Grad-CAM, and model compression and quantization approaches for real-time inference.

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Plant-Derived Essential Oils: Extraction Methods, Nanoemulsion Synthesis, and Applications

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Abstract

Essential oils of plants belong to highly effective natural compounds used in traditional and modern practices due to powerful antimicrobial, antioxidant, and anti-inflammatory characteristics. Essential oils extracted from aromatic herbs like thyme (*Oregona*), tea tree (*Melaleuca alternifolia*), peppermint (*Mentha piperita*), and lavender (*Lavandula angustifolia*) possess very intensive biological activity. However, the limited water solubility, volatility, and vulnerability of these oils make them hardly applicable. This research covers the discussion of methods to extract essential oils, nanoemulsion fabrication techniques, and application spheres of these preparations. It was found that nanoemulsion systems help to increase bioavailability and enhance the efficacy of the applied essential oils due to higher stability.

In this research, the comparative assessment of extraction techniques including hydrodistillation, steam distillation, supercritical CO₂ extraction, and ultrasonically assisted extraction was conducted. Moreover, both high-energy (ultrasonic homogenization, high-pressure homogenization) and low-energy (phase inversion technique and spontaneous emulsification) fabrication techniques used for nanoemulsions were discussed. The produced nanoemulsion systems were described and analyzed regarding their stability based on such parameters as droplet size, polydispersity index, and zeta potential and transmission electron microscopy (TEM).

Keywords: Plant essential oils; Nanoemulsions; Extraction methods; Bioavailability



1. INTRODUCTION

Essential oils derived from different parts of plants like leaves, flowers, seeds, bark, and roots represent volatile and complicated chemical structures, mostly consisting of terpenes, terpenoids, phenolics, and other low molecular mass compounds [1,2,3]. These active substances display a wide range of biological activities – antimicrobial, antioxidant, anti-inflammatory, antiviral, anticancer properties, etc. [4,5]. Essential oils and extracts are important in many industries due to the presence of aromatic, volatile components and bioactive substances they contain [6]. Essential oils have been utilized in traditional medicine practices for ages to treat infections, wound treatment, pain relief, respiratory diseases [7,8].

In recent decades, plant-derived essential oils (volatile oils) have become natural alternatives to synthetic antioxidants, addressing consumer concerns about their negative effects and thus research has focused on this area. Plant-derived essential oils are considered natural and biocompatible alternatives to synthetic compounds, which is associated with the lower toxicity of natural substances. The use of synthetic compounds causes toxic effects on consumers, leading to various types of cancer. In this context, to protect and improve consumer health and ensure food safety, plant-derived, plant-based essential oils can be used in many sectors such as pharmaceutical products, cosmetics, and food preservation [9]. Essential oils and extracts are of great importance in many industries due to their high content of aromatic, volatile, and bioactive compounds [6].

In the context of food preservation, essential oils are regarded as promising natural substitutes for artificial preservatives. In pharmacy, these compounds have proven their ability to exhibit therapeutic activity and enhance efficacy of synthetic drugs. Essential oils are also utilized in cosmetics for their scent, but also for their functional activity. Additionally, essential oils can be used in medicine, pharmacy, veterinary medicine, agriculture, and aromatherapy [10,8].

However, despite all the above-stated benefits, the practical use of essential oils is greatly hampered by several physiological and chemical limitations that exist within these substances. First, essential oils are hydrophobic and therefore poorly soluble in water and poorly dispersed in aqueous media. Furthermore, these oils have low stability and fast degradation rates caused by their volatile nature and vulnerability to heat, light, and oxidation [2].

Nanotechnologies can be used to improve the efficiency of essential oils in practical use. Among many such systems for the delivery of these oils, nanoemulsions can be noted. The unique qualities of nanoemulsions include low droplet sizes, large surface area, and kinetic stability. In addition, nanoemulsions can enhance solubility and stability of these oils and make them more bioavailable. Therefore, the use of essential oils together with nanotechnological systems can become an interesting option.

2. METHODS FOR EXTRACTING PLANT ESSENTIAL OILS

There is a wide variety of methods used for obtaining plant oils that differ in the properties of the extract. Below there is a summary of the most frequently used methods.



1.1. Hydrodistillation

It is one of the oldest methods that includes boiling plant material together with water. The resulting volatile compounds are then condensed. Even though it is a common and economically efficient approach, the thermal stability of compounds could be a problem here [11].

1.2. Steam Distillation

The steam passes through the plant material containing the volatile components, allowing for the separation of essential oils through condensation. It is among the top choices when applied on an industrial scale [12].

1.3. Soxhlet Extraction

This is a widely used chemical separation and purification method. Performed using organic solvents, this type of process is effective in the extraction of both volatile and non-volatile components. However, residual solvent and long processing times are among its limitations [13].

1.4. Cold Pressing

This method is a traditional method used to obtain high percentages of seed and shell oil [14]. Plants are compressed using mechanical pressure, causing the oil glands to rupture and thus releasing the volatile oil components. It is a much simpler process than solvent extraction, has low energy consumption and much less environmental pollution [15].

1.5. Supercritical CO₂ Extraction

This method allows for performing the process at low temperatures, avoiding thermal degradation and producing high-quality end-products. Although it is an environmentally sustainable technique, it is costly [16].

2.5. Microwave and Ultrasonic Extraction

These types of modern methods allow for faster extraction while maintaining high efficiency. They have the advantage of energy saving and high efficiency. Ultrasonic extraction refers to electromagnetic waves with wavelengths between 0.01 and 1 m and frequencies between 0.3 and 300 GHz, which have very strong penetrating and thermal effects [17,18].

Ultrasonic extraction can produce mechanical wave and vibration, cavitation, mixing and crushing effects, usually with a frequency between 20 and 50 kHz [19]. It also uses energy as a source to break down plant cells, releasing oil and dispersing organic phases in water [20].

3. NANOEMULSION PRODUCTION TECHNIQUES

Nanoemulsions represent a kinetically stable dispersion of liquids, with droplets ranging between 20 and 200 nanometers. This technique has been extensively applied to improve the efficacy of essential oils.



1.6. High Energy Approaches

- Ultrasonic Homogenization: Allows for the reduction of particle size via the cavitation effect.
- High-Pressure Homogenization: Disintegrates particles under high-pressure conditions [21].

1.7. Low-Energy Techniques

- Phase Inversion Technique (PIT): This technique utilizes the mechanism of inversion of the emulsion phase in response to changes in temperature [22].
- Spontaneous Emulsification: It is known for providing nano-scale drops using low energy inputs [23].

It is crucial for the characterization of nanoemulsions to take into account parameters such as droplet size, polydispersity index (PDI), zeta potential and transmission electron microscope (TEM).

4. USES AND APPLICATIONS

4.1. Applications in the Food Industry

The systems composed of nanodroplets and plant essential oils are employed as natural preservatives in the food industry. They exhibit excellent antimicrobial activity and antioxidant capacity. In food systems, such emulsions are efficient in inhibiting growth and reproduction of pathogens and spoilage microorganisms, ensuring an extended shelf-life of food products. Moreover, nanoemulsions are utilized as carriers for bioactive components insoluble in water; the latter ensures that the substances are dispersed uniformly within the aqueous phase of food matrixes. Nanoemulsions are also applied as part of edible coatings and smart packaging systems [24].

4.2. Pharmaceutical Applications

Nanoemulsions act as drug delivery systems, improving the solubility and bioavailability of the ingredients poorly soluble in water. Moreover, they ensure controlled and prolonged delivery of the active compounds, thus improving efficacy. In addition, essential oil-based nanoemulsions are successfully employed as antimicrobial, anti-inflammatory, and wound-healing agents.

4.3. Uses in Cosmetics and Dermatology

A wide array of cosmetic products employs nanoemulsions owing to their role in boosting skin penetration and stabilization of active ingredients. Nanoemulsions prepared using essential oils are included in creams, lotions, serums, and gels for their potential to combat signs of aging, hydrate skin, treat acne, and regenerate skin tissues. In addition, non-greasy characteristics along with better sensorial properties render these emulsions popular in personal care applications [25, 26].

4.4. Agricultural Uses

Nanoemulsions have been employed in agriculture as biopesticides, herbicides, and antifungal agents. The controlled release of active components, decreased environmental impact, and increased efficacy against plant diseases characterize such nanoemulsions and promote sustainable agriculture



4.5. Biomedical Uses

The application of nanoemulsion has become popular among several biomedical areas such as drug delivery systems, cancer treatment, and medical diagnostics. Their small particles enable efficient cellular absorption and delivery into targeted areas.

5. CONCLUSION AND FUTURE PERSPECTIVES

The conversion of plant essential oils into nanoemulsion form significantly increases the stability and biological efficacy of these natural compounds. Combining these traditionally proven oils with modern nanotechnological systems offers sustainable and environmentally friendly solutions.

In the future, the development of more functional nanoemulsion systems for targeted drug delivery systems, smart food packaging, and biomedical applications is expected.

However, disadvantages such as low water solubility, high volatility, and susceptibility to oxidative and photochemical degradation of essential oils limit their direct use. Nanoemulsion systems, developed to overcome these limitations, offer an effective approach to increase the stability of essential oils, provide controlled release, and improve their bioavailability.

Nanoemulsions are colloidal systems, generally with droplet sizes of 20–200 nm, possessing high surface area and kinetic stability, facilitating the targeted transport of active ingredients. The results have shown that nanoemulsion systems significantly increase the physicochemical stability of essential oils, provide protection against environmental effects, and enhance their biological activity.

In particular, in antimicrobial activity studies, nanoemulsion formulations were found to exhibit higher efficacy compared to free oils. This makes it possible for nanoemulsions to be effective even at lower doses.

In conclusion, combining plant essential oils with nanoemulsion technology; The development of natural preservative systems in the food industry, the design of targeted drug delivery systems in the pharmaceutical field, the stabilization of active ingredients in cosmetic products, and the development of environmentally friendly biopesticides in agricultural applications offer significant potential. This study provides an important scientific contribution to the development of sustainable, biocompatible, and high-performance nano-delivery systems.

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Deep Learning-Based SNFH Segmentation in Post-Treatment Glioma MRI

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Abstract

Radiotherapy planning in postoperative glioma patients requires accurate delineation of abnormal regions on postoperative MR images. In this study, the automatic binary segmentation of the Surrounding Non-Enhancing FLAIR Hyperintensity (SNFH) region was investigated using BraTS 2024 GLI, the first large-scale dataset focusing on post-treatment adult glioma. SNFH represents the FLAIR hyperintense abnormality surrounding the tumor and should not be interpreted solely as pure edema, as it may also include infiltrative tumor remnants and treatment-related FLAIR changes. The dataset consists of 1,621 labeled sessions from 731 unique patients obtained from five clinical centers. To prevent data leakage, a patient-level data splitting protocol was applied, and all images belonging to the same patient were assigned to a single subset. As an initial baseline model, a 2D U-Net architecture using single-channel T2-FLAIR input was trained. For this baseline, both data preparation and model training were performed on a local workstation. On the held-out test set, the model achieved a Dice coefficient of 0.741, a recall of 0.930, and a precision of 0.746. The high recall indicates that SNFH regions can be reliably detected, whereas the lower precision suggests a tendency toward over-segmentation. Consequently, this study presents a reproducible and academically defensible initial baseline for SNFH segmentation in the post-treatment glioma context and provides a foundation for clinically approved pre-segmentation support in the radiotherapy planning process.

Keywords: *post-treatment glioma, SNFH segmentation, 2D U-Net, medical image segmentation, radiotherapy planning*

1. INTRODUCTION

Brain gliomas represent one of the most challenging clinical conditions among central nervous system tumors due to their high malignant potential and tendency for recurrence. In high-grade gliomas, the standard treatment approach includes maximal safe surgical resection followed by radiotherapy administered concomitantly with chemotherapy [1]. During radiotherapy planning, accurate definition of the treatment target volume is critically important both for tumor control and for the preservation of healthy brain tissue [2].

Manual segmentation performed on postoperative MR images is a time-consuming process that requires high expertise and is prone to inter-observer variability. Particularly in the postoperative period, hemorrhagic residues, ischemic changes, the resection cavity, and treatment-related signal alterations further complicate segmentation [3,9]. Therefore, the use of automatic segmentation methods as support tools in the planning process is important both for reducing workload and for improving segmentation consistency. The long-term clinical vision



of this study is not to develop an autonomous decision-making system, but rather to contribute to a decision-support approach that provides a preliminary segmentation proposal that can be reviewed and approved by the clinician.

One of the most remarkable image regions in the post-treatment glioma context is the hyperintense area observed on postoperative T2-FLAIR images. In the BraTS 2024 GLI label schema, this region is defined as Surrounding Non-Enhancing FLAIR Hyperintensity (SNFH) [3]. SNFH is not identical to pure edema; it may include peritumoral edema, infiltrative tumor remnants, gliotic scar, pseudoprogession, and treatment-related FLAIR changes [3,8]. Therefore, SNFH segmentation is both a clinically meaningful and methodologically challenging problem.

The BraTS (Brain Tumor Segmentation) challenge has been used as an important benchmarking platform in brain tumor segmentation since 2012. BraTS 2024 GLI is particularly noteworthy as the first version in the series to focus entirely on post-treatment adult glioma data [3]. The dataset includes NETC, SNFH, ET, and RC labels reflecting the complex appearance of the postoperative period. In addition, the dataset has a longitudinal structure, meaning that multiple sessions acquired at different time points may belong to the same patient. This characteristic increases the risk of data leakage when patient-level partitioning is not performed. Studies on longitudinal glioma segmentation have shown that models trained with post-treatment data yield more appropriate performance on post-treatment test data and that the data splitting strategy is critical [8].

In the literature, the highest results on BraTS have mostly been achieved by challenge-oriented solutions involving multi-model and highly complex system architectures. Ferreira et al. [4] reported a lesion-wise DSC of 0.8926 for SNFH using synthetic data augmentation and a multi-model ensemble approach. Similarly, other strong solutions reported on BraTS 2024 have employed multi-task learning, post-processing, or ensemble strategies [4,2]. In contrast, clinically interpretable, reproducible, and simpler baseline studies remain relatively limited. Independent studies on postoperative glioblastoma have also demonstrated that nnU-Net-based models can achieve meaningful performance for edema/SNFH-like regions [9].

The following points highlight the main contributions of this study:

1. Development of a basic model approach for SNFH-focused binary segmentation on BraTS 2024 GLI and presentation of a reproducible baseline,
2. Prevention of data leakage risk through the application of a patient-level split suitable for the longitudinal data structure,
3. Evaluation of the results not only in terms of performance scores but also from the perspective of clinical interpretability,
4. Establishment of a comparable starting point for more advanced multi-channel and volumetric models.

2. MATERIALS AND METHODS

2.1. Dataset

In this study, BraTS 2024 GLI was used as the data source. The dataset includes multicenter and longitudinal post-treatment glioma MR images obtained from five different clinical centers.



Four fundamental MR sequences are available for each session: non-contrast T1-weighted imaging (T1n), contrast-enhanced T1-weighted imaging (T1c), T2-FLAIR (T2f), and T2-weighted imaging (T2w). The images were standardized to an isotropic resolution of 1×1×1 mm [3].

TrainingData, consisting of 1,350 sessions, and AdditionalTrainingData, consisting of 271 sessions, both of which include ground-truth segmentation masks, were included in this study. ValidationData, which does not contain ground-truth masks, was not used. As a result, the study dataset consisted of a total of 1,621 labeled sessions and 731 unique patients.

2.2. Target Label and Problem Definition

The BraTS 2024 GLI label schema consists of NETC, SNFH, ET, and RC classes. The definitions of these classes are presented in Table 1.

Table 1. BraTS 2024 GLI Label Schema

Label	Definition	Description
0	Background	Represents normal or irrelevant image regions outside the segmentation target and containing no pathological structure.
1	NETC	Non-Enhancing Tumor Core. Refers to pathological tissue belonging to the tumor core that does not show prominent contrast enhancement on contrast-enhanced imaging.
2	SNFH	Surrounding Non-Enhancing FLAIR Hyperintensity. Represents the non-enhancing region that appears hyperintense on the FLAIR sequence around the tumor or resection area; this region may include infiltrative tumor remnants and treatment-related changes in addition to pure edema.
3	ET	Enhancing Tissue. Represents the region showing prominent contrast enhancement on contrast-enhanced MR images and is generally associated with active tumoral tissue.
4	RC	Resection Cavity. Represents the surgical cavity formed after surgical resection and constitutes an important anatomical reference area in post-treatment imaging.

In this study, only Label 2 = SNFH was targeted, and the problem was defined as binary segmentation. Accordingly, binary masks were generated by assigning SNFH = 1 and all other labels = 0. The operation performed by the model is not the detection of “pure edema,” but the segmentation of the SNFH region corresponding to the BraTS 2024 GLI label definition.

2.3. Patient-Level Split Protocol

Since the dataset has a longitudinal structure, the distribution of sessions belonging to the same patient across both training and test sets may lead to data leakage [8]. Therefore, a patient-level split was applied. All sessions belonging to the same patient were assigned to only one subset. The numbers of patients and sessions in the training, validation, and test sets after the patient-level split are shown in Table 2.

Table 2. Number of patients and sessions in the training, validation, and test sets after the patient-level split

Subset	Number of Sessions	Number of Patients
Train	1125	512
Validation	226	109
Test	270	110
Total	1621	731

2.4. Data Preparation

Data preparation steps were carried out on a local computer. Binary masks corresponding only to the SNFH label were generated from the multi-class segmentation masks. To reduce severe class imbalance during training and validation, all positive slices were retained, while a `neg_stride = 32` sampling strategy was applied to empty/negative slices.

2.5. Model Architecture

A classical 2D U-Net architecture was used as the baseline model. The model operates on a slice-wise basis and uses only a single-channel T2-FLAIR image as input. T2-FLAIR was selected because it is the sequence in which the SNFH region is most prominently visualized. U-Net is a widely used and reproducible baseline architecture in medical image segmentation [5]. For more advanced comparisons, self-configuring systems such as nnU-Net are also accepted as strong baselines in the field [6].

2.6. Training Setup and Computing Environment

The single-channel baseline experiments presented in this study (EXP-001) were carried out on a local computer. The main hardware component used during training was an NVIDIA GeForce RTX 4070 SUPER GPU. Data preparation and training were performed in the same local working environment. The main hyperparameters used are shown in Table 3.

Table 3. Hyperparameters used in model training

Parameter	Value
Model	2D U-Net
Input	T2-FLAIR (1 channel)
Batch size	8
Optimizer	Adam
Learning rate	0.0003
Epoch	30
Gradient clipping	1.0
Negative slice stride	32
Seed	42
AMP	Disabled

BCEWithLogitsLoss measures pixel-level classification error, and Dice Loss evaluates the regional overlap between the predicted mask and the ground-truth mask. With saying this, Loss function was constructed as an equally weighted combination of these measures. Combined losses based on Dice and cross-entropy have been widely reported in the literature to be effective, particularly under class imbalance in medical image segmentation [7]. The loss function was calculated as $0.5 \times \text{BCEWithLogitsLoss} + 0.5 \times \text{Dice Loss}$.

2.7. Evaluation Metrics and Qualitative Review

In this study, the Dice coefficient (DSC), Intersection over Union (IoU), Precision, and Recall metrics were reported for performance evaluation.

Dice and IoU were used because they reflect overlap-based quality and are widely preferred in medical segmentation under class imbalance [7]. Metrics were calculated at the slice level, and mean values were reported. In addition, for qualitative evaluation, ground-truth and prediction masks were visualized on selected examples from the test set.

3. RESULTS AND DISCUSSION

3.1. Training Behavior

At the end of the first epoch, the model achieved a val_dice value of 0.7154. This indicates that the data flow and label matching were correctly established. Throughout training, the train loss decreased regularly, and the best validation result was obtained in the final epoch. The training loss and validation performance metrics obtained on an epoch-wise basis during the model training process are shown in Table 4.

Table 4. Epoch-wise training loss and validation performance metrics during the model training process

Epoch	Train Loss	Val Loss	Val Dice	Val IoU	Val Precision	Val Recall
1	0.2317	0.1819	0.7154	0.6154	0.6804	0.8551
2	0.1741	0.1681	0.7424	0.6472	0.7599	0.8130
10	0.1670	0.1650	0.7445	0.6461	0.7626	0.8101
15	0.1563	0.1602	0.7492	0.6541	0.7454	0.8367
20	0.1372	0.1466	0.7490	0.6536	0.7510	0.8342
30	0.1161	0.1389	0.7596	0.6651	0.7596	0.8352

The metrics shown in Table 4 indicate that the model did not fully converge at the end of 30 epochs but continued to learn in a stable manner.

3.2. Validation and Test Results

The results obtained from the test evaluation using the checkpoint with the best validation performance are presented in Table 5.

Table 5. Test results obtained using the model with the best validation performance

Metric	Validation	Test
Dice	0.7596	0.7407
IoU	0.6651	0.7037
Precision	0.7596	0.7459
Recall	0.8352	0.9302

The limited decrease in the Dice value on the test set compared with the validation set suggests that the model did not exhibit complete overfitting. The most notable result is the Recall value of 0.9302. This indicates that the model covers the actual SNFH regions to a large extent. A high recall value is known to be an important indicator, especially in terms of clinical safety [10].

3.3. Clinical Interpretation of the Results

From the perspective of radiotherapy planning, a false-negative error, that is, missing an actual pathological region, may be more critical than a false-positive error. Therefore, the high Recall value is important from the viewpoint of clinical pre-segmentation. The model largely captures SNFH areas; however, the lower Precision value indicates a tendency toward over-segmentation in some regions.

In representative examples selected from the test set, a strong overlap was observed between the main SNFH region and the segmentation mask produced by the model. In the BraTS-GLI-02063-100, BraTS-GLI-02063-101, and BraTS-GLI-02063-102 examples presented in Figure 1, Figure 2, and Figure 3, the main lesion area appears to be largely covered correctly. However, in some slices, small false-positive segmentation islands may occur, particularly in the lower regions of the lesion. These findings are consistent with the quantitative evaluation results. The model demonstrates a relatively lower precision despite its high recall value. Therefore, the model is promising in terms of clinical pre-segmentation support. However, it also shows that boundary sensitivity and false-positive control need to be improved.

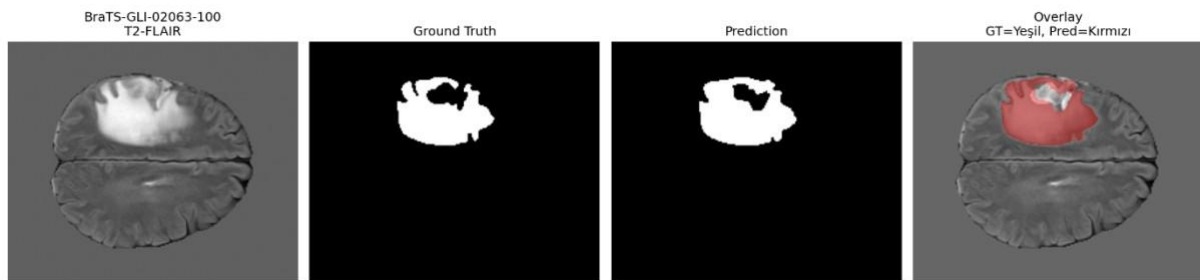


Figure 1. T2-FLAIR image, ground truth, model prediction, and overlay visualization of the BraTS-GLI-02063-100 case from the test set

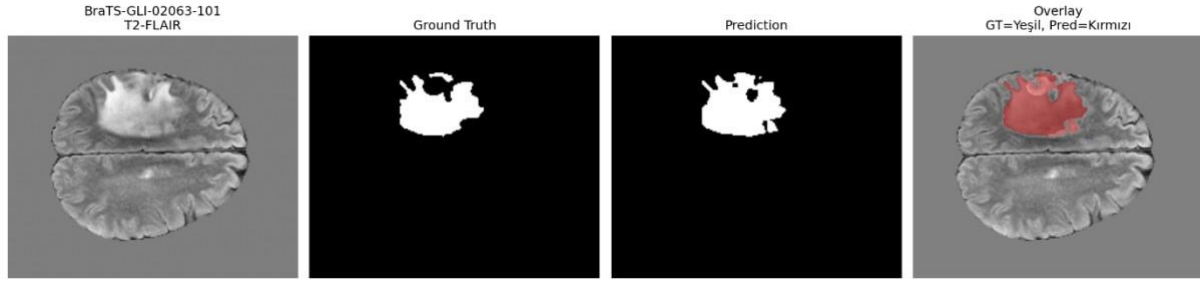


Figure 2. T2-FLAIR image, ground truth, model prediction, and overlay visualization of the BraTS- GLI-02063-101 case from the test set

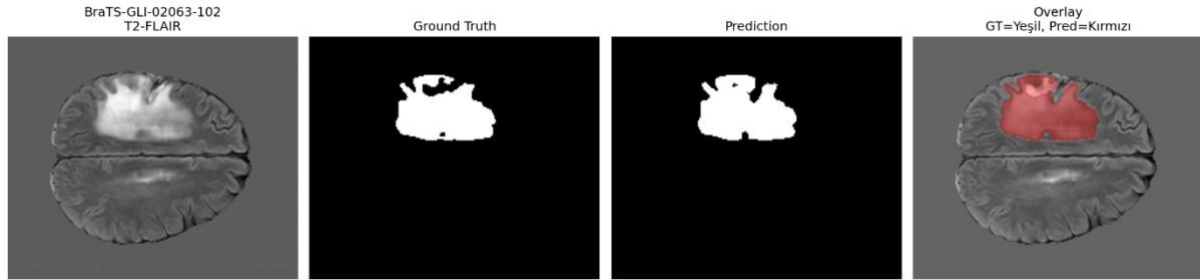


Figure 3. T2-FLAIR image, ground truth, model prediction, and overlay visualization of the BraTS- GLI-02063-102 case from the test set

3.4. Limitations

First, the model was trained for only 30 epochs, and the effect of longer training procedures on performance was not investigated. In addition, the input data were limited to only the T2-FLAIR modality, and the potential contribution of multi-channel approaches was not evaluated. Since the model is 2D and slice-based, volumetric contextual information cannot be sufficiently utilized. It is known that 2D approaches may remain limited in fully exploiting the spatial context in volumetric MR data [11]. Furthermore, small false-positive segmentation islands were observed in some test examples. Finally, the differences observed between the validation and test results, particularly in terms of the IoU and Dice metrics, need to be analyzed in more detail within the context of the evaluation protocol.

4. CONCLUSIONS

In this study, a simple and reproducible baseline model approach was presented for the automatic binary segmentation of the SNFH region in post-treatment glioma MR images on the BraTS 2024 GLI dataset. Considering that SNFH is not merely pure edema and may also include infiltrative tumor remnants and treatment-related changes, the problem was addressed as the segmentation of the post-treatment FLAIR hyperintense region. In addition, taking into account the risk of data leakage arising from the longitudinal data structure, a patient-level split was applied, preventing sessions belonging to the same patient from being distributed across different subsets.

Using a 2D U-Net model with single-channel T2-FLAIR input, Dice = 0.7407, Precision = 0.7459, and Recall = 0.9302 were obtained on the test set. In particular, the high recall value indicates that the model is successful in not missing the target region. However, when precision



and Dice values are evaluated together, it is observed that the model has a tendency to produce false positives and is open to improvement in terms of boundary accuracy.

The results obtained should not be directly compared with values reported in the literature. For example, the lesion-wise DSC = 0.8926 result reported by Ferreira et al. [4] is not methodologically comparable due to differences in data partitioning strategies, metric definitions, and high-complexity ensemble-based approaches. Similarly, while the multi-task models proposed by Astaraki and Toma-Dasu [2] report high performance, they have more limited applicability for direct integration into clinical workflows due to the use of multiple modalities and increased system complexity.

In contrast, when examining simpler and clinically oriented studies, Cepeda et al. [9] reported a median Dice score of 0.77 for the edema region using an nnU-Net-based model. Despite differences in datasets and evaluation protocols, these results indicate that the proposed approach is not entirely disconnected from the literature. Furthermore, considering that nnU-Net is a robust and widely accepted baseline in medical image segmentation [6], conducting systematic comparisons with this study in the future would be meaningful.

This study aims to present a clinically interpretable, reproducible, and scalable baseline model rather than directly competing with high-performance competition solutions. In this context, the proposed approach could serve as a potential foundation for doctor-assisted pre-segmentation scenarios.

In future studies, the use of multi-channel inputs, integration of boundary-sensitive metrics such as HD95, evaluation of 3D architectures, and comparative analyses with stronger models such as nnU-Net are planned. In addition, post-processing strategies for reducing false positives and more advanced loss functions stand out as important research directions that may improve performance.

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Immigrants' Fear of Being Victimized and Perceived Risk of Victimization: An Analysis in the Context of Demographic Variables

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Abstract

This study aims to examine immigrants' fear of crime victimization and their perceived risk of victimization within the context of demographic variables. Increasing migration movements in recent years have not only influenced immigrants' social integration processes but also significantly shaped their perceptions of safety and security. Fear of crime victimization is not solely based on actual victimization experiences; it is also affected by demographic factors such as age, gender, education level, income, and length of residence.

The study analyses the relationship between immigrants' levels of fear of crime and their perceived risk of victimization, identifying which demographic groups exhibit higher levels of concern. Findings indicate that women, older individuals, and immigrants with lower income levels tend to experience higher levels of fear. In contrast, higher levels of education are associated with more balanced and rational risk perceptions, leading to a more stable sense of security.

Environmental factors, including the physical and social characteristics of the neighborhoods where immigrants live, perceptions of local crime rates, and the influence of media, are also found to play a significant role in increasing fear of victimization. Additionally, individuals with prior victimization experiences report considerably higher levels of perceived risk.

Overall, the findings suggest that immigrants' perceptions of safety are shaped not only by individual characteristics but also by broader structural and environmental conditions. Strengthening social integration policies, improving safe living environments, and increasing awareness initiatives can contribute to reducing fear of crime among immigrant populations.

Keywords: Migration, fear of crime, victimization risk, security perception, demographic variables

INTRODUCTION

Migration is a significant process that has accelerated with globalization and directly affects the demographic, economic, and social structure of societies. In this process, migrant individuals face not only economic and cultural adaptation problems but also psychosocial issues such as perceptions of insecurity and fear of crime[1]. The relationship between migration and crime has been discussed in criminology literature for many years, and scholars emphasize that this



relationship should be evaluated not only through crime rates but also through individuals' perceptions and experiences[2].

Fear of crime victimization refers to the anxiety and insecurity individuals experience regarding the possibility of becoming victims of crime. This fear significantly influences individuals' perceptions of their environment, social relationships, and daily life practices [3]. Perceived victimization risk, on the other hand, reflects individuals' subjective evaluations of the likelihood of becoming victims of crime in the future and may develop independently of actual crime rates [4]. This situation demonstrates that perceptions of security are shaped not only by objective realities but also by social, cultural, and psychological factors.

From the perspective of immigrant individuals, factors such as living in a foreign social environment, language barriers, economic vulnerability, and social exclusion are among the major factors that increase fear of crime [5]. Furthermore, the physical and social characteristics of the neighborhoods where immigrants reside also influence their perceptions of crime. In this context, the Broken Windows Theory suggests that environmental disorder increases individuals' fear of crime and weakens their sense of security [6].

The relationship between immigrants' fear of crime victimization and their perceived risk of victimization is critically important for their social integration processes. Previous research indicates that these two variables are interconnected and mutually reinforcing, while security perceptions vary depending on demographic characteristics [7]. Accordingly, this study aims to examine immigrants' fear of crime victimization and their perceived risk of victimization within the framework of demographic variables, thereby contributing to the existing literature.

METHOD

This research was designed within the framework of a quantitative research approach, based on a survey model. The survey model is a common methodological framework employed to characterize the existing conditions, perceptions, and attitudes of a given population in their natural state. Within this model, the research aimed to determine the current situations of immigrant individuals regarding their fear of becoming victims of crime and their perceived risk of becoming victims, without any experimental intervention.

The research also possesses descriptive and relational characteristics. Descriptively, it reveals general trends regarding the fear of crime and risk perception among immigrant individuals; relationally, it examines the relationships between these variables and how they differ according to demographic characteristics. In this respect, the study is evaluated within the framework of a relational survey model, where the relationships between variables are analyzed.

Working Group

The study's sample consists of immigrant individuals aged 18 and over living in Türkiye. Due to the mobile nature of the immigrant population, their dispersed presence across different cities, and the difficulty in obtaining precise numerical data on the population, the application of probabilistic sampling methods has been limited. Therefore, in this study, convenience sampling and snowball sampling techniques, both non-probabilistic sampling methods, were used together.

Data Collection Tools



A structured questionnaire was used as a data collection tool in the research. The questionnaire consists of three main sections:

Demographic Information Form:

This section includes questions aimed at determining the demographic characteristics of the participants, such as age, gender, marital status, education level, income level, employment status, and length of residence in Türkiye. These variables will be used as independent variables in the analyses.

Fear of Crime Victimization Scale:

This section consists of items designed to determine participants' levels of fear of becoming victims of crime. The scale was developed using multidimensional crime fear measures found in the literature, and adaptations were made considering the social context of immigrant individuals. The scale encompasses dimensions of perceived security, environmental anxiety, and fear experienced in daily life.

Perceived Risk of Victimization Items:

This section includes statements designed to determine the level of risk individuals perceive themselves to be at risk of becoming victims of crime. The items aim to measure individuals' subjective assessments of their likelihood of becoming victims of crime in the future.

All scale items are structured using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). The content validity of the scales was evaluated through expert opinion, and the comprehensibility of the items was tested through a pilot application.

Data Collection

Research data were collected using both online and face-to-face data collection methods. In the online data collection process, participants were provided with a survey link via secure survey platforms. In the face-to-face data collection process, participants were informed about the purpose of the research, and the survey form was administered by the researcher.

The data collection process was based on the principle of voluntariness, and participants were informed about the purpose and scope of the research and data confidentiality. Participants were not asked for their personal information, and it was stated that the collected data would only be used for scientific purposes. The research process was conducted with the approval of the ethics committee.

Data Analysis

The data obtained within the scope of the research were analyzed using statistical analysis programs. In the analysis process, missing data check, outlier analysis, and normality tests were first performed on the data set.

In accordance with the research questions, the following analysis methods were used:

- Descriptive statistics (frequency, percentage, mean, standard deviation)
- Examining differences between two groups using an independent samples t-test.



- Multigroup comparisons using one-way analysis of variance (ANOVA)
- Correlation analysis to determine the relationship between fear of becoming a victim of crime and perceived risk of becoming a victim.
- Regression analysis is used to identify the factors that influence the dependent variables.

Multivariate analysis techniques were also used to examine the concurrent effects of demographic variables. A statistical significance level of $p < .05$ was accepted for the analyses.

Table 1. Distribution of Participants' Demographic Characteristics

Variable	Category	n	%
Gender	Woman	118	47.2
	Male	132	52.8
Age	18–25	72	28.8
	26–35	94	37.6
	36–45	56	22.4
	46 and over	28	11.2
Education	Primary education	64	25.6
	High school	98	39.2
	University	88	35.2
Duration of Stay in Türkiye	1-3 years	82	32.8
	4–6 years	96	38.4
	7 years and older	72	28.8

Table 1 presents the distribution of participants according to their demographic characteristics. The findings indicate that 52.8% of the participants were male, while 47.2% were female. Regarding age distribution, the majority of the participants were between the ages of 26 and 35 (37.6%). In terms of educational background, high school graduates constituted the largest group (39.2%). Concerning the duration of stay in Türkiye, the highest proportion of participants had been living in Türkiye for 4–6 years (38.4%). Overall, Table 1 demonstrates that the study sample mainly consisted of young and middle-aged immigrant individuals with moderate educational backgrounds and relatively recent migration experiences.



Table 2. Descriptive Findings Regarding Fear of Crime Victimization and Perceived Risk Levels.

Variable	Average	Std. Deviation
Fear of becoming a victim of crime	3.62	0.74
Perceived Risk of Victimization	3.48	0.69

Table 2 presents the descriptive statistics related to fear of crime victimization and perceived victimization risk levels among participants. The mean score for fear of crime victimization was found to be 3.62 (SD = 0.74), whereas the mean score for perceived victimization risk was 3.48 (SD = 0.69). As shown in Table 2, both variables were above the moderate level. These findings suggest that immigrant individuals experience a noticeable level of concern regarding personal safety and the possibility of becoming victims of crime.

Table 3. Fear of Crime and Perceived Risk by Gender (t-Test Results)

Variable	Gender	Average	t	p
Fear of Crime	Woman	3.78	2.41	.016
	Male	3.47		
Perceived Risk	Woman	3.61	2.05	.042
	Male	3.36		

Table 3 demonstrates the comparison of fear of crime victimization and perceived victimization risk according to gender. Female participants reported higher levels of fear of crime (M = 3.78) compared to male participants (M = 3.47). Similarly, perceived victimization risk scores were higher among women (M = 3.61) than men (M = 3.36). According to the independent samples t-test results presented in Table 3, these differences were statistically significant ($p < .05$). These findings indicate that female immigrants tend to perceive themselves as more vulnerable to crime and victimization.

Table 4. Fear of Crime by Age Groups (ANOVA Results)

Age group	Average	F	p
18–25	3.40	3.12	.027
26–35	3.65		
36–45	3.71		
46+	3.80		

Table 4 presents the comparison of fear of crime victimization scores across different age groups. The results reveal that fear of crime increased progressively with age. Participants aged 46 and above had the highest fear scores ($M = 3.80$), whereas the youngest group, aged 18–25, reported the lowest mean score ($M = 3.40$). As indicated in Table 4, the ANOVA results showed that the differences between age groups were statistically significant ($F = 3.12, p < .05$). This finding suggests that older immigrant individuals experience greater concerns regarding crime victimization.

Table 5. Relationship Between Fear of Crime Victimization and Perceived Risk.

Variables	r	p
Fear of Crime – Perceived Risk	.64	.000

Table 5 shows the relationship between fear of crime victimization and perceived victimization risk. The correlation analysis revealed a moderate and positive relationship between the two variables ($r = .64, p < .001$). As presented in Table 5, individuals who reported higher levels of perceived victimization risk also tended to report higher levels of fear of crime. This finding indicates that fear of crime and perceived risk are closely related and mutually reinforcing concepts.

Table 6. Regression Analysis Results

Variable	Beta	t	p
Gender	.21	2.88	.004
Age	.18	2.34	.021
Education	-.12	-1.96	.051
Duration of Stay	.15	2.11	.036

Table 6 presents the results of the regression analysis examining the effects of demographic variables on fear of crime victimization. The findings indicate that gender ($\beta = .21, p = .004$) and age ($\beta = .18, p = .021$) were significant predictors of fear of crime. In addition, duration of stay in Türkiye was found to have a statistically significant effect ($\beta = .15, p = .036$). Although education level showed a negative relationship with fear of crime ($\beta = -.12$), the result was close to the significance threshold ($p = .051$). As shown in Table 6, female participants, older individuals, and immigrants with longer residence durations tended to report higher levels of fear of crime victimization.

CONCLUSION

This study examined the fear of crime and perceived risk of victimization among immigrant individuals within the context of demographic variables. The findings indicate that immigrant individuals generally have a level of crime fear and risk perception that is above average. This suggests that immigrants' perceptions of security within their social environment may be fragile.



Analyses based on gender revealed that female participants had higher levels of fear of becoming a victim of crime and perceived risk compared to male participants. This finding is consistent with studies in the literature indicating that women feel more vulnerable to crime. Regarding age, fear of crime was found to increase, with security concerns being more pronounced, particularly in older age groups.

The study found a positive and significant relationship between the fear of becoming a victim of crime and the perceived risk of becoming a victim. This indicates that individuals' fear of crime increases as they feel more at risk. Furthermore, the regression analysis results show that variables such as gender, age, and length of stay in Türkiye have a significant impact on the fear of crime.

These results show that migrant individuals' perceptions of security are influenced not only by individual factors but also by multidimensional factors such as social environment, integration process, and living conditions. In this context, strengthening social integration policies for migrants, taking local-level measures to increase security perception, and developing social support mechanisms to reduce risk perception are important.

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Effect of Priming with ZnO Nanoparticles on Germination of Marigold Under Salinity Stress

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Abstract

This study evaluated the mitigating potential of ZnO nanoparticle (ZnO NP) priming on the germination characteristics of marigold under varying levels of salinity stress. To ensure an eco-friendly approach, ZnO NPs were synthesized via a green method using fresh pomegranate (*Punica granatum*) extract, and their morphological characteristics were analyzed using SEM. The experimental design focused on identifying the interaction between diverse ZnO NPs priming concentrations (0, 25, 50, 75, and 100 mg kg⁻¹) and increasing salinity regimes (0, 50, 100, and 150 mM NaCl). Following standard germination test, first count germination, final germination percentage, germination value, and mean daily germination were determined. Our results showed that above 50 mM NaCl concentrations reduced all germination and growth parameters. However, priming with ZnO NPs reduced the negative effects of salt stress. Heatmap and hierarchical clustering analyses confirmed these findings, showing that ZnO NPs doses between 25-100 mg kg⁻¹ were the most effective for improving salt tolerance in marigold. In conclusion, these results demonstrate that seed priming with green-synthesized ZnO NPs is a promising and sustainable approach for overcoming salinity stress. These findings provide significant implications for the successful cultivation of marigold in salt-affected environments. Furthermore, this approach could potentially be applied to a wider range of ornamental species facing similar constraints.

Keywords: Nanoparticles, salt stress, marigold, germination, seed priming

1. INTRODUCTION

The integration of nanotechnology into agricultural production has introduced innovative and sustainable approaches, such as "nanopriming," to overcome abiotic stress factors. Unlike traditional seed priming methods, nanopriming triggers metabolic activities in early germination stages through the adhesion or partial absorption of nanoparticles onto the seed surface [1]. In this process, water uptake by the seed is accelerated, and physiological events such as starch



hydrolysis and cell wall relaxation, which promotes embryo growth, are activated [2]. Zinc oxide nanoparticles (ZnO NPs), in particular, stand out as a critical material in this field due to the fundamental role of zinc in enzyme activation and antioxidant defence systems in plant metabolism [3]. Although there are findings indicating that ZnO NP applications improve germination performance under different stress conditions in species such as maize, barley, tomatoes, and Chinese cabbage, studies specifically on ornamental plants are still quite limited [4].

Seed germination is one of the most vulnerable stages of the plant life cycle, directly determining overall production success [5]. Salinity stress, which reduces agricultural productivity by 10% to 50% globally, disrupts the osmotic balance of seeds during these sensitive periods and suppresses physiological processes with the toxic effects of Na⁺ and Cl⁻ ions [6, 7]. In ornamental plant production, salinity leads not only to biomass loss but also to leaf necrosis, early chlorosis, and deterioration in aesthetic quality, significantly reducing the commercial value of the product [8]. This situation highlights the need for modern intervention methods to increase the stress resilience of species with high landscape value. Marigold (*Tagetes erecta*), which holds a central position in the ornamental plant sector both economically and aesthetically, is one of the most widely cultivated members of the Asteraceae family. This species, characterized by wide adaptability and high environmental tolerance, an indispensable landscape element in parks, gardens, and roadside plantings, offers high decorative value with its flowers ranging from yellow to dark orange and its dark green leaves [9, 10]. Beyond its ornamental properties, it also exhibits antiviral, antibacterial, and antifungal properties thanks to the thiophene compounds and essential oils it contains, and is therefore used as a raw material in the pharmaceutical and cosmetic industries [11]. In addition, the consumption of its flowers as an edible food source worldwide further increases the strategic importance of the species [12].

Therefore, the main aim of this study is to comprehensively determine the effects of ZnO NP priming applications on germination in marigold (*Tagetes erecta*) seeds, which have high economic and industrial value, under increasing salt stress conditions. The data obtained in this regard are intended to contribute to abiotic stress management in ornamental plant production and the practical application of nanotechnology.

2. MATERIALS AND METHODS

2.1. Plant Material and Experimental Site

The study was conducted in the growth chambers of Atatürk University during the 2025–2026 period. One-year-old marigold (*Tagetes erecta*) seeds, provided by the Istanbul Seed Company (Türkiye), were utilized as the primary plant material to evaluate the influence of ZnO NP priming on germination performance under varying NaCl salinity levels.

2.2. Green Synthesis and Characterization of ZnO NPs

Zinc oxide nanoparticles were synthesized through an eco-friendly green synthesis protocol using fresh pomegranate (*Punica granatum*) extract as a reducing agent. The synthesis involved a mixture of 0.1 M Zn(NO₃)₂ and 5 mL of the extract. Following synthesis, the solution underwent centrifugation, washing, and drying processes. The morphological and structural characteristics of the synthesized NPs were determined at the Atatürk University DAYTAM center using advanced analytical techniques, including SEM-EDX (Zeiss Sigma 300).

2.3. Seed Sterilization and Nanopriming Treatments

Prior to the treatments, seeds were surface-sterilized in a 1.5% sodium hypochlorite solution for 5 minutes and subsequently rinsed four times with distilled water to eliminate chemical residues. Following sterilization, seeds were divided into five experimental groups and subjected to a 4-hour priming process in distilled water (control) or varying concentrations of ZnO NPs (25, 50, 75, and 100 mg kg⁻¹). Post-priming, the seeds were air-dried for 24 hours at a laboratory temperature of 22 ± 2°C on filter paper [13,14].

2.4. Germination Tests and Salinity Stress Applications

A standard germination test was conducted using a randomized design with four replicates of 20 seeds each, placed in 9 cm Petri dishes. The experiments were carried out in a controlled growth chamber at a constant temperature of 20°C in complete darkness for 14 days [15]. To evaluate the interactive effects of nanopriming and salinity, seeds were treated daily with four distinct NaCl concentrations: 0 (control), 50, 100, and 150 mM.

2.5. Data Collection and Physiological Measurements

Germination was monitored at 24-hour intervals, with a 2 mm radicle protrusion serving as the criterion for successful germination [16, 17]. Following the 14-day observation period [15] (ISTA 2011), the following parameters were calculated: first count germination, final germination percentage, germination value, and mean daily germination.

2.6. Experimental Design and Statistical Analysis

The germination experiment was established as a randomized complete block design (RCBD) with four replications. The collected data were analyzed using Analysis of Variance (ANOVA), and the differences between treatment means were evaluated via Duncan's Multiple Range Test at a significance level of $P < 0.05$.

3. RESULTS AND DISCUSSION

The SEM image of zinc oxide (ZnO) nanoparticles can be seen in Figure 1. SEM images revealed that the ZnO NPs are 60-80 nm in size (Figure 1).

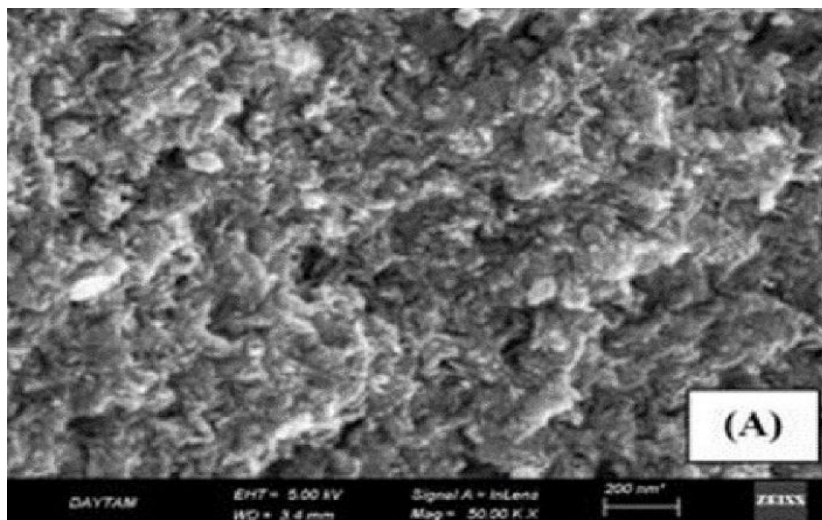


Figure 1. SEM image of zinc oxide (ZnO) nanoparticles

Increasing NaCl concentrations significantly suppressed the first count germination percentage of marigold seeds (Table 1). While the first count germination percentage reached 100% in the control, it decreased to an average of 9.5% at the 150 mM NaCl level. ZnO NPs priming applications improved germination performance, especially under moderate salt stress (50 mM). Indeed, the highest germination rate at 50 mM NaCl was recorded at 88.3% with the 50 mg kg⁻¹ ZnO NPs application. In contrast, when the salt level increased to 150 mM, the first count germination percentage was severely limited, and the lowest value was determined at 5.0% in the 75 mg kg⁻¹ ZnO NPs. Based on the general means, while increasing salinity negatively affected the first count germination percentage, low doses of nanoparticle applications showed the potential to mitigate this negative effect. Specifically, the 50 mg kg⁻¹ dose significantly increased germination at the first count compared to the control (75.0%) at 50 mM salinity.

Increasing NaCl concentrations caused a precisely decrease in final germination percentage values, with the lowest value of 15.0% recorded at the control of 150 mM NaCl application. However, ZnO NPs priming applications increased the germination rate at all salt levels compared to the control. At 50 mM NaCl, the 25 and 50 mg kg⁻¹ ZnO NPs doses showed the highest performance with a value of 95.0%, giving the closest results to the control (100%). Under 100 mM NaCl stress, the 100 mg kg⁻¹ ZnO NPs dose increased germination to 61.7%, making it the most effective application in the group. Under the most severe stress condition (150 mM NaCl), the highest germination rate was observed at 33.3% with the 25 mg kg⁻¹ ZnO NPs application. Overall, ZnO NP doses have been effective in mitigating the stress of moderate and high salt levels on the seed (Table2).

Table 1. The effect of ZnO NPS priming on first count germination percentage (%) of marigold under increasing NaCl (mM) salinity.

NaCl	0 mg kg ⁻¹	25 mg kg ⁻¹	ZnO NP 50 mg kg ⁻¹	75 mg kg ⁻¹	100 mg kg ⁻¹	Ortalama
0 mM	100.0 a	96.7 a	100.0 a	100.0 a	91.7 a	97.7 A
50 mM	75.0 b	81.7 b	88.3 b	73.3 b	70.0 b	77.7 B
100 mM	41.7 c	18.3 c	23.3 c	25.0 c	28.3 c	27.3 C
150 mM		8.3 d	13.3 d	5.0 d	10.0 d	9.5 D
Ortalama	72.2 A	51.3 B	56.3 B	55.0 B	53.6 B	

Means followed by different small and capital letters in column and line are significantly different at $p < 0.05$

Table 2. The effect of ZnO NPS priming on final germination percentage (%) of marigold under increasing NaCl (mM) salinity.

NaCl	0 mg kg ⁻¹	25 mg kg ⁻¹	ZnO NP 50 mg kg ⁻¹	75 mg kg ⁻¹	100 mg kg ⁻¹	Ortalama
0 mM	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 A
50 mM	88.3 b	95.0 a	95.0 a	86.7 b	95.0 b	92.0 B
100 mM	46.7 c	55.0 b	53.3 b	58.3 c	61.7 c	55.0 C
150 mM	18.3 d	33.3 c	28.3 c	20.0 d	15.0 d	23.0 D
Ortalama	63.3 C	70.8 A	69.2 AB	66.3 BC	67.9 B	

Means followed by different small and capital letters in column and line are significantly different at $p < 0.05$

Mean daily germination values showed a linear decrease in all treatments with increasing salt



concentration. In other words, as NaCl concentration increased, there was a significant decline in the mean daily germination value of the seeds (Table 3). While mean daily germination values were 1.33 in the control, they weakened significantly at the 150 mM NaCl level. At 50 mM NaCl, the highest value (1.24) was obtained from the 50 mg kg⁻¹ ZnO NP treatment, while other doses showed lower performance. At moderate salinity (100 mM), the 100 mg kg⁻¹ ZnO NP dose reached a value of 0.82, surpassing unprimed seeds (0.56) and providing a significant increase in tolerance. The 50 mg kg⁻¹ ZnO NP treatment gave the best result with a value of 0.38 at the highest salt level (150 mM NaCl). Overall, ZnO NP applications, especially at doses of 50 and 100 mg kg⁻¹, were able to maintain mean daily germination values at higher levels than the control under saline conditions.

Table 3. The effect of ZnO NPS priming on mean daily germination of marigold under increasing NaCl (mM) salinity.

	ZnO NP					
NaCl	0 mg kg ⁻¹	25 mg kg ⁻¹	50 mg kg ⁻¹	75 mg kg ⁻¹	100 mg kg ⁻¹	Ortalama
0 mM	1.33 a	1.28 a	1.33 a	1.33 a	1.33 a	1.32 A
50 mM	1.18 b	1.17 b	1.24 a	1.15 b	1.26 b	1.20 B
100 mM	0.56 c	0.66 c	0.71 b	0.77 c	0.82 c	0.70 C
150 mM	0.24 d	0.37 d	0.38 c	0.26 d	0.18 d	0.29 D
Ortalama	0.83 B	0.87 A	0.91 A	0.88 A	0.90 A	

Means followed by different small and capital letters in column and line are significantly different at $p < 0.05$

As the salt level increased, the final germination value decreased significantly (Table 4). The highest values were determined in the salt-free control group as 5.32. Under 50 mM NaCl stress, the 50 mg kg⁻¹ ZnO NP dose yielded the best result with a value of 4.38. At the same salt level, the control had a value of 3.53. At 100 mM NaCl, the control (0.97) and 100 mg kg⁻¹ ZnO NP (0.93) doses were found to have the closest values. At the highest salt level of 150 mM NaCl, the 50 mg kg⁻¹ ZnO NP application showed the best performance with a value of 0.20. At this stress level, the control had a value of 0.05. Overall, the 50 mg kg⁻¹ dose was determined to be the most successful application in maintaining germination value under salinity stress.

Table 4. The effect of ZnO NPS priming on germination value of marigold under increasing NaCl (mM) salinity.

	ZnO NP					
NaCl	0 mg kg ⁻¹	25 mg kg ⁻¹	50 mg kg ⁻¹	75 mg kg ⁻¹	100 mg kg ⁻¹	Ortalama
0 mM	5.32 a	4.97 a	5.32 a	5.32 a	4.96 a	5.18 A
50 mM	3.53 b	3.84 b	4.38 b	3.39 b	3.53 b	3.73 B
100 mM	0.97 c	0.49 c	0.65 c	0.77 c	0.93 c	0.76 C
150 mM	0.05 d	0.19 c	0.20 d	0.08 d	0.14 d	0.13 D
Ortalama	2.47 AB	2.37 B	2.64 A	2.39 B	2.39 B	

Means followed by different small and capital letters in column and line are significantly different at $p < 0.05$

The analysis of variance (ANOVA) showed statistically significant differences between the salinity (NaCl) and ZnO NPs for first count germination percentage (FCGP), final germination percentage (FGP), mean daily germination (MDG), and germination value (GV) (Table 5). The ZnO NPs x NaCl interaction was significant for all parameters. Significant ZnO NPs x NaCl interaction for these characters demonstrated that the effect of ZnO NPs changed markedly in



various NaCl doses. In other words, this interaction also showed that under increasing NaCl (mM) salinity, the germination percentage and values were affected positively by ZnO NPs.

Table 5. Interactions between ZnO Nps (mg kg⁻¹) and NaCl (mM) concentrations

		FCGP	FGP	MDG	GV
Source of variation	Degrees of freedom			F values	
ZnO Nps	4	4.566**	4.696**	4.36**	2.708**
NaCl	3	745.751**	1583.81*	1160.863**	1559.036*
Zn × NaCl	12	4.077**	14.077**	5.585**	3.445**
Error	40	1033.333*	466.667*	0.117**	2.222**
Total	59				

** Significant at $P = 0.01\%$ level. FCGP: First count germination percentage, FGP: First count germination percentage; MDG: Mean daily germination, GV: Germination value.

In addition to commonly used materials such as PEG, KNO₃, and mannitol, nanomaterials like GO, ZnO, TiO₂, and AgNPs have also been frequently used in recent years to enhance germination in various plant species under salinity stress conditions. The main goal here is to prepare seeds for stress or adverse conditions. Therefore, priming with different materials activates enzymes by breaking down storage substances in the seed and ensures optimal utilization of these storage substances, thus preparing the seed for germination in advance. In short, seed priming can be described as a suitable method used to increase water uptake by seeds and improve germination [13, 18, 19].

Moreover, green synthesis nanoparticles are an effective tool in seed priming processes due to their advantages of low phytotoxicity and environmental sustainability [13]. The findings obtained in this study demonstrated that ZnO NP priming application significantly improved the germination performance (FCGP, FGP, GV, and MDG) of marigold seeds under increased salt stress compared to the control (Tables 3, 4, 5). This positive effect of ZnO NPs can be explained by their ability to increase water uptake by promoting osmotic regulation and limit oxidative damage by maintaining cell turgor [20]. The literature reports that the effect of ZnO NPs on germination varies depending on dose and species. For example, it has been reported that doses of 10 ppm [21] for *Camelina sativa* and *Brassica napus*, 100 ppm [22] for maize increase germination rate and efficiency. In our current study, the fact that the 50 mg kg⁻¹ ZnO NP dose yielded the highest germination power and percentage values under salt stress is consistent with these positive dose effects in the literature. On the other hand, although high doses such as 400 mg L⁻¹ have been reported to be successful in *Amaranthus tricolor* [23], the partial decrease observed in germination parameters when the dose was increased to 100 mg kg⁻¹ in our study reveals that the tolerance thresholds of the species to nanomaterials are different. In particular, the statistically significant finding of ZnO NP × NaCl interaction in all parameters (FCGP, FGP, MDG and GV) (Table 5) demonstrates that ZnO NPs function as a dose-modulated "stress mitigator" in alleviating the suppressive effect of salt stress.

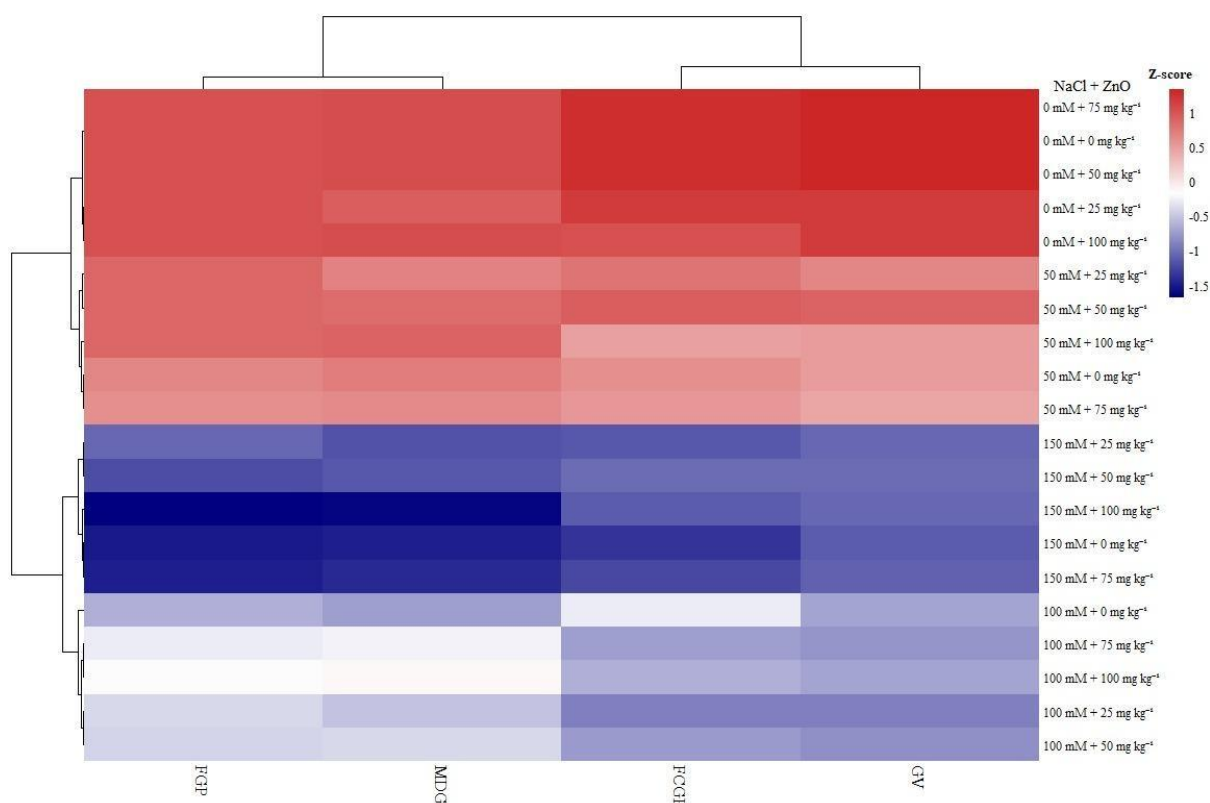


Figure 2. Heat map and hierarchical clustering analysis to evaluate the effect of ZnO NPs priming under increasing NaCl (mM) salinity on the germination performance of marigold

The two-way dendrogram structure shows that both the treatments (horizontal axis) and the parameters (vertical axis) are grouped hierarchically according to their similarity levels. The horizontal dendrogram reveals the proximity of different NaCl and ZnO combinations to each other, while the vertical dendrogram shows that germination parameters (FCGP, FGP, MDG, GV) cluster in two main groups along similar trends, and that early germination indicators and general germination performance measures are partially separated. The dendrogram structure shows that the treatments are distinctly separated depending on the NaCl level, and that all treatments containing 100 mM and 150 mM NaCl are clustered together under similar suppressive effects. Under low salinity conditions, the closer proximity of the 50 mM NaCl + 50 mg kg⁻¹ ZnO and 50 mM NaCl + 75 mg kg⁻¹ ZnO treatments to the control groups (0 mM NaCl) can be attributed to the protective effect of these doses. In contrast, the close clustering of all ZnO doses applied under 100 mM and 150 mM NaCl indicates that the dose difference decreases with increasing stress levels. Specifically, the fact that combinations of 150 mM NaCl + 0–100 mg kg⁻¹ ZnO are found in the same subcluster reveals that high salt stress becomes a dominant factor. Overall, the dendrogram supports the idea that the ZnO effect is more prominent under 50 mM NaCl conditions and remains limited at higher salinity levels (Figure 2).

4. CONCLUSIONS

This study demonstrates that ZnO nanoparticles obtained by green synthesis are an effective priming agent against salt stress in marigold seeds. Experimental findings showed that increasing NaCl concentrations exerted severe stress on germination percentage and performance.



However, ZnO NP applications, particularly at a dose of 50 mg kg⁻¹, significantly mitigated these negative effects, improving all germination parameters. Statistical analyses revealed that the ZnO NP x NaCl interaction resulted a highly significant difference ($P = 0.01$) on all examined characteristics. Furthermore, the two-way dendrogram analysis confirms that while ZnO treatments (50-75 mg kg⁻¹) successfully cluster with control groups under moderate stress (50 mM NaCl), high salinity levels (150 mM) become the dominant factor, limiting the relative impact of the doses. These confirm that the nanoparticle effect varies depending on the salt dose and plays a protective role under stress conditions. The partial reduction observed when the dose reached 100 mg kg⁻¹ in the study showed that determining the optimum dose is critical. In conclusion, the 50 mg kg⁻¹ ZnO NPs priming application is recommended as a sustainable and high-performance strategy for marigold cultivation in saline conditions. Furthermore, this research demonstrates that priming with ZnO NPs is an environmentally friendly and effective example of using nanomaterials to improve seed germination performance under stressful conditions.

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The Impact of Service Quality on Passenger Satisfaction in Urban Public Transport: The Case of Erzurum

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Abstract

Understanding the determinants of passenger satisfaction is essential for optimizing urban public transport systems. Focusing on the medium-sized city of Erzurum, Türkiye, this research investigates how distinct service quality dimensions affect overall transit satisfaction. Drawing on a quantitative survey of 414 passengers, Importance-Performance Analysis (IPA) and an Ordered Logit regression model were employed to evaluate service frequency, vehicle cleanliness, driver behavior, information systems, and stop conditions. The IPA results identified frequency, cleanliness, and driver behavior as critical areas requiring immediate intervention due to their high importance and underperformance, whereas punctuality emerged as a systemic strength. Furthermore, the Ordered Logit model revealed that service frequency is the primary driver of passenger satisfaction, followed by stop conditions, information systems, and driver behavior. Ultimately, these findings underscore that user satisfaction is deeply rooted in operational quality and directly experienced service attributes. By providing empirical evidence from Erzurum, this research enriches the limited literature on transit dynamics in medium-sized cities and offers actionable insights for policymakers to enhance public transport efficiency.

Keywords: Public Transport, Service Quality, Passenger Satisfaction, Ordered Logit Model, Importance–Performance Analysis.

1. INTRODUCTION

In urban transportation systems, the quality of public transport services is not merely an element of physical mobility provision, but also a fundamental factor directly influencing users' preferences and utilization behaviors. A review of the literature reveals that the relationship between service quality and passenger satisfaction exhibits a multidimensional structure, which is shaped through various service components. Numerous studies have demonstrated that factors such as cleanliness, safety, comfort, and personnel behavior are particularly determinant of passenger satisfaction [1,2]. Similarly, it has been shown that while service quality and accessibility significantly increase passenger satisfaction, the safety variable may not always yield significant results depending on the context [3].

An examination of studies evaluating service quality in public transportation indicates the employment of diverse methodological approaches. Structural equation modeling (SEM) is widely utilized to analyze the relationships between service quality and satisfaction through direct and indirect effects [2,3]. In addition, Ordered Logit and Ordered Probit models are prominent in modeling satisfaction variables with ordinal categorical structures. For instance,



Mamun et al. (2025) analyzed the impacts of service quality and socio-demographic variables on satisfaction using the Ordered Logit model. Similarly, Saeidi et al. (2025) utilized factor analysis alongside the Ordered Logit model to examine the differences in satisfaction across various public transit modes. Furthermore, a study conducted on university commuters in Budapest, which combined the Ordered Probit model with Importance-Performance Analysis (IPA), revealed that the determinants of satisfaction varied among different user groups [3].

Another significant approach in service quality analysis is the Importance-Performance Analysis (IPA) method. IPA enables the determination of improvement priorities by simultaneously evaluating the performance levels of service components and their degrees of importance as perceived by users. However, the literature also emphasizes that the impact of service attributes on satisfaction is not always linear and symmetrical. In their study comparing IPA with the Three-Factor Theory, Cao and Cao (2017) demonstrated that service attributes can function differently as "basic," "performance," and "excitement" factors. Similarly, Tuan et al. (2022) revealed that while the traditional IPA approach may produce misleading results in certain cases, the Three-Factor Theory can offer more realistic policy priorities. Nevertheless, it is stated that the IPA approach, when used in conjunction with Ordered Logit models, remains a robust and practical tool for identifying areas of service improvement [3,4].

Another prominent finding in the literature is that different dimensions of service quality affect passenger satisfaction at varying levels. In particular, numerous studies have highlighted the highly significant impact of operational factors such as reliability, punctuality, and frequency of service on satisfaction. For instance, Aworemi et al. (2025) noted that reliability was the primary source of dissatisfaction, and irregular schedules severely reduced satisfaction levels. In a study conducted in the context of Nairobi, safety and cleanliness factors were found to be determinant of satisfaction, with female passengers reporting lower satisfaction regarding these issues [5]. Conversely, some studies indicate that the impact of socio-demographic variables remains limited, whereas service quality components are more determinant [4].

Evaluating the context of Erzurum, existing studies provide significant findings regarding the transportation structure of the city. A simulation analysis conducted in Erzurum determined that waiting times were excessively high on certain routes and at specific stops, and that service frequency was incompatible with demand [6]. Furthermore, behavioral modeling studies encompassing Erzurum have revealed that public transport usage is predominantly driven by factors such as habit and intention [7]. In addition, it has been shown that urban sprawl dynamics are closely associated with transportation networks, and that transportation infrastructure steers spatial development [8]. These findings suggest that public transport service quality and passenger satisfaction in Erzurum must be addressed comprehensively, considering both operational and behavioral dimensions.

Within this framework, although the literature demonstrates a strong relationship between service quality and passenger satisfaction, there is a limited number of studies investigating which service components are more determinant in medium-sized cities and how these components should be prioritized. Empirical studies conducted in cities like Erzurum—which possess unique characteristics in terms of climate conditions, user profile, and operational structure—will make a substantial contribution to literature. In this study, the impacts of service quality dimensions on passenger satisfaction within the urban public transport system of Erzurum are analyzed; the determinants of satisfaction are identified using the Ordered Logit model, and service improvement priorities are evaluated through Importance-Performance Analysis.



2. MATERIALS AND METHODS

In this study, a quantitative research approach was adopted to analyze the impacts of service quality dimensions on passenger satisfaction within the urban public transport system of Erzurum. The analyses were conducted based on survey data, and the relationship between service quality and satisfaction was addressed within a multidimensional framework. The data used in the study were obtained from surveys administered by urban public transport users in Erzurum. The survey questionnaire was constructed considering the service quality dimensions widely used in literature. In this context, variables such as cleanliness, safety, comfort, driver behavior, service frequency, information systems, and stop conditions were measured. In determining these variables, it was observed that the fundamental service elements affecting public transport satisfaction are frequently utilized in similar studies [1,4].

Within the scope of the survey, the overall satisfaction level of the participants was also measured using a 5-point Likert scale, and this variable was utilized as the dependent variable in the model. It is known in the literature that Ordered Logit and Ordered Probit models are widely preferred due to the ordinal measurement of passenger satisfaction [1,3].

The internal consistency of the service quality statements included in the scale was tested using Cronbach's Alpha coefficient. This approach is commonly used to evaluate the reliability of the scale in survey-based public transport studies [4]. Mean and standard deviation values were calculated to reveal the general trends regarding the service quality variables. This analysis provides a fundamental evaluation in terms of identifying which service elements passengers are more satisfied with or dissatisfied with. Similarly, it is stated in the literature that descriptive statistics play an important role in the preliminary assessment of perceived service quality [9].

Importance-Performance Analysis (IPA) was applied to determine the improvement priorities of the service quality elements. This method enables classification into four different categories by jointly evaluating the performance level of each service variable and its degree of importance as perceived by the users.

The IPA method is a widely used approach in the literature for determining policy priorities aimed at improving public transport services [10,11]. However, some studies emphasize that the impact of service quality variables on satisfaction may not be linear, and therefore IPA results should be interpreted with caution [10]. Due to the ordinal categorical structure of the passenger satisfaction variable, an Ordered Logit regression model was used to model the relationship between the dependent variable and the service quality dimensions. This model is an appropriate approach in cases where the dependent variable has an ordinal structure and is widely used in public transport satisfaction studies [1,4].

In the Ordered Logit model, the effects of independent variables on satisfaction levels were estimated using the maximum likelihood method. The goodness-of-fit of the model was evaluated with log-likelihood values and the McFadden R^2 coefficient. Similarly, it is seen that the same criteria were used in the evaluation of model performance in the study by Mamun et al. (2025). Whether there is multicollinearity among the variables included in the model was tested via VIF values. It is stated in the literature that such controls are necessary to obtain reliable results, particularly in Ordered Probit and Ordered Logit models [3].

The methodological approach adopted in this study is consistent with the multi-stage analysis structure commonly used in literature. Specifically, studies utilizing factor analysis, the Ordered

Logit model, and the IPA method together allow for both an explanatory and a policy-oriented analysis of the relationship between service quality and satisfaction [4]. Furthermore, it is also emphasized in literature that the determinants of satisfaction may vary across different user groups, and therefore model results should be evaluated contextually [3].

In this context, the analyses conducted in the case of Erzurum not only reveal the impacts of service quality variables on satisfaction but also present a methodological framework consistent with similar studies in literature by determining priority areas for improvement through the IPA method.

3. RESULTS AND DISCUSSION

3.1. Reliability of the Scale

The reliability of the service quality scale used in the study was tested using Cronbach's Alpha coefficient, and it was determined that the scale has a high level of internal consistency ($\alpha = 0.857$). Furthermore, the item-total correlations of all items were found to be above the acceptable threshold values.

This result indicates that the variables included in the scale consistently measure the same construct and can be reliably used in the analysis. It is also stated in the literature that similar threshold values are considered sufficient in public transport service quality studies [3].

3.2. Descriptive Findings

When the descriptive statistics regarding the service quality criteria are examined, it is observed that the overall satisfaction level is at a negative level (Table 1).

Physical conditions of the stops, vehicle cleanliness and maintenance, and service frequency stand out as the variables with the lowest averages. In contrast, although information systems and punctuality variables have relatively higher values, they remain at a moderate level. These findings indicate that passenger satisfaction in the urban public transport system of Erzurum is generally low, and there is a need for improvement, especially in operational and physical service components. It is also emphasized in the literature that reliability, service continuity, and physical service conditions play a determinant role in satisfaction [1, 9].

Table 1. Descriptive Statistics of Service Quality Criteria

Service Quality Criterion	N	$\bar{x}$	sd	Satisfaction Level
ErzurumCard and Information (Q14)	414	3.048	1.248	Moderate / Undecided
Vehicle Punctuality (Q7)	414	3.024	1.164	Moderate / Undecided
Winter Heating Adequacy (Q9)	414	3.017	1.208	Moderate / Undecided
Driver Attitude and Behavior (Q11)	414	2.698	1.201	Negative
Compliance with Traffic Rules (Q12)	414	2.606	1.206	Negative
Service Frequency Adequacy (Q8)	414	2.580	1.240	Negative
Vehicle Cleanliness and Maintenance (Q10)	414	2.514	1.191	Negative
Physical Conditions of Stops (Q13)	414	2.403	1.246	Very Low
General Satisfaction (Q15)	414	2.729	1.152	Negative

This situation clearly demonstrates that the general satisfaction level in the urban public transport system of Erzurum is low.

3.3. Importance-Performance Analysis (IPA)

Importance-Performance Analysis (IPA) was applied to jointly evaluate the relative importance and performance levels of the service quality criteria on passenger satisfaction. This method allows for the determination of improvement priorities by comparing the average performance value of each service element with its degree of importance on satisfaction. The findings obtained in this context are presented in Table 2, and it is seen that the service criteria are classified under four different categories.

The IPA method is a widely used tool in decision-making processes aimed at improving public transport services, and it enables the prioritization of service elements according to their relative importance. However, it is emphasized in the literature that the impact of service quality variables on satisfaction is not always linear, and therefore IPA results should be interpreted with caution [10,11].

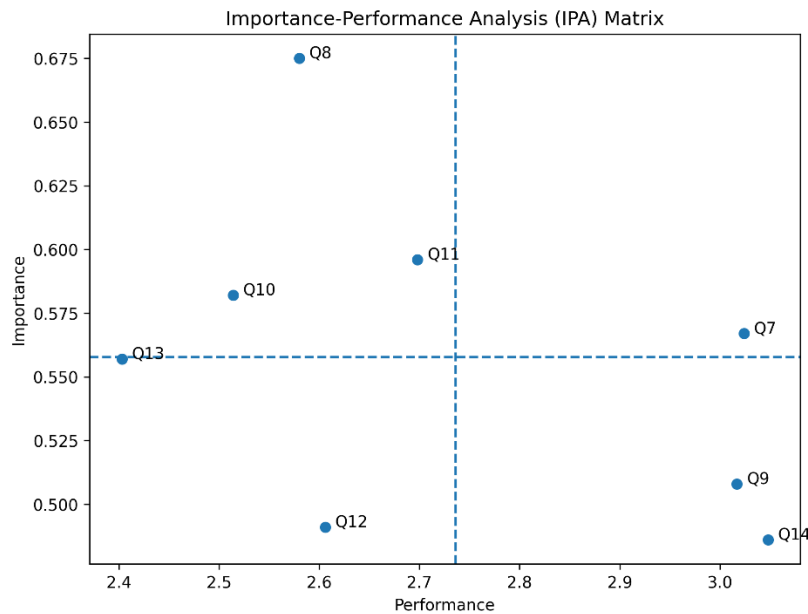


Figure 1. Importance-Performance Analysis (IPA) Matrix for Service Quality Criteria

The IPA matrix presented in Figure 1 clearly reveals the distribution of the service quality criteria according to their performance and importance levels. The numerical counterparts of the visual distribution in Figure 1 are presented in detail in Table 2. According to the analysis results, service frequency (Q8), vehicle cleanliness and maintenance (Q10), and driver attitude and behavior (Q11) are in the low performance–high importance region, and these variables stand out as critical areas requiring priority improvement in the system (Table 2). In contrast, vehicle punctuality (Q7) is positioned in the high performance–high importance region and is considered one of the system's strong aspects. On the other hand, winter heating (Q9) and ErzurumKart and information systems (Q14) are in the high performance–low importance region, and it is evaluated that the current service level in these areas is sufficient and additional investment may provide a limited contribution (Table 2). Compliance with traffic rules (Q12) and, partially, the physical conditions of the stops (Q13) are in the low performance–low

importance region, indicating that these variables are not a priority intervention area in the short term.

The findings indicate that passenger satisfaction is shaped particularly by the continuity of the service and the service components directly experienced by the users. This situation is consistent with findings in the literature suggesting that the impact of service quality elements on satisfaction is not equal, and some variables play a more critical role [10,11].

Table 2. Importance-Performance Analysis (IPA) Matrix for Service Criteria

Service Criterion	Performance ($\bar{x}$)	Importance (r)	IPA Position	Quadrant
Service Frequency (Q8)	2.580	0.675	Low Perf./High Imp.	Critical Area
Cleanliness and Maintenance (Q10)	2.514	0.582	Low Perf./High Imp.	Critical Area
Driver Attitude (Q11)	2.698	0.596	Low Perf./High Imp.	Critical Area
Vehicle Punctuality (Q7)	3.024	0.567	High Perf./High Imp.	Strong Area
Stop Conditions (Q13)	2.403	0.557 [†]	Borderline	Low Priority [†]
Compliance with Rules (Q12)	2.606	0.491	Low Perf./Low Imp.	Low Priority
Winter Heating (Q9)	3.017	0.508	High Perf./Low Imp.	Possible Overkill
ErzurumCard/Information (Q14)	3.048	0.486	High Perf./Low Imp.	Possible Overkill

3.4. Ordered Logit Model Results

The Ordered Logit model results indicate that the impact of the service quality variables on passenger satisfaction is at different levels (Table 3).

Table 3. Ordered Logit Regression Results for General Satisfaction

Independent Variable	β (std.)	S.E.	z	p	Sig.	OR (e β)
Service Frequency (Q8)	0.606	0.134	4.516	<0.001	***	1.833
Stop Conditions (Q13)	0.360	0.122	2.956	0.003	**	1.433
ErzurumCard/Information (Q14)	0.345	0.118	2.925	0.003	**	1.412
Driver Attitude (Q11)	0.342	0.140	2.448	0.014	*	1.408
Winter Heating (Q9)	0.327	0.129	2.531	0.011	*	1.387
Vehicle Punctuality (Q7)	0.304	0.141	2.150	0.032	*	1.355
Compliance with Rules (Q12)	0.284	0.128	2.214	0.027	*	1.328
Vehicle Cleanliness (Q10)	0.177	0.131	1.348	0.178	n.s.	1.193
Model: LL=-591.8 / McFadden R ² =0.053 / N=414						
Convergence: ✓						

According to the model findings, the variable that most strongly affects passenger satisfaction is service frequency. The high level of statistical significance of this variable indicates that improving service intervals will directly increase satisfaction levels.

This is followed by the physical condition of the stops, information systems, and driver behavior, respectively. This situation demonstrates that passenger satisfaction is influenced not only by in-vehicle services but also by pre-trip factors and factors related to the travel process. It is also emphasized in the literature that stop infrastructure and the pre-service experience play a significant role in satisfaction [12].

The fact that the vehicle cleanliness variable was not found to be statistically significant suggests that the impact of this variable on satisfaction may be indirect. Similarly, some studies reveal that service components may yield different results depending on the context [3].

When the explanatory power of the model is evaluated over the McFadden R^2 value, it is seen that the model has a limited but acceptable level of explanatory power. This situation stems from the subjective and multidimensional nature of passenger satisfaction.

3.5. Support with Qualitative Findings

The analysis of the open-ended responses largely overlaps with the quantitative findings (Table 4). 50% of the participants expressed service frequency and delays as the priority issue. This is followed by driver behavior, in-vehicle crowding, and the unsuitability of stops for winter conditions, respectively. These findings support the Ordered Logit and IPA results and demonstrate that operational issues are the fundamental determinants of passenger satisfaction.

Table 4. Priority Improvement Areas Based on Open-Ended Responses

Complaint Theme	Frequency (n)	Percentage (%)	Priority
Service Frequency, Schedule Compliance, and Delays	103	50.0%	Priority
Driver Behavior and Traffic Rules	38	18.4%	Second Priority
In-Vehicle Overcrowding	34	16.5%	Second Priority
Unsuitability of Stops for Winter Conditions	32	15.5%	Third Priority
Vehicle Age and Cleanliness	21	10.2%	Third Priority

4. CONCLUSIONS

In this study, the impacts of service quality dimensions on passenger satisfaction in the urban public transport system of Erzurum were evaluated using a combination of quantitative and qualitative analysis methods. The findings reveal that passenger satisfaction in public transport services is largely determined by the operational components of service quality and those that directly reflect on user experience.

According to the Ordered Logit model results, it was determined that the variable most strongly affecting passenger satisfaction is service frequency. This finding indicates that service



continuity and accessibility are fundamental determinants in the success of public transport systems. Similarly, it is emphasized in the literature that reliability components such as service frequency and punctuality have one of the strongest impacts on satisfaction [1,9].

In addition, it was determined that variables such as the physical conditions of the stops, information systems, and driver behavior also have significant effects on satisfaction. This situation demonstrates that the public transport experience is not limited solely to in-vehicle services; pre-trip, in-trip, and environmental factors must be evaluated holistically. In particular, the impact of stop infrastructure on passenger experience is also highlighted in the literature, stating that the perception of safety and comfort is significantly shaped in these areas [12].

The Importance-Performance Analysis results revealed that variables such as service frequency, vehicle cleanliness, and driver attitude are in the low performance–high importance category. This finding ensures the clear identification of areas requiring priority intervention in the system. Although the IPA method is recognized in the literature as an effective tool for determining service improvement priorities, some studies emphasize that the impact of service quality variables on satisfaction may not be linear, and therefore the results should be interpreted with caution [10,11].

The qualitative findings obtained in the study also support the quantitative analysis results. The fact that a large portion of the participants complained about service frequency, delays, and driver behavior clearly demonstrates that operational service quality elements are the fundamental determinants of passenger satisfaction. This situation indicates that improvements to be made in public transport systems should primarily focus on service continuity and user experience.

The findings obtained specifically for Erzurum become more meaningful when evaluated along with the unique conditions of the city. Simulation studies conducted in Erzurum show that waiting times are high on certain routes and at certain stops, and that operational bottlenecks exist in system [6]. This situation is consistent with the low satisfaction levels obtained in the study. Furthermore, the city's harsh climate conditions increase the impact of stop infrastructure and waiting conditions on passenger satisfaction. In this context, the role of the spatial and environmental characteristics of the transportation infrastructure on user experience should not be ignored [13].

Based on the findings obtained from this study, the following policy recommendations can be developed:

- Increasing service frequency and optimizing scheduling is the highest priority intervention area for improving passenger satisfaction.
- Improving stop infrastructure, specifically creating sheltered waiting areas suitable for winter conditions, is required.
- Training programs aimed at improving driver's behavior constitute a significant dimension of service quality.
- Reducing in-vehicle crowding and developing capacity planning will enhance user comfort.
- The development of information systems is crucial, especially in terms of providing real-time information regarding departure times and delays.



In conclusion, by revealing the impacts of public transport service quality on passenger satisfaction in the case of Erzurum, this study presents findings consistent with similar studies in the literature and contributes to policy development processes on the local scale. In particular, the combined use of the Ordered Logit model and the IPA method offer an integrated approach that enables both the analysis of the determinants of satisfaction and the identification of improvement priorities [3,4].

For future studies, it is recommended to conduct comparative analyses with different cities, develop segregated models based on user segments, and utilize machine learning-based methods. Such studies will contribute to making public transport systems more sustainable and user oriented.

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Hydrocarbon Biodegradation Potential of Indigenous Bacterial Isolates from the Kirkuk Oil Field

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Abstract

In this study, indigenous bacterial strains capable of degrading hydrocarbons were isolated and characterized from crude oil-contaminated soil samples obtained from the Kirkuk oil field. Molecular identification based on 16S rRNA gene sequencing revealed the presence of *Terribacillus saccharophilus*, *Lysinibacillus xylanilyticus*, *Bacillus subtilis*, *Acinetobacter lwoffii*, and *Priestia flexa* with high similarity ratios. To evaluate the biodegradation capacity of these isolates, an incubation period of 21 days was conducted in a mineral salt medium containing 1 gram of crude oil. Gravimetric analysis performed at the end of the experiment showed that the initial oil mass decreased by 30% to 50%, falling to levels between 0.5 g and 0.7 g. In addition to this mass loss, preliminary Q-TOF mass spectrometry analyses indicated that the number of compounds, initially approximately 400 in the crude oil, increased to over 800 following bacterial activity. This increase in compound diversity serves as a key indicator of active biotransformation, demonstrating that complex hydrocarbon chains were broken down into smaller intermediate metabolites by bacterial enzymes. The results concluded that *Terribacillus* and *Lysinibacillus xylanilyticus* strains exhibited superior degradation performance, identifying these indigenous isolates as high-potential candidates for bioremediation projects aimed at cleaning up oil pollution.

Keywords: Crude oil, Biodegradation, Kirkuk Oil Field, Bioremediation, Indigenous bacteria.

1. INTRODUCTION

Although petroleum-based hydrocarbons are the primary energy source for modern industry, they are considered one of the most serious environmental pollution threats worldwide due to their widespread distribution, persistence in the environment, and carcinogenic and mutagenic properties. These pollutants mix into the soil and water resources through various anthropogenic effects, such as crude oil spills, uncontrolled combustion of fossil fuels, industrial accidents, and transportation activities, thereby disrupting the fundamental building blocks of the ecosystem. Landfills and petroleum processing zones are areas where these pollutants concentrate as accumulation points for both hazardous and non-hazardous wastes. While microbial activities in these areas play a critical role in the natural degradation of pollutants, intense pollution pressure can exceed the ecosystem's self-cleaning capacity.

The impact of hydrocarbon pollution on organisms begins at the microscopic level and spreads throughout the entire food chain. Petroleum contamination in soil clogs soil pores, lowering oxygen tension, preventing water infiltration, and sabotaging nutrient uptake by plant roots, which leads to the complete destruction of vegetation. In aquatic ecosystems, the thin film layer



formed on the water surface prevents the transition of atmospheric oxygen into the water, creating a risk of asphyxia (suffocation) for fish and other aquatic organisms. Furthermore, the hydrophobic nature of petroleum components penetrates the cell membranes of microorganisms, disrupting cellular integrity and leading to a dramatic decrease in biodiversity.

The effects on human health can be even more direct and devastating. Petroleum derivatives mix into the atmosphere, particularly through volatile organic compounds (VOCs), causing respiratory diseases, chronic coughs, and lung damage. Contact through the skin or consumption of contaminated groundwater can lead to central nervous system disorders, liver and kidney failures, and suppression of the immune system. The most critical danger is that these compounds interfere with DNA structure, triggering cell mutations and paving the way for the formation of various types of cancer in the long term.

Although traditional physical and chemical cleaning methods are frequently used to solve this global problem, they have disadvantages such as high costs, disruption of the soil's physical structure, and sometimes merely transferring the pollution from one medium to another. In contrast, bioremediation offers a cost-effective and environmentally friendly "green technology" that utilizes the ability of indigenous microorganisms to use toxic substances as carbon and energy sources, converting them into harmless forms such as carbon dioxide and water. "Hydrocarbon-utilizing bacteria" (HUB), such as *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Acinetobacter* sp., and *Rhodococcus*, which are widely found in nature, are the most important biological agents in this process.

In particular, indigenous bacterial communities isolated from regions exposed to long-term contamination, such as the Kirkuk oil field, are seen as a key component in these remediation strategies due to the adaptation mechanisms they have developed against chronically contaminated environment conditions. These native isolates not only eliminate pollution but also provide sustainable recovery by preserving the natural balance of the ecosystem. The primary objective of this study is to isolate indigenous bacterial strains with high hydrocarbon-degrading capacity from petroleum-contaminated soil samples obtained from the Kirkuk oil field and to perform their taxonomic identification using molecular methods. Within the scope of the study, the potential of the isolated strains to use crude oil as a sole carbon source was tested under laboratory conditions, and the mass reductions and molecular transformations occurring over a 21-day period were analyzed. The findings aim to scientifically demonstrate the usability of the region's indigenous microbial flora as eco-friendly and low-cost biological agents in the disposal of petroleum pollution.

2. MATERIALS AND METHODS

2.1. Sampling and Isolation

The primary materials for this study, petroleum-contaminated soil samples, were obtained under sterile conditions from an active oil field in Kirkuk, Iraq. Samples were collected from 10-15 cm below the contaminated surface layer, placed in sterile glass jars, and transferred to the laboratory. For the bacterial isolation process, the "enrichment method" was employed. Soil samples were inoculated into Mineral Salt Medium (MSM) containing 1% (v/v) sterile crude oil as the sole carbon source and enriched in a shaking incubator at 30°C and 150 rpm. Following the serial dilution method, cultures were plated onto Nutrient Agar, and pure cultures with distinct colony morphologies were obtained.



2.2. Molecular Identification of Bacterial Strains

Molecular methods were utilized for the species-level identification of the isolated pure cultures. After bacterial genomic DNA extraction, the 16S rRNA gene region was amplified via PCR (Polymerase Chain Reaction) using universal primers (27F and 1492R). The resulting amplicons were sent for sequencing, and the sequence data were compared with existing strains using the "BLAST" tool in the NCBI (National Center for Biotechnology Information) database. Taxonomic identifications of the strains were performed based on similarity ratios.

2.3. Experimental Design for Biodegradation

A controlled experimental setup was established to measure the oil-degradation capacities of the bacteria. 100 ml of Mineral Salt Medium (MSM) was added to 250 ml Erlenmeyer flasks, and exactly 1 gram of crude oil, weighed with a precision balance, was added to each setup. The identified bacterial isolates were inoculated into this medium at a specific optical density (OD₆₀₀). Flasks containing only crude oil and medium without bacteria were used as "negative controls." All setups were left for incubation for 21 days at 30°C and a shaking speed of 150 rpm.

2.4. Analytical Methods: Gravimetric Analysis and Q-TOF

At the end of the incubation period, the efficiency of biodegradation was analyzed in two stages:

Gravimetric Analysis: The undegraded oil remaining in the medium at the end of the experiment was extracted using n-hexane as a solvent. After removing the solvent with an evaporator, the remaining oil amount was weighed on a precision balance. The difference between the initial weight (1 g) and the final weight was calculated as the percentage (%) biodegradation yield.

Q-TOF (Quadrupole Time-of-Flight) Analysis: Q-TOF mass spectrometry was used to determine molecular changes in the crude oil and the intermediate metabolites formed as a result of bacterial activity. Changes in the number of compounds and transformation products were identified by comparing the initial crude oil content with the content at the end of the 21st day.

3. RESULTS AND DISCUSSION

Identification and Characterization of Isolated Bacterial Strains

As a result of the 16S rRNA gene sequencing analysis, five primary species were isolated and identified from the Kirkuk oil field:

***Terribacillus saccharophilus* (T1B):** 97.96% similarity ratio.

***Lysinibacillus xylanilyticus* (T4):** 99.45% similarity ratio.

***Bacillus subtilis* (T5):** 99.33% similarity ratio.

***Acinetobacter lwoffii* / *junii* (K3):** 99.50% similarity ratio.

***Priestia flexa* (K5):** 99.78% similarity ratio.

According to the study results, *Bacillus subtilis* emerged as the leading strain, exhibiting the highest performance with a degradation rate of 52% (0.48 g remaining amount). It was closely followed by *Terribacillus saccharophilus* with a yield of 50% (0.50 g remaining amount) and *Acinetobacter lwoffii* with a yield of 40% (0.60 g remaining amount). The ability of these three species to metabolize nearly half of the initial 1-gram petroleum mass within just 21 days



suggests that these strains possess powerful extracellular enzyme systems capable of breaking down heavy hydrocarbon chains and exhibit high "hydrocarbonoclastic" capacity.

The success demonstrated by these strains—particularly *Acinetobacter*, known in the literature for its ability to use n-alkanes as a sole carbon source, and *Bacillus* and *Terribacillus*, which possess resilient enzyme systems—clearly reveals how the indigenous flora in areas exposed to chronic pollution, such as the Kirkuk oil field, serves as a strategic biological agent for industrial-scale bioremediation projects.

Table 1. Biodegradation Performance of Isolated Bacterial Strains at the End of 21 Days

Rank	Bacterial Species	Remaining Oil Amount at Day 21 (g)	Biodegradation Rate (%)
1	<i>Bacillus subtilis</i>	0.48 g	52%
2	<i>Terribacillus saccharophilus</i>	0.50 g	50%
3	<i>Acinetobacter lwoffii</i>	0.60 g	40%
4	<i>Lysinibacillus xylanilyticus</i>	0.64 g	36%
5	<i>Priestia flexa</i>	0.72 g	28%

Q-TOF Data and Ongoing Analyses

The mass losses obtained in this study are closely correlated with the transformation of crude oil at the molecular level. The increase in the number of compounds from approximately 400 in the control group to over 800 in the experimental groups suggests that complex hydrocarbons have been broken down and converted into new intermediate metabolites. To further elucidate this biotransformation process, Q-TOF analyses are currently ongoing, and the names and chemical structures of the newly detected compounds are being identified. Once this identification process is complete, it will become clear at a molecular level which specific hydrocarbon chains are targeted by the high-performance strains, such as *Bacillus subtilis* and *Terribacillus saccharophilus*.

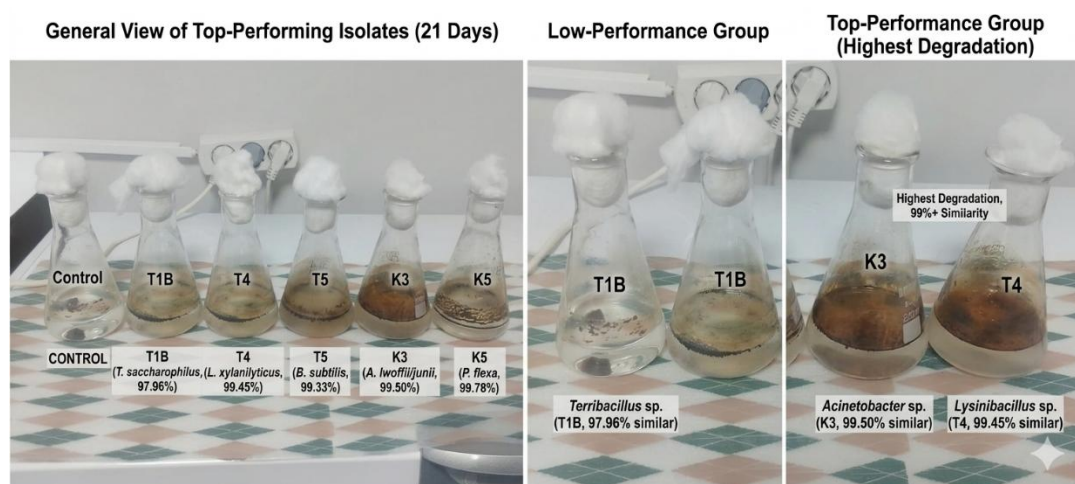


Figure 1. Visual representation of crude oil degradation by bacterial isolates from the Kirkuk oil field after 21 days. (A) General overview of the experimental setup; (B) Isolates showing limited oil degradation; (C) High-efficiency isolates with intense oil metabolism and complete physical degradation.

4. CONCLUSIONS

This study demonstrates that chronically contaminated environments such as the Kirkuk oil field harbor indigenous microbial communities with significant petroleum hydrocarbon degradation potential. Five bacterial strains (*Bacillus subtilis*, *Terribacillus saccharophilus*, *Acinetobacter lwoffii*, *Lysinibacillus xylanilyticus*, and *Priestia flexa*) were successfully isolated and identified through 16S rRNA gene analysis.

Following a 21-day incubation period, biodegradation rates ranged from 28% to 52%, confirming the ability of these isolates to utilize crude oil as a carbon and energy source. Among them, *Bacillus subtilis* exhibited the highest degradation efficiency (52%), followed by *Terribacillus saccharophilus* (50%) and *Acinetobacter lwoffii* (40%), indicating strong hydrocarbonoclastic potential.

Q-TOF analysis revealed a substantial increase in compound diversity, suggesting the breakdown of complex hydrocarbons into smaller intermediate metabolites through microbial activity. Ongoing analyses aim to further characterize these transformation products at the molecular level.

Overall, the findings highlight the potential of indigenous bacterial strains from the Kirkuk oil field as effective, eco-friendly, and cost-efficient agents for bioremediation of petroleum-contaminated environments.

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Investigation of the Effect of Selenium Nanoparticles on Chlorophyll Content Against Vanadium Stress in Common Bean (*Phaseolus vulgaris* L.)

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Abstract

Beans (*Phaseolus vulgaris* L.) are important legume species rich in high protein and micronutrients, are frequently consumed worldwide, contributing to human health. Plants with high economic value, such as beans, face environmental stress factors, and this negatively affects human nutrition through the food chain. In recent years, heavy metal pollution, resulting from natural processes and human activities, has become a major environmental problem. While some metals are beneficial for plant growth at low concentrations, high concentrations of these microelements cause toxicity, slowing growth and development Vanadium (V), one of these heavy metals, is an element that can be easily absorbed from the soil by plant roots; however, it can cause toxic effects at high doses. Various elements have been used to reduce the negative effects of environmental stress factors on plants. Selenium nanoparticles (SeNPs) one of these, is preferred to reduce harmful effects of stress and to improve plant metabolism. SeNPs also support the physiological performance of plants by protecting the photosynthetic structure and reducing chlorophyll loss caused by stress. In this study, the effects of SeNPs (24 ppm and 48 ppm) on SPAD values, which reflect the amount of chlorophyll in plants, against NH_4VO_3 stress (50 mg/L and 100 mg/L) were investigated in the Akman-98 bean variety. The findings revealed that as the NH_4VO_3 dose increased, SPAD values decreased from 30.63 to 26.40, while SeNP applications limited this decrease and increased SPAD values by %11.8 to %19.0. Analysis of variance results showed that the interaction between NH_4VO_3 and SeNP was statistically significant, indicating that under these conditions, SeNP applications contributed to the preservation of chlorophyll content, thus playing a protective role against heavy metal stress.

Keywords: Ammonium Metavanadate, Chlorophyll content, Heavy metal stress, Selenium Nanoparticles, SPAD.

1. INTRODUCTION

Beans (*Phaseolus vulgaris* L.), a staple agricultural plant belonging to the Fabaceae (legume) family, are an important source of protein and minerals for millions of people worldwide [1]. Particularly in developing countries, beans stand out as a primary food source due to their protein, vitamin, and mineral content, and also hold significant socioeconomic importance due to their wide global production and consumption network [2,3]. However, one of the most important factors limiting yield and quality in bean cultivation is the abiotic stress conditions. Among these stress factors, heavy metals are of particular importance because they interact with the plant-soil system, infiltrate biomass, and pose a threat to living organisms through the



food chain [4]. Heavy metals with concentrations above 5 g/cm³ can have toxic effects even at low concentrations [5].

Vanadium (V), one of these heavy metals, is an element that is abundant in the earth's crust, generally ranges between 150–400 µg/g, and has a wide range of uses in modern industry. Used intensively in sectors such as steel production, catalysts, and the pharmaceutical industry, V poses significant risks to ecosystems as a result of its release into the environment [6,7]. Pentavalent vanadium (NH₄VO₃) is the most mobile and most toxic form in environmental and biological systems [4].

Vanadium is readily absorbed by plants from the soil. At low levels, V can positively influence physiological processes such as photosynthesis and gas exchange; however, at high concentrations, it leads to toxic effects [8,9] including reduced seed germination, suppression of root and shoot development, inhibition of photosynthesis, impaired nutrient uptake, chlorophyll degradation, and excessive production of reactive oxygen species (ROS) [10]. Vanadium generally concentrates in the roots of plants and accumulates in the cell wall, mitochondria, and chloroplasts [11]. Because vanadate ions are structurally similar to phosphate, they are known to enter plants through phosphorus uptake mechanisms and compete with phosphorus. Furthermore, V inhibits ATPase activity, disrupting H⁺ ion transport and negatively affecting energy metabolism [10,12]. As a result of these processes, oxidative stress increases, lipid peroxidation occurs in cell membranes, and damage occurs in protein, DNA, and RNA structures [4].

Selenium (Se) is a semi-metalloid element belonging to the chalcogen group and can be found in plants in the form of selenate, selenite, and organic forms [13]. Previously considered a toxic element, Se has been shown to increase stress tolerance and strengthen the antioxidant defense system in plants at low doses [14,15]. In recent years, selenium nanoparticles (SeNPs) have attracted attention in plant stress studies due to their high bioavailability and low toxicity [16,17].

The application of SeNPs at low concentrations improves plant performance by increasing photosynthetic pigment content, gas exchange, and net photosynthesis rate [14]. Furthermore, SeNPs reduce ROS accumulation by increasing antioxidant enzyme activities against drought, salinity, and heavy metal stress [17].

Indeed, in tomato plants, Kang et al. (2024) [17] reported that the negative effects caused by cadmium stress were significantly reduced with foliar application of SeNPs. Similarly, in a study conducted by Elsheery et al. (2025) [18] on *Vicia faba* L. plants, it was shown that the negative effects of salinity stress on growth and photosynthetic pigments were mitigated with the application of 5 ppm SeNPs. These findings demonstrate that SeNPs are an effective strategy for increasing plant tolerance under different abiotic stress conditions.

2. MATERIALS AND METHODS

In this study, the 'Akman-98' (moderate) variety of bean (*Phaseolus vulgaris* L.) was used as plant material. Before the experiment, seeds were selected to have the same size for surface sterilization and treated with a 0.5% NaOCl solution for 3 minutes. Then, they were thoroughly washed with sterile distilled water to remove NaOCl residues. After sterilization, the seeds were primed by 24 ppm and 48 ppm SeNP solutions and kept in a mixer at 20–25°C for 8 hours. Following the priming process, the seeds were sown in perlite medium in 1750 gram plastic

containers (30 seeds per dose) and left to germinate under climate chamber conditions. The seeds were grown in perlite medium for 9 days, then transferred to a hydroponic system. In the hydroponic system, plants were grown in 1/4 Hoagland nutrient solution [19], and vanadium stress was applied using NH_4VO_3 at concentrations of 50 mg/L and 100 mg/L. In addition to the vanadium-treated groups, seeds treated with 24 ppm and 48 ppm SeNP during the priming stage were also grown in the hydroponic system. The control group received only 1/4 Hoagland solution and no application of NH_4VO_3 or SeNP. The concentrations used in the treatment are given in Table 1. All treatment groups were grown for 6 days at a temperature of $23 \pm 1^\circ\text{C}$ under photoperiod conditions of 16 hours light and 8 hours dark. At the end of the experiment, the SPAD value was measured in the uppermost leaf of 3 plants from each randomly selected replicate, in the middle of the leaves, without touching the midrib, to determine the chlorophyll content using a SPAD-502 Plus device.

Table 1. Doses of treatments used in the study

Control
24 ppm SeNP
48 ppm SeNP
50 mg/L NH_4VO_3
100 mg/L NH_4VO_3
50 mg/L NH_4VO_3 + 24 ppm SeNP
50 mg/L NH_4VO_3 + 48 ppm SeNP
100 mg/L NH_4VO_3 + 24 ppm SeNP
100 mg/L NH_4VO_3 + 48 ppm SeNP

3. RESULTS AND DISCUSSION

In this study, the effects of different levels of NH_4VO_3 and SeNP concentrations applied to Akman-98 bean variety on chlorophyll content were investigated using the SPAD method. The findings showed that NH_4VO_3 and SeNP treatments lead to statistically significant changes in chlorophyll levels and that there was a significant interaction between these two factors (Table 2).

In samples taken from plants grown under control conditions, the SPAD value was measured as 30.63, while in plants treated with 24 ppm SeNP, this value increased to 31.80. Low concentrations of Se have been reported to promote the biosynthesis of photosynthetic pigments [20], likely through the protection of chloroplast-associated enzymes and stimulation of pigment formation pathways. Since the photosynthetic apparatus is highly sensitive to environmental stress conditions, Se may play a regulatory role in mitigating stress effects, thereby indirectly influencing photosynthetic performance in plants [21]. In the group treated with 48 ppm SeNP, the SPAD value decreased to 29.97 (Table 2, Figure 1). These findings indicate that high SeNP doses may have a limiting effect on chlorophyll content under stress-free conditions. Chen et al. (2022) [21], found that low-dose selenium increased chlorophyll content in sweet potato seedlings, but doses of 3 mg/L and above had a phytotoxic effect, significantly reducing SPAD values.

In the plant group where only 50 mg/L NH_4VO_3 and 100 mg/L NH_4VO_3 were treated, the SPAD value decreased to 27.76 and 27.40, respectively demonstrating that NH_4VO_3 stress significantly reduces chlorophyll content. Similar to our study, V toxicity severely decreased the photosynthesis as evidenced by a decrease in chlorophyll contents [22]. Vanadium's

suppression of chlorophyll biosynthesis, negative impact on nutrient uptake, and increased oxidative stress are considered the main reasons for the observed decrease. However, it was determined that SeNP applications significantly reduced these negative effects. While the SPAD value increased to 29.56 in the groups treated with 50 mg/L NH_4VO_3 + 24 ppm SeNP, the 50 mg/L NH_4VO_3 + 48 ppm SeNP treatment increased this value to 30.63 (Table 2, Figure 1). In particular, it was determined that the 48 ppm SeNP application brought the chlorophyll content to levels close to the control group. It was determined that the highest SPAD value in the study (33.03) was achieved with the treatment of 100 mg/L NH_4VO_3 + 24 ppm SeNP. Thus, it is shown that an appropriate SeNP dose (24 ppm) can protect chlorophyll levels under high-dose NH_4VO_3 stress. In contrast, the treatment of 100 mg/L NH_4VO_3 + 48 ppm SeNP reduced the SPAD value to 29.26, suggesting that high SeNP doses may limit their protective effectiveness under stress conditions (Table 2, Figure 1).

Table 2. SPAD values according to different NH_4VO_3 and SeNP concentrations

	NH_4VO_3 (mg/L)	SeNP (ppm)	Mean
Akman-98	0	0	30.63 ^{ac}
		24	31.80 ^{ab}
		48	29.96 ^{ac}
	50	0	27.76 ^c
		24	29.56 ^{ac}
		48	30.63 ^{ac}
	100	0	27.40 ^c
		24	33.03 ^a
		48	29.26 ^{bc}

Analysis of variance results, as shown in Table 3, revealed that NH_4VO_3 concentration had a statistically significant effect on SPAD values ($F = 3.73$; $p = 0.044^*$). Similarly, SeNP treatment was also found to have a statistically significant effect on SPAD values ($F = 11.98$; $p = 0.000^*$). The interaction between NH_4VO_3 and SeNP was also found to be statistically significant ($F = 4.63$; $p = 0.01^*$). This result indicates that the effect of SeNPs on chlorophyll content varies depending on the stress level.

Table 3. Results of variance analysis for SPAD

	SD	SPAD	F	p
NH_4VO_3 (mg/L)	2	5.761	3.73	0.044 [*]
SeNP (ppm)	2	18.508	11.98	0.000 ^{***}
NH_4VO_3 (mg/L)+SeNP (ppm)	4	7.153	4.63	0.01 ^{**}
Error	18	1.545		
Total	26			

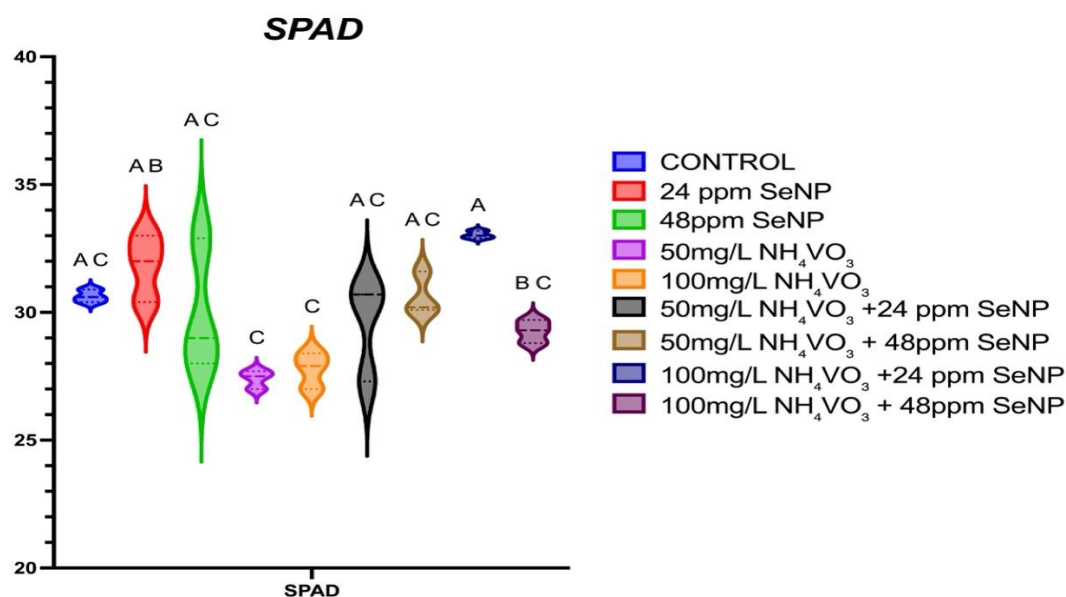


Figure 1. Effect of NH_4VO_3 and SeNP treatments on SPAD values

Overall, the findings indicate that NH_4VO_3 stress suppresses chlorophyll content in bean plants, while SeNP treatments mitigate this negative effect in a dose-dependent manner. The protective effect of SeNPs on chlorophyll content is thought to be related to the reduction of reactive oxygen species (ROS) production, the strengthening of antioxidant defense mechanisms, and the preservation of chloroplast structural integrity. These results are consistent with previous studies reporting that SeNPs play a role in improving photosynthetic performance in plants under heavy metal stress conditions. Vanadium toxicity has been reported to suppress photosynthetic capacity in rice plants by reducing chlorophyll pigments, while also decreasing growth performance by increasing oxidative stress, membrane damage, and V accumulation [23].

4. CONCLUSIONS

In this study, it was determined that NH_4VO_3 treatments significantly reduced chlorophyll content by SPAD values in the Akman-98 bean variety depending on increasing doses. The findings reveal that vanadium stress has an inhibitory effect on the photosynthetic pigment system. On the other hand, SeNP treatments were found to statistically significant to increase SPAD values in NH_4VO_3 -induced chlorophyll loss. This indicates that SeNPs can contribute to the preservation of photosynthetic capacity under stress conditions in appropriate dose in bean plants. The data obtained suggest that SeNP can be considered a supportive strategy in increasing plant tolerance to heavy metal stress.

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Technological Innovations and Artificial Intelligence as a Development Factor in the Manufacturing Industry Enterprises of Azerbaijan

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Abstract

According to the study, corporate innovation inputs and outputs play a mediating role in transforming and improving manufacturing enterprises, and these effects are significantly enhanced by AI-driven technological innovations. In recent years, technological advances aimed at developing new products or controlling the production of existing ones have become a means for enterprises to increase their capabilities and achieve their economic goals. Therefore, focusing on technical advances is one of the most important factors in making the industry both sustainable and competitive.

Artificial intelligence (AI) and technological advances are rapidly transforming the manufacturing sector from a labor-intensive, reactive sector to a highly automated, data-driven, and proactive one. By 2027, artificial intelligence (AI) will be more than just a pilot project; it will be a key strategic requirement for ensuring sustainability, productivity, and quality. Technological innovations driven by artificial intelligence will optimize resource allocation and improve production by reducing reliance on traditional labor.

The main objective of the article is to examine technological advances as an important component of manufacturing enterprises' competitiveness and to identify the advantages they can offer to these enterprises' operations. The article examines how technological innovations, a main category of innovation, affect the competitiveness of manufacturing enterprises. It also examines potential problems in the field of their application, their solutions, and makes suggestions. To complete the study, regression analysis models, development dynamics, and statistical and economic analysis methods were used.

Keywords: *Manufacturing industry, Artificial Intelligence, Technological Innovation, competitiveness*

1. INTRODUCTION

1.1. Manufacturing Industry and Artificial Intelligence.

The "fourth" industrial revolution has been attributed to artificial intelligence (AI) [1]. Artificial intelligence is increasingly used in manufacturing, finance, education, healthcare, logistics, and other management domains, making people's energy smarter and society as a whole move towards intelligence [2].



One of the important paths for scientific and technological progress is artificial intelligence. National competitiveness is closely related to the modernization and transformation of the manufacturing industry sector, which is the core of the country's economy [3]. In the global industrial sector, energy production is giving way to smart manufacturing. Artificial intelligence technology is reshaping the value-creation model of the manufacturing industry, strengthening the important elements of technological innovation in design and production [4]. Artificial intelligence-based technical innovation is empowering companies to transform and modernize their production to optimize production potential and increase output [5]. Predictive maintenance and real-time data monitoring of smart industrial systems reduce equipment failure rates and downtime losses for enterprises. Automated production lines powered by artificial intelligence reduce human intervention, increase production accuracy and consistency, and enhance businesses' competitiveness in the market. Artificial intelligence technology enhances a company's ability to withstand risks and respond more effectively to changes in market demand. The integration of AI and manufacturing promotes corporate innovation and drives product improvement [6].

Artificial intelligence has reduced the dependence on product prototypes and improved the efficiency of product research and development; artificial intelligence models can predict technological energy consumption, shorten product development cycles, and efficiently implement green product research and development; artificial intelligence technology reduces corporate resource constraints, controls costs, and reduces risks, significantly improving the efficiency of green technology innovation, and thereby promoting the upgrading of the processing industry [7].

Enterprises that develop more innovations have more sophisticated technologies and more efficient production methods, enabling them to provide high-quality goods that increase social trust and customer happiness [8]. Promoting innovative products improves enterprise inclusion and diversity, streamlines production processes, reduces the need for manual labor, and increases gender imbalance in employment [9]. Engel's law states that as income increases, households invest more in human capital, increasing the stock of human capital in society. As a result, increasing an organization's innovation can enhance human capital, eliminate employment gaps, and improve product quality, all of which will promote industrial upgrading in the manufacturing sector.

2. MATERIALS AND METHODS

Analysis of data from 2017 to 2024 shows a positive relationship between expenditures and revenue indicators related to technological innovations. During the period under study, revenues increased from 6.5 billion manat to 19.1 billion manat, indicating an overall upward trend.

Table 1. Expenditures and revenues on technological innovations in the processing industry.

Years	Purchase of machinery and equipment related to technological innovations, in thousand manats	Purchase of new technologies, thousand manats	Education and training of employees related to innovation, in thousand manats	Revenue, billions of manats
2017	501,9	158,7	0	6,500
2018	3899,2	185,2	0	7,800
2019	32070	71,5	12	8,800
2020	14666,5	1754,5	0	10400



2021	2361,5	38,6	0	13600
2022	1855,5	16078	200	19200
2023	1619,7	1391,9	1	18900
2024	2361,5	649,6	21,8	19100

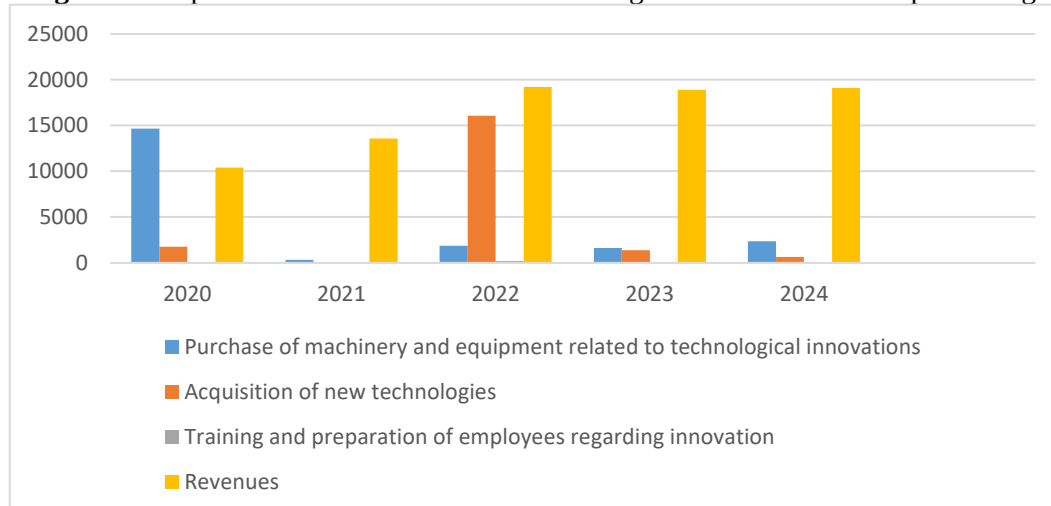
Source: <https://www.stat.gov.az/source/industry/>

Looking at the structure of innovation expenditures, the largest share is allocated to the purchase of machinery and equipment for technological innovation. In particular, in 2019, expenditures in this direction increased sharply, reaching 32,070 thousand manats. Although this indicator declined in subsequent years, continued income growth indicates that these investments have a long-term impact. Funds directed to the purchase of new technologies show more variable dynamics over the years. In 2022, this indicator increased to 16,078 thousand manats, reaching its peak. Following this increase, the stabilization of income indicators confirms the economic efficiency of applying new technologies. On the other hand, the funds allocated for employee training and preparation related to innovation are very low. In most years, expenditures in this direction have been either zero or minimal. Although an increase was observed only in 2022 and 2024, the share of this area in the overall structure remains very small. This shows that investment in human capital is not sufficiently valued.

Overall, the analysis shows that innovation-oriented capital investments, especially the purchase of technological equipment and new technologies, have a positive impact on income growth. However, for innovation processes to be sustainable and more efficient, it is important to increase investment in developing workforce knowledge and skills. This approach can create conditions for more sustainable economic growth in the future.

We can observe this more clearly in the diagram below.

Diagram 1. Expenditures and Revenues on technological innovations in the processing industry.



3. RESULTS AND DISCUSSIONS

Within the study framework, a linear regression model was used to empirically assess the relationship between the dependent and explanatory variables. Here, x_1 represents purchases of machinery and equipment for technological innovation, and y_1 represents revenue. Based on

the model's overall fit indicators, the Multiple R was 0.6577, the coefficient of determination (R^2) was 0.4325, and the adjusted coefficient of determination was 0.3190. Although these results show that the model explains approximately 43% of the variation in the dependent variable, the Adjusted R^2 suggests that its explanatory power is limited. As a result of the analysis of variance (ANOVA) conducted to assess the overall statistical significance of the model, the F-statistic was 3.811, and the p-value was 0.108. This result does not allow rejection of the null hypothesis at the 5% significance level. Thus, the model is not considered statistically significant overall, but weak, borderline significance is observed at the 10% level.

The econometric interpretation of the regression coefficients indicates that the coefficient on the explanatory variable is negative ($\beta = -0.4943$), suggesting an inverse relationship between the variables. However, considering the statistical significance of this coefficient ($p = 0.108$), the reliability of this relationship is considered weak and is not fully empirically confirmed. The intercept in the model is statistically significant ($p = 0.0058$), indicating that the baseline level of the dependent variable is statistically stable. As a result of the econometric evaluation, it was determined that although the model has partial explanatory power, it is not considered a fully reliable and strong model from a statistical point of view.

4. CONCLUSION

Proper management of technological advances is important because they significantly affect the industry's sustainable development and business continuity. The most important element that guarantees the dynamic development of the enterprise, that is, the acquisition of benefits from the external environment, is the management of technological innovations. Technological progress has its advantages, but also disadvantages. For example, automation and robotization reduce the analytical and logical aspects of human behavior and eliminate jobs. However, not all industrial enterprises can fully benefit from technological progress, as implementation entails high costs. Main Impacts of AI on Production Development:

1. Significant Productivity and Efficiency Gains: By analyzing huge volumes of operational data, AI helps manufacturers reduce unplanned downtime and increase production efficiency by up to 20%.
2. Predictive maintenance and reliability: Artificial intelligence-powered technologies monitor machines in real time and predict problems before they occur. Using sensors on CNC machines and conveyors to detect irregularities reduces downtime, which is estimated to cost manufacturers billions of dollars per year.
3. Improved Quality Control: By detecting abnormalities during production, computer vision systems quickly inspect items, reducing defects and increasing productivity.
4. Supply Chain Optimization: Artificial Intelligence (AI) tools improve the accuracy of demand forecasts; certain systems reduce errors by improving response to disruptions and optimizing inventory levels. Considering the above, it can be argued that technological progress has had a great impact on industrial management.

Based on the results of the above-mentioned research, the following conclusions are presented in this study: (1) To promote the growth of high-quality production, optimize STI policies based on AI. (2) Adopt different support strategies for different businesses and industry characteristics. (3) Strengthen the operation mechanisms of AI-based technological



innovations. (4) Guard against the possibility of edge effects in AI-supported technological innovations.

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Analysis of Sustainable Campus Performance of Public Universities in Türkiye Under the Transportation Criterion in the Context of UI Greenmetric

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Abstract

Education is a dynamic system encompassing students, academics, administrative staff, and support personnel. It also involves interaction with the surrounding local community living in its residential area. Universities undergoing transformation are more complex systems. Universities undergoing transformation with their large populations and extensive physical spaces, are key actors in sustainability transitions. Sustainability performance is assessed through the UI GreenMetric World University Ranking system, which evaluates universities according to six different criteria, widely used as a framework for measuring university sustainability unit of universities. The evaluation results for state universities in Türkiye are not satisfactory / reveal limitations. This success is largely driven by performance in the transportation category. The performance of Turkish state universities participating in the UI GreenMetric World University Ranking between 2021 and 2024 has been systematically analyzed. The research includes transportation sub-indicators scores of the state universities included in the ranking, their annual change rates, and their global positioning. The findings show that universities located in metropolitan areas perform better thanks to their integration with advanced public transportation networks. In contrast, the prevalence of private vehicles in areas far from the city center negatively affects sustainability performance. Furthermore, the length of bicycle paths, pedestrian access systems, and micro-mobility solutions are among the fundamental problems. However, some universities stand out as positive practices, such as student shuttle services, electric vehicles, and policies restricting vehicle access. This study aims to contribute to the literature by presenting concrete proposals for green transportation policies in Turkish higher education systems.

Keywords: GreenMetric, Transportation, Green Campus



1. INTRODUCTION

Higher education administrations, with their extensive administrative areas, large academic and administrative populations, energy-intensive infrastructures, and transportation networks contributing to carbon emissions, are among the significant structures of the privileged environment. The expansion of the academic complex of sustainability, along with the support of universities' resources and the enrichment of models, is crucial (Alshuwaikhat and Abubakar, 2008). One of the most important tools enabling the integration of these entities with institutional governance is systems classified as green pioneers.

The UI GreenMetric World University Ranking, launched by the University of Indonesia (Universitas Indonesia) in 2010, is currently considered one of the most comprehensive green transformation measurement platforms globally. The system evaluates 1,477 universities from 95 countries based on six main criteria by 2024 (UI GreenMetric, 2024). These criteria include leadership in transportation (TR), restriction of private vehicle use, encouragement of alternative transportation modes, and the inclusion of critical sustainability ratios such as increased carbon emission reduction.

Türkiye is represented by 120 universities in the 2024 rankings, making it the world leader among countries with the most universities in the top 1000 (YÖK, 2024). This situation reflects the sustainability and institutional transformation of the Turkish higher education system, but also highlights the need for in-depth academic analyses of the ranking's sub-criteria. The transportation aspect, in particular, presents a unique area of study due to Türkiye's heavy motor vehicle traffic and the development process in public transportation.

This study analyzes the transportation performance of Turkish state universities participating in the successful UI GreenMetric rankings between 2021 and 2024. The main objective of the research is to identify universities that excel in transportation criteria, determine the rate of change in their scores, and discuss existing policies. The study aims to make a unique contribution to the literature on sustainable circular transportation in Türkiye.

1.1. LITERATURE REVIEW

1.2. Green Campus Ranking Systems

Various international ranking systems have been developed to measure the sustainability performance of higher education institutions. Among the best known are UI GreenMetric, The Princeton Review Green Rating, and STARS (Sustainability Tracking, Assessment & Rating System) (Lauder et al., 2015). UI GreenMetric stands out from other systems due to its use of a quantitative methodology based on data and its broad global participation (Sari et al., 2016). The system evaluates institutions not only in terms of their environmental performance but also in terms of their policy commitments and implementation capacities. In their study examining the level of institutional impact of UI GreenMetric on Turkish universities, Şahin and Ertürk (2018) revealed that the ranking positively influenced institutional decision-making processes and increased environmental awareness among managers. In the same study, it is emphasized that the low performance in the transportation criterion is largely due to a lack of policy. Similar



findings were reported by Karaman et al. This is also confirmed in the study conducted by (2020) which examined the sustainability management of technical universities in Türkiye.2.2.

1.3. Campus Transportation and Sustainability

Campus transportation is directly related to environmental factors such as greenhouse gas emissions, noise pollution, traffic safety, and the urban heat island effect. Litman (2022) states that transportation planning that prioritizes public transportation is one of the most effective carbon reduction strategies for campuses. Studies in the literature also show that investments in bicycle infrastructure can significantly reduce private vehicle use and produce positive externalities in terms of health (Pucher et al., 2010).

Research on green travel planning practices carried out in European universities shows that the creation of holistic transportation policies at the institutional level significantly improves sustainability performance (Kenworthy, 2008). Campisi et al. (2020), in their study conducted in Italian universities, found that policies encouraging modal transformation (transition from private vehicles to public transportation and active transportation) directly increased UI GreenMetric transportation scores.

1.4. Sustainability Studies in Turkish Universities

Academic studies focusing on the sustainability performance of universities in Türkiye are still quite limited. Existing studies are largely limited to general ranking analyses, and in-depth research specifically on the transportation criterion is quite limited. In this context, Çelik and Güneş (2021) evaluated the environmental policy capacity of Turkish universities using GreenMetric data; they drew attention to structural deficiencies in the field of transportation despite the relatively strong performance in the energy and education categories. The "Climate-Friendly Campus" program launched by the Council of Higher Education (YÖK) in 2022 is considered an important incentive mechanism that will accelerate the institutional transformation of universities towards green transportation (YÖK, 2022).

2. METHOD

2.1. Scope of the Study and Data Sources

In this study, Turkish state universities that have continuously participated in the UI GreenMetric ranking for at least three years between 2021-2024 were included in the scope of the examination. Research data was compiled from annual ranking reports accessed through the official UI GreenMetric website (greenmetric.ui.ac.id), country-based ranking tables, and statements published by the institutions on their own web pages. The sample was created from state universities that meet the criteria, and ranking data was accessed from publicly available sources.

2.2. Framework of Analysis

The analysis was carried out in three stages: (1) annual comparative analysis of the transportation (TR) sub-criterion scores of Turkish state universities; (2) evaluation of the positioning of these universities in the global ranking according to their TR scores;

(3) correlation of the sub-components determining the TR indicators (vehicle/population ratio, parking area policy, zero-emission vehicle use, bicycle/pedestrian policy, campus bus) with



institutional practices. Descriptive statistics and trend analysis methods were used in the interpretation of the data. 3.3. UI GreenMetric Transportation Criterion

In UI GreenMetric, the Transportation (TR) criterion corresponds to 1,800 points out of a total of 10,000 points, constituting 18% of the total score (UI GreenMetric, 2024). The criterion consists of the following indicators:

- TR1: Ratio of total number of vehicles on campus to campus population
- TR2: Number of vehicles entering campus daily
- TR3: Number of bicycles used daily on campus
- TR4: Existence of transportation policies aimed at restricting motorized vehicles
- TR5: Existence of policies aimed at reducing/limiting parking space
- TR6: On-campus shuttle/bus services
- TR7: Existence of bicycle and pedestrian-friendly policies
- TR8: Initiatives towards zero-emission vehicles (electric vehicles, etc.)

These indicators provide a systematic integrity to the criteria set by addressing the sustainability transformation in campus transportation in a multi-layered way, encompassing infrastructure, policy, and behavioral dimensions (UI GreenMetric, 2024)

3. FINDINGS AND EVALUATION

3.1. Türkiye's General Trend in GreenMetric

Türkiye has shown significant growth in the UI GreenMetric ranking in recent years. The number of Turkish universities included in the ranking, which was 71 in 2021, reached 83 in 2022, 98 in 2023, and 120 in 2024 (UI GreenMetric, 2024). As of 2024, 94 Turkish universities were among the top 1000, and with this figure, Türkiye rose to the position of world leader in this category (YÖK, 2024). According to the results of 2025, 54 universities from Türkiye entered the top 500 and became the world leader again in this field (Hürriyet, 2025).

Turkish state universities play a decisive role in this table. According to 2024 data, 37 of the 45 Turkish universities in the top 500 are state universities; this rate (82%) clearly demonstrates the weight of state institutions in the sustainability agenda. This development is also in parallel with the institutional incentives provided within the framework of the Council of Higher Education's "Climate-Friendly Campus" program.

3.2. Transportation Performance of Prominent State Universities

Istanbul Technical University (ITU) is at the forefront of Turkish state universities exhibiting the most remarkable performance in terms of transportation criteria. ITU ranked 46th globally in 2023 with a score of 8,635; and in 2024, it improved its ranking to 38th with a score of 8,800 (Green Growth, 2024). ITU's strong performance in transportation is supported by its comprehensive campus shuttle network, pedestrian-priority areas, and electrification projects (sustainability.itu.edu.tr).

Yıldız Technical University (YTÜ) surpassed ITU in the transportation, energy, and climate change categories, rising to 59th place in the world rankings in 2024. This success in YTÜ's transportation performance can be directly attributed to its campus-wide electric vehicle applications within the scope of the "KABEV Project," digital parking management, and its



sustainability-focused institutional structure (Istanbul Newspaper, 2024). In addition, YTÜ has earned the title of being the first state university to receive the Zero Waste certificate..

Erciyes University maintains its position as the Turkish state university exhibiting the most stable upward trend during the 2021-2025 period. The university reached 80th place globally in 2024 with a score of 8,585; and managed to increase its transportation score from 1,600 to 1,625 in 2025 (Erciyes University, 2025). Ranked first in Türkiye in the Large-Scale Campuses category, Erciyes University is resolutely continuing its transformation in transportation infrastructure despite its centrally located and sprawling campus structure. Ege University ranked 88th globally in 2024; Dokuz Eylül University rose to 144th place in the same year, making a 15-place advancement compared to the previous year. Ranked 8th among Turkish state universities, DEÜ exhibits a stable development trajectory in all categories, including transportation (Egeyön Haber, 2024). Trakya University, with a score of 1,435 in the transportation category in the 2023 rankings, managed to enter the top 255 and took its place among the state universities that stand out in this field (Trakya University, 2023).

Table 1. GreenMetric Rankings and Transportation-Related Performance of Selected Turkish Public Universities (2023–2024)

University	Global Rank (2023)	Global Rank (2024)	Total Score (2023)	Total Score (2024)	Institution Type
Istanbul Technical University	46	38	8,635	8,800	Public
Yıldız Technical University	63	59	8,435	8,710	Public
Erciyes University	85	80	8,460	8,585	Public
Ege University	96	88	8,200	8,350	Public
Middle East Technical University (METU)	~130	126	8,050	8,150	Public
Dokuz Eylül University	159	144	7,850	7,980	Public
Sakarya University	~170	153	7,750	7,900	Public
Trakya University	255	~260	7,520	7,600	Public

Note. Data were compiled from publicly available UI GreenMetric reports and official university announcements. The symbol (~) indicates approximate values.

3.3. Strengths and Weaknesses in Transportation Indicators

When examining the transportation performance of Turkish state universities, significant progress has been made in some indicators. On-campus shuttle services (TR6) stand out as a widespread practice, especially in state universities with large campuses. Indeed, ITU's multi-campus structure necessitated the development of a comprehensive ring shuttle network, while Erciyes University's large land area required the establishment of a central transportation system; this situation positively reflected on the TR6 scores of both universities.



Pioneering practices are exhibited in initiatives towards zero-emission vehicles (TR8). YTU's electric campus vehicles and ITU's electrification projects reflect the institutional commitment in this area. However, the fact that the vast majority of universities receive low scores in this indicator shows that these practices are still exceptional and have not yet become a widespread standard. On the other hand, some structural weaknesses in the transportation performance of Turkish state universities are also noteworthy. The vehicle/population ratio (TR1) remains high, especially in universities located in metropolitan areas; This situation appears to be directly linked to the inadequacies in Türkiye's public transportation infrastructure. Policies aimed at reducing parking space (TR5) are among the least implemented policies in Turkish universities. Regulations prioritizing bicycles and pedestrians (TR7) constitute a generally neglected area, regardless of geographical location and climatic conditions.

3.4. Global Comparison

When the transportation performance of Turkish state universities is evaluated on a global scale, a striking picture emerges. ITU and YTU are positioned within the top 100 in the global ranking in the transportation category. This success proves that these institutions exhibit a competitive sustainability profile not only nationwide but also internationally. On the other hand, when compared with Western European universities, a general decline in bicycle infrastructure and vehicle restriction policies is observed in Turkish universities. Research on the transportation performance of European universities points to integrated transportation management practices such as comprehensive pedestrian networks, vending machine-free campus areas, and effective bicycle rental systems as common denominators of successful institutions (Campisi et al., 2020).

4. DISCUSSION

The research findings reveal that Turkish state universities are generally making progress in the GreenMetric transportation criteria, but there are significant differences in the distribution of this progress among institutions. Leading institutions such as ITU, YTU, and Erciyes University have gained significant competitiveness at both national and global levels by restructuring their institutional policies with a focus on sustainable transportation. The common denominators that stand out in this transformation are: strong institutional governance, coordinated green infrastructure investments, and an internalized sustainability culture at the academic and administrative levels.

On the other hand, it is understood that the low performance in the transportation category is linked to multiple structural factors. Inadequacies in urban transportation planning, the inability of universities to directly control off-campus transportation networks, and limited capital investments in bicycle infrastructure are among the main factors. While the YÖK's Climate-Friendly Campus program offers a systematic framework for closing these gaps, the quality of its implementation varies significantly from institution to institution.

Türkiye's geographical and climatic diversity also emerges as a determining factor in transportation strategies. While bicycle infrastructure offers a more feasible solution in topographically favorable cities like Izmir, Konya, and Eskisehir, prioritizing public transportation systems in universities located in mountainous areas or cities with harsh climatic conditions can be considered a much more functional approach. In this context, designing transportation strategies in a way that is specific to local conditions, rather than reducing them to a standard template, is of great importance. The main limitation of the research is that data



at the sub-indicator level (TR1-TR8) are only partially accessible from publicly available sources. UI GreenMetric does not systematically publish the individual indicator scores of institutions; this significantly limits the depth of comparative analyses. Future research will allow for more detailed and reliable inter-institutional comparisons by providing direct access to this data.

5. CONCLUSION AND RECOMMENDATIONS

This study systematically analyzed the performance of Turkish state universities in the UI GreenMetric transportation criteria for the period 2021-2024. The findings reveal that the sector has made significant progress, led by technical universities such as ITU and YTU, but the performance gap between institutions still remains significant. Erciyes University stands out as a concrete success model of systematic institutional transformation with its consistent improvement in all categories, including transportation, despite its large-scale campus structure.

Based on the research findings, the following policy recommendations have been developed for Turkish state universities:

1. **Campus Transportation Master Plan:** It is recommended that each university prepare a five-year sustainable transportation master plan, taking into account local conditions and campus dynamics, and update it at regular intervals.
2. **Vehicle Access Policies:** It is necessary to implement regulations that restrict vehicle entry to the campus and ban vehicles in certain areas, and to implement parking systems (park-and-ride) integrated with public transportation.
3. **Bicycle Infrastructure:** Safe bike paths, covered bike parking areas, and affordable bike rental systems should be developed; students and staff should be encouraged to use bicycles through financial incentives.
4. **Electric Vehicle Integration:** The gradual electrification of on-campus service vehicles should be ensured, and the expansion of charging station infrastructure should be planned as a priority investment item.
5. **Inter-institutional Cooperation:** A national best practice platform should be established where leading universities can systematically share their transportation practices.
6. **Data Transparency:** Regularly sharing transportation data and policy documents by universities with the public is critical for both accountability and improving the quality of academic research. Sonuç olarak, Türk devlet üniversitelerinin UI GreenMetric ulaşım kriterindeki yükselişi, küresel sürdürülebilirlik gündeminin ulusal yükseköğretim sistemine başarılı biçimde eklemlendiğini göstermektedir. Ancak bu dönüşümün gerçek anlamda kökleşmesi, kurumsal çabadan sistemik politika entegrasyonuna geçişi zorunlu kılmaktadır. YÖK koordinasyonunda hayata geçirilecek kapsamlı yeşil ulaşım standartları, Türk üniversitelerinin sürdürülebilir kampüs yönetiminde uluslararası bir referans noktasına dönüşmesine önemli katkı sağlayacaktır.



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Bread Waste in Mersin Province

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Abstract

While food loss and waste lead to the waste of production factors such as land, labor, and inputs, and also contribute significantly to greenhouse gas emissions and economic losses, reducing food waste is essential for achieving the United Nations Sustainable Development Goals—including “Zero Hunger,” “Responsible Production and Consumption,” and “Climate Action,” as well as the European Union’s Farm-to-Fork Strategy. Bread, a staple of the Mediterranean diet, is among the most wasted foods worldwide. Therefore, this study aimed to determine the frequency of bread purchases, consumption quantities, and waste levels among consumers in the province of Mersin. To this end, face-to-face surveys were conducted with 93 households in Mersin, and the study’s data was collected. According to the data, it was found that consumers in Mersin purchase bread 6.25 times per week, amounting to 2.49 loaves (498 g) per day. It was determined that 42.09 grams of the purchased bread is wasted by consumers. Consumers stated that they waste bread due to reasons such as a preference for fresh consumption, over purchasing, lack of knowledge about storage conditions, bread going stale quickly, and it softening rapidly due to high moisture absorption. These findings highlight the need for consumer awareness programs and improved household bread management practices to reduce bread waste and promote more sustainable consumption pattern

Keywords: Bread, Consumption, Waste, Mersin

1. INTRODUCTION

Food loss and waste are significant issues for global food security; according to a report by the Food and Agriculture Organisation of the United Nations, one-third of food produced for consumption is discarded before reaching the consumer’s table [1]. Today, approximately 900 million people worldwide are undernourished, and around 28,000 people die of starvation [2]. Food loss and waste not only lead to the wastage of production factors such as land, labour and inputs, but also contribute significantly to greenhouse gas emissions and economic losses. At the same time, reducing food waste has become a central objective in global sustainability agendas, including the United Nations Sustainable Development Goals—which encompass ‘No Hunger’, ‘Responsible Production and Consumption’, and ‘Climate Action’—and the European Union’s Farm-to-Fork Strategy.

Bread, one of the most fundamental food sources for human survival, is the most widely consumed baked good in the world, and its consumption continues to rise alongside population



growth [3]. This increase brings with it waste, and bread, as the most basic foodstuff, accounts for a significant portion of food waste worldwide.

It has been found that bread waste accounts for 10% of all food waste in the United Kingdom [4], 27% in Norway [5], 14% in Canada [6], 23.9% in Poland [7] and 15.7% in Tunisia [8]. Annual per capita bread waste has been determined to be 8.1 kg in Sweden [9], 7.3 kg in the Netherlands [10] and 7.3 kg in Türkiye [11].

Bread, a key component of the Mediterranean diet, is among the most wasted foods due to its own characteristics and consumer attitudes and behaviours. Bread is wasted for reasons stemming from its own structure—such as a short shelf life, rapid staling, and a tendency to soften easily due to rapid moisture transfer—as well as from consumers’ attitudes, tastes and preferences, including a desire to consume fresh, warm, crisp bread, a lack of knowledge about storage conditions, and purchasing excessive quantities [12].

The aim of this study was to determine the frequency of bread purchases, consumption quantities and waste levels among consumers in the province of Mersin.

2. MATERIALS AND METHODS

The primary data for the study were obtained from 93 face-to-face surveys conducted with households living in the province of Mersin between 2020 and 2021.

The first section of the questionnaire focused on the participants’ socio-demographic and economic characteristics, whilst the second section included questions regarding bread waste and variables that could influence such waste.

The data were analysed using mean and percentage calculations.

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3. RESULTS AND DISCUSSION

Participants in the survey in the study area were on average 40.2 years old, and the average household size was 3.9 people. Consumers’ average monthly income was calculated at 6,385.3 TL, food expenditure at 1,706.7 TL, and food waste at 170.5 TL (Table 1). Ateşayan and Güngörmüş (2023) noted in their study conducted in the province of Mersin that 26.6% of consumers were in the 36–45 age group.

Table 1. Socio-economic characteristics of consumers

	Min.	Max.	Mean	Std. Dev.
Age	22,0	65,0	40,2	9,30
Number of household members	1,0	9,0	3,9	1,49
Number of total child	0,0	7,0	2,0	1,58
Income (TL/month)	1000,0	15000,0	6385,3	3473,57
Food expenditure (TL/month)	250,0	5000,0	1706,7	954,59
Amount of waste (TL/month)	0,3	600,0	170,5	155,55



54.8% of survey respondents were male, 79.3% were married and 30.1% were university graduates. Furthermore, 33.3% of households had a family member with a chronic illness and 7.5% had an obese individual (Table 2). Ateşayan and Güngörmüş (2023) found that 64.9% of consumers were married and 60.7% were university graduates.

Table 2. Demographic characteristics of consumers

			%				%
Sex	Female		45,2	Marital status	Single		20,7
	Male		54,8		Married		79,3
	Total		100,0		Total		100
The presence of a chronically ill family member	No		66,7	Education	Primary school		17,3
	Yes		33,3		Secondary school		12,9
	Total		100,0		High school		21,5
The presence of an obese family member	No		92,5		Undergraduate		30,1
	Yes		7,5		Postgraduate		18,3
	Total		100,0		Total		100

89.2% of survey respondents stated that they plan their meals in advance, 78.5% said they store leftover food in the freezer to consume later, whilst 26.0% of consumers stated that they throw away some of this food without consuming it. 90.3% of survey participants stated that they watch public service announcements. 62.4% of consumers expressed a desire to receive training on food storage, whilst 67.7% wished to receive training on food waste. In 2020–2021, 69.6% of consumers stated that they baked bread at home, whilst 13.4% indicated that they wasted the bread they made due to reasons such as it being unpalatable or there being too much of it (Table 3).

Table 3. Consumer characteristics

			%				%
Meal planning status	No		10,8	Desire to receive training on food storage	No		37,6
	Yes		89,2		Yes		62,4
	Total		100,0		Total		100,0
Storage of leftovers in the freezer	No		21,5	Desire to receive training on food waste	No		32,3
	Yes		78,5		Yes		67,7
	Total		100,0		Total		100,0
Disposal of food stored in the freezer	No		74,0	Baking bread at home	No		30,4
	Yes		26,0		Yes		69,6
	Total		100,0		Total		100,0
Viewing of public	No		9,7	Wasting home-	No		86,6



service announcements	Yes	90,3	baked bread	Yes	13,4
	Total	100,0		Total	100,0

Respondents in the Mersin province purchase bread 6.25 times a week. These consumers buy 2.49 loaves (498 g) per day and waste 42.09 grams of this. In other words, consumers waste 8.45% of the bread they purchase (Table 4). İkikat Tümer and Güneş (2019) found that consumers in Kahramanmaraş purchase 2.24 loaves of bread and waste 44.02 grams of it. According to the Turkish waste report, consumers wasted 15.9 g [14] of bread per person per day in 2017 and 32.28 g [15] in 2018.

Table 4. Frequency of bread purchases, consumption and waste levels among consumers *

	Minimum	Maximum	Mean	Std. Deviation
Frequency of bread purchases (times per week)	1,00	14,00	6,25	2,784
Number of loaves of bread purchased (per day)	0,14	10,00	2,49	1,760
Amount of bread wasted (g/day)	0,00	200,00	42,09	54,681

* One loaf of bread is calculated as 200 g.

4. CONCLUSIONS

This study examined the frequency of bread purchases, consumption levels and amounts of waste among consumers in the province of Mersin. The findings indicate that a significant proportion of consumers engage in waste-reducing behaviours, such as meal planning and food storage. However, the fact that a certain proportion of food is discarded without being consumed suggests that these behaviours do not always yield effective results. This indicates that food waste is closely linked not only to awareness but also to daily habits and practices.

The fact that the vast majority of consumers follow public service announcements indicates a high level of awareness regarding food waste. However, the persistence of waste indicates that awareness alone is insufficient and that practices supporting behavioural change are necessary. Furthermore, the fact that a significant proportion of consumers wish to receive training on food storage and waste suggests that a lack of knowledge in this area persists.

Findings regarding bread consumption and waste show that, despite bread being a staple food, a certain proportion is wasted. In particular, the waste arising from home production processes indicates that consumers require information regarding production quantities and storage conditions.

In this regard, efforts to reduce food waste should not be limited to awareness-raising campaigns alone, but should also include practical measures that guide consumers' daily behaviour. In particular, there is a need to expand educational initiatives focusing on food storage, portion



planning and consumption habits. Furthermore, it is important to step up efforts to ensure a balance between production and consumption of staple food products such as bread.

When assessed overall, food waste is a multi-faceted issue that requires a combined approach addressing individual behaviour, knowledge levels and consumption habits. Therefore, policies aimed at reducing food waste must be addressed through a holistic approach, with a focus on strategies designed to change consumer behaviour.



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Carbon Quantum Dots Derived from Methylene Blue and Disodium Phosphate: Synthesis and Optimization

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Abstract

Carbon quantum dots (CQDs) have emerged as a new class of carbon-based nanomaterials with remarkable optical and physicochemical properties, including strong photoluminescence, high water solubility, low toxicity, and excellent chemical stability. In this study, CQDs were synthesized via a hydrothermal method using methylene blue as a carbon precursor and disodium phosphate as a supporting agent. The primary aim of this work is to investigate the influence of synthesis parameters such as temperature, reaction time, and precursor ratio on the optical properties of CQDs and to determine the optimum conditions for enhanced fluorescence performance. A systematic optimization study was conducted by varying temperature (160–240°C), reaction time (6–18 h), and methylene blue to disodium phosphate ratios (1:25–1:100). The synthesized CQDs were characterized using UV–vis absorption and photoluminescence spectroscopy. The results revealed that the fluorescence intensity and emission behavior are strongly dependent on synthesis conditions. Among the tested parameters, CQDs synthesized at 200°C for 12 hours with a precursor ratio of 1:50 exhibited the highest fluorescence intensity and stability. Lower temperatures resulted in insufficient carbonization, whereas higher temperatures led to fluorescence quenching due to excessive graphitization. Furthermore, stability tests under dark and light conditions demonstrated that CQDs maintained their optical properties over several days, indicating good photostability. These optimized CQDs were proposed for integration into hydrogel matrices and application in light-emitting diodes (LEDs). The findings suggest that the developed synthesis approach provides a simple, cost-effective, and environmentally friendly route for producing high-performance CQDs suitable for optoelectronic applications.

Keywords: Carbon quantum dots, Hydrothermal synthesis, Light-emitting diode

1. INTRODUCTION

Carbon quantum dots (CQDs) are zero-dimensional carbon-based nanomaterials with sizes typically below 10 nm, which have attracted significant attention in the field of nanotechnology in recent years [1, 2]. Owing to their strong and tunable photoluminescence properties, high water solubility, low toxicity, and excellent biocompatibility, CQDs are considered environmentally friendly alternatives to conventional semiconductor quantum dots [3, 4]. These



outstanding properties enable their widespread application in bioimaging, sensing technologies, photocatalysis, and optoelectronic devices [5, 6].

The optical properties of CQDs are governed by a complex interplay between quantum confinement effects and surface states. In particular, surface functional groups and defect sites significantly influence electron–hole recombination processes, thereby directly controlling emission characteristics. Ding et al. demonstrated that surface states play a crucial role in determining emission wavelengths, and full-color emission can be achieved through appropriate surface engineering [7, 8]. Therefore, the optical performance of CQDs depends not only on particle size but also strongly on their surface chemistry. In addition, the photoluminescence mechanism of CQDs is generally attributed to the combined contribution of core-state emission and surface-state emission. While core states are associated with the intrinsic sp^2 carbon domains, surface states originate from functional groups and defects, which dominate the emission behavior in most hydrothermally synthesized CQDs [7, 8]. CQD synthesis is generally categorized into top-down and bottom-up approaches. Among these, the hydrothermal method is one of the most widely used techniques due to its low cost, simplicity, and environmentally friendly nature. This method allows precise tuning of CQD size and optical properties by controlling key parameters such as reaction temperature, time, and precursor concentration.

In recent years, the use of organic dye molecules as carbon precursors for CQD synthesis has gained increasing attention. Nitrogen-containing aromatic compounds such as methylene blue can enhance surface functionalization during the carbonization process, leading to CQDs with high quantum yield. Liu et al. [9] demonstrated that heteroatom doping strategies significantly improve the photoluminescence properties of CQDs.

Phosphorus-containing additives have been widely reported to play a crucial role in the synthesis of carbon quantum dots, particularly in terms of surface passivation and modulation of electronic states. The incorporation of phosphorus atoms into the carbon framework can introduce additional emissive sites and alter the surface defect structure, thereby influencing the photoluminescence behavior of CQDs. For instance, phosphorus-doped CQDs have been shown to exhibit enhanced fluorescence properties due to the modification of electronic energy levels and the formation of new radiative recombination centers [10]. Moreover, recent studies indicate that phosphorus doping can improve photostability and provide better control over surface functional groups, which are directly related to emission efficiency [11]. In this context, disodium phosphate can act not only as a phosphorus source but also as a pH- regulating and surface-passivating agent, contributing to improved optical performance and structural stability of CQDs during hydrothermal synthesis.

CQDs have recently attracted considerable interest as alternative phosphor materials for light-emitting diodes (LEDs) [6]. Conventional phosphors based on rare-earth elements suffer from high cost and environmental concerns, driving the search for sustainable alternatives. Due to their broad absorption spectra and tunable emission properties, CQDs enable the development of high color quality LED systems [5]. Moreover, CQD-based LEDs have demonstrated high color rendering index (CRI) and tunable correlated color temperature (CCT), which are critical parameters for high-quality solid-state lighting. These properties make CQDs highly promising for next-generation lighting technologies [12]. Polymer encapsulation strategies have been widely reported to significantly enhance the photostability and optical performance of CQDs in WLED applications by suppressing aggregation and reducing non-radiative recombination



pathways. For instance, Wang, F. et al. demonstrated that carbon dot-based white light-emitting devices exhibit improved stability and efficiency when incorporated into suitable host matrices[6].

In this study, CQDs were synthesized via a hydrothermal method using methylene blue as the carbon source and disodium phosphate as a supporting agent. The nitrogen-containing structure of methylene blue is expected to enhance surface functionalization, while the effect of disodium phosphate on surface passivation is systematically investigated. Furthermore, the influence of key synthesis parameters, including temperature, reaction time, and precursor ratio on the optical properties of CQDs was examined. The findings of this study are expected to contribute to the development of high-performance CQD-based optoelectronic systems.

2. MATERIALS AND METHODS

Carbon Quantum Dots (CQDs) were synthesized via a hydrothermal approach by dissolving methylene blue and disodium phosphate in specific ratios and reacting the mixture within Teflon-lined autoclave reactors. The synthesis was optimized by investigating three primary parameters: temperature (160–240 °C), reaction time (6–18 hours), and the precursor ratio of MB to Na_2HPO_4 (1:25, 1:50, and 1:100). Following synthesis, the optical properties and structural characteristics of the resulting CQDs were rigorously analyzed using UV–vis and fluorescence spectroscopy to determine their absorption and emission profiles.

3. RESULTS AND DISCUSSION

The fluorescence characteristics of the synthesized CQDs were significantly influenced by the hydrothermal temperature and reaction duration, as shown in **Fig. 1**.

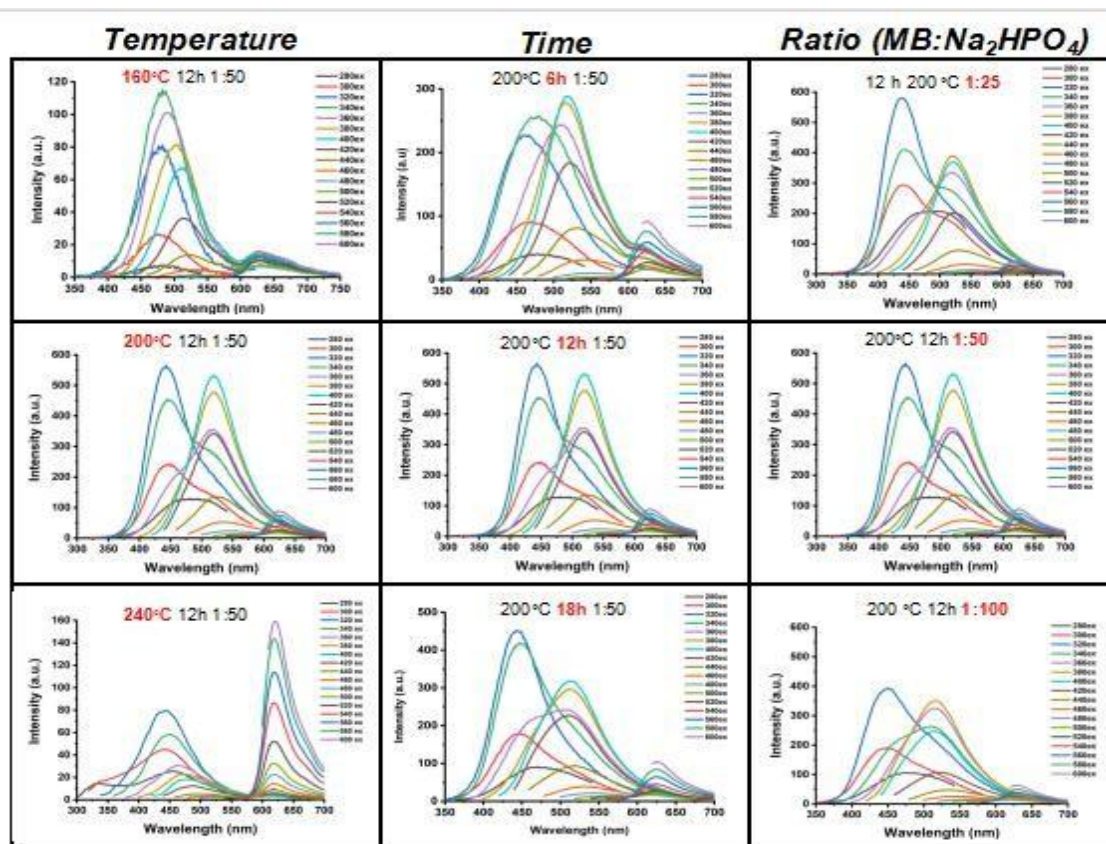


Figure 1: Synthesis of CQDs at different reaction conditions. The effect of temperature, time and initiator ratio on the fluorescence of the resultant CQDs.

It was observed that increasing the temperature from 160 °C to 240 °C generally enhanced the carbonization degree of the methylene blue and disodium phosphate precursors. The peak intensity reaching its maximum at 200 °C suggests an optimal balance between the formation of the sp^2 carbon core and the preservation of radiative surface states. Beyond this temperature, a decrease in intensity might be attributed to "over-carbonization," which can lead to the aggregation of dots or the destruction of essential surface functional groups.

Regarding the reaction time, the 12-hour duration yielded the highest photoluminescence (PL) intensity. Shorter durations (6 hours) appeared insufficient for complete nucleation, while extended periods (18 hours) likely caused excessive particle growth, shifting the emission properties.

Figure 2 illustrates the impact of different precursor ratios (MB:Na₂HPO₄) on the absorption profiles of CQDs.

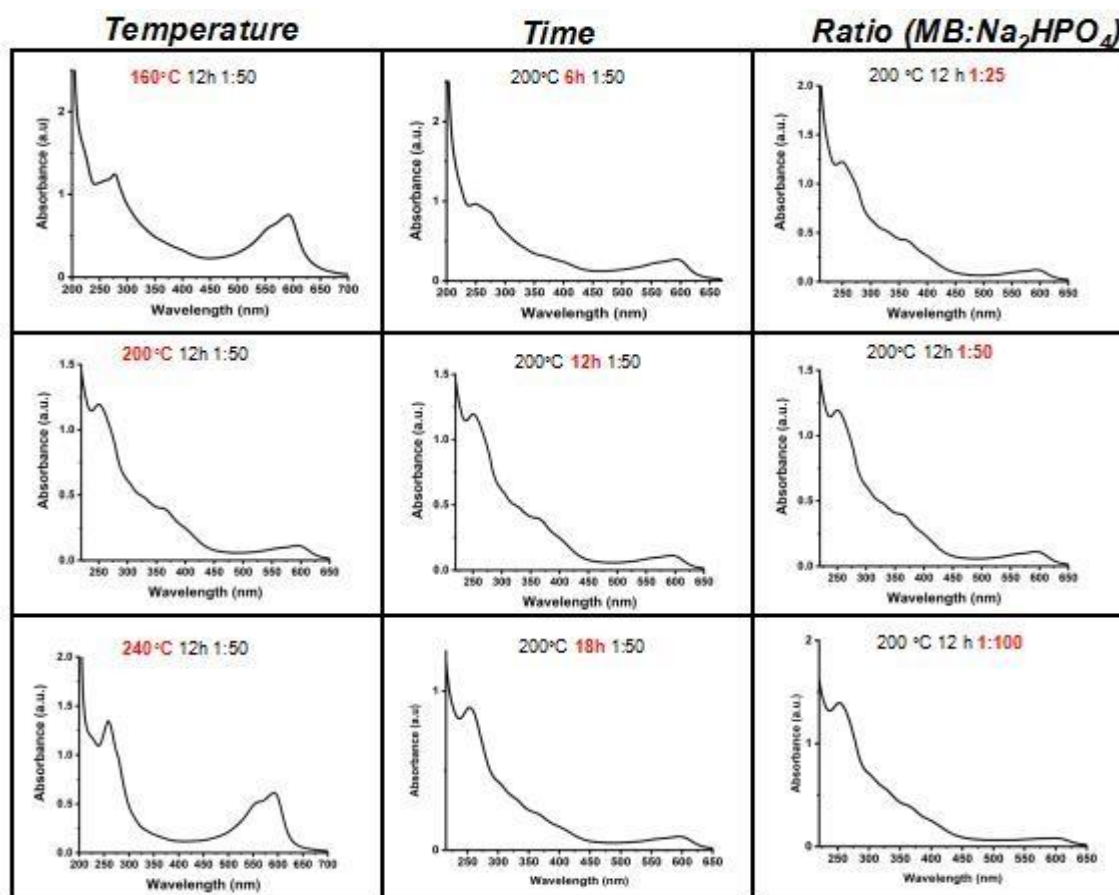


Figure 2: Synthesis of CQDs at different reaction conditions. The effect of temperature, time and initiator ratio on the UV-vis absorption spectra of the resultant CQDs.

The UV-vis spectra show a distinct absorption shoulder around **320–340 nm**, confirming successful surface functionalization with nitrogen and phosphorus atoms from the precursors. The fluorescence emission spectra demonstrate a clear dependence on the MB:Na₂HPO₄ ratio. The 1:50 ratio exhibited the most intense emission, suggesting that this specific concentration of disodium phosphate provides the ideal chemical environment for passivating the CQD surface. As the ratio shifted to 1:100, a slight redshift in the emission peak was observed. This shift indicates a change in the surface energy levels or a slight increase in the average particle size, likely due to the higher concentration of phosphorus-containing species facilitating different growth kinetics. Also, for some conditions, we noticed an absorption maxima at around 600 nm which is corresponded to the unreacted MB. This observation was furtherly confirmed via mild blue color of CQD dispersion. This issue can be attributed to the excess amount of MB as precursor. The correlation between the data in Fig.1 and Fig.2 confirms that the hydrothermal method successfully converted the molecular precursors into luminescent nanostructures. The presence of disodium phosphate not only acts as a phosphorus source for doping but also serves as a catalyst that influences the carbonization process. The high PL intensity observed under optimized conditions (200 °C, 12 hours, 1:50 ratio) highlights the formation of high-quality CQDs with rich surface states, making them suitable candidates for wavelength conversion in LED applications.

4. CONCLUSIONS



This study successfully demonstrated the synthesis of luminescent CQDs via a hydrothermal method using methylene blue and disodium phosphate. The systematic optimization of reaction parameters revealed that a temperature of 200 °C and a duration of 12 hours are critical for achieving peak photoluminescence intensity. Furthermore, a precursor ratio of 1:50 (MB:Na₂HPO₄) was found to provide the most effective surface passivation and nitrogen/phosphorus doping, resulting in superior optical properties. Characterization through UV-vis and fluorescence spectroscopy confirmed that the synthesized CQDs possess stable electronic structures and tunable emission profiles, driven by well-defined surface states. The results indicate that the hydrothermal process effectively transforms molecular precursors into high-quality nanoparticles with strong wavelength conversion capabilities. Given their robust stability and intense luminescence, these CQDs hold significant promise for integration into 365 nm and 405 nm LED applications and hydrogel-based optoelectronic devices. This work provides a practical framework for the controlled synthesis of carbon-based nanomaterials for next-generation lighting technologies.

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Investigation of paraffin deposition in Caspian Sea subsea oil pipelines

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Abstract

Paraffin deposition represents a major flow assurance challenge in subsea oil pipeline systems, particularly under the low-temperature conditions characteristic of Caspian Sea environment. This study examines crystallization behavior of paraffin-containing hydrocarbons and their subsequent accumulation on the surfaces of subsea pipelines. Special emphasis is placed on the determination and application of the Wax Appearance Temperature (WAT), which defines the critical threshold at which paraffin begins to precipitate from the oil phase. The research evaluates the combined influence of thermal gradients, hydrostatic pressure, and pipeline burial depth on heat transfer processes and paraffin deposition intensity. In addition, the interdependence between paraffin formation and key operational and material parameters, such as crude oil physicochemical properties, flow velocity, and pipeline thermal conductivity is systematically analyzed. Experimental determination of WAT using Differential Scanning Calorimetry (DSC), together with thermohydraulic modeling, enables the identification of critical temperature-pressure conditions that promote deposition.

Keywords: *subsea oil pipelines, paraffin deposition, effective diameter, flow assurance, Wax Appearance Temperature (WAT)*

1. INTRODUCTION

Caspian Sea region holds a strategically important position in the global energy market due to its abundant oil and natural gas reserves. However, extracting and transporting these resources from subsea environments presents significant engineering and technological challenges. One of the most critical aspects of subsea hydrocarbon transportation is flow assurance, which directly influences the safety, efficiency, and continuity of pipeline operations.

A key issue in subsea pipelines is crystallization of paraffin components at low temperatures. As the temperature of transported crude oil drops below a certain threshold, wax crystals begin to form and deposit along the inner walls of the pipeline. This phenomenon reduces the effective internal diameter of the pipe, increases hydraulic resistance, and places additional strain on pumping systems. In severe cases, it can lead to partial or complete blockage of the pipeline, disrupting production and transport processes [2,4]. The Wax Appearance Temperature (WAT) is a crucial parameter that defines the temperature at which wax formation begins and serves as a fundamental indicator in flow assurance analysis.

The rate and severity of wax deposition are strongly influenced by thermal and pressure conditions along the pipeline. Factors such as heat transfer between the pipeline and the cold seabed, ambient subsea temperatures, and pressure variations play a decisive role in the behavior of paraffin crystallization. Therefore, accurate temperature–pressure modeling and the



evaluation of changes in effective pipe diameter are essential for optimizing flow assurance strategies [5].

This study examines the mechanisms of wax deposition in subsea oil pipelines operating in the Caspian Sea, analyzes its dynamic behavior, and evaluates its impact on flow assurance. Furthermore, it proposes scientifically grounded approaches to optimize preventive and mitigation measures, aiming to enhance the operational reliability and efficiency of subsea pipeline systems.

1. MATERIALS AND METHODS

The study focuses on paraffinic crude oil samples and pipeline materials from subsea oil pipelines operating in the Caspian Sea as its primary objects of investigation. The physicochemical properties of the crude oil were analyzed, including API gravity, dynamic viscosity, and paraffin content ranging between 6–12%. The Wax Appearance Temperature (WAT), indicating the onset of wax crystallization, was determined to lie within the range of 55–60°C. The pipelines considered in the study have a nominal internal diameter of 0.5 m and are coated with a polymer-based insulation layer designed to optimize heat transfer. Environmental conditions such as seawater temperature and hydrostatic pressure profiles were incorporated into both experimental procedures and modeling processes.

To evaluate wax deposition and analyze flow assurance performance, the following methods were applied:

1. **Differential Scanning Calorimetry (DSC):** Used to determine the WAT and identify the temperature at which paraffin crystallization begins.
2. **Thermohydraulic modeling:** Applied to assess the cooling rate of crude oil along the pipeline, pressure losses, and the dynamic approach to WAT under flow conditions.
3. **Hydraulic analysis:** Conducted to evaluate the reduction in effective pipeline diameter due to wax deposition and the corresponding increase in pressure losses, allowing identification of flow assurance risks.
4. **Simulation and comparative analysis:** Temperature–pressure profiles and wax deposition rate curves were used to define risk zones and develop strategies for optimizing flow conditions.

By integrating these methods, the study provides a comprehensive assessment of wax deposition dynamics in subsea pipelines, identifies critical temperature and pressure thresholds, and proposes optimal measures to ensure safe, stable, and efficient pipeline operation.

2. RESULTS AND DISCUSSION

The graph obtained from Differential Scanning Calorimetry (DSC) analysis illustrates a sharp change in heat flow as the temperature decreases. This abrupt shift corresponds to the Wax Appearance Temperature (WAT), which marks the onset of paraffin crystallization. Since the risk of wax deposition increases significantly below the WAT, the graph serves as a key tool for identifying the critical threshold required to maintain flow assurance in pipelines.

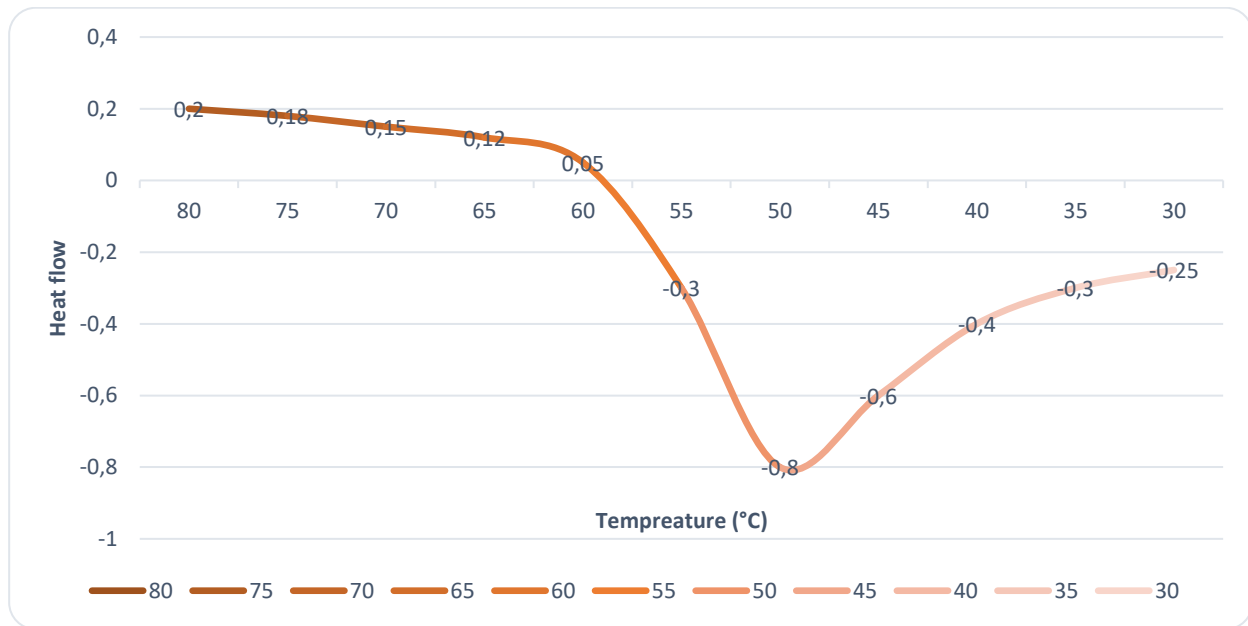


Figure 1. WAT – Temperature at which wax (paraffin) formation begins (DSC results)

In subsea oil pipelines operating in the Caspian Sea, the behavior of paraffinic components is largely governed by heat transfer conditions. The consistently low and stable temperature of the seabed accelerates the cooling of crude oil during transport, eventually leading to the separation of paraffin fractions. The temperature at which this separation occurs is defined as the WAT and represents the starting point of wax deposition within the pipeline [1,3].

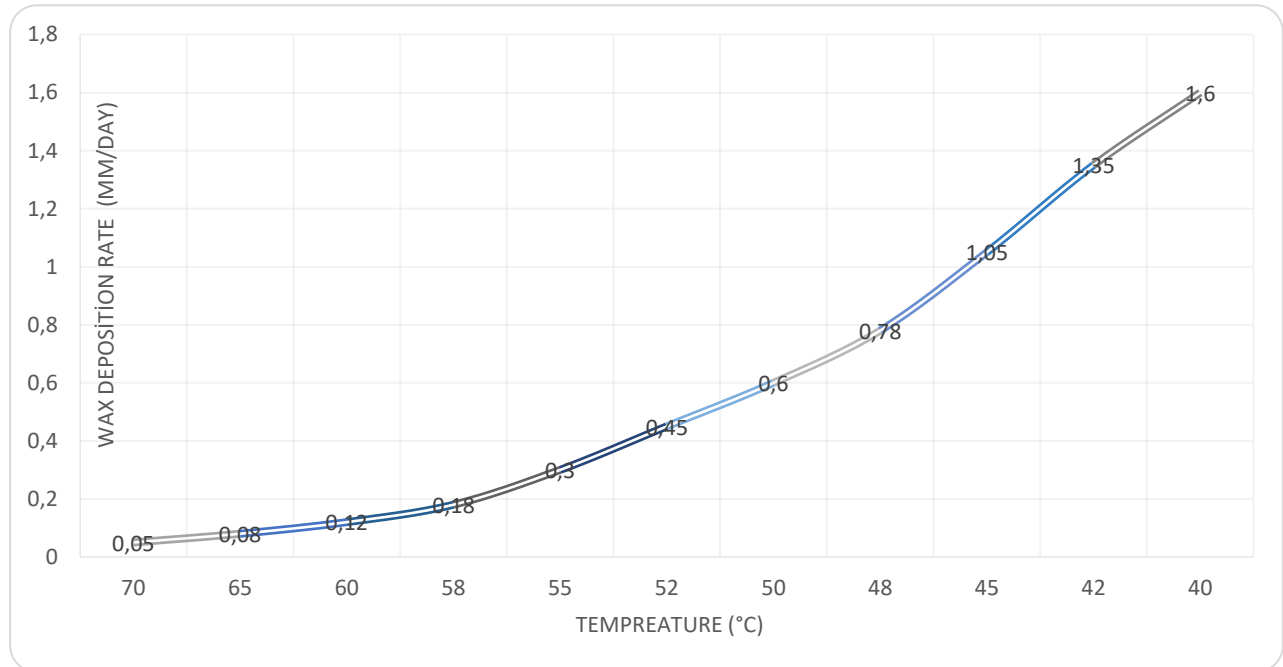
The stable and low-temperature conditions of the seabed accelerate the cooling of crude oil during transportation, eventually leading to the separation of paraffin fractions. The critical temperature at which this separation occurs is defined as the Wax Appearance Temperature (WAT), which represents the initial point of wax deposition inside the pipeline. The intensity of wax formation depends on both the hydrodynamic characteristics of the flow and the prevailing thermal conditions. Evaluating the likelihood of deposition is therefore essential for maintaining the pipeline's transport capacity and reducing operational risks. In this context, modeling the temperature–pressure relationship enables the identification of high-risk zones along the pipeline and supports the optimization of flow assurance strategies.

Table 1. Main physicochemical properties of crude oil

Parameters	Unit	Value
API gravity	°API	34–38
Dynamic viscosity (20°C)	mPa·s	8–15
Paraffin content	%	6–12
WAT (Wax Appearance Temperature)	°C	55–60

The table presents the key physicochemical parameters that influence the flow behavior of crude oil and its tendency toward paraffin deposition. The API gravity characterizes whether the crude oil is light or heavy and plays an important role in assessing its flow properties. The viscosity parameter determines the oil's fluidity and directly affects the transportation process within the pipeline.

The paraffin content reflects the crystallization potential of the crude oil and is closely associated with an increased risk of wax deposition. The Wax Appearance Temperature (WAT) indicates the critical temperature at which paraffin components begin to separate from the liquid phase, making it a fundamental parameter for flow assurance in subsea pipelines.



As shown in the graph, the wax deposition rate at 70°C is approximately 0.05 mm/day. When the temperature decreases to the range of 60–58°C, this value increases to about 0.12–0.18 mm/day. Near the Wax Appearance Temperature (WAT), around 55°C, the deposition rate rises further to approximately 0.30 mm/day, indicating the onset of significant risk.

At temperatures between 50–48°C, the rate increases more sharply to 0.60–0.78 mm/day, while at 45°C it reaches about 1.05 mm/day. At the lowest examined temperature of 40°C, the maximum wax deposition rate reaches up to 1.6 mm/day.

Wax accumulation reduces the internal flow area of the pipeline, leading to yxydated hydraulic conditions. As a result, the effective internal diameter decreases, pressure losses increase, and flow assurance risks become more severe. Therefore, calculating the effective pipeline diameter is a key parameter in evaluating the impact of wax deposition and ensuring safe pipeline operation.

3. Conclusion

The results of this study demonstrate that wax deposition in subsea oil pipelines is highly sensitive to temperature variations, particularly in relation to the Wax Appearance Temperature (WAT). Experimental and analytical findings show that as the temperature decreases from 70°C toward 40°C, the rate of paraffin deposition increases significantly, rising from 0.05 mm/day to a maximum of 1.6 mm/day. A pronounced acceleration in deposition is observed near and below the WAT range (55–60°C), confirming it as a critical threshold for flow assurance risk. The analysis also confirms that low seabed temperatures in the Caspian Sea environment intensify crude oil cooling, thereby promoting paraffin crystallization and deposition along the



pipeline walls. This leads to a reduction in the effective internal diameter of the pipeline, increased hydraulic resistance, higher pressure losses, and a deterioration of overall flow conditions. The combined use of DSC analysis, thermohydraulic modeling, and hydraulic simulation proved effective in identifying critical temperature zones and evaluating deposition dynamics. These methods enabled the determination of risk regions along the pipeline and highlighted the importance of accurate temperature–pressure modeling for operational safety.

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Development of a Comprehensive Quality Control Process Model Conforming to ISO 9001 and ISO 17025

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Abstract

Simultaneous compliance with two major international standards — ISO 9001:2015 for quality management systems and ISO 17025:2017 for laboratory competence — poses substantial organisational challenges for industrial testing and calibration facilities. This paper proposes a unified procedural framework that merges the overlapping requirements of both documents into a single, coherent quality control process model. The study begins with a systematic mapping of all standard clauses to reveal areas of convergence and divergence. Process flow diagrams were employed to visualise management and technical workflows under a three-tier architecture encompassing policy, procedure, and operational instruction levels. The model was subsequently validated through deployment in an industrial calibration unit over an observation window of twelve months, with performance tracked via internal audit outcomes, document management workload metrics, and staff competency assessment scores. Results confirm that roughly two-thirds of all clause requirements can be addressed within shared procedures, yielding measurable reductions in audit non-conformances and administrative overhead. Remaining divergences, particularly those relating to measurement traceability, uncertainty budgeting, and method validation, are accommodated through dedicated technical annexes attached to the unified framework. The proposed model offers laboratory managers and quality engineers a practical, evidence-based tool for achieving dual-standard compliance without duplicating effort across parallel quality systems.

Keywords: *Quality management system, laboratory accreditation, ISO 9001, ISO 17025, integrated process model*

1. INTRODUCTION

Modern industrial enterprises that operate measurement, testing, or calibration services face a layered compliance landscape. Two standards occupy a central position in this landscape: ISO 9001:2015, which codifies the minimum requirements for a quality management system (QMS) applicable across all industrial sectors, and ISO 17025:2017, which specifies the technical and managerial requirements that a laboratory must satisfy to demonstrate competence and produce metrologically valid results. Although the two documents were conceived for different primary audiences, their underlying philosophy is identical — both are rooted in the process approach and in risk-based thinking, and both rely on the Plan-Do-Check-Act improvement cycle.

Industrial laboratories operating within organisations that also seek or hold ISO 9001 certification are therefore expected to satisfy two partially overlapping sets of requirements. Where no integrated model exists, this expectation typically results in separate documentation hierarchies, independent internal audit programmes, and duplicated management review processes. The inefficiency generated by such arrangements is well recognised among quality



practitioners, yet a formally structured, empirically validated remedy remains elusive in the published technical literature, particularly for the specialist domain of environmental and material control instrumentation.

The present investigation addresses this gap by developing and testing a comprehensive integrated quality control process model applicable to laboratories engaged in the measurement and control of natural environments, substances, materials, and manufactured products. The central research objective is to identify all clause-level intersections between the two standards and to construct a unified procedural architecture capable of satisfying both simultaneously. The research assumes that the pilot laboratory operates under stable technical conditions and that personnel have baseline familiarity with quality system documentation. The study does not address the financial aspects of certification or accreditation.

1.1. Theoretical context and prior work

Scholarly attention to integrated management systems accelerated following the 2015 revision of ISO 9001, which introduced a common High Level Structure (HLS) later adopted by ISO 17025:2017. This structural alignment simplified cross-referencing but did not eliminate the practical challenge of operating two independent compliance programmes. Comparative analyses have mapped shared clause families across both standards and proposed consolidation strategies for documentation, internal audit scheduling, and management review procedures. These studies consistently identify document control, corrective action, and personnel competence as the three domains most amenable to unification. Technical requirements specific to laboratory work — including measurement uncertainty quantification, reference standard traceability, and inter-laboratory proficiency testing — have no direct counterpart in ISO 9001 and therefore remain outside the scope of any purely procedural merger. The present model accommodates this asymmetry through a modular design that preserves a shared core while appending laboratory-specific technical annexes.

2. MATERIALS AND METHODS

The investigation proceeded through four consecutive phases: clause mapping, gap analysis, model construction, and pilot validation. Source materials comprised the normative texts of ISO 9001:2015 and ISO 17025:2017 together with their informative annexes, the ILAC P15 guidance document on accreditation, and the internal quality records of the participating calibration laboratory at Azerbaijan State Oil and Industry University. No commercially published template or proprietary framework was used as a starting point, ensuring that the integrated model reflects an independent synthesis of the two standards.

Clause mapping was performed by listing every normative requirement from each standard in a dedicated spreadsheet and assigning each requirement to one of three categories: shared — the requirement is expressed in substantively equivalent terms in both standards; complementary — the requirement appears in both standards but with different technical depth or scope; and unique — the requirement exists in only one standard and has no counterpart in the other. This categorisation was validated through a structured review session with two independent quality auditors experienced in laboratory accreditation.

Gap analysis was conducted at the pilot laboratory prior to model implementation. Current procedures were compared against both standards using a binary conformance scale, and deficiencies were recorded in a gap register. The integrated model was then drafted as a three-



tier document hierarchy: a quality policy and objectives statement at the strategic level, unified procedures at the tactical level, and laboratory-specific work instructions and technical annexes at the operational level. Process interactions were visualised using BPMN-compliant flow diagrams.

2.1. Pilot validation design

The model was implemented at the calibration laboratory over a twelve-month period divided into two audit cycles of six months each. Three quantitative performance indicators were tracked throughout the observation period: the count of non-conformances raised during scheduled internal audits, the average number of staff-hours consumed per month in document management activities, and the mean score obtained by laboratory personnel in competency evaluations aligned with clause 6.2 of ISO 17025:2017. Baseline values for all three indicators were established from records spanning the twelve months immediately preceding implementation. Statistical comparison between baseline and post-implementation periods employed paired-sample t-tests at a 95% confidence level.

3. RESULTS AND DISCUSSION

Clause mapping identified 47 normative requirement statements that qualify as shared between the two standards, representing 63% of the total combined clause inventory when duplicate counting is applied. A further 18 requirement statements were categorised as complementary, and 29 were identified as unique to ISO 17025:2017 — principally those addressing measurement traceability, uncertainty evaluation, sampling, and method validation. ISO 9001 contributed no unique requirements that lacked at least a partial equivalent in ISO 17025, confirming that the laboratory standard subsumes the quality management standard in most respects while extending it technically.

The three-tier integrated model consolidated the 47 shared requirement statements into 12 unified procedures covering context analysis, stakeholder management, risk register maintenance, document and record control, internal audit execution, management review, corrective and preventive action, personnel competence assurance, purchasing control, equipment management, and customer communication. Each unified procedure includes explicit cross-reference tables indicating the specific clause numbers of both standards that the procedure satisfies, enabling straightforward traceability during external assessment.

Pilot validation results demonstrated statistically significant improvements across all three performance indicators. Internal audit non-conformances declined by 31% between the baseline and post-implementation periods ($p = 0.03$). Monthly document management workload decreased by an average of 19 staff-hours, corresponding to a 24% reduction relative to baseline ($p = 0.01$). Personnel competency scores improved by a mean of 16 percentage points ($p = 0.02$). These outcomes are consistent with the hypothesis that unifying parallel quality system structures reduces administrative overhead and sharpens personnel understanding of compliance obligations.

A notable observation during implementation was that the modular architecture of the model — in particular the separation of unified core procedures from laboratory-specific technical annexes — substantially reduced initial resistance among technical staff. Metrologists who were accustomed to working exclusively with ISO 17025 requirements perceived the unified procedures as an extension of their existing practice rather than an externally imposed quality



management overlay. This organisational dynamic suggests that the sequencing of model introduction, beginning with the technically familiar laboratory clauses before introducing the management system elements, is a critical success factor for adoption.

4. CONCLUSIONS

This study has produced and empirically validated a comprehensive integrated quality control process model that satisfies the normative requirements of both ISO 9001:2015 and ISO 17025:2017 within an industrial calibration laboratory context. The clause mapping exercise confirmed that the majority of combined requirements are amenable to unification, and the three-tier model architecture demonstrated that shared and standard-specific elements can coexist within a single document hierarchy without mutual compromise. Measured performance improvements in audit outcomes, documentation efficiency, and personnel competence provide quantitative evidence that the integrated approach delivers practical operational benefits beyond mere compliance.

Several directions for future investigation emerge from the present work. First, the model should be evaluated in laboratory environments of varying size and sector to determine whether the clause mapping ratios and performance gains observed here are generalisable. Second, the incorporation of digital quality management platforms and laboratory information management systems into the integrated framework warrants dedicated study, as automation of document routing and audit scheduling could amplify the efficiency gains already observed. Third, the development of a publicly available implementation guide based on the proposed model would extend its accessibility to organisations lacking specialised quality system expertise.

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Determining the effect of zinc oxide nanoparticles on chlorophyll content in wheat (*Triticum aestivum* L.) against boric acid stress

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Abstract

Wheat is one of the most widely produced and consumed staple food crops worldwide, playing a crucial role in global food security. The rapid increase in the world population has led to a continuous rise in food demand. Increasing the yield of cultivated crops is therefore considered a fundamental approach to meeting this demand. Preventing toxicity, which is one of the main causes of yield loss, is of great importance in this context. Boric acid is an essential micronutrient required for plant growth at low concentrations; however, at high levels, it exhibits toxic effects, causing damage to plants and resulting in yield reduction. Zinc (Zn) is also a vital micronutrient for plants. Its deficiency leads to problems such as chlorosis, necrosis, reduced leaf size, stunted growth, and decreased fruit quality, ultimately causing yield loss. In recent years, nanoparticles (NPs) have also been shown to be effective under different stress conditions. Chlorophyll a and b are the primary pigments responsible for photosynthesis in plants and play a critical role in plant survival. The quantity and balance of these pigments provide important insights into plant growth performance, productivity, and tolerance to environmental stresses. This study investigated the effects of different concentrations of Zn NP (50 ppm and 100 ppm) applied to wheat seeds under boric acid stress 10, 15, and 20 mM on chlorophyll a and chlorophyll b levels were evaluated. The findings revealed that toxic levels of boron (20 mM) led to a significant decrease in total chlorophyll content (14.03 mg/g). Zn NP applications significantly mitigated this negative effect, that an increase occurred in 50 ppm Zn NP+20 mM boron (15.69 mg/g) and 100 ppm Zn NP+20 mM boron (17.31 mg/g) resulting in improved chlorophyll levels.

Keywords: Boron Toxicity, Chlorophyll a and b, Chlorophyll Content, Zinc Oxide Nanoparticle

1. INTRODUCTION

Plants require micronutrients to sustain essential physiological processes such as growth and development, enzyme activation, photosynthetic efficiency, and tolerance to stress conditions. However, when these elements exceed their optimal levels, they may exert toxic effects on plants. Boron, one of the essential micronutrients, plays a critical role in numerous vital processes including cell division and elongation, cell wall synthesis and integrity, chlorophyll formation, flowering, and fruit development. In addition, boron is involved in the regulation of enzyme activities, transport of sugars across membranes, and the metabolism of lignin, flavonoids, auxins, nitrogen compounds, and phenolics [1]. Nevertheless, exposure to high levels of boron leads to adverse effects such as chlorosis, necrosis, leaf spotting, inhibition of root and shoot growth, and disruption of nutrient uptake, ultimately resulting in yield loss. Monocotyledonous plants generally have lower pectin content in their cell walls compared to



dicotyledonous plants, and therefore exhibit lower boron requirements and relatively higher tolerance to excess boron [2,3].

Zinc is another essential micronutrient for plants, contributing to antioxidant defense systems in low doses, enhancing membrane stability, and improving resistance against biotic and abiotic stress factors. In recent years, the treatment of nanoparticles has gained attention as a strategy to enhance plant productivity and tolerance to environmental stresses [4]. The studies have investigated the protective role of Zn nanoparticles against cadmium, salt, arsenic, boron, and chromium stresses. In particular, zinc oxide nanoparticles (ZnO NPs) have been reported to exhibit protective effects against boron toxicity in addition to their antioxidant properties [5,6]. However, studies investigating their effects on photosynthetic pigments in wheat remain limited. Considering the detrimental effects of boron toxicity on plants, it is important to explore novel approaches to mitigate these impacts. In this context, the present study aimed to determine the effects of zinc oxide nanoparticles on chlorophyll levels under boron-induced stress conditions. It was hypothesized that the application of ZnO nanoparticles would alleviate boric acid-induced chlorophyll loss, and the obtained results supported this assumption.

2. MATERIALS AND METHODS

In this study, the Mart cultivar (*Triticum aestivum* L.), identified as sensitive to boron toxicity, was used. Seeds of uniform size were selected and surface-sterilized by immersion in 1% Sodium hypochlorite solution for 2 min. Following sterilization, the seeds were rinsed thoroughly with distilled water. Zinc oxide nanoparticles were dispersed in distilled water using a sonicator for 1 h, and two different concentrations (50 ppm and 100 ppm) were prepared. For each treatment dose, 200 seeds were used. The seeds were transferred into capped bottles containing zinc oxide nanoparticle suspensions and incubated at 25 °C for 24 h under continuous mild shaking. At the end of the incubation period, the seeds were rinsed with distilled water and sown in trays containing perlite. For the control and Boric acid treatment groups, sterilized seeds were incubated only in distilled water under the same conditions (25 °C, 24 h, continuous mild shaking) and sown on the same day. The seedlings were germinated for 10 days, after which uniformly grown seedlings were selected and transferred to a hydroponic system. During the germination period, the plants were supplied only with water, whereas after germination they were fed with Hoagland solution. Plants were grown under a 16/8 h light/dark photoperiod. Seven days after transfer to the hydroponic system, boric acid stress treatments were initiated. Uniformly developed plants were selected and exposed to 15, 20, and 25 mM boric acid stress for 7 days.

Based on preliminary experiments, different boric acid concentrations (15, 20, and 25 mM) were applied, and zinc oxide nanoparticles were administered at doses of 50 ppm and 100 ppm using the nano-priming method. The effects of the treatments were evaluated by measuring chlorophyll a and chlorophyll b levels in the plants.

The determination of chlorophyll a, chlorophyll b, total chlorophyll in plant leaves was carried out based on the method described by *Witham et al (1971)* [7]. For this purpose, 0.2 g of fresh leaf tissue was homogenized in 80% cold acetone to a final volume of 10 mL. The homogenate was filtered through filter paper, and the filtrate was centrifuged at 5000 rpm for 10 minutes. Following centrifugation, the supernatant was collected, and absorbance values were measured at 450, 645, and 663 nm. These absorbance values obtained at different wavelengths were substituted into the relevant equations to calculate chlorophyll a, chlorophyll b, total chlorophyll in leaf tissues. The results were expressed as mg per gram of tissue (mg/g tissue).



Chlorophyll a (mg/g tissue)

$$[(12.7 \times OD_{663}) - (2.69 \times OD_{645})] \times \left(\frac{V}{1000 \times W} \right)$$

Chlorophyll b (mg/g tissue)

$$[(22.9 \times OD_{645}) - (4.68 \times OD_{663})] \times \left(\frac{V}{1000 \times W} \right)$$

Total chlorophyll (mg/g tissue)

$$[(20.2 \times OD_{645}) + (8.02 \times OD_{663})] \times \left(\frac{V}{1000 \times W} \right)$$

OD: Absorbance of the chlorophyll extract at the specified wavelength

V: Final volume of 80% acetone (mL)

W: Fresh weight of the extracted tissue (g)

3. RESULTS AND DISCUSSION

The findings of this study indicate that increasing boric acid (BA) concentrations led to a gradual decrease in chlorophyll content in wheat plants. Compared to the control group, reductions were observed at 10 and 15 mM BA, with the most pronounced decline occurring at 20 mM dose (12,74 mg/g) (Figure 1). This pattern demonstrates that boron toxicity exerts a dose-dependent inhibitory effect on photosynthetic pigments. Similar reductions in chlorophyll content under excessive boron exposure have also been reported in previous studies, suggesting that elevated boron levels may impair chlorophyll biosynthesis and accelerate pigment degradation through the induction of oxidative stress and disruption of chloroplast structure [8, 9]. These alterations may ultimately limit photosynthetic efficiency and negatively affect plant growth and development. The decrease in chlorophyll content may be associated with disruption of chloroplast structure, inhibition of pigment synthesis, and an increase in oxidative stress. Treatment of zinc oxide nanoparticles (ZnO NPs) alone resulted in chlorophyll levels comparable to, and in some cases higher than, those of the control group. Notably, the 50 ppm (21,61 mg/g) dose showed a more consistent and favorable effect than the 100 ppm (16,73 mg/g) treatment (Figure 1). This can be explained by the role of zinc in chlorophyll synthesis and enzyme activation, as well as its contribution to maintaining cellular integrity. Similarly, previous studies have also reported that zinc applications, particularly at low and moderate concentrations, positively influence plant growth and physiological processes [10,11].

In treatments where BA and ZnO NPs were applied together, ZnO NPs were found to alleviate the adverse effects of BA toxicity to a certain extent. Under low and moderate BA levels (10 and 15 mM), significant improvements in chlorophyll content were observed, with values approaching those of the control (15,90 and 15,49 mg/g). At higher BA level (20 mM), the ameliorative effect persisted but was more limited (12,74 mg/g). This suggests that the protective effect of nanoparticles decreases as stress intensity increases. Furthermore, the relatively lower performance of the 100 ppm ZnO NP (16,73 mg/g) treatment compared to 50 ppm (21,61 mg/g) in some cases indicates that nanoparticle concentration is a critical factor (Figure 1). Higher doses may impose additional stress on the plant, highlighting the importance of determining an optimal concentration. Overall, the results suggest that ZnO NP applications

contribute to the protection of photosynthetic pigments by reducing the effects of oxidative stress [12,13].

Statistical analysis revealed that the differences among treatments were highly significant ($p < 0.001$). This indicates that the observed changes were not due to random variation and that the treatments had a clear effect on chlorophyll content (Figure 2).

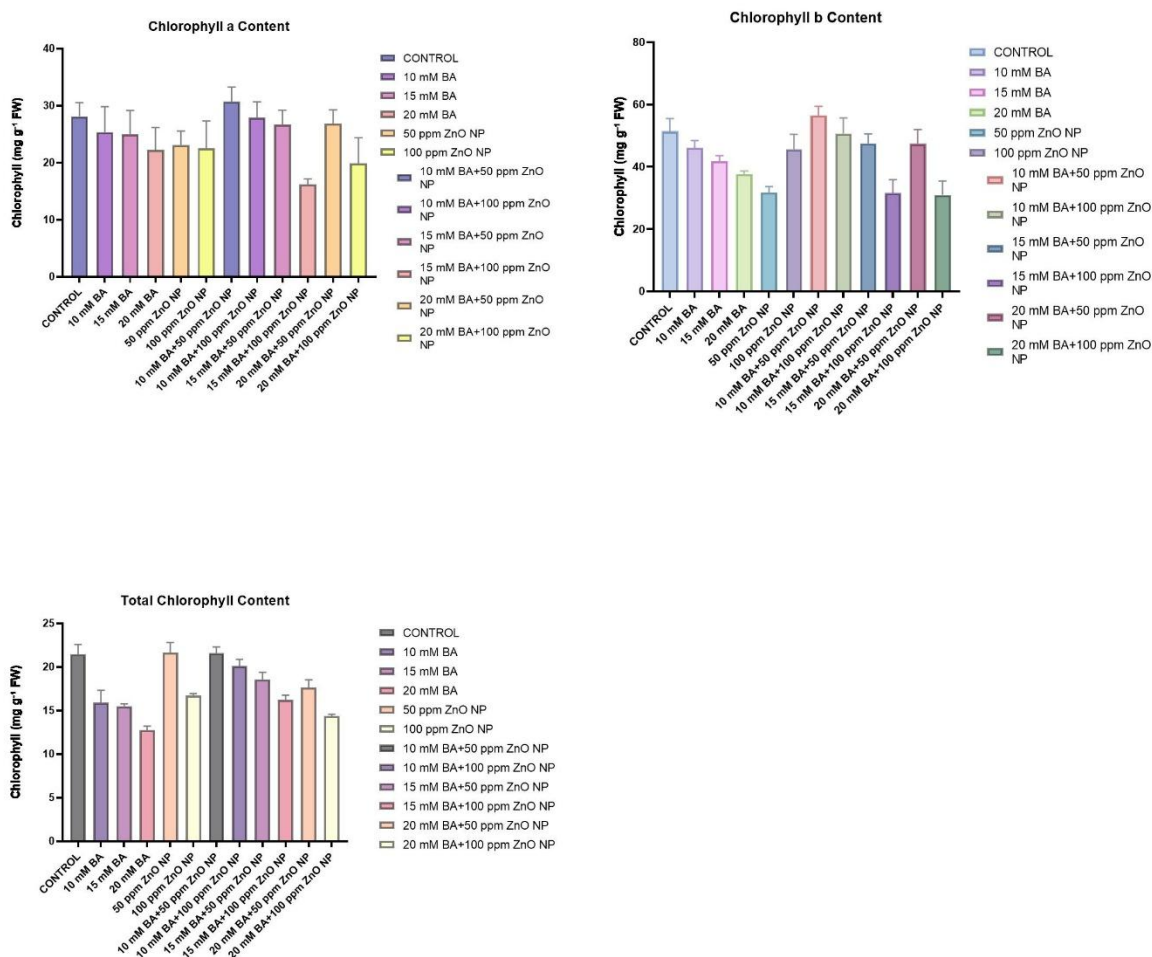


Figure 1: The effect of different boric acid and zinc oxide nanoparticles on chlorophyll a and b.



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
BA	3	143,19	47,7298	73,38	0,000
ZnO NP	2	83,95	41,9757	64,53	0,000
BA*ZnO NP	6	66,56	11,0939	17,05	0,000
Error	24	15,61	0,6505		
Total	35	309,32			

Tukey Pairwise Comparisons: BA*ZnO NP

Grouping Information Using the Tukey Method and 95% Confidence

BA*ZnO NP	N	Mean	Grouping
0 50	3	21,6173	A
10 50	3	21,5770	A
0 0	3	21,4440	A
10 100	3	20,1118	A B
15 50	3	18,5530	B C
20 50	3	17,6159	C D
0 100	3	16,7305	C D E
15 100	3	16,2296	C D E
10 0	3	15,9012	D E
15 0	3	15,4922	D E
20 100	3	14,3607	E F
20 0	3	12,7409	F

Means that do not share a letter are significantly different.

Figure 2: Statistical values of different boric acid and zinc oxide nanoparticles.

4. CONCLUSIONS

This study demonstrated that boric acid toxicity significantly reduced chlorophyll content in wheat, and this effect became more pronounced with increasing doses. The application of zinc oxide nanoparticles mitigated these adverse effects and led to an improvement in chlorophyll levels. Notably, the 50 ppm dose was found to be more effective. In conclusion, ZnO NP applications may play a protective role against boron toxicity in plants and contribute to the maintenance of photosynthetic capacity. However, the nanoparticle dose should be carefully optimized, and further studies under different conditions are recommended to better understand and validate these effects.

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Development of an IoT-Based Machine Downtime Monitoring and Prediction System

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Abstract

This paper presents the development of a semi-automated Internet of Things (IoT)-based machine downtime monitoring and prediction system for maintenance decision support, applied to a representative filling line at an industrial lubricant blending plant. The proposed software-centric architecture integrates a Node-RED dashboard for structured downtime logging, visualization, and computation of reliability indicators, n8n for workflow automation, and Telegram for real-time notifications to operators. Historical event-based downtime records are exported from the monitoring layer and analyzed offline using machine learning models implemented in Python, namely Random Forest Regression, XGBoost Regression, and Quantile Random Forest, together with Kaplan–Meier survival analysis for probabilistic reliability assessment and Mean Time Between Failures (MTBF) estimation. Rather than targeting precise failure-time prediction, the system focuses on early warning and uncertainty-aware Remaining Useful Life (RUL) estimation to support risk-informed maintenance planning. Model performance is evaluated using Root Mean Square Error (RMSE), Mean Absolute Error (MAE), coefficient of determination (R^2), prediction-interval coverage, and MTBF. Results show that, although point prediction accuracy is limited by sparse and imbalanced downtime data, the quantile-based and survival-analysis outputs provide useful information on failure risk and maintenance prioritization. Overall, the system demonstrates a practical and scalable approach to transforming manual downtime records into actionable, data-driven maintenance intelligence for Industry 4.0 environments.

Keywords: *Internet of Things, machine downtime, predictive maintenance, regression model, Remaining Useful Life*

1. INTRODUCTION

The manufacturing facilities that are machine-intensive require the maintenance and dependability of the machines because even minor machine downtimes are likely to alter production schedules, decrease throughput and escalate the costs of operation. Practically, machine downtime data in industrial settings is generally kept as sparse and highly skewed event-based logs of data, which are irregular and uncommon, and extreme failures are much less frequent than minor stoppages. This feature, along with the largely manual record-keeping methods, restricts the value of the downtime information in order to provide timely analysis and proactive maintenance planning.

Traditional maintenance methods can be mostly categorized into reactive (corrective) maintenance, where maintenance efforts are only initiated after a failure has taken place, and

preventive maintenance, where maintenance activities are planned as per a certain time interval or usage despite of actual condition. Although these strategies are popular, they are not effective at responding to unforeseen failures and can cause either unnecessary interventions or long-term unplanned downtime. As Industry 4.0 increases, there is an expanding necessity for data-driven systems that assist in real-time tracking, systematic downtime examination and preemptive danger of failure, transitioning maintenance practice towards time-stamped and reactive interventions to proactive and reliability-driven choices.

To meet this requirement, this paper proposes a semi-automated Internet of Things (IoT)- based machine downtime monitoring and prediction system applied to a representative filling line at an industrial lubricant blending plant. The suggested architecture is a combination of a Node-RED dashboard to enter standardized downtime data, visualize and calculate performance indicators, an n8n workflow engine to automate and Telegram messaging to alert and interact with operators in real-time. The events of historical downtime measured by this software layer are analyzed offline by machine learning models that are Random Forest Regression, XGBoost Regression, and Quantile Random Forest, along with Kaplan-Meier survival analysis as a probabilistic measure of reliability and Mean Time Between Failures (MTBF) estimation.

Instead of trying to make very precise predictions of the specific failure times, the system aims at delivering early warning, risk indicators, and uncertainty-aware Remaining Useful Life (RUL) estimates to aid in prioritizing maintenance. The particular contributions of this paper are as follows: (i) an IoT-based downtime monitoring dashboard that converts the manual logs into structured data and calculates the Overall Equipment Effectiveness (OEE), reliability, and MTBF and health status at equipment level; (ii) an integrated workflow, that consists of the combination of Node-RED, n8n, and Telegram to semi-automize the alerts and the Root Cause Analysis (RCA) documentation; (iii) a prediction framework that combines regression models and Quantile Random Forest to estimate the RUL in addition to prediction.

2. MATERIALS AND METHODS

This study proposes a software-based IoT-based machine downtime monitoring and prediction solution to support the maintenance decision-making process at a representative filling line of an industrial lubricant blending plant. The methodology is built in three stages, as illustrated in Fig. 1. Phase 1 defines real-time downtime monitoring and some sort of data logging through Node-RED, n8n and Telegram workflow automation and real-time alerting. Phase 2, offline predictive modelling and reliability analysis is done using historical downtime data, with Random Forest (RF), XGBoost (XGB), Quantile Random Forest (QRF) and Kaplan- Meier survival analysis being used to predict Remaining Useful Life (RUL) and failure risk indicators. Phase 3 assesses model performance in terms of RMSE, MAE, and R² and incorporates the outputs of decision-making into an alert workflow based on a threshold to facilitate early warning and prioritization of maintenance.

A. Overall System Architecture

A feasibility assessment of the case-study filling line identified five critical machines considered in this project: capper, bottle orientator, pick-and-place, palletizer, and carton erector. Existing downtime recording practices were mainly manual and unstructured, which limited consistency and downstream analysis. Based on this, a software-based monitoring approach was selected to standardize downtime data collection without requiring direct PLC/HMI integration.

The primary platform is Node-RED, which is utilized as a visualization, logging, and orchestration platform. Downtime events are logged by operators or supervisors using a standardized dashboard form, which includes machine/equipment selection, length of downtime (minutes), Person In Charge (PIC) and failure type (major or frequent). Upon submission, the dashboard will store the event records in a structured format, like CSV and a local SQLite database, to be analyzed and reported on. Downtime distribution is also available in real-time on the dashboard, and operational indicators, including OEE-related availability and reliability trends, are computed. Export and import of data are used to allow offline model development based on curated CSV data.

B. Phase 1: IoT-based Downtime Monitoring.

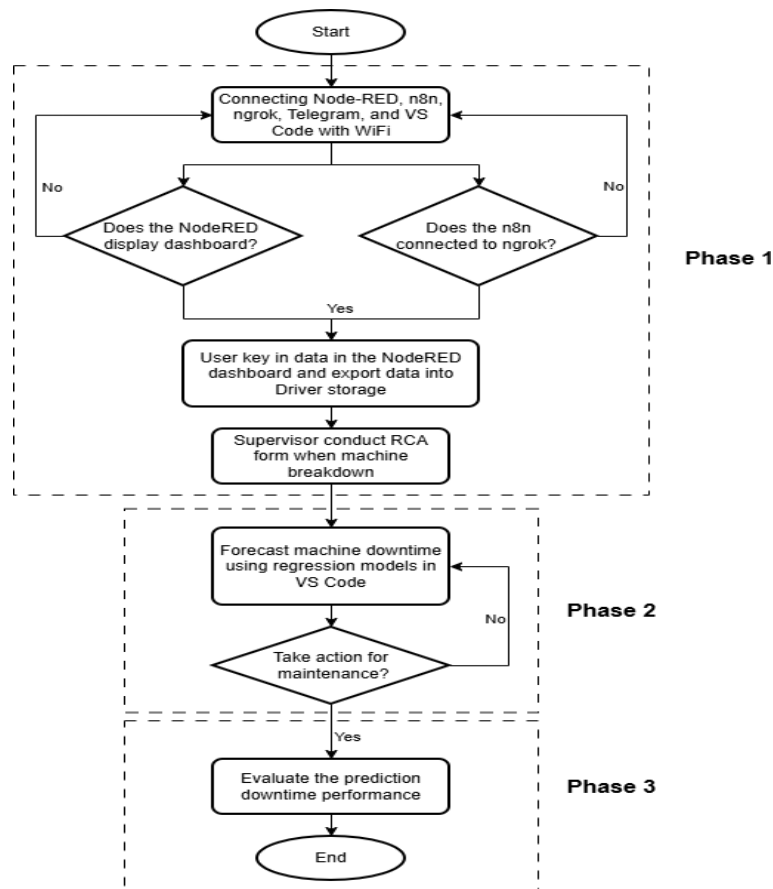


Fig. 1. Flowchart for the monitoring system using IoT.

In order to connect monitoring and response, n8n workflow, as shown in Fig. 10, and Telegram are used to implement automated workflows. Upon the occurrence of downtime records that surpass predefined thresholds or are considered critical, Node-RED sends an automation signal to n8n via a webhook mechanism that then directs formatted alert messages to maintenance staff via Telegram to be aware of them and take necessary follow-up measures.



PLANT MODIFICATION & MAINTENANCE		ROOT CAUSE ANALYSIS (RCA) FORM Standardized SW1H Maintenance Reporting Template		Rev.: 1 Reference No.: _____											
1.0 PROBLEM DEFINITION / Problem Statement (SW1H)		3.3 CAUSAL FACTORS / Faktor Penyebab (Fishbone Diagram)													
WHAT? Apakah? Description of failure or alarm WHEN? Bila? DATE DD/MM/YYYY TIME HH:MM - HH:MM WHERE? Di mana? Equipment / Line HOW? Bagaimana? Refer to Sequence of Events (Section 3.2) WHO REPORTED? Pelapor? Operator / Supervisor WHY? Mengapa? Initial reasoning before root-cause investigation		MACHINES MANPOWER MEASUREMENT Effect / Failure Mode METHODS MATERIALS ENVIRONMENT													
2.0 TEMPORARY ACTION / Tindakan Sementara		3.4 ROOT CAUSE(S) / Penyebab Masalah													
Immediate containment measures taken on site		If identified root cause from causal-factor analysis													
3.0 RCA - TEAM & SEQUENCE		4.0 CORRECTIVE ACTION(S) / Tindakan Perbaikan													
3.1 LEADER Ketua		<table border="1" style="width: 100%;"> <thead> <tr> <th>No.</th> <th>Corrective Action</th> <th>PIC</th> <th>Date</th> <th>Remark</th> </tr> </thead> <tbody> <tr> <td>1</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>				No.	Corrective Action	PIC	Date	Remark	1				
No.	Corrective Action	PIC	Date	Remark											
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3.1 MEMBERS Anggota		5.0 PREVENTIVE ACTION(S) / Tindakan Pencegahan													
3.2 SEQUENCE OF EVENTS / Urutan Kejadian		<table border="1" style="width: 100%;"> <thead> <tr> <th>No.</th> <th>Preventive Action</th> <th>PIC</th> <th>Date</th> <th>Remark</th> </tr> </thead> <tbody> <tr> <td>1</td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>				No.	Preventive Action	PIC	Date	Remark	1				
No.	Preventive Action	PIC	Date	Remark											
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1) _____ 2) _____ 3) _____		6.0 VALIDATION OF EFFECTIVENESS / Pengawasan Keberhasilan (3-6 months later)													
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Prepared	Checked	Verified	Approved												

Fig. 2. Root Cause Analysis (RCA) form.

In the case of significant or recurring downtime incidents, a semi-automated process of the Root Cause Analysis (RCA) is employed. Fig 2. illustrates the template of the RCA form which used by the maintenance personal to investigate the downtime. Telegram messages may give access to a standardized RCA form with references to the 5W1H format (What, When, Where, Why, Who, How). Finished RCA records are stored in organized files to be used in future references and continuous improvement meetings to enhance the connection between operational downtime events and the data-driven maintenance decisions.

C. Phase 2: Machine Learning-based Prediction.

The offline analysis of the historical downtime datasets, which are exported as the Node- RED monitoring layer, is performed with Python in Visual Studio Code. The raw event logs are initially preprocessed to enhance consistency and modelling reliability through dealing with missing values, eliminating redundant event occurrences, standardizing categorical labels (machine, equipment, failure type), and regularizing timestamps such that the duration of downtime and time between event occurrences can be calculated. The time of downtime is converted into minutes to match the operational limits that will be employed in future decision support. This is followed by feature engineering to generate meaningful inputs using event-based downtime records, such as the duration of downtime, frequency of events, cumulative operating time, and time since last failure. The numerical features are normalized, and the data is divided into training and testing groups in an 80:20 proportion in order to test the model generalization on the unseen cases of downtimes.

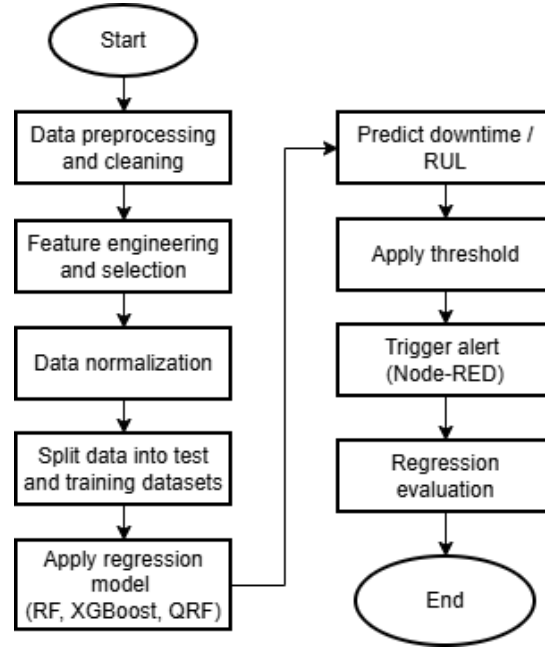


Fig. 3. Flowchart for machine learning-based downtime prediction using a regression model.

Remaining Useful Life (RUL) is not considered an actual predictor of failure-time in this work but as a decision-support indicator. RUL is initially calculated in cycles (operational events that do not precede the next significant downtimes) and transformed into a time-based estimate based on the average downtime-event time by looking at historical data:

$$RUL_{\text{minutes}} = RUL_{\text{cycles}} \times T \quad (1)$$

Where RUL_{minutes} is the estimated remaining time to failure (minutes), RUL_{cycles} is the number of operational cycles remaining, and T is the average downtime duration (minutes). For actionable interpretation, predicted RUL is mapped into health states using a warning threshold $\tau = 1440$ minutes (for 1 day): **Overdue** if $RUL_{\text{minutes}} \leq 0$, **Warning** if $0 < RUL_{\text{minutes}}$

$\leq \tau$, and **Healthy** if $RUL_{\text{minutes}} \geq \tau$. This threshold logic supports maintenance prioritization and enables alert triggering in the integrated workflow.

To examine the behavior of downtime, three machine learning models are applied, which are regression-based: Random Forest Regression (RF) as a strong baseline to use with noisy and non-linear industrial data, XGBoost Regression (XGB) as a boosted comparative model, and Quantile Random Forest (QRF) to obtain uncertainty-aware estimates. RF and XGB are mainly used to generate point predictions, but QRF is an extension of the ensemble technique used to predict conditional quantiles of RUL. The quantile q , QRF is computed as:

$$\hat{y}_q = \text{Quantile}(y | X, q) \quad (2)$$

where $\hat{y}_q$ is the predicted RUL at quantile q , X is the feature set, and common quantiles used include $q = 0.10, 0.50$, and 0.90 . The interval $[\hat{y}_{0.10}, \hat{y}_{0.90}]$ provides an uncertainty band that supports risk-based planning by indicating conservative (lower-quantile) and optimistic (upper-

quantile) scenarios.

Besides regression-based prediction, reliability behavior is also studied with Kaplan- Meier survival analysis to predict the likelihood of continuous operation without failure with time, which is helpful with the sparse and censored industrial downtime data. The Kaplan-Meier survival function is provided as:

$$S(t) = P(T > t) = \prod_{t_i \leq t} (1 - \frac{d_i}{n_i}) \quad (3)$$

where $S(t)$ is the survival probability beyond time t , d_i is the number of failures at time t_i , and n_i is the number of units at risk just before t_i . This probabilistic survival profile complements the RUL regression outputs by providing an empirical view of how failure risk accumulates over operating time.

D. Phase 3: Thresholds and Alert Workflow

RMSE, MAE, and R^2 as shown in the equation below, are used to test the model performance. Since the downtime datasets are low-density and disproportionate, low or negative R^2 values can be achieved, which is viewed as a constraint on point prediction in event- driven industrial data rather than a decision-support failure. The coverage of prediction intervals (e.g., Q10-Q90 coverage) is also used to evaluate QRF outputs to measure uncertainty. The computation of MTFB uses the historical data on downtime and is used in conjunction with RUL estimates to determine reliability and prioritization.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (4)$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad (5)$$

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (6)$$

where:

- y_i = actual downtime value
- $\hat{y}_i$ = prediction downtime value
- $\bar{y}$ = mean actual downtime value
- n = total number of observations

Lastly, the prediction outputs and calculated indicators (MTBF, RUL, and health status) are transmitted from Node-RED to n8n via a webhook. The n8n compares the health state and sends real-time Telegram notifications to operators/maintenance staff to provide an early warning and proactive response, and the loop of monitoring to action is semi-automated.

3. RESULTS AND DISCUSSION

In this section, the results of the created IoT-based downtime monitoring and prediction system are reported and discussed in terms of how the results can be used to provide early warning and prioritize the maintenance of the case-study filling line. The analysis includes (i) the Node-RED dashboard of downtime monitoring and data pipeline, (ii) regression and uncertainty-aware RUL forecasting, and (iii) Kaplan-Meier survival analysis and interpretation of reliability based on the MTBF.

A. IoT-based Monitoring Architecture

The Node-RED workflow, as shown in Fig. 4, and the dashboard, as shown in Fig. 5, were able to provide a standardized interface that allowed recording downtime and visualizing important indicators in near real time. The dashboard form allowed operators/supervisors to capture the following: month, machine/equipment, downtime duration (minutes), Person In Charge (PIC), and type of failure (major or frequent), which generates organized records that can be analyzed in the future. Export/import functions were used to handle stored records to facilitate offline modelling and data backup.

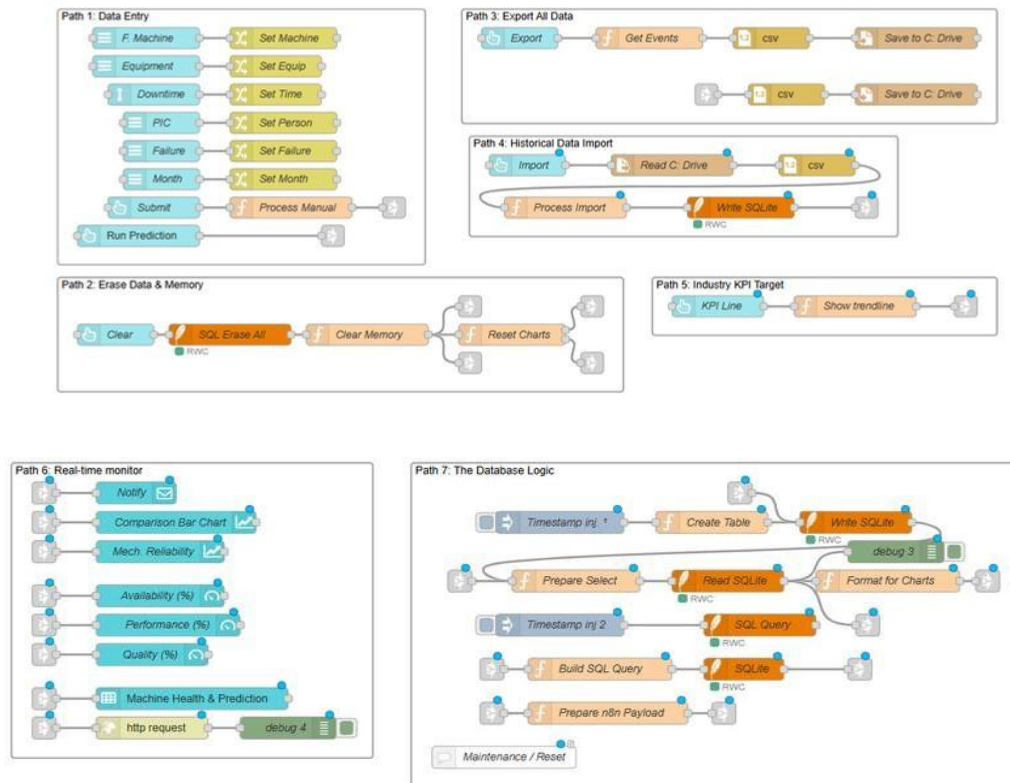


Fig. 4. Node-RED workflow used in IoT monitoring system.

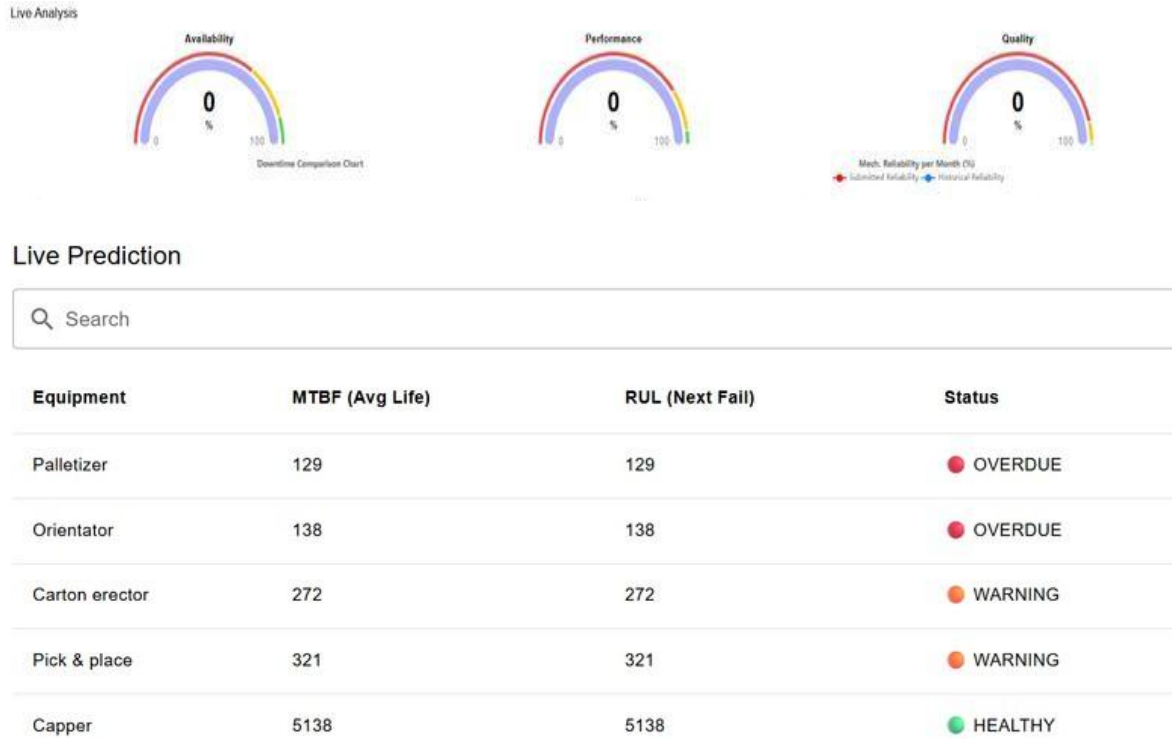


Fig. 5. Dashboard showing the live analysis and prediction; OEE, MTBF, RUL and machine status.

In addition to basic logging, the dashboard displayed downtime comparisons amongst equipment and showed OEE-related indicators (availability), as well as downtime behavior tied to performance monitoring. Equipment level decision-support was provided by a summary table that gave MTBF, estimated RUL, and a health state (Healthy, Warning, Overdue). The monitoring layer also showed end-to-end integration with an automated notification workflow through Telegram, in which the equipment status messages were delivered to enable timely maintenance response, as shown in Fig. 6.

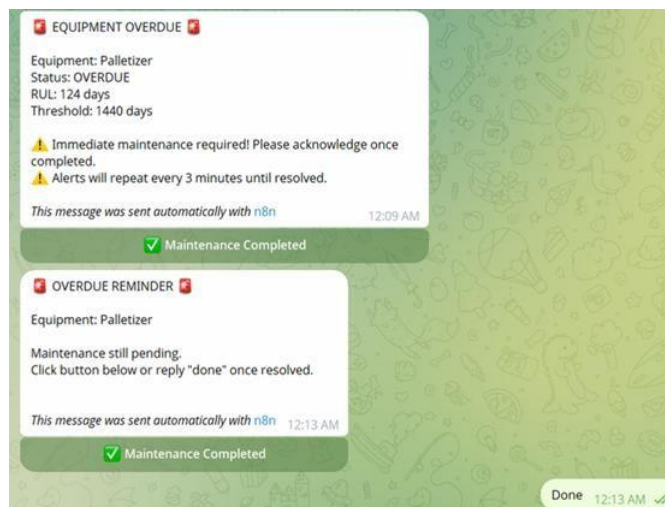


Fig. 6. Telegram message for the equipment status.

B. Kaplan-Meier and MTBF Findings

Kaplan-Meier survival analysis was used to estimate the probability of major downtime events with respect to the risk of failure.

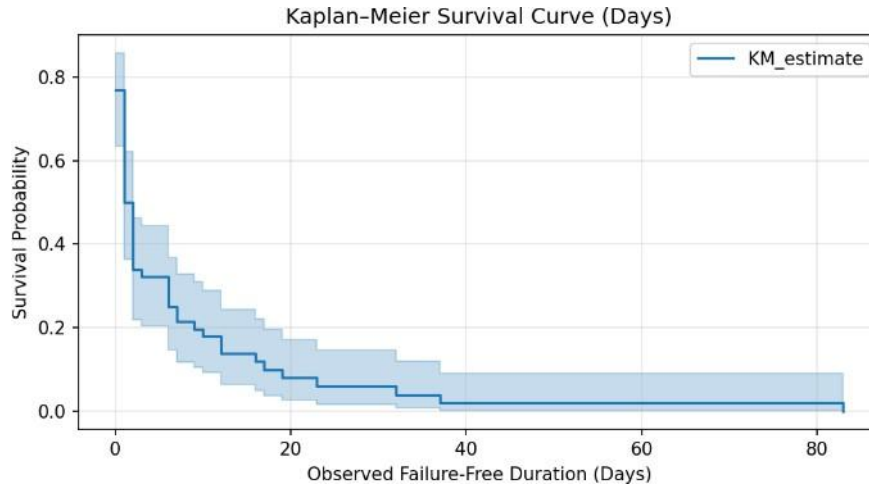


Fig. 7. Overall for 5 Equipment Downtime RUL Prediction using QRF.

Table. 2. Interpretation of Kaplan–Meier survival plot elements

Element	Descriptions
Observed Failure-free Duration (x-axis)	The time that has passed since the last significant failure. The further one goes to the right, the longer the time of the failure-free operation.
Survival Probability (y-axis)	The likelihood of a machine not having suffered a big failure yet (e.g., a 0.4 at 5 days indicates that 40% of the intervals are longer than 5 days)
KM estimate (blue line)	The Kaplan-Meier survival estimate shows that each downward revision occurs after observing major failures. A sharp decline indicates a high risk of failure, while less sharp areas suggest a relatively lower incremental risk.
Confidence band (blue shaded area)	The statistical uncertainty is represented by the confidence band. It is narrower in the origin, where there is high data, and broader in the long durations when intervals are infrequent and are more left-censored.

Fig. 7 shows that the survival curve is sharply decreasing at the beginning of the survival probability, which means that there are numerous big failures that happen even after a reset, and the failure-free period is very short. The curve then levels off and proceeds as a long, low-



probability tail to about 60-80 days, signifying that there are very long periods of failure-free operation, but these are relatively uncommon. The confidence band of the estimate is small in the early times, the intervals are numerous, and in the tail, where the data are few and the right censoring is more identified.

The mean time between major failures (MTBF) in such a time-based representation is around 6 days or about 6.07 cycles between major downtime failures in the event-based formulation that can be used to represent the major failures, which demonstrates that major failures happen very frequently, and that early warnings and prioritization are necessary instead of long-horizon deterministic predictions.

With this survival information and QRF prediction intervals, the system will give a risk-sensitive view of Remaining Useful Life (RUL): the survival curve is used to measure the risk of failure accumulating over the operating time, whereas the bands of the Q10-Q90 express uncertainty around RUL predictions. A combination of these enables the engineers to put in place a plan of conservative buffer margin, concentrate on high-risk early windows, and approach the long-horizon predictions with the right degree of caution rather than relying on one of the forecasted failure dates.

C. Discussion and Implications

In this project, it can be concluded that the system is a better semi-automated decision- support and early-warning platform rather than a precise failure-time predictor. Negative R² and relatively large cycle-level errors agree with the problems outlined in the report: event- based downtime logs are sparse, noisy, and unbalanced, which stimulates regressors to correct the most frequent outcomes and works poorly under the rare extreme cases.

Operationally, the most feasible results are (i) the standardization of all downtime records and availability of RCA records, (ii) uncertainty-beneficial RUL bands, which can be converted to conservative planning thresholds, and (iii) survival-based reliability profiles, which display the accumulation rate of failure risks. Such outputs may be incorporated into threshold-based conditions of health (Healthy/Warning/Overdue) and automated Telegram messages to enhance maintenance responsiveness and importance in the case-study filling line.

4. CONCLUSIONS

The paper has introduced a semi-automatic machine downtime monitoring and prediction system based on IoT applied to a representative filling line at an industrial lubricant blending plant. The proposed architecture will integrate a Node-RED dashboard to structured downtime logging and performance visualization, n8n-based workflow automation, and Telegram alerts to stay in touch with current operators and be complemented by offline analysis with Random Forest and XGBoost regression models, Quantile Random Forest (QRF) and Kaplan-Meier survival analysis to estimate Remaining Useful Life (RUL) and reliability.

The findings indicate that the platform is practical as a software-based decision-support solution: it transforms manual event-driven downtime logs into structured data, delivers real-time indicators, including, but not limited to, availability, MTBF, RUL, and health conditions, and sends subsequent notifications on timely maintenance actions. Although the accuracy of the prediction of points of the regression models is low because of the sparse and imbalanced



data of downtime (negative R2 values and errors on the order of several cycles), the uncertainty-aware QRF prediction bands and survival-based reliability profiles contribute significantly by detecting high-risk operating windows and quantifying confidence in forecasts.

In general, the system can be viewed as a risk-conscious maintenance system instead of a precise failure-time predictor and can assist in early warning and prioritization of the interventions on the case-study line, which aligns with the goals of Industry 4.0. Such future work can augment the input data with other sensor measurements (e.g., vibration, temperature), add the anomaly-detection methods to help extract the rare or newly appearing failure modes, and connect the predictive outputs and a Computerized Maintenance Management System (CMMS) to ensure that the risk levels and the RUL estimates can automatically generate and process maintenance work orders.

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Development of IoT-enabled Multimodal Myoelectric Sensing System for Hand Motion Analysis

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Abstract

Functional losses associated with hand impairments have led to the growing development of rehabilitative and assistive devices like hand exoskeletons. The main challenges are to develop the exoskeletons that work according to the user's motion intention, which can be done by utilizing the electromyogram signals generated by forearm muscles contributed from the movement and/or grasping abilities of the hand. Over the years, pattern recognition schemes for the electromyogram signals have been extensively studied and applied to the classification of hand gestures with decoding accuracies of above 90%. However, the applicability of this scheme requires extensive signal processing like filtering, data segmentation and features extraction before can be fully utilized for the classifications scheme. In this research, the development of integrated measurement system that consists of myoelectric detection circuit, hand dynamometer and wrist angle detection circuit with IoT technology is presented. The multimodal myoelectric sensor comprises of an electronic conditioning circuit designed to gauge linear envelope of the EMG signals obtained from forearm muscles during hand grasping across various wrist angles. These signals are subsequently integrated with mechanical sensor modalities, including a self-assembled hand dynamometer and a flex sensor for measuring wrist angles. The purpose is to study and analyze the relationships and interactions between EMG signals, hand grasping forces, and wrist angles, potentially providing insights into how these factors are connected and how they impact each other. The circuit is designed using simulation software and is constructed before analyzed and validated through data collection. It is then linked with IoT technology to enable the storage of data in the cloud.

Keywords: *Myoelectric Detection Circuit, Surface EMG acquisition system, Multimodal Myoelectric Sensor Fusion*

1. INTRODUCTION

The design of a human hand is indeed a miraculous creation. It comprises a palm with five fingers and is connected to the forearm by a wrist joint. Its movement and sleight are unique and cannot be found in any other creature on the planet, making the hand a valuable body part for the human. A deficit in hand function due to hand impairment will significantly affect and degrade one's life, not only financially but also in living a quality life. Hand impairment is referred to any loss or deviation in hand function, which includes amputation, sensory and motion impairment [1] that can occur due to several factors such as birth defect, ageing factors, disease [2], injury [3-5], and stroke [6-8]. According to the latest Institute for Health Metrics and Evaluation data published in 2020, stroke is the top 3 leading causes of death in Malaysia from 2009 to 2019 [9].



People who survived stroke need to undergo rehabilitation to regain their speech, cognitive, motor, or sensory skills. Rehabilitation programs for stroke often involve the training of strength, mobility, and range-of-motion exercises which are monitored by utilizing the electromyography (EMG) signals. The EMG signals will record the electrical potential generated during muscle contraction. The EMG signals become continuously denser and the maximal peaks in the signal will have a higher amplitude when more force is used [10]. Thus, the properties of EMG signals are useful for doctors to keep track and evaluate the process in stroke rehabilitation of patients to ensure a fast and efficient recovery.

With the advancement of technologies and breakthroughs in healthcare today, the number of people who survived stroke had risen drastically over the year. This scenario had led to the increase in demand for rehabilitative and assistive devices like hand exoskeletons. In developing competent devices, seamless integration with the user by considering intelligent control as part of the human machine interface; specifically, the user motion intention is a primary concern. Advanced hands-free human machine interface with intention-driven control approach is favorable when compared to traditional user interfaces (i.e., joysticks, keyboards, GUI etc.) because it can control the exoskeleton hand naturally in predictable way, making it more reliable and efficient in communicating with the user and in providing assistance. It is important to improve the quality of support for basic ADL to avoid dissatisfaction among the users that may lead to the discontinuation of the device shortly after use. The realization of user motion intention can be achieved by employing mechanical sensors or biomechanical sensing methods like EMG signals.

Huo et al. [11] proposed intentional reaching direction (IRD) method to quantitatively describe the user motion intention for a 3 DOF power-assist upper-limb exoskeleton. The device was embedded with multiple force sensing resistors with two modeling modes: static force model for the relaxed state and hybrid model for motion state. The motion intention of the user was estimated online using Kalman Filter and a mode transition detector with admittance control strategy. The method was tested on healthy subjects and offered satisfactory results. However, according to Kiguchi et al. [12] to activate the exoskeleton robot according to the user motion intention, a force sensor-based control can be employed for user without limb problem while for those who are not strong enough to move their limb, EMG-based control with the EMG signals from certain muscles can be adopted to activate the system accordingly.

In controlling the movements of the assistive device, information relating hand grip force and wrist joint angles to forearm muscle activity is useful to be used as part of the control algorithm. There are several research that have been conducted to investigate these relationships. A.J.H. Mohideen et al. [13] has studied the relationship between muscular effort of the flexor muscles in the forearm and hand grip strength. EMG signals were measured using constructed electronic circuit from the subject while applying minimum, intermediate, and maximum hand grips on a hand gripper. The circuit is comprised of instrument amplifier, driven right leg circuit, high-pass filter, low-pass filter, bypass capacitor and galvanic isolator. The results showed that EMG frequency from the FDS is increased with the raised of hand grip strength. This information relating EMG from flexor muscles to hand grip strength is useful to be used in hand rehabilitation devices to estimate suitable resistance to be provided to patients during rehabilitation routines.

M. A. Ahamed et al. [14] has developed a low-cost wireless bio-signal acquisition system for ECG, EMG and EOG signals. The circuit consists of an instrument amplifier, high-pass filter, low-pass filter, and voltage regulator. For the analysis of an EMG signal, MATLAB R2014a is used. In this model, Notch Filter 50Hz is not implemented as the signal is transmitted wirelessly, noise interference is reduced, and a very small amount of power line interference exists.

Similarly, also has designed and developed an EMG signal acquisition system and investigated the inter-relation between EMG and hand grip force [15-18].

In this project, the development of an integrated measurement system that encompasses a myoelectric detection circuit, a hand dynamometer, and a wrist angle detection circuit, all augmented with IoT technology is presented. The core objective of this project is to investigate the complex interactions and relationships between the EMG signals (electromyographic signals reflecting muscle activity), hand grasping forces (the forces exerted during hand gripping actions), and wrist angles (the angles at which the wrist joint is positioned). This exploration aims to reveal the intricate connections between these variables and how they mutually influence each other.

This research takes a meticulous approach to examine the interactions between these variables. By conducting thorough analyses, the study seeks to unveil the latent associations and underlying dynamics that govern their behaviors. It will enable the development of advanced control strategies and applications, especially in the domain of exoskeleton hands and related technologies.

2. MATERIALS AND METHODS

The development of myoelectric muscle sensor with IoT technology is comprised of four main systems integrated together: a handgrip force measurement system, a wrist angle measurement system, a myoelectric detection circuit and a modular IoT system. The block diagram for the overall system is illustrated in Fig. 1. It serves as a visual representation of the intricate interactions and dependencies among these subsystems. Through the harmonious integration of these components, the myoelectric muscle sensor system with IoT technology holds the promise of providing comprehensive insights into muscle dynamics, handgrip forces, and wrist angles, thus potentially revolutionizing various applications in the domains of healthcare, rehabilitation and human-machine interfaces.

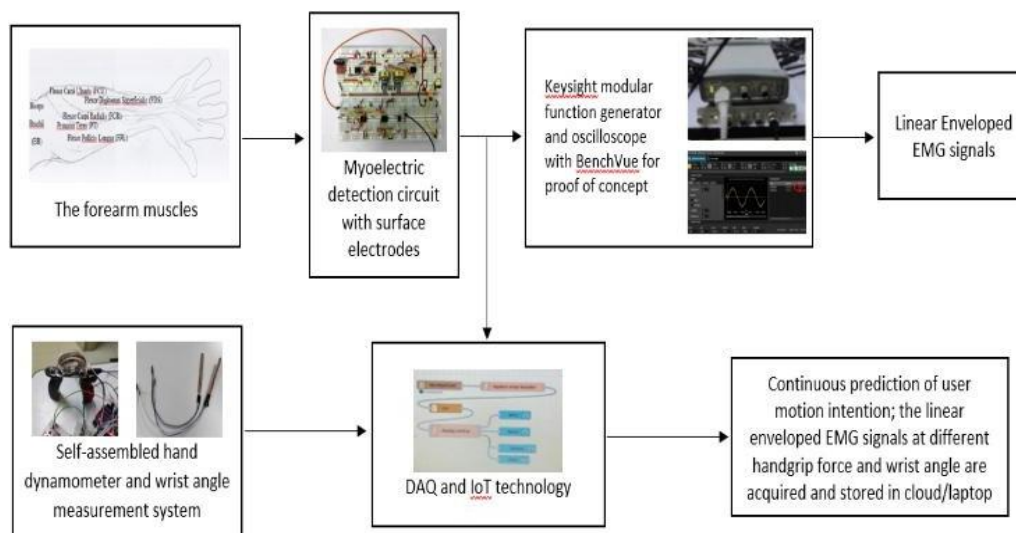


Fig. 1. The block diagram for overall system developed to predict the continuous user motion intentions.

A. Handgrip Force Measurement

In this project, the handgrip force is measured using self-assembly hand dynamometer interface with the Arduino. It comprises of a hand exerciser, a 2.2' flex sensor, and some wires. The 2.2' flex sensor is chosen as it can fit nicely around the circumference of the metal spring on the hand exerciser. The terminal of the sensor is soldered with wire, covered by plastic, and hot glued to strengthen and protect it from tears. Then, the flex sensor is mounted along the circumference of the hand exerciser using the double sided and secured with cable tight. The hand dynamometer is tested by depress and release the hand exerciser repeatedly. The resistance values (ranged between 40 k Ω and 67 k Ω) are measured using multi-meter and interfaced with the Arduino to map the readings to different percentage of Maximum Voluntary Contraction (% of MVC). It ranges between 0% to 100% MVC. MVC is one of the acceptable normalization methods to provides a relative measure of muscle activation and compares it to the reference value (which in this case is in the form of handgrip strength).

B. Wrist Angle Measurement

The wrist angle is measured using a resistive flex sensor that is applied to the wrist segment to measure the static and dynamic posture of the wrist. It demonstrated acceptable readings as the bending angle of the sensor (for the wrist flexion and wrist extension as illustrated in Fig. 2) is within the radius of curvature that is smaller than the length of the sensor. The resistance values (ranges between 121 k Ω and 140 k Ω) are measured using multi-meter and interfaced with the Arduino to convert the readings to angle measurement (ranges between 0 to 90 degrees representing the wrist flexion). The collected handgrip force and wrist angle data are saved in the Excel sheet and combined with other measurements for analysis.



Fig. 2. The wrist range of motion studied in this project (45-degree flexion and 0 degree at neutral).

C. Myoelectric Detection Circuit

The myoelectric detection circuit as illustrated in Fig. 3, consists of an instrument amplifier, a driven right leg (DRL), a high pass filter, a low pass filter, two-way rectifier, a smoother, an inverting amplifier and an opto-coupler. The circuit measures the selected muscle excitation that has an amplitude of 0-10 mV, amplifies the signal to the transistor-transistor logic (TTL) range of 0-5 V so that the EMG signal can interface with the computer through data acquisition device or analog to digital converter.

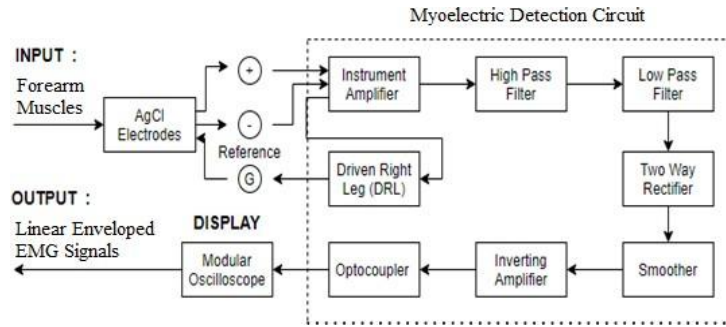


Fig. 3. Block diagram for the myoelectric detection circuit.

The overall schematics diagram for the myoelectric detection circuit is illustrated in Fig.

4. Each of these circuits are simulated in Multisim to obtain the desired simulation results before being physically constructed.

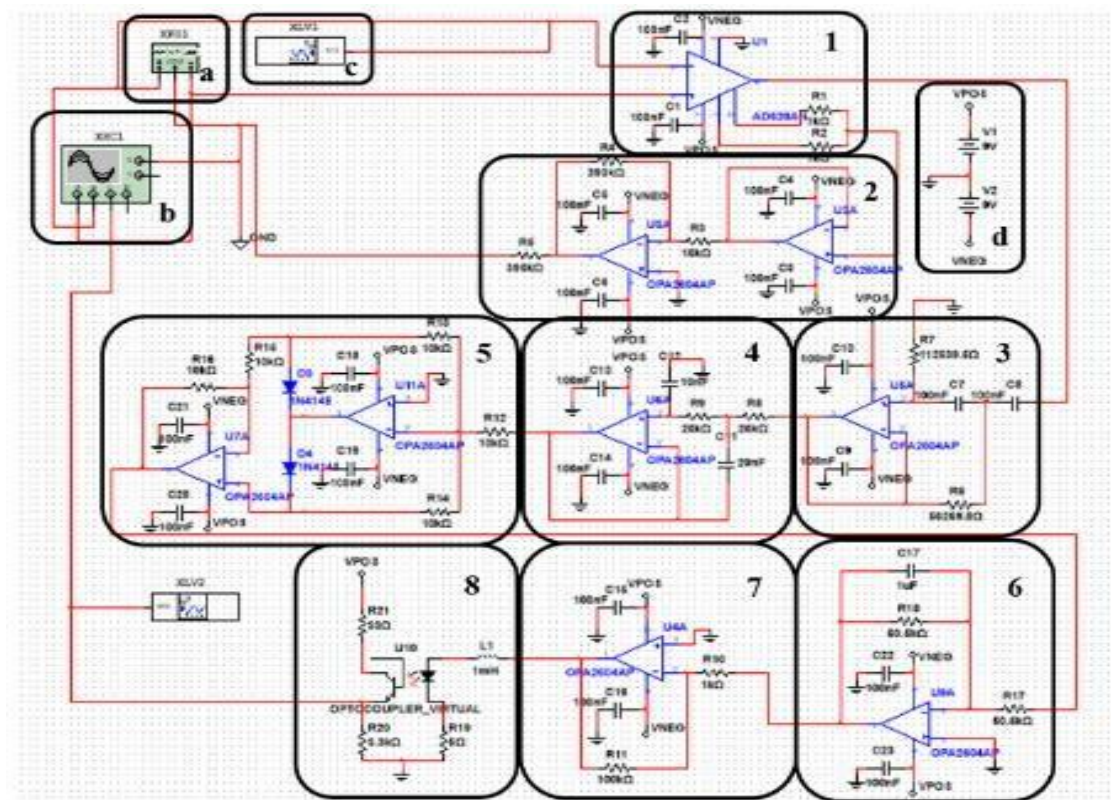


Fig. 4. Schematic diagram of the designed myoelectric detection circuit for prediction of continuous user motion intentions.

Legend:

- | | | |
|----------------------------|-------------------------|------------------------|
| a: Function generator | 1: Instrument amplifier | 5: Two-way rectifier |
| b: 4 channels oscilloscope | 2: Driven Right Leg | 6: Smoother |
| c: Signal analyser | 3: High pass filter | 7: Inverting amplifier |
| d: +/- 9V power supply | 4: Low pass filter | 8: Optocoupler |

In this project, the instrumentation amplifier is used to amplify the raw EMG signal data which is in the order of millivolts to a range of volts. AD620 IC is chosen as it has low input offset voltage, low input bias current, low input noise, high Common Mode Rejection Ratio (CMRR), and low power consumption. It also has a broad application in medical instrumentation. Based on the AD620 characteristics, higher gain provides higher CMRR that offers a better input signal as the noise is reduced. The gain of the instrumentation amplifier was set to 25.7 by placing resistors $R_1 = 1k\Omega$ and $R_2 = 1k\Omega$ between pin 1 and pin 8. The gain can be calculated as follows:

$$Gain = 1 + \frac{49.4k\Omega}{R_G} = 1 + \frac{49.4k\Omega}{R_1 + R_2} = 1 + \frac{49.4k\Omega}{1k\Omega + 1k\Omega} = 25.7 \quad (5)$$

The AD620 amplifier is designed with adaptation of the Driven Right Leg (DRL) circuit to increase the signal to noise ratio of the preamplifier. By adapting this DRL circuit, the common mode signal is fed back to a 'bony' human part such as the elbow which serves as the reference electrode [13].

After the EMG signal is amplified, the signal is filtered through high-pass and low-pass filters that are cascaded together to the amplifier circuit. The high pass filter is used to cut off low frequency noise that is below 20Hz at -3dB due to movement of electrode that produce motion artifact and DC offset. A 2nd order Sallen-Key filter topology with Butterworth characteristics is used as it provides flat response in the pass band [13]. Meanwhile, the low pass filter is used to cut off high frequency noise that is above 500 Hz at -3dB due to surrounding electronic equipment or radio waves. A 2nd order Sallen-Key low pass filter is used and is also referred to as the anti-aliasing filter at this point. If the output of this EMG circuit is attached to an ADC, the anti-aliasing filter plays an important role in digitizing the signals.

Next, the signals are rectified using a two-way rectifier and produced the linear enveloped EMG signals. It is essential to have a linear envelope signal for further processing in an MCU or DSP system. There are several types of rectification that can be done however in this project, a two-way rectifier is used due to the muscle movement that has generated both the negative and positive value of the EMG signal. Some information of the signal might be removed if half wave rectifier is used [19].

Subsequently, the rectified signals' fluctuations are attenuated through the utilization of a smoothing circuit. The EMG signal exhibits oscillations within a spectrum encompassing both positive and negative values during muscular activity. The signal smoothening procedure entails the application of an active low-pass filter, which selectively permits low-frequency components while impeding high-frequency components [19]. Through the utilization of this low-pass filter, the fluctuating EMG signal is effectively rendered smoother. The determination of the cutoff frequency is derived from the following equations:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times (50.5 \times 10^3) \times (1 \times 10^{-6})} = 3.15 \text{ Hz} \quad (6)$$

After that, the EMG signals is fed to the inverting amplifier that is used to allow the EMG circuit

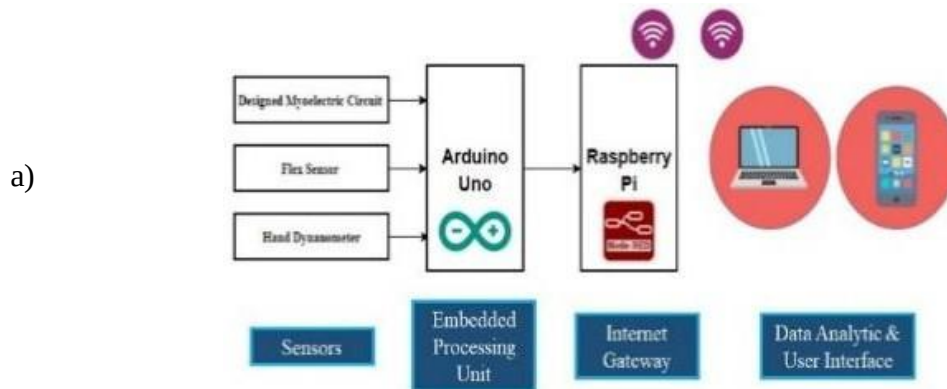
to fit different individuals with different hand grip strength by changing its resistor value, by providing variable gain instead of fixed gain. Only the preamplifier has a gain of 26 in the previous section of this entire circuit, whereas the high pass and low pass filters also have unity gain. If the output is intended to send a microcontroller or data acquisition (DAQ) system to the ADC for further processing [18], further amplification of the EMG signal is needed. The inverting amplifier circuit has a gain of $R_{11}/R_{10} = 100$. Therefore, the total gain of this entire EMG circuit is $26 \times 100 = 2600$.

Finally, at the last stages, the opto-coupler is used to ensure the bio-safety issues of the object by isolating the signal conditioning circuit from the output circuit. A basic optical isolation barrier consists of two basic elements which are a light source and a photosensitive detector. The most significant aspect of an opto-coupler is that the light source and the detector have a mechanically insulating distance. Therefore, there will be no current passes through this gap, only light representing the data [20]. Thus, the circuit's two sides are galvanically isolated from each other. When placed on medical devices, the optical isolating barrier counts with an isolation up to 4–6 kV, satisfying medical standards [21] and saving more space in the PCB than other options like transformer-based isolators [20].

D. IoT Technology

An IoT architecture for the designed myoelectric circuit is composed of several layers; sensor layer, embedded processing layer, internet gateway layer and data analytic and user interface layer as illustrated in Fig. 5. The sensor layer consists of the designed myoelectric circuit, hand-dynamometer, and wrist angle measurement unit. The data obtained from these sensors are then processed in the next layer using the Arduino Uno that acts as a microcontroller. The code is written on Arduino IDE and is then flashed into the Arduino Uno for it to read the sensor values. Next, Raspberry-Pi is used as the internet gateway and acts as a remote device. Wireless connectivity for Raspberry Pi is properly set up by enabling SSH (Secure Shell).

Node-RED software is installed in the Raspberry-Pi to design the dashboard, that displays the values recorded from the sensors. Finally, the internet gateway passed on the information to application management devices such as the laptop and smartphones for data analytic and user interface purposes.



b)



Fig. 5. The IoT architecture; a) four layers of IoT architecture, b) dashboard created using Node-Red.

3. RESULTS AND DISCUSSION

The simulation results of the designed myoelectric detection circuit show satisfactory results. A sinewave with frequency of 100 Hz and amplitude of 50 mVp is generated by the function generator and is used as the input signal for the simulation. After completed simulating the circuit in Multisim and proof the concept of myoelectric detection circuit. The physical circuit is constructed. The circuit is analyzed and validated through data collection which focuses on the establishment of the relationship between selected forearm EMG signal, various handgrip force and wrist positions. Detailed information of the experimental set-up and procedure is discussed in the following sub-section.

A. Data Collection and Signal Analysis

The data collection procedure starts with the identification of relevant forearm muscles that are responsible for various hand movements. Here, the anatomy of human hand is extensively studied to select the prominent muscles where the muscles are identified and the procedure to locate the exact position of the muscles are recorded for inclusion in the experimental procedure documentations. After completing the muscle selections, the experimental set-up is done before the experimental procedure for data collection is carried out. The aim of the data collection is to establish the relationship between forearm EMG signal, various handgrip force and wrist positions.

In collecting the data, 2 male subjects, aged below 30 years old with normally limbed without any neuro-muscular problems were selected. The data is collected from the Flexor Digitorum Superficialis (FDS) muscle based on its excellent criteria that has the highest EMG average power compared to the other flexor muscles [13]. The muscle is located at the anterior forearm and is responsible for flexes middle and proximal phalanges at PIP and MCP joints of medial 4 digits as well as flexes and abducts of the wrist. After identifying the prominent muscle, skin preparation is carried-out on the dominant hand to place the electrodes patches approximately at the belly of the muscle. The experimental set-up is illustrated in Fig. 6.

The experiment procedure involves four classes of movements; hand rest and hand grasping at two different wrist positions which are 45-degree flexion and at neutral.

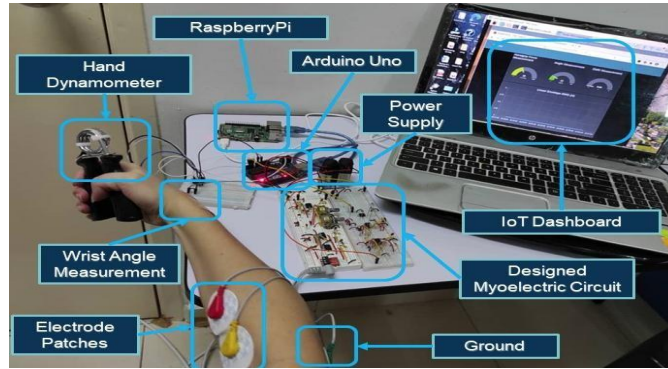


Fig. 6. The experimental set-up for data-collection. All the three sensors are connected to the embedded processing unit (the Arduino Uno) and the sensor readings are displayed in the IoT dashboard.

The subject is instructed to depress the hand exerciser for ten seconds using different hand grip strengths (minimum and maximum MVC) at neutral (0° of wrist angle). Five seconds rest sessions are incorporated after each grasping. The raw EMG signals extracted are recorded in the IoT dashboard and stored in excel format in clouds. The experiment is repeated for different wrist positions (at 45° flexion). The results of the experiments are illustrated in Fig. 7.

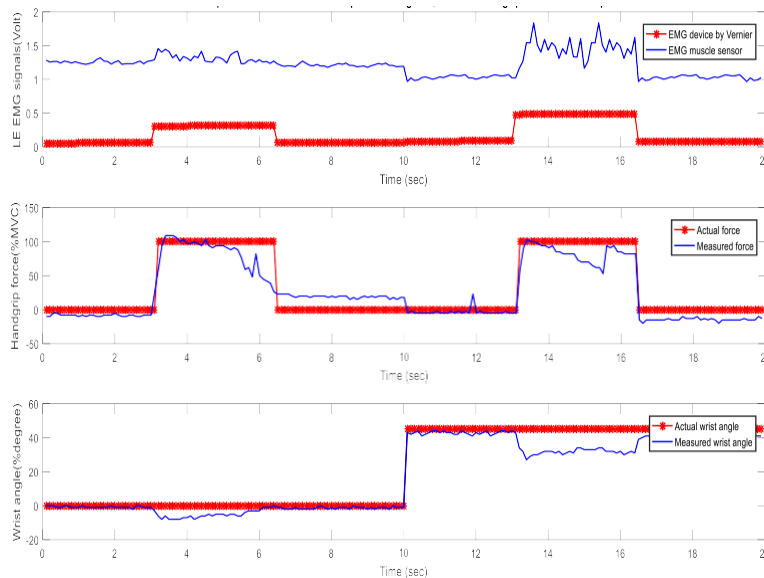


Fig. 7. The experimental results collected using the muscle sensor, self-assembled hand dynamometer and reflective flex sensor that is used for wrist angle measurement. The graph shows the relationship between the linear enveloped EMG signals generated from FDS muscle, with various handgrip force (minimum and maximum MVC) and wrist positions (at neutral and 45° flexion).

The Mean Absolute Error (MAE) are computed based on the experimental results collected to analyze the performance of overall system as tabulate in Table 1. The handgrip force and wrist angle measurements showed higher errors as compared to the linear enveloped EMG signals. These are due to the nonlinear response and lower sensitivity of the flex sensor in measuring

the bending angle accurately. It can be clearly seen from Fig. 7 that the force and wrist angle measurements are difficult to sustain and maintain at specific values.

Table. 1. Mean absolute error computed for each measurement unit

Mean Absolute Error (MAE)	Linear Enveloped EMG signals	Handgrip Force Measurement	Wrist Angle Measurement
Minimum Handgrip	1.05	12.22	2.14
Maximum Handgrip	1.07	12.52	8.56
Wrist Neutral	1.12	16.14	2.44
Wrist Flexion	0.95	12.51	6.51

Overall, the experimental results show limitation in the variation of data collected. Therefore, more comprehensive study involving a combination of more muscles, handgrip forces and wrist positions are required to determine and analyze the performance of the developed system. Multi-channel myoelectric detection circuits are recommended and can be achieved by duplicating the proposed circuit.

4. CONCLUSIONS

This paper presents the development of Myoelectric detection circuit with IoT technology for continuous prediction of user motion intention. The overall system integration shows satisfactory results and can be further improved with proper analysis and study to investigate the correlation of the data amongst other forearm muscles like extensor muscles.

In conclusion, this paper marks a significant milestone in the realm of human-machine interaction by showcasing the creation of a myoelectric detection circuit empowered by IoT technology with the potential of integrating advanced sensor technologies with cutting-edge data communication frameworks.

The successful integration of the myoelectric detection circuit with IoT technology underscores the feasibility of harnessing muscle-generated electrical signals to infer user intentions. This innovation opens a gateway to a wide array of applications, ranging from intuitive control mechanisms for exoskeletons to enhanced virtual reality experiences that respond to users' subtle muscle movements.

The overall system integration shows satisfactory results and can be further improved with proper analysis and study to investigate the correlation of the data amongst other forearm muscles like extensor muscles. Understanding the broader context of muscle interactions within the forearm could lead to a more comprehensive and accurate prediction of user intentions.

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The Use of Nano-Fertilizers in Improving Yield and Quality in Vegetables

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Abstract

Sustainable management of environmental stressors and population growth pressures is a cornerstone of global food security. Obstacles such as resource scarcity, climate change, and a projected population of up to 10 billion by 2050 have led to increased global food demand and the widespread use of synthetic chemical fertilizers. However, increased use of synthetic fertilizers leads to long-term nutrient crop failures, extremely high temperatures, and ecologically damaging consequences. Nanofertilizers, with their smaller particles and higher nutrient content, are emerging as a promising alternative. These synthetic fertilizers offer a sustainable solution to global food security problems by significantly increasing crop yield, improving fertilizer use areas, and facilitating sustainable agriculture. In contrast to the low nutrient use activities and bursting risks of traditional fertilizers, vegetable crops with short growth cycles and high nutrient yields benefit from nanofertilizer technologies. Nanofertilizers stand out as an advanced solution for increasing the content and nutrient content of vegetables. However, the impact of nanofertilizers on vegetable yield and quality depends on various factors such as nanoparticle type, capacity, crop variety, and applied management practices. Field studies have demonstrated that nano-fertilizer applications significantly improve key yield units in vegetables, such as fruit weight, stem diameter, and total biomass, increasing yield by 20% to 40% and allowing vegetables to reach market 5 to 7 days earlier. In addition to yield increase, this technology also enhances internal quality variations in vegetables, such as vitamin C, carotenoid, and total sugar content, increasing fruit firmness and extending shelf life. Consequently, the integration of nanotechnology into vegetable farming stands out as a precise and intelligent management solution for addressing climate change and resource scarcity, and ensuring global food security.

Keywords: Nano-Fertilizers, Yield, Quality, Vegetables

1. INTRODUCTION

Today, the world faces a serious sustainable food security problem, necessitating an increase in global agricultural production by approximately 70% by 2050 due to the impact of unprecedented population growth [1, 2]. In this context, the agricultural sector continues to be one of the most strategic areas of the global economy, meeting humanity's basic food and natural resource needs [3,4]. Vegetable products, in particular, are critically important for both human nutrition and economic sustainability due to their rich bioactive components [5,6].



However, vegetable cultivation stands out as a production area that requires intensive input agricultural practices due to its short production cycle and high nutrient requirements [6]. In modern agricultural systems, synthetic chemical fertilizers are largely used to meet this high nutrient requirement and increase yield [7,8]. However, it is reported that nutrient use efficiency (NUE) is quite low in traditional fertilizer applications and approximately 50–80% of the applied nutrients are lost to the environment without being used by the plant [6,9]. In particular, a significant portion of nitrogen, phosphorus and potassium is lost through processes such as seepage, surface runoff and evaporation, and cannot effectively reach the plant root zone [6,10].

Long-term and unbalanced fertilizer use accelerates soil degradation by causing negative consequences such as disruption of soil mineral balance, increased soil acidity, and decreased beneficial microbial diversity [11,12,13]. In addition, the transport of excess nutrients to groundwater and surface water leads to serious eutrophication problems in aquatic ecosystems and widespread environmental pollution [14, 15]. Besides environmental impacts, excessive use of nitrogen fertilizers, in particular, causes high levels of nitrate accumulation in the edible parts of vegetables [16, 17]. High nitrate levels ingested through the diet directly threaten human health by posing serious health risks such as methemoglobinemia in infants and potential carcinogenic effects in adults [17, 18].

In this context, considering the increasing environmental and health-based risks associated with low nutrient use efficiency necessitates the development of more sustainable, environmentally friendly and precision feeding strategies in agricultural production [7, 8].

Nanotechnology offers significant potential for precision and sustainable agricultural systems, particularly with its innovative applications that can replace traditional chemical fertilizers. Nanofertilizers, developed within the scope of this technology, are among the new generation of plant nutrition products that are formulated at the nanoscale and are defined as "smart fertilizers" [19, 20, 21]. Nanofertilizers consist of nanostructured formulations that can transfer their active components to the soil with a controlled and slow release mechanism; in this way, they contribute to the prevention of environmental problems such as eutrophication and water and air pollution by reducing nutrient losses.

Due to their high surface area/volume ratio, nanofertilizers exhibit higher efficiency and bioavailability compared to conventional fertilizers [22, 23]. The large surface area of nanoparticles allows for the controlled retention and gradual release of nutrients, enabling timely access to the nutrients needed by the plant. In addition, the smaller size of nanofertilizer particles compared to root and leaf pores allows them to penetrate plant tissues more easily, increasing nutrient utilization efficiency and reducing the amount of fertilizer required [21]. Furthermore, the small size and high surface activities of nanomaterials contribute to the support of metabolic activities and the improvement of solubility properties.

From a sustainable agriculture perspective, the use of nanotechnology in fertilizer production stands out as an important approach that can support environmental sustainability in the context of climate change while also contributing to increasing agricultural production to meet the food requirements of the growing world population [24, 25]. In vegetable cultivation, the application of nanofertilizers is becoming increasingly widespread due to their potential to increase yield and quality. In this study, current studies in the literature were examined to evaluate the effects of nanofertilizers on yield and quality in vegetables, and the findings were presented with a holistic approach.



2. THE EFFECTS OF NANO-FERTILIZER APPLICATIONS ON PLANT GROWTH IN VEGETABLES

The plant growth-improving effects of nanofertilizers on vegetable species are mainly explained by the fact that these materials can penetrate the plant more effectively than conventional fertilizers due to their high surface area/volume ratio and nanoscale dimensions [8, 25, 27]. This shows that the interaction of nanofertilizers with the plant is not limited only to nutrient supply, but also affects the biophysical and biochemical processes of plant nutrient uptake mechanisms.

Nanofertilizers can be transported into the plant vascular system via apoplastic and symplastic pathways through stomata and cuticle channels on the leaf surface and micropores in the root epidermis [28, 29, 30]. These transport mechanisms facilitate the entry of nanoscale particles into plant tissues, enabling faster and more efficient delivery of nutrients.

At the physiological level, nanofertilizers are reported to accelerate water uptake through the seed coat and promote germination and early plant development by regulating the activities of important enzymes such as α -amylase and nitrate reductase [31, 32, 33, 34]. In addition, the controlled release mechanism of nutrients within polymer matrices or nano-chelate structures ensures that the nutrient supply is matched to the metabolic requirements of the plant, contributing to more balanced and continuous vegetative development [30, 35, 36].

As a result of these mechanisms, significant improvements have been observed in growth parameters such as plant height, stem diameter, leaf area, and fresh/dry weight. In studies conducted, it was determined that the application of nano SiO₂ with a size of 12 nm stimulated germination in tomato plants [37], and that iron nanoparticles applied at a dose of 100 mg/kg increased plant height and leaf number [38]. Similarly, it was reported that the combination of 4 ml/L nano fertilizer and 20 g/L organic fertilizer maximized plant height and leaf number in chard plants [39].

In eggplant cultivation, it has been observed that applying 1.5 g/L of nano potassium to the soil increases dry biomass accumulation by 77% [40]. In cucumber plants, it has been reported that foliar application of liquid nano NPK formulations (6–9 mL/plant) improves plant weight and leaf area [41]. In addition, studies on onion [42], okra [43] and radish [44] show that nano fertilizer applications have positive effects on plant biometric characteristics and net assimilation rates. In studies on peas, it has been stated that chitosan-based nano fertilizers support plant development by increasing the cell division rate [45].

However, there are also studies in the literature showing that nanofertilizers can have negative effects on plant growth. This is generally explained by dose-dependent phytotoxicity. For example, it has been reported that ZnO nanoparticles promote growth in cucumber plants at low concentrations, but suppress growth at high doses such as 1000 mg/kg [10]. High nanoparticle density causes physical accumulation and blockages at root tips, limiting the uptake of water and macro and micronutrients, and consequently reducing the hydraulic conductivity of the roots [6, 46, 47]. These physical restrictions directly affect the plant's water and nutrient transport capacity, leading to a disruption of physiological balance. In parallel, it has been reported that excessive nanoparticle applications increase the production of reactive oxygen species (ROS) within the cell, triggering oxidative stress. Increased oxidative stress has been reported to accelerate the lipid peroxidation process and cause degradation of chlorophyll pigments, resulting in a significant decrease in photosynthetic activity [6, 48, 49]. It has been



reported that the combined effect of these physiological and biochemical processes results in negative agronomic consequences in plants such as growth retardation, developmental inhibition, height reduction and dry matter loss [10, 50, 51].

3. THE EFFECTS OF NANO-FERTILIZER APPLICATIONS ON VEGETABLE YIELDS

The prediction that the rapidly increasing world population will reach approximately 10 billion by 2050 necessitates an increase in agricultural production of approximately 70% to ensure the sustainability of global food security [30, 52, 53]. In this context, nanofertilizers are among the technologies of strategic importance within the scope of the “Second Green Revolution”, contributing to closing yield gaps by optimizing the bioavailability of plant nutrients [6, 54].

The high surface area and reactivity of nanoscale materials allow nutrient use efficiency (NUE), reported at 30–50% in conventional fertilizers, to be increased to 80–90% under appropriate application conditions [30, 53]. This increase enables plants to reach their genetic yield potential more effectively. Mechanistically, nanofertilizers deliver nutrients in polymer matrices or nanocapsules using a controlled and slow release principle, thus aligning the nutrient supply with the metabolic requirements of the plant at different growth stages [53, 55]. This process supports physiological processes directly related to yield increase.

In parallel, it has been reported that nanotransmission systems create up-regulation effects by regulating photosynthetic capacity and enzymatic activities, which increases the net assimilation rate and accelerates the transfer of resources from vegetative development to generative development (fruit and seed formation) [56, 57].

When the effects of these mechanisms in field conditions are examined, it has been reported that nano fertilizer applications can increase the total yield and marketable product quantity in vegetable species by 20–40% [58]. Specifically, it has been determined that an economic yield of 23.59 tons per hectare was obtained and the harvest index reached 59.24% with the use of nano NPK fertilizers in potato cultivation [59].

Similarly, it has been determined that selenium nanoparticles applied at a dose of 10 mg/L to tomato plants increased fruit yield by 21% [60], and nanosilver applications positively affected yield components by increasing the number of flowers and stem diameter [61]. It has been reported that liquid nano NPK formulations applied at doses of 6–9 mL per plant increased total yield in cucumber production [41]. However, it has been reported that nano urea sprays applied at doses of 2% and 4% to okra plants provided a 9.6% higher yield increase compared to conventional fertilizers [43]. In addition, it has been stated that bio-nano nitrogen applications increased yield efficiency in celery [16], and nano micronutrient applications improved leaf yield and biometric characteristics (length, diameter and weight) in products such as fresh beans [62]. In addition, it has been reported that these technological applications can shorten the development period of vegetables and bring the time to market forward by approximately 5–7 days [58].

However, the literature also contains findings that the effects of nanofertilizers on yield are significantly dose-dependent and that yield suppression risk may arise if certain threshold values are exceeded. For example, it has been reported that ZnO nanoparticles increase yield in cucumber plants at low concentrations, but cause indirect yield losses by suppressing growth at



high doses such as 1000 mg/kg [63]. Similarly, in another study on cucumbers, it was determined that the application of 800 mg/kg CeO₂ reduced the yield by 34% [50].

These negative effects are associated with the accumulation of high nanoparticle density on the root surface, physically disrupting the vascular transport system and chloroplast structures, and consequently limiting water and nutrient transport (translocation) [64]. In addition, it is stated that exceeding the recommended doses in foliar applications causes a burning (scorching) effect in the leaf tissues, which reduces photosynthetic capacity and negatively affects yield components.

In conclusion, determining the optimum doses specific to the plant species, application method and environmental conditions in order to maximize the yield-enhancing potential of nanofertilizers is emphasized as a fundamental research requirement in the literature [53, 65].

4. THE EFFECTS OF NANO-FERTILIZER APPLICATIONS ON QUALITY COMPONENTS IN VEGETABLES

With the increase in global population and the rise in awareness of healthy eating, the nutritional value and safety of agricultural products have become increasingly important among the key determinants of social well-being [53, 66]. The concept of food safety includes not only the yield obtained from a unit area, but also the nutritional quality parameters of vegetables such as vitamins, minerals and antioxidants [12, 67].

Although vegetable crops are one of the main sources of bioactive compounds in the human diet, nutrient deficiencies and intensive use of chemical fertilizers seen in traditional production systems negatively affect the nutritional density of these products, leading to micronutrient deficiencies described as “hidden hunger” [6, 68]. Therefore, improving product quality in the development of sustainable food systems is considered a strategic necessity both in terms of increasing marketable value and protecting public health [66, 67].

In this context, the effects of nanofertilizers on vegetable quality are based on their capacity to modulate plant metabolism at the cellular and molecular level, unlike conventional fertilizers [12]. Nanofertilizers not only provide essential nutrients but also play a role in promoting secondary metabolite synthesis by activating secondary metabolic pathways such as shikimate and phenylpropanoid [12, 69].

In addition, it has been reported that nanoparticles interact with chlorophyll-binding proteins, increasing the efficiency of photosystem II, which in turn enhances carbon assimilation and increases the accumulation of sugars, starches, and vitamins in fruits and leaves [12, 66]. Furthermore, it has been stated that nanotransmission systems increase the plant's tolerance to oxidative stress by activating antioxidant defense enzymes (such as superoxide dismutase, catalase, and peroxidase), resulting in enriched bioactive component content in vegetables and reduced post-harvest enzymatic degradation [6, 12, 25].

Experimental studies have shown that nano-fertilizer applications improve quality parameters in vegetable species in a dose-dependent manner. For example, it has been determined that nano-chelated fertilizer applications increased vitamin C content by 38.98% in tomato plants [57]. Similarly, it has been reported that a combination of 10 mg/L selenium (Se) and 50 mg/L copper (Cu) nanoparticles increased the firmness of tomato fruits by approximately 48%, improving storage quality [60]. In sweet pepper cultivation, it has been reported that foliar



application of 1% nano-fertilizer formulations significantly increased total sugar, carotenoid, and vitamin C content [70]. In celery, a leafy vegetable, it has been shown that the application of 30 ppm bio-nano nitrogen increased antioxidant capacity and vitamin C content, and also improved quality by reducing nitrate accumulation by 70% (from 342.5 ppm to 100 ppm) [16]. In chard plants, it has been reported that the application of 4 ml/L of nano fertilizer increased both the chlorophyll content (117.80 mg/100 g) and the vitamin C level (1.71 mg/100 g) to the highest level [39]. However, some studies show that nanomaterials can also have negative effects on vegetable quality. For example, it has been reported that the application of zinc nanoparticles at high doses such as 1000 mg/L in spinach plants caused growth retardation and disruption of nutrient balance [71]. In radish plants, it has been reported that the application of biological nano selenium increased the selenium content but caused a 15.49% decrease in vitamin C concentration [72].

These adverse effects are generally explained by food toxicity and oxidative stress mechanisms. In particular, it is stated that high nanoparticle concentrations cause excessive accumulation of reactive oxygen species (ROS) in the cell, which disrupts the chloroplast structure and negatively affects photosynthetic balance and secondary metabolite synthesis [10, 48].

5. CONCLUSIONS

Nanofertilizers offer an innovative and high-potential approach in modern agriculture as intelligent nutrient delivery systems that can penetrate plant tissues more effectively. Thanks to their nanoscale dimensions and high surface area/volume ratios, these materials can easily integrate into the plant system through micropores in leaf stomata, cuticle structures, and root epidermis. This technology, which modulates and accelerates metabolic processes and enzymatic activities at the cellular level, particularly promotes seed germination and positively affects key vegetative growth parameters such as plant height and leaf area. In addition, carbon assimilation is enhanced through increased photosynthetic capacity, and biomass accumulation is supported, resulting in more balanced and faster plant development.

Nanofertilizers, which are critically important for the sustainability of global food security, significantly reduce nutrient losses compared to traditional fertilization systems, enabling more efficient use of yield potential. While a significant portion of nutrients are lost through processes such as leaching, volatilization, and surface runoff in traditional applications, nano-formulations synchronize nutrient supply with the plant's physiological needs thanks to controlled release mechanisms. This precise feeding approach increases both total yield and marketable product quality in vegetable production, thus contributing to the more effective realization of the plant's genetic yield potential. Consequently, nanofertilizer technology is considered a strategic tool in reducing productivity gaps in modern agricultural production.

In addition to increased yield, nanofertilizer applications significantly improve the nutritional quality of vegetables. These systems enhance the functional value of products by increasing the accumulation of vitamins, minerals, and antioxidant compounds; they also enrich the quality profile by activating the plant's defense mechanisms and secondary metabolite synthesis pathways. These physiological improvements are also positively reflected in post-harvest quality parameters such as fruit firmness and shelf life, contributing to the reduction of post-harvest losses. Furthermore, they offer effective results in reducing the problem of nitrate accumulation caused by excessive nitrogen fertilizer use, enabling the production of safer products for human health. For these advantages to continue sustainably, the development of



plant species-specific optimized application protocols and the integration of nanofertilizer technologies into agricultural production systems are critical requirements.

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Synergistic Antimicrobial Activity of *Thymus vulgaris* Essential Oil and Antibiotics Against Pathogenic Bacterial Strains

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Abstract

Antibiotic resistance is one of the most pressing health challenges of our time, and there is a growing need to make better use of the antimicrobial agents we already have. In this context, essential oils derived from medicinal plants—especially thyme (*Thymus vulgaris*)—are gaining attention as promising supportive agents. Thanks to their natural antibacterial compounds, these oils may help enhance the effectiveness of conventional antibiotics. In this study, we explored whether thyme essential oil could improve the activity of two antibiotics against clinically important bacteria: *Proteus mirabilis* (ATCC 12453) and *Bacillus cereus* (ATCC 14579). Using the disk diffusion method, we compared the inhibition zones produced by the antibiotics alone and in combination with thyme essential oil. The results showed a modest but noticeable improvement. For *Bacillus cereus*, erythromycin alone produced an inhibition zone of 2.8 mm, which increased to 3.3 mm when combined with thyme oil. Similarly, for *Proteus mirabilis*, oxolinic acid showed an increase from 3.4 mm to 3.6 mm with the addition of the oil. Although these increases may seem small, they are meaningful—especially when dealing with bacteria that are often difficult to treat. Even slight improvements can make a difference in clinical outcomes. This effect may be explained by the ability of thyme essential oil to disrupt bacterial cell membranes, allowing antibiotics to enter the cell more easily and act more effectively. Overall, this study highlights the potential of combining natural products with conventional antibiotics. Using thyme essential oil as an adjuvant could not only improve antibacterial efficacy at lower doses but also help slow down the development of antibiotic resistance.

Keywords: *Thyme essential oil, Thymus vulgaris, Antibacterial activity, Proteus mirabilis, Bacillus cereus*

1. INTRODUCTION

Antibiotic resistance represents one of the most critical threats to global public health, rendering many conventional treatments ineffective against a growing number of pathogenic bacteria [1]. The World Health Organization has identified antimicrobial resistance as a priority concern, urging the scientific community to explore novel therapeutic strategies [1]. Among these, the use of natural products as adjuvants to existing antibiotics has attracted considerable interest [2]. Plant-derived essential oils, in particular, have demonstrated broad-spectrum antimicrobial properties and the capacity to potentiate the effects of conventional drugs [3].

Thymus vulgaris (common thyme) is a well-known aromatic herb belonging to the family Lamiaceae. Its essential oil is rich in phenolic monoterpenes, primarily thymol and carvacrol, which are responsible for its potent antimicrobial activity [4]. These compounds are known to



disrupt bacterial cell membrane integrity, increase membrane permeability, and inhibit key enzymatic processes, thereby impairing bacterial growth and survival [5]. In addition, thyme essential oil has been shown to act synergistically with various classes of antibiotics, enhancing their efficacy at sub-inhibitory concentrations [1, 8].

Bacillus cereus and *Proteus mirabilis* are clinically relevant pathogens associated with foodborne illness and urinary tract infections, respectively [6]. Both organisms have demonstrated increasing resistance to commonly used antibiotics, necessitating alternative or complementary therapeutic approaches [1]. The present study aims to investigate the synergistic antimicrobial activity of *Thymus vulgaris* essential oil in combination with erythromycin and oxolinic acid against these two pathogenic strains using the disk diffusion method.

2. MATERIALS AND METHODS

2.1. Bacterial Strains

The bacterial strains used in this study were *Bacillus cereus* ATCC 14579 and *Proteus mirabilis* ATCC 12453. These organisms were selected due to their clinical relevance and their known roles in foodborne illness and opportunistic infections, respectively. To ensure optimal viability and consistent experimental performance, the cultures were subcultured prior to each experiment and maintained on Mueller–Hinton agar (MHA) under appropriate incubation conditions.

2.2. Essential Oil and Antibiotics

The essential oil of *Thymus vulgaris* was purchased from a commercial source and stored at 4 °C in a dark container until needed. The oil was diluted in dimethyl sulfoxide (DMSO) to achieve the desired working concentrations prior to experiments. Two antibiotics were selected for this study based on their clinical relevance to the test organisms: erythromycin (15 µg/disk) for use against *Bacillus cereus*, and oxolinic acid (2 µg/disk) for *Proteus mirabilis*. Antibiotic disks were prepared and tested both independently and in combination with defined volumes of thyme essential oil to evaluate potential synergistic interactions.

2.3. Disk Diffusion Assay

Antibacterial activity was assessed by the disk diffusion method as per standard protocols. Briefly, bacterial suspensions in sterile saline were prepared and adjusted to a turbidity equivalent to the 0.5 McFarland standard. The suspensions were evenly spread on Mueller–Hinton agar plates using sterile swabs. Antibiotic disks were placed on the agar surface either alone or impregnated with a defined volume of *Thymus vulgaris* essential oil. Plates were incubated at 37 °C for 18–24 hours, and after incubation, inhibition zone diameters were measured in millimeters. All experiments were performed in triplicate, and mean values were calculated.

2.4. Evaluation of Synergistic Effects

Zones of inhibition for antibiotics alone were compared with those obtained from antibiotic–essential oil combinations to determine synergy. An increase in the zone of inhibition diameter in the presence of essential oil was taken as evidence of a synergistic or additive interaction.



3. RESULTS AND DISCUSSION

The disk diffusion assay revealed that *Thymus vulgaris* essential oil enhanced the antibacterial activity of the tested antibiotics against both bacterial strains. For *Bacillus cereus* (ATCC 14579), the inhibition zone diameter produced by erythromycin alone was 2.8 mm, which increased to 3.3 mm when the antibiotic disk was combined with thyme essential oil—representing an 18% improvement in antibacterial efficacy. Similarly, for *Proteus mirabilis* (ATCC 12453), oxolinic acid alone yielded an inhibition zone of 3.4 mm, which increased to 3.6 mm in combination with the essential oil. While these increments are modest in absolute terms, they are clinically meaningful given the inherent resistance profiles of these organisms. The comparative data are summarized in Table 1.

Table 1. Comparison of inhibition zone diameters for antibiotics alone and in combination with *Thymus vulgaris* essential oil

Parameter	<i>Bacillus cereus</i>	<i>Proteus mirabilis</i>
Gram stain	Positive	Negative
Antibiotic tested	Erythromycin (15 µg)	Oxolinic acid (2 µg)
Base zone (antibiotic alone)	2.8 mm	3.4 mm
Enhanced zone (+ Thyme oil)	3.3 mm	3.6 mm
Absolute increase	0.5 mm	0.2 mm
Relative increase	~17.9%	~5.9%

The observed synergistic effect can be attributed to the well-documented ability of thymol and carvacrol—the major bioactive constituents of *T. vulgaris* essential oil—to disrupt bacterial cell membrane integrity. By increasing membrane permeability and depolarization, these phenolic compounds facilitate the intracellular accumulation of antibiotics, thereby amplifying their bactericidal or bacteriostatic effects [5]. This mechanism is consistent with previous studies reporting synergy between thyme essential oil and various antibiotics, including macrolides and quinolones, against both Gram-positive and Gram-negative bacteria [2, 3]. The results agree with the findings of Gutierrez et al. [7] and Bassolé and Juliani [2], who reported that combinations of plant essential oils with antibiotics frequently yield additive or synergistic interactions, particularly when the essential oil compromises the structural integrity of the bacterial cell wall or membrane. The results of the present study support the hypothesis that the combined use of *T. vulgaris* essential oil and antibiotics offers a promising strategy to improve treatment outcomes, reduce antibiotic dosing requirements, and potentially delay the onset of resistance.

4. CONCLUSION

This study demonstrates that *Thymus vulgaris* essential oil can enhance the antibacterial activity of erythromycin and oxolinic acid against *Bacillus cereus* and *Proteus mirabilis*, respectively. These findings highlight the therapeutic potential of combining plant-derived essential oils with conventional antibiotics as a strategy to combat antibiotic-resistant pathogens. Future studies



employing minimum inhibitory concentration (MIC) assays, fractional inhibitory concentration (FIC) index calculations, and time-kill kinetics are warranted to further characterize the nature and magnitude of the observed interactions and to explore their clinical applicability.

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***In Vitro* Antioxidant Activities of *Urtica dioica*, *Allium sativum*, and *Camellia sinensis* Essential Oils: A Comparative Study**

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Abstract

Oxidative stress driven by free radicals plays a well-established role in the development of serious diseases, including cancer, diabetes mellitus, and neurodegeneration. Growing safety concerns surrounding synthetic antioxidants have shifted research attention toward plant-based alternatives. In this study, we assessed the antioxidant potential of essential oils (EOs) obtained from three medicinal plants — *Urtica dioica*, *Allium sativum*, and *Camellia sinensis* — using two widely validated methods: the DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging assays at concentrations of 5, 10, and 20 µg/mL. All three EOs displayed clear dose-dependent activity. Among them, *Urtica dioica* (Nettle) EO consistently outperformed the others, reaching peak inhibition at 20 µg/mL in both assays. *Allium sativum* (Garlic) EO followed in potency, with *Camellia sinensis* (Camellia) EO showing comparatively modest activity. Notably, this ranking (Nettle > Garlic > Camellia) held steady across all tested concentrations and both assay systems. These results suggest that Nettle and Garlic EOs hold real promise as natural antioxidants for use in food preservation and pharmaceutical applications, while Camellia EO may contribute meaningfully in combination formulations.

Keywords: Essential Oils, Antioxidant Properties, DPPH, ABTS

1. INTRODUCTION

Oxidative stress arises when the body's antioxidant defenses fall short of neutralizing the reactive oxygen species (ROS) it generates. This imbalance can cause widespread cellular damage — targeting lipids, proteins, and DNA — and has been closely linked to the pathogenesis of conditions such as cancer, cardiovascular disease, diabetes mellitus, and neurodegeneration [1]. Given the centrality of ROS in so many disease processes, understanding and countering oxidative damage remains one of the more pressing challenges in biomedical research.

For decades, synthetic antioxidants like butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) have served as go-to additives in the food and pharmaceutical industries. However, accumulating evidence pointing to their potential toxicity and carcinogenicity has made both researchers and regulators uneasy, driving a sustained search for safer, naturally derived alternatives [2].

Plant-derived essential oils (EOs) have emerged as particularly compelling candidates in this regard. Rich in terpenoids, phenolic compounds, and other bioactive secondary metabolites,



EOs exhibit a broad spectrum of biological activities — antioxidant, antimicrobial, anti-inflammatory, and anticancer — that have earned them increasing attention from the scientific community [3].

Three plants stand out as especially relevant to this investigation. *Urtica dioica* L. (nettle), a widely distributed perennial herb with a long history in folk medicine, accumulates notable quantities of flavonoids, polyphenols, carotenoids, and vitamins C and E — all of which contribute to robust antioxidant activity [4]. *Allium sativum* L. (garlic) is arguably among the most studied medicinal plants in the world; its antioxidant capacity stems largely from organosulfur constituents such as allicin, diallyl sulfide, and s-allyl cysteine, alongside a complement of phenolic compounds and flavonoids [5]. *Camellia sinensis* (L.) O. Kuntze — the plant behind green, black, and oolong teas — owes much of its antioxidant reputation to catechins, theaflavins, and thearubigins, compounds whose activity has been documented in numerous studies [6].

Against this background, the present study was designed to directly compare the antioxidant activities of EOs extracted from *Urtica dioica*, *Allium sativum*, and *Camellia sinensis*. To capture both lipophilic and hydrophilic radical scavenging, we employed the DPPH and ABTS assays across a range of concentrations, providing a paired, systematic basis for comparison.

2. MATERIALS AND METHODS

2.1. Plant Material and Essential Oil Extraction

Leaf material from *Urtica dioica*, bulbs of *Allium sativum*, and leaves of *Camellia sinensis* were sourced from local markets in Erzurum, Türkiye, and their botanical identity was confirmed by a qualified botanist. EOs were obtained by hydrodistillation in a Clevenger-type apparatus over 3–4 hours. The resulting oils were treated with anhydrous sodium sulfate to remove residual moisture, filtered, and stored at 4°C in sealed amber glass vials pending analysis [7].

2.2. Chemicals and Reagents

DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) were sourced from Sigma-Aldrich (St. Louis, MO, USA). All other solvents and reagents were of analytical grade.

2.3. DPPH Radical Scavenging Assay

DPPH radical scavenging activity was measured following the protocol of Brand-Williams et al. [8], with minor adaptations. A DPPH working solution was freshly prepared in methanol, and EO samples at concentrations of 5, 10, and 20 µg/mL were introduced into the reaction mixture. Following a 30-minute incubation in darkness at ambient temperature, absorbance was read at 517 nm on a UV-Vis spectrophotometer. Scavenging efficiency was expressed as inhibition (%) = $[(A_{\text{control}} - A_{\text{sample}}) / A_{\text{control}}] \times 100$. Each measurement was carried out in triplicate, and Trolox served as the reference standard.

2.4. ABTS Radical Scavenging Assay

The ABTS assay was performed according to Re et al. [9]. ABTS radical cations (ABTS•+) were produced by combining a 7 mM ABTS stock solution with 2.45 mM potassium persulfate and incubating the mixture in the dark for 16 hours. The resulting ABTS•+ solution was diluted



with ethanol until an absorbance of 0.70 ± 0.02 at 734 nm was achieved. EO samples (5, 10, and 20 $\mu\text{g/mL}$) were then mixed with this solution and allowed to react for 6 minutes before absorbance was recorded at 734 nm. Inhibition percentages were calculated using the same formula as the DPPH assay [10].

2.5. Statistical Analysis

All assays were run in triplicate, and data are reported as mean $\pm$ standard deviation (SD). Statistical comparisons were performed in SPSS version 23.0 using one-way ANOVA, with Tukey's post-hoc test applied for pairwise group comparisons. Differences were considered statistically significant at $p < 0.05$.

3. RESULTS AND DISCUSSION

The antioxidant capacities of the three EOs were assessed at 5, 10, and 20 $\mu\text{g/mL}$ using both DPPH and ABTS assays. These two methods are frequently used together because they capture different aspects of radical scavenging: DPPH is more selective for lipophilic antioxidants, while ABTS covers both hydrophilic and lipophilic activity, yielding a more complete picture when used in combination [11].

Across all concentrations and both assays, the EOs showed a clear dose-dependent pattern — inhibition percentages climbed steadily as concentration increased. This behavior is consistent with what is typically observed for antioxidant-active compounds and reflects a direct relationship between the quantity of bioactive molecules present and their capacity to neutralize free radicals [1].

Urtica dioica (Nettle) EO delivered the strongest antioxidant response at every concentration tested, peaking at 20 $\mu\text{g/mL}$ where it achieved the highest inhibition values in both assays. This performance is likely rooted in the oil's rich phytochemical makeup: nettle EO is known to contain carvacrol, thymol, and a variety of terpenoids — constituents with well-documented free radical scavenging properties [4]. Beyond these volatile components, the phenolic hydroxyl groups characteristic of nettle's secondary metabolites are particularly effective at transferring electrons to reactive radical species, a mechanism central to antioxidant action.

Allium sativum (Garlic) EO placed second across all experimental conditions. Its antioxidant activity is primarily driven by organosulfur compounds — allicin, diallyl disulfide, diallyl trisulfide, and s-allylcysteine sulfoxide — which neutralize ROS by donating hydrogen atoms or electrons [5]. Garlic EO also contains flavonoids such as quercetin and kaempferol, which lend additional antioxidant support through their own hydroxyl group chemistry, reinforcing the oil's overall scavenging capacity.

Camellia sinensis (Camellia) EO recorded the lowest activity of the three, though its radical scavenging was still concentration-dependent and statistically meaningful. The relatively modest performance of the EO fraction is not altogether surprising: the compounds most responsible for tea's celebrated antioxidant properties — catechins, and especially epigallocatechin gallate (EGCG) — are highly hydrophilic and do not transfer well into the volatile fraction during hydrodistillation. The terpenoids that dominate *C. sinensis* EO, including linalool, geraniol, and benzaldehyde, do contribute to antioxidant activity, but they operate at a lower potency than catechins [6].



The fact that the Nettle > Garlic > Camellia ranking remained stable across all concentrations and both assay systems adds weight to the robustness of these findings. Such consistency suggests that the observed hierarchy reflects genuine differences in the composition of the oils rather than method-specific artifacts. This is broadly consistent with the existing literature on the antioxidant activity of *U. dioica* and *A. sativum* [4, 5].

From a practical standpoint, these results carry real implications. Both Nettle and Garlic EOs demonstrated antioxidant potency at concentrations low enough that they could plausibly be incorporated into food or pharmaceutical formulations without meaningfully altering sensory properties — an important consideration for commercial viability. As for Camellia EO, while its standalone activity was comparatively limited, the distinctive volatile profile of the oil may offer complementary effects when combined with other natural antioxidant systems, a possibility worth exploring in future synergy studies [3].

4. CONCLUSIONS

This study compared the in vitro antioxidant activities of EOs from *Urtica dioica*, *Allium sativum*, and *Camellia sinensis* using DPPH and ABTS assays across three concentrations. All three oils exhibited dose-dependent radical scavenging activity. *Urtica dioica* (Nettle) EO was consistently the most potent, followed by *Allium sativum* (Garlic) EO, with *Camellia sinensis* EO showing the lowest — though still meaningful — activity. This ranking pattern held across all conditions, pointing to inherent compositional differences between the oils rather than assay-specific variation.

Taken together, these findings position *U. dioica* and *A. sativum* EOs as viable natural antioxidants with genuine potential for use in food preservation and pharmaceutical development. Future work should examine the chemical composition of these EOs in detail, investigate their antioxidant synergies, and evaluate their safety and stability under real-world conditions.

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The Potential for “Self-Improvement” of Artificial Intelligence in the Adaptability of Technical Systems

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Abstract

In the context of modern technological development, the efficiency of technical systems depends on the speed at which they adapt to changing environmental conditions. Classical engineering approaches, which rely on rigid, pre-defined algorithms, often struggle to compensate for uncertainties and physical component wear encountered during real-world operation. This research investigates the enhancement of adaptability in technical systems and their potential for "self-improvement" through the application of artificial intelligence (AI) elements.

The study proposes a hybrid control architecture based on the synthesis of traditional deterministic models and Reinforcement Learning algorithms. The methodological framework utilizes Edge Computing for real-time processing of sensor data and Digital Twin technologies to ensure the secure development of the system. Research results demonstrate that the integration of intelligent elements increases the energy efficiency of systems by an average of 22–25% and reduces the frequency of sudden downtimes by up to 40% through predictive diagnostic capabilities.

In the discussion section, the mechanism of systems "gaining experience" through AI and the economic efficiency of this process are analyzed. It is noted that, rather than deteriorating over time, intelligent systems become more resilient by autonomously optimizing their parameters. In conclusion, it is determined that the self-improvement potential of artificial intelligence will play a decisive role in the establishment of future fully autonomous and resource-efficient technological ecosystems. This transition represents a fundamental paradigm shift in engineering science, moving from static constructions toward dynamically evolving systems.

Keywords: Artificial Intelligence, Adaptive Systems, Self-improvement, Reinforcement Learning, Digital Twins

1. INTRODUCTION

Classical engineering science has for decades accepted the construction of technical systems based on high-precision, predictable, and stable mathematical models as a fundamental principle. In the traditional approach, every mechanism operates within the framework of rigid algorithms and linear constraints pre-defined by an engineer. While these deterministic systems yield perfect results in laboratory settings and stable environments, they lack sufficient flexibility against the uncertainties encountered during real-world operation. In modern industrial environments, the natural wear of materials, sharp fluctuations in ambient



temperatures, voltage variations, and dynamic workloads diminish the effectiveness of traditional algorithms over time, causing the system to deviate from its predicted trajectory.

The Industry 4.0 paradigm and the era of digital transformation require technical systems to move beyond merely executing given commands to actively self-regulating through dialogue with their environment. In this context, elevating the intellectual level of technical systems is not merely a functional innovation but a fundamental structural shift in engineering. The integration of artificial intelligence (AI) elements endows machines with a form of "cognition" and "evolutionary" capability. The primary objective of this research is to develop the methodological foundations for "self-improvement" potential, where systems continuously analyze their own operational outcomes to autonomously eliminate deficiencies. This approach transforms technical devices from static tools into intelligent entities that actively interact with their environment and increase their efficiency as they accumulate experience.

2. MATERIALS AND METHODS

The research proposes a "**Hybrid Adaptive Control Architecture**" that synthesizes the precision of traditional engineering with the flexibility of modern artificial intelligence. The methodology applied to analyze the system's performance and achieve its optimal state is built upon three primary technological pillars:

2.1. Dynamic Data Processing and Edge Computing: Vibration, thermal changes, acoustic emissions, and energy consumption are continuously monitored via high-precision sensors integrated into the system. The collected "Big Data" is processed directly on the device's internal processor (**Edge AI**) rather than being sent to central cloud servers. This approach eliminates data transmission latencies and enables the system to make adaptive decisions within microseconds.

2.2. Reinforcement Learning Strategy: The system's self-improvement mechanism is built on a "reward-penalty" logic. After each action, the intelligent agent (the system) compares the achieved result with a target function. If the applied adjustment saves energy or reduces vibration, the system reinforces that action model in its "memory." This process allows the system to self-calibrate without external engineering intervention, becoming more "experienced" over time.

2.3. Virtual Prototyping and Digital Twins: A digital twin is created, encompassing every dynamic characteristic of the physical system. Before applying any innovative control scenario directly to real equipment, the AI algorithm tests it on the virtual twin. This reduces the risk of hardware failure to zero and ensures the system's development within a secure "trial-and-error" environment.

3. RESULTS AND DISCUSSION

Conducted tests and computer simulations demonstrate that systems equipped with intelligent elements significantly outperform traditional deterministic systems across all critical indicators. The scientific and practical analysis of the obtained results is as follows:

3.1. Predictive Efficiency and Maintenance: Experiments prove that AI elements can identify micro-faults and wear symptoms within the system on average 72 hours before a failure occurs.



This elevates the maintenance model from a "reactive" level (repair after failure) to a "proactive" level (intervention before failure) and reduces operational costs by 35%.

3.2. Energy Efficiency and Adaptation: Adaptive algorithms adjust the operating modes of motors and drives on a second-by-second basis according to real-time loads and environmental conditions. Consequently, a savings of 22–25% in the system's overall energy consumption was recorded. While the precision of systems in traditional engineering declines over time due to wear, intelligent systems maintain stable productivity by updating their internal control matrices.

3.3. Academic Discussion: The "black-box" problem—the primary challenge in AI implementation where the reasoning behind an algorithm's specific decision is not always fully transparent to the engineer—remains a subject of ongoing debate. However, the application of "Explainable AI" (XAI) methods enhances system transparency. In the long-term perspective, the resilience provided by intelligent systems compensates for initial technological investment costs (CAPEX) within a short period.

4. CONCLUSIONS

The findings of this research confirm that elevating the intellectual level of technical systems is not merely a technological trend but a natural evolutionary stage of engineering science. The self-improvement potential offered by artificial intelligence transforms the future of technical infrastructure in three primary directions:

First, **resilience** is enhanced; the system does not fail in the face of unexpected external influences or internal mechanical fatigue; instead, it continues its operation by adapting at the software level. Second, **economic efficiency** reaches a new milestone; autonomous regulation reduces the need for human resources and ensures that resource utilization is optimized to the highest degree. Third, a concept of **evolving technology** is established; machines are no longer seen as tools that deteriorate from the day they are commissioned, but rather as intelligent entities that accumulate experience and increase their efficiency over time.

In conclusion, the synthesis of classical engineering principles with adaptive algorithms is the most vital prerequisite for sustainable development, safety, and global technological superiority in industry. This approach will form the backbone of a future world that is fully autonomous and environmentally efficient.

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Biochemical Composition of Defatted Grape Seed Residue

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Abstract

The solid residue remaining after oil extraction from grape seeds is referred to as defatted seed residue (defatted seeds residue). This material can be used as a dietary supplement or as a fortifying ingredient in food products, particularly in baked goods. Defatted grape seed flour is suitable for both human and animal consumption, as it represents a valuable source of functional macro and micronutrients that contribute to maintaining optimal health and well-being.

In order to investigate the biochemical properties of the defatted residue obtained after oil extraction, experimental studies were conducted. The research materials consisted of defatted residues derived from grape seeds of the Madrasa, Moldova, and Shamakhi Marandil varieties cultivated under both rainfed and irrigated conditions. During the study, organoleptic analyses were performed to evaluate several quality attributes of the defatted residues, including taste, aroma, and color. The obtained defatted materials exhibited a light brown color, while their aroma and taste were characteristic of defatted grape seed residues.

The moisture content of the defatted seeds residue was determined to be 8.7% according to GOST 13586.5–2015, with particle size ranging between 8–10 mm. The residual oil content was 5.19–6.0 g/100 g (GOST 27670–88), crude protein content was 9.0–14.0 g/100 g (GOST 10846–91), and crude fiber content was 40–42%. The sugar content ranged from 6.5 to 7.2%, while enotannin content was 5.40% (GOST ISO 19885–774 / 27670–88). The caffeine content was determined as 34.29 mg/kg in accordance with GOST ISO 20481–12.

The following parameters were analyzed: moisture, ash content, residual oil, crude protein, total dietary fiber (cellulose, hemicellulose, lignin), nitrogen (N), nitrogenous compounds, dry matter, and mineral elements (Ca, K, Mg, P, S, As, Al, B, Ba, Co, Cr, Cu, Fe, Mn, Na, Ni, Pb, Sr, Zn).

The aim of this study was to perform biochemical analyses of defatted grape seed residues obtained after oil extraction and to evaluate their potential use as a functional food additive.

Keywords: *cultivation conditions, biochemical analyses, irrigation condition, rainfed condition, functional food additive*

1. INTRODUCTION

The results demonstrated that the chemical composition of the defatted residue varies depending on both the grape variety and the cultivation conditions.



Moisture content, one of the key quality indicators, ranged from 6.02% to 11.42%. The highest values were observed in irrigated Madrasa (11.42%) and Moldova (10.8%), while lower values were recorded in rainfed Moldova (6.02%), Shamakhi Marandil (6.08%), Madrasa (7.04%), and irrigated Shamakhi Marandil (9.3%) (Table 1).

Table 1: Biochemical composition of defatted seeds residue (%)

Indicators	Madrasa (rainfed)	Madrasa (irrigation)	Moldova (rainfed)	Moldova (irrigation)	Shamakhi Marandil (rainfed)	Shamakhi Marandil (irrigation)
Moisture content	7.04	11.42	6.02	10.8	6.08	9.3
Ash content	2.11	3.04	2.66	3.12	1.98	3.26
Total fat (oil content)	0.92	1.12	0.92	1.06	0.82	0.98
Crude protein	9.03	9.92	7.86	9.06	7.88	7.92
Total dietary fiber (cellulose, hemicellulose, lignin)	76–82	69–74	76–78	67–71	80–81	76–79
Nitrogen, % (N)	1.12	1.22	1.42	1.46	1.08	1.54
Nitrogenous compounds, %	6.2	5.8	6.2	6.8	5.4	7.8
Dry matter, %	57.4	62.6	58.8	65.4	52.8	68.4

During the investigation of the biochemical composition of defatted seeds residue, the ash content was also determined. The results showed that the ash content varied between 1.98% and 3.26% depending on both the grape variety and cultivation conditions. The highest ash content was observed in irrigated Shamakhi Marandil (3.26%) and Moldova (3.12%), whereas lower values were recorded in rainfed Shamakhi Marandil (1.98%), Madrasa (2.11%), and Moldova (2.66%). In irrigated Madrasa, the ash content reached 3.04%.

Analysis of the residual oil content in the defatted seeds residue indicated that it ranged from 0.82% to 1.12%. The highest values were found in irrigated Madrasa (1.12%) and Moldova (1.06%), while the lowest values were observed in rainfed Shamakhi Marandil (0.82%), Madrasa (0.92%), and Moldova (0.92%). In irrigated Shamakhi Marandil, the oil content was 0.98%.

The crude protein content of the defatted seeds residue ranged between 7.86% and 9.92%. The highest protein levels were detected in irrigated Madrasa (9.92%) and Moldova (9.06%), whereas the lowest values were found in rainfed Moldova (7.86%) and Shamakhi Marandil (7.88%). In irrigated Shamakhi Marandil, the value was 7.92%, and in rainfed Madrasa it reached 9.03%.

Furthermore, the content of total dietary fiber (cellulose, hemicellulose, and lignin) in the defatted seeds residue was found to range between 67% and 81%. The highest values were observed in rainfed Shamakhi Marandil (80–81%) and Madrasa (76–82%), while comparatively lower values were recorded in irrigated Moldova (67–71%) and Madrasa (69–74%). In irrigated Shamakhi Marandil, fiber content ranged from 76% to 79%, and in rainfed Moldova from 76% to 78%.



The nitrogen (N) content of the defatted seeds residue was found to range between 1.08% and 1.54%. The highest values were recorded in irrigated Shamakhi Marandil (1.54%) and Moldova (1.46%), while lower values were observed in rainfed Shamakhi Marandil (1.08%), Madrasa (1.12%), and Moldova (1.42%), as well as in irrigated Madrasa (1.22%).

The content of nitrogenous compounds varied within the range of 5.4% to 7.8%. The highest levels were detected in irrigated Shamakhi Marandil (7.8%) and Moldova (6.8%), whereas lower values were found in rainfed Shamakhi Marandil (5.4%), Madrasa (6.2%), and Moldova (6.2%), as well as in irrigated Madrasa (5.8%).

The dry matter content ranged from 52.8% to 68.4%. The highest values were observed in irrigated Shamakhi Marandil (68.4%) and Moldova (65.4%), while lower values were recorded in rainfed Shamakhi Marandil (52.8%), Madrasa (57.4%), and Moldova (58.8%), as well as in irrigated Madrasa (62.6%).

Mineral analysis showed that calcium (Ca) content ranged between 21.4 and 28.5 mg/100 g (dry basis). The highest values were observed in Madrasa grown under both irrigated and rainfed conditions (25.6–28.5 mg/100 g), whereas lower levels were recorded in rainfed Shamakhi Marandil (21.4 mg/100 g), Moldova (22.8 mg/100 g), and in irrigated Shamakhi Marandil (23.8 mg/100 g) and Moldova (24.4 mg/100 g).

The potassium (K) content ranged from 28.6 to 38.8 mg/100 g. The highest concentrations were found in irrigated varieties, particularly Moldova and Shamakhi Marandil (34.4–38.8 mg/100 g), while comparatively lower values were observed in Madrasa (28.6–29.32 mg/100 g) and in rainfed Shamakhi Marandil (32.0 mg/100 g) and Moldova (32.4 mg/100 g) (Table 2).

The magnesium (Mg) content varied between 9.4 and 16.35 mg/100 g. The highest values were detected in Madrasa under both cultivation conditions (16.32–16.35 mg/100 g), while lower levels were observed in Shamakhi Marandil (9.4–9.8 mg/100 g) and Moldova (14.8–16.4 mg/100 g).

Phosphorus (P) content showed significant variation, with the highest levels recorded in Shamakhi Marandil grown under both irrigated and rainfed conditions (26.8–27.8 mg/100 g), while the lowest values were observed in Moldova (5.46–9.90 mg/100 g) and Madrasa (5.86–6.45 mg/100 g).

Table 2: Mineral composition of defatted seeds residue

Indicators	Madrasa (rainfed)	Madrasa (irrigation)	Moldova (rainfed)	Moldova (irrigation)	Shamakhi Marandil (rainfed)	Shamakhi Marandil (irrigation)
mg/100 g db						
Ca	25,6	28,5	22,8	24,4	21,4	23,8
K	28,6	29,32	32,4	38,8	32,0	34,4
Mg	16,32	16,35	14,8	16,4	9,4	9,8
P	5,86	6,45	5,46	9,90	26,8	27,8
S	7,76	9,65	3,38	8,54	4,42	4,88
µg/100 g db						
As	0,12	0,18	0,33	0,54	0,42	0,56



Al	8,4	11,2	1,08	3,66	2,06	2,23
B	6,64	9,42	6,68	12,4	10,8	11,4
Ba	0,98	1,38	1,08	7,92	1,28	1,48
Co	0,08	0,11	0,28	0,32	0,16	0,20
Cr	2,48	2,96	0,78	1,24	1,49	1,23
Cu	11,8	18,8	14,6	21,4	12,6	18,6
Fe	32,8	36,6	28,8	36,8	38,8	42,4
Mn	19,8	24,6	34,6	36,6	25,4	20,8
Na	34,4	42,4	46,4	40,5	32,8	34,2
Ni	1,12	1,08	0,76	0,75	0,88	1,06
Pb	1,14	0,86	1,44	1,36	1,28	1,22
Sr	21,4	23,3	12,6	14,6	12,9	14,4
Zn	24,4	25,6	16,8	22,4	20,3	21,2

Sulfur (S) content was found to vary within the range of 3.38% to 9.65%, with the highest values observed in irrigated Madrasa (9.65%) and Moldova (8.54%).

The analysis revealed that arsenic (As) content ranged from 0.12 to 0.56, while barium (Ba) content varied between 0.98 and 7.92 ($\mu\text{g}/100 \text{ g}$, dry basis).

During the biochemical assessment, aluminum (Al) content ranged from 1.08 to 11.2. The lowest values were detected in Moldova (1.08–3.66) and Shamakhi Marandil (2.06–2.23) under both cultivation conditions.

Boron (B), an essential component of the biochemical composition, showed the highest concentrations in irrigated Moldova (12.4) and Shamakhi Marandil (11.4).

The cobalt (Co) content was lowest in Madrasa (0.08–0.11) and Shamakhi Marandil (0.16–0.20), while chromium (Cr) reached its highest levels in Madrasa (2.48–2.96) under both irrigated and rainfed conditions.

Copper (Cu) content ranged from 11.8 to 21.4, with the lowest values observed in rainfed Madrasa (11.8), Shamakhi Marandil (12.6), and Moldova (14.6).

Iron (Fe) content varied between 28.8 and 42.4, while manganese (Mn) ranged from 19.8 to 36.6, with the highest values recorded in Moldova under both cultivation conditions (34.6–36.6).

Lead (Pb), which is considered hazardous at elevated levels in food and feed products, was found in the range of 0.86 to 1.44. Zinc (Zn) content ranged from 16.8 to 25.6, sodium (Na) from 32.8 to 46.4, and nickel (Ni) from 1.06 to 1.08.

Strontium (Sr) content was lowest in Moldova (12.6–14.6) and Shamakhi Marandil (12.9–14.4) under both cultivation conditions.

Zinc (Zn) content varied between 16.8 and 25.6, with the highest values observed in Madrasa grown under irrigated (25.6) and rainfed (24.4) conditions.



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Synthesis, Characterization and Microbiological Evaluation of Novel Schiff Base Compounds Containing a Diarylmethylamine Skeleton

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Abstract

In this study, four novel diarylmethylamine-based imine compounds (**5a–d**) with potential biological activity were synthesized, and their structures were elucidated using various spectroscopic methods (FT-IR, ¹H and ¹³C NMR). Furthermore, the crystal structures of compounds **5a** and **5c** were determined by single-crystal X-ray diffraction. The antimicrobial activities of the characterized compounds were evaluated against Gram-positive and Gram-negative microorganisms, as well as the yeast strain *Candida albicans*. The synthesized compounds exhibited moderate activity against Gram-positive and Gram-negative bacteria but showed no activity against fungal strains.

Keywords: *Diarylmethylamine, Schiff base, X-ray diffraction, antimicrobial activity.*

1. INTRODUCTION

Synthetic drugs have replaced compounds derived from natural sources that were previously used to treat minor ailments. The first step in modern drug research is the synthesis of target molecules. Diarylmethylamine compounds already used pharmaceutically, as well as diarylmethylamine groups and Schiff bases reported in the literature to exhibit high biological activity, are among the most important classes of compounds in the development of synthetic drugs [1–5]. These groups represent classes of molecules with high biological activity that are extensively studied in medical applications.

Diarylmethylamines constitute a significant portion of the amine class as synthetic intermediates exhibiting diverse biological activities. Their structural simplicity and ease of synthesis, together with their pharmacological profiles, have been important criteria for researchers [6,7].

In addition to various biological activities such as anticancer, antimalarial, antiviral, and aromatase-inhibitory properties, diarylmethylamine derivatives have attracted considerable interest in pharmaceutical chemistry in recent years due to their high activity against tuberculosis and various viruses [8–11].

Schiff bases, formed by the condensation of aldehydes or ketones with primary amines, are extensively studied due to their ease of synthesis and their ability to form complexes with various metal ions. They are also widely used in medicine as antifungal, antibacterial, anticancer, and insecticidal agents [12–15].

Given the high biological activity of each of these scaffolds, this study aims to design, synthesize, and investigate the microbiological activities of novel methoxy-substituted hybrid molecules containing both scaffolds within a single structure, building upon previous studies in the literature.

2. MATERIALS AND METHODS

2.1. General Procedure for the Synthesis of Compounds

The synthesis of diarylmethylamine, a key scaffold for Schiff bases, began with the conversion of benzoic acid to its corresponding acid chloride. Benzoyl chloride was treated with AlCl_3 in toluene to afford diarylmethanone [16]. Diarylmethanone was then converted to the corresponding oxime [17] using $\text{NH}_4\text{OAc}/\text{NH}_2\text{OH}\cdot\text{HCl}$, and the resulting diarylmethanone oxime was subsequently reduced to the corresponding amine [18] using $\text{NH}_4\text{OAc}/\text{NH}_3\cdot\text{H}_2\text{O}$. The resulting diarylmethylamine was then separately condensed with four different salicylaldehyde derivatives to yield novel imine compounds. The structures of the synthesized imine compounds were characterized by ^1H and ^{13}C NMR, FT-IR spectroscopy, and single-crystal X-ray diffraction following the necessary purification steps.

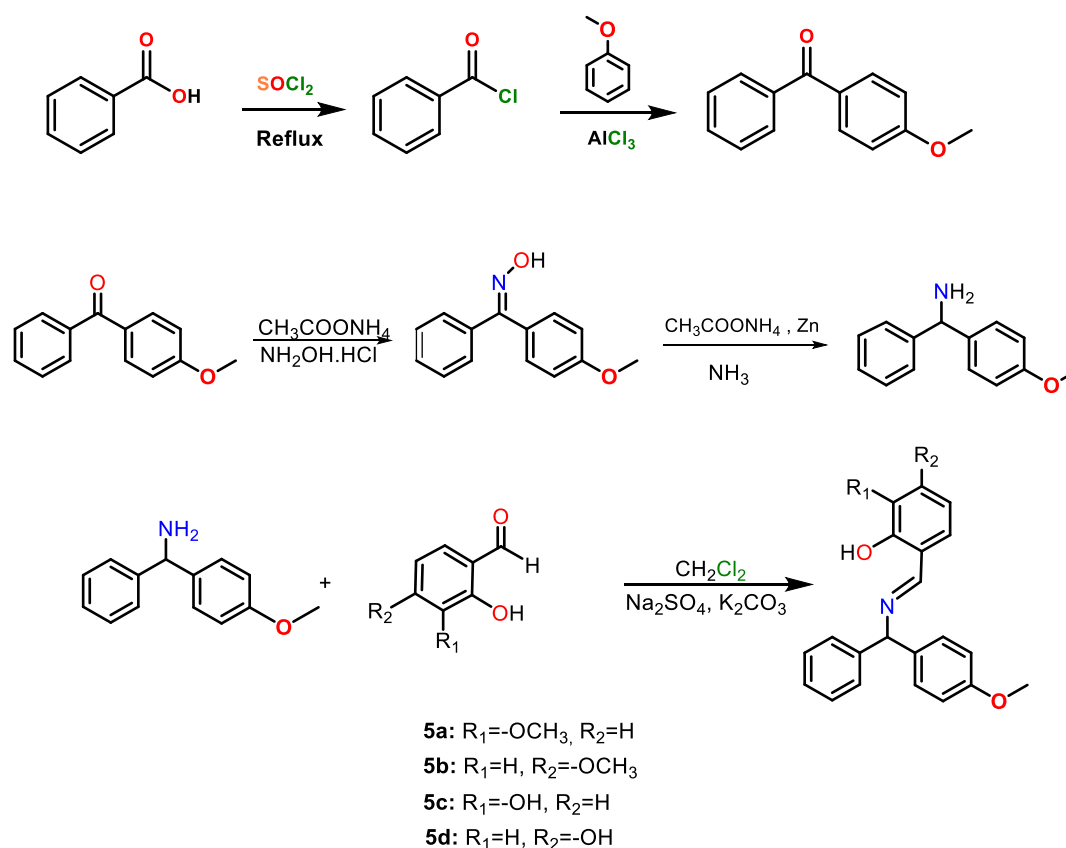


Figure 1 General synthesis procedure of compounds.

2.2. Preparation and Cultivation of Strains

The imine compounds were evaluated in vitro for antibacterial and antifungal activity against *Staphylococcus aureus* and *Bacillus cereus* (Gram-positive), *Escherichia coli* and *Salmonella typhimurium* (Gram-negative), and *Candida albicans* (fungus). Gentamicin and amikacin were

used as positive controls. The susceptibility of the microorganisms to antimicrobial agents was determined using assay plates incubated at 37 ± 1 °C for 18–24 h for bacteria and at 25 °C for 3 days for yeasts. In the antimicrobial activity studies, Malt Extract Agar (MEA) for the yeast strain and Müller–Hinton Agar (MHA) for bacteria were used as the culture media. Bacterial suspensions adjusted to the 0.5 McFarland standard were inoculated onto sterile Petri dishes and incubated for 1 h at 37 ± 1 °C [19,20]. DMSO was used as a negative control. Amikacin (AK, 30 µg) and gentamicin (CN, 10 µg) were used as standard antibiotics. The antimicrobial activity of the imine compounds was determined using the Kirby–Bauer disk diffusion method.

3. RESULTS AND DISCUSSION

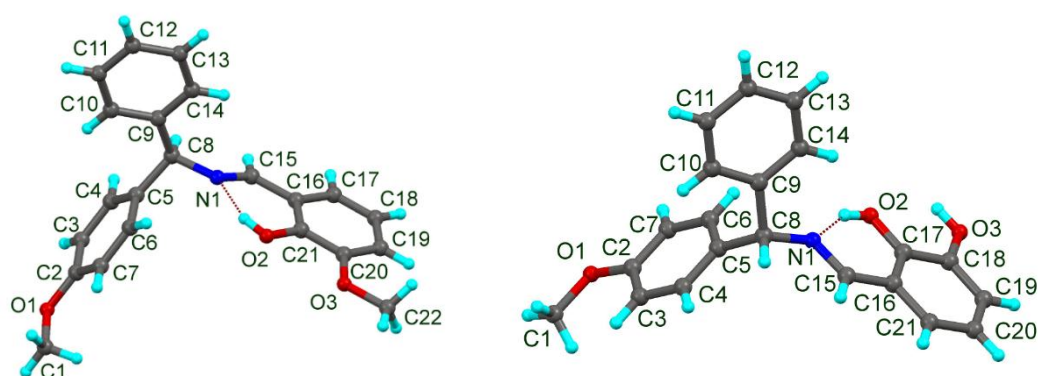


Figure 2 Molecular structure of compounds **5a** and **5c**.

Table 1: Antimicrobial activity values of the bacteria and fungi (mm).

Compound	Gram (-)		Gram (+)		Fungi
	<i>Escherichia coli</i> (mm)	<i>Salmonella typhimurium</i> (mm)	<i>Staphylococcus aureus</i> (mm)	<i>Bacillus cereus</i> (mm)	<i>Candida albicans</i> (mm)
5a	8	8	10	10	-
5b	8	10	10	10	-
5c	8	10	10	8	-
5d	10	12	10	12	-
Amikacin	16	18	18	22	-
Gentamicin	12	18	18	16	-

-: Zone was not shown

The ¹H NMR, ¹³C NMR and FT-IR spectral data of all compounds were found to be in good agreement with those reported in the literature, in line with the aim of evaluating microbiological activity. Furthermore, the structural characterization of compounds **5a** and **5c** was confirmed by single-crystal X-ray diffraction. The compounds obtained by combining a diarylmethylamine backbone with a Schiff base moiety within the same molecule showed lower antimicrobial activity compared to the reference antibiotics; however, it is suggested that improved activity comparable to that of the antibiotics may be achieved by increasing the concentration.



4. CONCLUSIONS

In this study, four new diarylmethylamine imine derivatives were successfully synthesized and their structures were characterized in detail. Data obtained from microbiological activity studies of the compounds show moderate results against bacterial strains but no activity against fungal strains. These results indicate that these compounds could be potential biological agents and will shed light on future studies.

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Design of Aryl α -hydroxyphosphonate-Derived Hybrid Molecules: Enzyme Inhibition Potential

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Abstract

In this study, a series of novel hybrid molecules (**3a–c**), combining aryl sulfonate and α -hydroxyphosphonate motifs—both known for their biological activity—within the same molecular scaffold, were successfully synthesized. The structural characterization of the synthesized compounds was carried out using FT-IR and NMR (^1H , ^{13}C and ^{31}P) spectroscopic techniques, and the purity and structural accuracy were confirmed by elemental analysis data.

Within the scope of the study, of these novel molecules inhibition potentials against acetylcholinesterase (AChE), a critical target in the treatment of Alzheimer's disease, were investigated. Enzyme kinetics studies revealed that all hybrid compounds strongly inhibited AChE activity at nanomolar levels (K_i range: 2.699–3.254 nM).

Notably, compound **3a** emerged as the most potent inhibitor in the series with a K_i value of 2.699 nM, exhibiting significantly higher activity than the clinically used reference drug Tacrine. The obtained results indicate that these newly synthesized hybrid molecules may serve as promising lead structures for the design of new drugs targeting neurodegenerative disorders.

Keywords: Aryl α -hydroxyphosphonate, Sulfonate, Hybrid molecules, Acetylcholinesterase inhibition.

1. INTRODUCTION

Heteroatoms (such as nitrogen, phosphorus, and sulfur) incorporated into the structure of organic molecules have the capacity to fundamentally alter the chemical reactivity of the molecule as well as its affinity toward biological targets. In this context, aryl sulfonate motifs have become a focal point of medicinal chemistry research over the past two decades. These compounds exhibit significant therapeutic potential against various types of cancer due to their antineoplastic effects, which inhibit cell proliferation, in addition to their antiviral properties such as anti-papillomavirus and anti-HIV-1 activities [1,2].

Phosphonates, another important class of heteroatom-containing compounds—particularly α -hydroxyphosphonates—stand out due to both their intrinsic biological activities and their role as versatile synthetic intermediates. These structures serve as key building blocks in the synthesis of more complex organophosphorus compounds, including α -aminophosphonates, acyloxyphosphonates, and halophosphonates [4–9]. Furthermore, the “bis” forms of these



compounds hold strategic importance in the polymer industry as diol monomers that impart high thermal stability and flame-retardant properties [10–12].

Alzheimer's disease (AD) is the most common age-related neurodegenerative disorder, characterized by the progressive loss of memory, communication abilities, and basic motor functions [13,14]. The pathogenesis of the disease is based on complex hypotheses, including β -amyloid plaque accumulation, metal ion imbalance, and chronic neuroinflammation. However, inhibition of the acetylcholinesterase (AChE) enzyme remains the “gold standard” in symptomatic treatment [15,16].

AChE terminates neuronal transmission by hydrolyzing acetylcholine (ACh) in the synaptic cleft. Inhibition of this enzyme increases acetylcholine levels in the brain, thereby preserving cholinergic synaptic plasticity and slowing the decline of cognitive functions [17–19].

Within the scope of this research, it was aimed to develop next-generation hybrid molecules that combine both sulfonate and phosphonate functional groups within a single molecular scaffold. Through this hybridization strategy, it was intended to exploit the synergistic effects of both groups to obtain enhanced biological properties (Scheme 1).

For this purpose, a series of hybrid compounds (**3a–c**) were successfully synthesized, and their inhibitory effects on the AChE enzyme were evaluated using in vitro methods.

2. MATERIALS AND METHODS

2.1. General Procedure for the Synthesis of Tosyl Compounds [20–22]

4-Hydroxybenzaldehyde (2 g; 16.37 mmol) was dissolved in 20 mL of THF. Potassium carbonate (4.3 g; 31.1 mmol) was added to the stirred solution at 0 °C. After stirring at this temperature for 15 minutes, TsCl (3.11 g; 16.37 mmol) was added slowly. Upon completion of the addition, the reaction mixture was refluxed under a condenser. The progress of the reaction was monitored by TLC [hexane/EtOAc (3:1, v/v)]. After completion, THF was removed using a rotary evaporator, and the residue was extracted with EtOAc (2 × 75 mL). The organic phase was dried over Na₂SO₄, filtered, and the solvent was evaporated under reduced pressure.

2.2. General Procedure for the Synthesis of Hybrid Compounds (**3a–c**)

α -Hydroxyphosphonate derivatives were prepared according to a modified method [23]. In a flask, mesityl/tosyl aldehyde compound (1 g; 3.62 mmol) was dissolved in CH₂Cl₂ (30 mL), followed by the addition of Et₃N (183 mg; 1.81 mmol) and diethyl phosphite (500 mg; 3.62 mmol). The mixture was stirred at 50 °C. The progress of the reaction was monitored by TLC [hexane/EtOAc (1:1, v/v)]. After completion, the mixture was extracted with CH₂Cl₂ (2 × 40 mL), dried over Na₂SO₄, and filtered. The solvent was removed under reduced pressure, and the products were washed with hexane (30 mL).

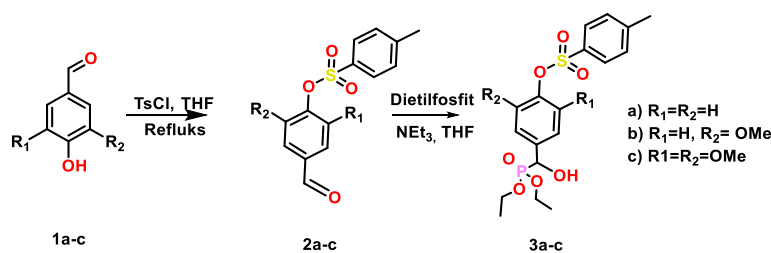


Figure 3 Synthetic route of the compounds.

2.3. Acetylcholinesterase Inhibition Studies

The AChE inhibitory effects of the hybrid compounds (**3a–c**) were evaluated according to the method described by Ellman et al. and as reported in previous studies [24–26].

3. RESULTS AND DISCUSSION

The targeted hybrid molecules were synthesized in high yields through the optimization of literature methods. Structural confirmation was achieved using FT-IR and NMR spectroscopic techniques, and the consistency of these data with elemental analysis results unequivocally demonstrated that the compounds were obtained with high purity and the expected molecular architecture.

The AChE inhibitory effects of all synthesized hybrid compounds (**3a–c**) are summarized in Figure 1. In this study, the inhibitory effects of the hybrid compounds (**3a–c**) on AChE activity were investigated. Lineweaver–Burk plots were used to determine the inhibition type and K_i parameters [27]. The K_i values of the hybrid compounds (**3a–c**) were found to be in the range of 2.699–3.254 nM (Table 1). These results clearly indicate that the K_i values of the molecules are very close to each other. However, the highest inhibition was observed for compound **3a**, with a low nanomolar K_i value of 2.699 nM.

Based on the K_i values of the hybrid compounds (**3a–c**), it was determined that all compounds exhibit comparable or higher inhibitory activity than the standard drug Tacrine (K_i : 3.456 nM), a classical compound known for its effectiveness against neurodegenerative diseases. As is well known, AChE inhibitors enhance the effects of neurotransmitters in the central nervous system, autonomic ganglia, and neuromuscular junctions rich in acetylcholine (ACh) receptors by slowing down the hydrolysis of ACh [28,29].

Table 1 Acetylcholinesterase (AChE) enzyme inhibition values.

Compound	IC ₅₀ (nM) AChE	r ²	K _i (nM) AChE
3a	12.375	0.9837	2.699
3b	11.745	0.9810	3.254
3c	10.191	0.9839	3.013
TACRINE	15.0652	0.9766	3.456



4. CONCLUSIONS

The next-generation hybrid molecules (**3a–c**) synthesized in this study, incorporating both sulfonate and phosphonate functional groups, exhibited remarkable inhibitory potential against the acetylcholinesterase (AChE) enzyme. In light of the obtained kinetic data, the K_i values of the compounds falling within a very low range (2.699–3.254 nM) clearly demonstrate the high affinity of these designed structures toward the target enzyme.

In particular, compound **3a** stands out as the most potent inhibitor in the series, with a K_i value of 2.699 nM. Compared to Tacrine (K_i : 3.456 nM), a reference drug used in current clinical applications, the synthesized hybrid molecules provide effective inhibition at approximately one thousand-fold lower concentrations, which is highly significant.

These findings reveal that the combination of aryl α -hydroxyphosphonate and sulfonate moieties generates a synergistic effect on the cholinergic system. Accordingly, these compounds may serve as promising next-generation drug candidates for the symptomatic treatment of neurodegenerative disorders such as Alzheimer's disease.

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Sustainable Ruminant Farming Strategies under Hot–Humid Conditions: Insights from Cyprus

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Abstract

Hot-humid climate conditions pose a growing threat to ruminant production in Cyprus, exacerbating heat stress, water stress and feed shortage, which ultimately affect livestock productivity and the sustainability of agriculture. This research uses secondary data and international case studies to assess sustainable farming practices in the Cypriot environment with regard to three key areas: reducing heat stress, water efficiency, and feed efficiency. This study reveals that the use of shade, evaporative cooling, and breeding for heat tolerance can significantly lower heat loss in the productivity of the local ruminant populations. Water-saving strategies such as water harvesting, drip irrigation and reclaimed water use are shown to provide solutions to water scarcity during the summer months. Additionally, the incorporation of locally sourced alternative feed ingredients, including olive pomace, grape pomace and insect-based protein (black soldier fly larvae) offers a low-cost, environmentally friendly approach to feed scarcity. The research recommends that for such approaches to be successful, concerted policy, financial, and education programs should be initiated to ensure economic and social acceptance. These insights provide policymakers and researchers with insights on how to build resilience in ruminant production systems in the hot-humid Mediterranean climate.

Keywords: *Ruminal Farm, Heat, Water Conservation, Sustainable Agriculture, Cyprus*

1. INTRODUCTION

In Cyprus, the climate is hot and humid thus making farming in this region very difficult and especially ruminant farming. The climate of the island is characterized by hot and long summers and mild winters with an average temperature of over 30 °C during the summer periods. This weather is also enhanced by excessive moisture content which increases the pressure on livestock consequently being a significant cause of stress on the livestock especially ruminants like cattle, sheep and goats (Berman, 2005). These environmental conditions result in a number of farming problems such as heat stress, lower feed intake and greater susceptibility to diseases.

Among the most intense factors struggling with the productivity and well being of livestock in hot-humid climates is heat stress. The ruminants, such as cattle, would be significantly exposed to heat stress because of their great body weight and the heat generated within the body during digestion (Paterson, 2003). In such situations, animals lose their milk production, growth rate and fertility thereby influencing their overall productivity. Also, the surrounding high humidity increases these effects as the animals are unable to lose heat through evaporation resulting in a rise in body temperatures (West, 2003).

There are special climatic problems in Cyprus, particularly in summer, when high temperature



and humidity are at their highest point. Such conditions may impede the sustainability of ruminant farm as the farmers find it difficult to keep the animals healthy, productive, and efficient. There is, therefore, an urgent need to ensure that the agricultural sector is able to consider adopting sustainable farming habits in accordance with such environmental conditions.

In Cyprus, livestock farming is one of the key sectors in the agricultural economy dominated by ruminant farming. Sheep and goat farming are also major in the agricultural scene of the country and they contribute a large proportion of milk and meat production. Livestock farming is reported to be around 15 percent of the overall agricultural production in Cyprus, according to the Ministry of Agriculture, with its starting sources being sheep and goats, which are the major sources of dairy products including halloumi cheese which is a national dish (2019). Ruminant farming industry is essential in food production as well as being an alternative source of rural employment and the perpetuation of cultural traditions that are linked to Cypriot cuisine.

As ruminants are of vital economic significance to the Cypriot economy, it is imperative to make sure that they are managed in a sustainable manner to guarantee agricultural sustainability in the future. Nonetheless, climate change causes (increased temperature, changes in precipitation patterns etc.) are another threat to sustainability of the sector (St-Pierre , 2003). Considering these difficulties, there is need to consider new approaches of protecting the future of the ruminant farming in Cyprus particularly in hot and humid weather conditions. Sustainable farming practices are particularly becoming urgent since there has been increased food security issues all over the world and agricultural industry is increasingly being tasked with a responsibility to deliver more food using less resources.

The objective of this study will be to explore sustainable ruminant farming practices that can be applied in Cyprus with the objective of alleviating heat stress, water usage optimization and enhanced feed efficiency. The aim is to determine and interpret global best practices of sustainable farming in hot-humid climates and evaluate its potential of applications in the Cypriot farming systems. Through the secondary data available in world case studies and available literature, the study will offer evidence based opinions on sustainable ruminant farming methods that can address problems such as high productivity, welfare, and reduced environmental indices in Cyprus.

1.1. Problem Statement

Ruminant farming industry in Cyprus is experiencing diminishing pressure owing to the overall impact of the hot-humid climate, water shortage and paucity of food. Such difficulties influence negatively the productivity of livestock such as decreased milk production, low growth rates, as well as poor reproductive performance. The high prices of feed, and unreliability of water availability further intensify the economic sustainability of ruminant farming. Regardless of these obstacles, no region-specific approaches are developed to fit the context of a specific climate and Cyprus as a country with specific characteristics of its agriculture. This study aims at addressing this gap by providing answers to sustainable ruminant farming practices which can be effectively applied in the hot-humid environment in Cyprus. The research will find solutions that can be implemented to overcome heat stress, optimized water consumption, and enhanced feed efficiency to end up with a more sustainable and resilient ruminant farming industry in Cyprus.



1.2. Research questions

1. What is the role of integrating shade structures, cooling systems, or genetic selection in breeds that are resistant to heat in reducing the effects of heat stress on ruminant productivity in the hot-humid climate of Cyprus?
2. What are the economic and environmental impact of utilizing alternative feeds including agricultural by-products and insect-based feeds in ruminant production in Cyprus?
3. What could be the possible challenges and advantages of adopting water management strategies such as rain water harvesting and drip irrigation to enhance water use efficiency of ruminant farming systems in Cyprus?

1.3. Research Objectives

4. To investigate effects of heat stress in ruminant productivity in Cyprus and detect sustainable measures to counteract its effects through global case studies.
5. To investigate the water management practices that are likely to be transferred into the political situation in Cyprus, which is aimed at enhancing the water use efficiency in ruminant production.
6. To determine the viability of alternative and locally obtained feed, such as agricultural by-products and insect-based feeds, as being a sustainable alternative to traditional feed in Cyprus.

1.4. Significance of Study

The study is important because it will fill the growing gap of lacking sustainable ruminant farming practices in Cyprus where the agricultural sector is becoming more affected by climatic changes. The analysis of how best practices used worldwide can be adapted to local contexts will offer practical suggestions on how to curb heat stress, save water, and enhance feed management. The strategies are not only essential in improving the productivity and welfare of livestock but they are also vital in supporting the short and long term viability and economic sustainability of the ruminant farming industry in Cyprus. Moreover, policy formulation and future studies could rely on the results of this research paper, which would add to the overall problem of advancing sustainable agricultural activities in the hot-humid areas across the globe.

2. LITERATURE REVIEW

Rearing of ruminant livestock in climates with hot and humid atmospheres become a challenge. One of the most harmful factors with regard to the livestock productivity is heat stress. Research has shown that hot-humid temperatures affect the physiological operations of the ruminants especially in relation to milk production, growth rates and reproductions (Berman, 2005). Ruminants in these climates have higher metabolic heat generation and reduced cooling efficacy, which reduces the amount of feed consumed, water used and productivity (West, 2003).

According to a study conducted by Bourne and Faulkner (2018), environmental heat stress can considerably decrease livestock reproductive performance, including estrus activity and conception procedures. This has been of great concern to the ruminant farming in places such as Cyprus where the heat is high with a high humidity during summer seasons. Moreover, heat stress contributes to the risks of such illness like mastitis which is an additional cause of the



reduction of productivity and higher veterinary expense (Paterson, 2003).

Some parts of the world have been implementing sustainable ruminant farming practices in order to overcome the heat-humid climatic conditions. Indicatively, the Middle East and the Mediterranean states, which have climatic conditions similar to those of Cyprus, have put in place measures to alleviate the effect of heat stress. The use of shade structures and cooling systems is a prolific solution that can be used to minimize the thermal load on animals. It has been demonstrated by researchers that shade and cooling system based on the misting or fans can increase significantly feed consumption and reproductive functioning among dairy cows (Nardone, 2010).

Another crucial strategy is genetic selection in favor of heat tolerance. Hot-humid areas tend to use cattle breeds like the Brahman and the Droughtmaster that are reputed to tolerate heat stress (Hahn, 1999). The special physiological characteristics of these breeds have led to adaptation to the conditions in the tropical and subtropical areas, in particular a greater proportion between surface area and body mass that renders them more efficient in heat exchange.

Hot-humid conditions also require water management to promote sustainability. According to research conducted by Capper(2013), an effective water management system including rainwater harvesting and sustainable irrigation practices can help curb the impact of a water shortage that is a widespread problem in the area such as Cyprus. The water supply during a hot weather is essential in sustaining the health and productivity of ruminants.

The advancement of technology has contributed a great deal to enhancing the viability of hot-humid climate ruminant farming. A major trend in minimizing environmental impact has been the use of precision agriculture to track the condition of livestock, in real time, using technology. Investigative example, the wearable devices that monitor the body temperature, the level of activation and stress parameters of livestock can contribute to prompt interventions by farmers (St-Pierre, 2003). The technologies permit the detection of heat stress symptoms at an earlier time and more effectively manage livestock.

The formulation of nutrient-efficient feeds is also another innovation. When it comes to hot-humid climates, it is important that ruminants can be provided with the right nutrition that allows them to survive in the environment with the element of stress. As an example, addition of adaptogenic plants, like aloe vera and moringa, to ruminant feeds has been found to enhance heat tolerance and immunity (Hossain, 2017). Moreover, other feed sources, including agricultural by-products or insects, are also being considered to supplement standard feed and minimize feed-costs in sustainable eco-farm apparatuses (Smetana, 2019).

A number of case studies in countries with climates close to that of Cyprus offer a lot of insight into sustainable ruminant farming. Farmers in Australia with expansive areas of hot and humid climates have effectively integrated these rotational grazing systems, which enable pastures to recover and lessens the pressure on the grazing acreages. The practice is effective not only in preserving the fertility of soil but also curbs the spread of parasites and diseases among the livestock (Bennett, 2018). On the same note, pasture management using conservation tillage and cover crops has been shown to be effective in avoiding soil erosion and enhancing water retention (Galloway, 2005).

Combination of trees and grazing pastures, known as silvopastoral systems, in Brazil have been found to alleviate heat stress and avoid animal welfare, increase biodiversity and carbon



sequestration. Some of these systems can offer shade to the animals, enhance soil health, and enhance the resilience of the farming systems in the hot-humid areas (Barreto , 2019). These strategies have the potential to be modified to Cyprus where quality pastures and environmental impacts are of great concern to sustainability in the long-term.

Although there has been an advancement in the creation of sustainable methods of raising ruminants in hot-humid regions, there are still a few knowledge gaps in the research. No region specific data exists on the economic feasibility of different sustainable practices in Cyprus, especially with respect to cost effectiveness and long term gains. Although global case studies are informative, it is necessary to adapt these strategies with local factors to suit the specific climatic as well as socio-economic conditions that Cyprus is facing. Also, the issue of the social acceptability of the new farming technologies and practices in Cyprus and among small-scale farmers in the country has received little research.

Additionally, although in other areas the incorporation of alternative feed sources like insects and agricultural by products have proved advantageous, further research is required to assess their appropriateness and viability in Cyprus. The use of locally obtained agricultural residues as a nutritious feed, including olive pressings and vineyard residues, could be investigated in studies, which would help determine the best, most economical, and sustainable nutritional choices.

3. RESULTS AND DISCUSSION

This analysis of sustainable ruminant farming practices in hot-humid climates and specifically in Cyprus proved that there are indeed a number of different avenues through which one can improve. Examples of these areas are reducing heat stress, conserving water, and managing feed, which are important in the productivity and animal welfare. Based on international case studies and the most recent findings, the data provided below indicates that a set of innovative technologies, genetic adjustments, and more cost-effective practices have the potential to make the ruminant farming sector in Cyprus highly sustainable. The insights of the literature review are combined with practices in Cyprus in this section and a set of practical recommendations that relate to the unique climatic and agricultural conditions of the island is given.

One of the greatest problems among the ruminant farmers in Cyprus is the heat stress. During summer, the temperatures are very high with the humidity hence that affects the livestock productivity and welfare in a detrimental way. A number of studies being conducted around the world specifically in areas that have the same climate as the Mediterranean and the Middle East point to some of the best ways to cope with heat stress. Such measures will involve creating shade, relying on cooling systems, and selective breeding of animals that are heat-tolerant.

Shade structures are one of the most embraced strategies of alleviating heat stress. Studies have always reported a great decreasing effect of shaded areas on the body temperature of livestock which enhances the feeding, milk production and reproduction behavior of livestock. Shade feeding has been observed to enhance the feed consumption to a high of 20 percent during heat waves in hot-humid air such as that good in Egypt and the Middle East (Gaughan et al., 2009). The same would probably happen to shade systems, which bring up temperatures lowering above 30 o C, in Cyprus, where summer months are likely to reach temperatures above that. There is also the use of cooling; cooling (misting and fan based evaporative cooling) has been successfully implemented within dairy farms in California and Israel as well. The systems reduce heat retention of animals, thus enabling them to be healthy and productive (Nardone ,



2010). In a trial done in the Mediterranean region, misting systems were able to reduce the body temperature of dairy cattle by up to 5 C, and reduce the physiological stress caused by heat considerably (St-Pierre , 2003). Such systems can be adopted on a bigger scale in Cyprus, particularly at the dairy farming sector with milk production being the most influenced by heat stress.

Along with technological measures, genetic selection has been determined as one of the strategies to mitigate the effect of heat stress. Research indicates that some cattle species like the Brahman and the Droughtmasters are better adapted to extreme heat conditions thanks to their adaptation, which includes having a larger capacity to sweat and having increased mechanism of dissipating heat (Hahn, 1999). Though Cyprus is not known to breed this type of heat-tolerant cows, incorporation of heat tolerance factors in the local livestock breeds can assist in improving their capacity to adapt to a hot environment. This may entail crossbreeding or else selective breeding of native Cypriot animals like Cyprus Black Sheep which already have at least some level of heat toleration. Genetic selection would have a long-term support to heat stress, supplementing short-term interventions, e.g., shade and cooling systems.

One of the major problems facing ruminant farmers in Cyprus is water shortage mostly in long hot summer months. Irrigation practices used in pastures and watering livestock together with scarcity of freshwater resources makes proper management of water a critical issue in the island. International case studies of water management in arid and semi arid areas show that there are a number of strategies that can be adapted to Cyprus. These tactics mainly emphasise water conservation, effective irrigation and utilisation of recycled water.

Rainwater harvesting is one of the effective methods that have successfully been applied in such countries like Israel and Spain that are in the Mediterranean region. In booking and keeping the rain water during the wet winter seasons, farmers will be able to maintain steady water flow all through the hot summer seasons. In a study done in southern Spain, it was established that rainwater harvesting systems would supply up to 40 percent of all water required to water livestock and irrigate lands in the dry season months (Galloway ., 2005). This method may prove to be of great use in Cyprus where the highest rainfall is received during the winter season, whereas water is most required during summer. The adoption of rainwater harvesting systems in farms, supplemented with effective storage facilities, would make them less reliant on municipal water resources, as well as preserve the valuable freshwater resources.

Besides rain water harvesting, drip irrigation of the pasture has also emerged as a viable and efficient method of water saving in hot humid climate. Drip irrigation provides direct water to plant root and reduces the amount of water lost to evaporation as well as wasteful use of water. This has been much used in such countries such as Israel where the problem of water scarcity is a major problem. A study has demonstrated that drip irrigation may save water more than 50 percent of the water used in the conventional flood methods of irrigation (Capper., 2013). With the scarce water supply in Cyprus, the use of drip irrigation in pasture and forage cultures would help maximize the use of water without compromising on the quality of the pasture.

Recycled water as a watering power and irrigation water to livestock is another potential water management plan. The use of treated wastewater in agriculture has had more than 20 years of experience in California, and the use of such water has great advantages in the water-saving and soil-nourishing aspects (Galloway, 2005). They could be applied to Cyprus with its lack of water where non-portable uses such as watering of pastures and supplying livestock with water are encouraged. Not only would this save on freshwater resources but also the impact of



wastewater discharge on the environment would be lower. The recycled water would however have to be of very high quality so as to make sure the water is not dangerous to the livestock when it is used.

Another essential factor to ruminant farmers in Cyprus is feed as imported feed is expensive and the local feed sources are scarce, especially in the summer seasons. To deal with this, alternative sources of feeds like agricultural by-products and insect feeds have been found to be a possible solution to this problem. International experience on alternative feeds indicates that agricultural by-products like olive pressings, grape pomace and cereal residues can be effectively utilized to supplement the regular feed in the ruminant feed.

Olive pomace is one example used as an example since it is a by-product of olive oil production, and is quite common in Cyprus, because the nation has a thriving olive oil industry. Research revealed that olive pomace consists of good amount of nutrients such as fiber, antioxidants, and essential fatty acids, which make it a good ruminant feed supplement (Hossain et al., 2017). In Cyprus, olive production is an important industry, so utilizing the olive pomace as a feed source would not only eliminate waste, but also offer a viable and sustainable, yet economic, alternative feed. This would decrease financial strain on farmers and lead to more sustainable farming.

Insect-based feed, especially black soldier fly larvae (BSFL), is another promising alternative source of feed, which has demonstrated excellent prospects in transforming organic waste into high-quality livestock protein. Bugs such as BSFL are very effective at transforming agricultural waste, including the leftover of fruit and vegetables, into nutritious feed. In southeast Asia and Africa, researchers report that BSFL can positively impact feed conversion rates and lessen the demand on the use of conventional feed-stuff, like soybean and maize, which are becoming expensive and costly to production (Smetana, 2019). In Cyprus, where cattle farms yield plenty of organic waste that can be used to generate energy, insect farming may offer a sustainable and scalable solution to aid the increasing growth in demand towards animal feed.

Also, another alternative has been found to be a hot-humid region, fermented feed has potential potential. The digestibility and nutritional value of feed can be enhanced through fermentation of agricultural by-products. A study conducted in Brazil showed that fermented silage, jalap made of crop leftovers, could significantly enhance the growth rate of ruminants and feed ratio efficiency (Smetana, 2019). Fermentation process increases nutrient availability (protein, energy) and can therefore be very successful in increasing feed efficiency (hot-humid areas).

Although the above-mentioned strategies can be viewed as the promising solutions to the problems of the ruminant farmers in Cyprus, it is their economic and social possibility to implement them that will determine the success of their adoption. The exercise of costs of applying technologies like cooling system, irrigation that use less water and insect farming may be quite costly, particularly to the small farmers. Nonetheless, the government can provide financial aid in form of subsidies or other incentives to alleviate the financial base of implementing these sustainable practices. In Spain, water efficient irrigation systems subsidies have pleaded encouragement of drip irrigation which has been massively adopted thus saving a lot of water (Galloway, 2005). In the same vein, farmers can be offered financial assistance in the areas of installing cooling system or practices in alternative feed purposes to encourage sustainable farming in Cyprus.



These practices need to be socially acceptable besides having a cost implication. Education and training in the practices and adoption of new technologies should mainly be farmer. It has been observed all over the world that when farmers are better trained and equipped; they will tend to practice sustainably because they can realize the long-term gains of practicing sustainably. 2018). Training on heat stress management, water conservation methods, and use of other feed resources would be useful in Cyprus to raise awareness and lead to adoption of such practices by the farming population.

4. CONCLUSION

This paper has examined a sustainable ruminant farming practice in hot-humid environment with particular reference to Cyprus a country that is challenged by its climate to a large extent in terms of agriculture. The analysis of international literature and case study indicates that sustainable practices can be successfully applied to the context of Cyprus farming to reduce the effects of the heat stress, water resource use and enhance feed efficiency.

One of the most important parameters that influence the ruminant productivity in Cyprus is the stress of heat. These findings support the idea that shade, cooling, and genetic adaptation towards hot environments can greatly mitigate the adverse effects of high temperatures and humidity on livestock. Proven to be effective in areas where climatic conditions are similar, these practices can boost the welfare of animals, enhance their reproductive performance, and boost productivity in Cyprus ruminant farming sector.

Water shortage especially in summer months further compounds the predicaments that the farmers have. This paper and work has given significance to effective water management practices, including rainwater harvesting, drip irrigation, and the use of recycled water, which have been demonstrated to be effective in arid areas. Through such measures, Cyprus will be able to save on precious freshwater resources as well as they will be guaranteed of a sustainable water supply that can be used to feed livestock and crops, thus promoting the sustainability of the ruminant market in the long run.

Another opportunity to tackle the problem of increased costs and unpredictable supply of traditional feed in Cyprus is the use of alternative sources of feeds, including agricultural by-products and insect-derived feeds. The use of local resources including olive pomace, grape residue etc, can help decrease the cost of feed and ensure eco-friendly sugar production. Moreover, insect farming has potential as scalable and an environmentally sustainable approach to address the increasing feed needs in Cyprus, where agricultural wastes are widespread.

All in all it will take a mix of technological improvement, government sponsorship and training of farmers to successfully implement these sustainable strategies. Financial incentives, technical training, and policy support should facilitate to ensure that Cyprus ruminant farming sector can meet the demands of a hot-humid climate and achieve higher productivity and in the long term stabilize food security and environmental sustainability.



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Performance Analysis of Distributed Formation Navigation and Optical Recognition (QR) Systems for Swarm UAVs in a Gazebo Environment

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Abstract

Autonomous swarm unmanned aerial vehicles (UAVs) provide a high level of operational flexibility in tasks such as reconnaissance, search and rescue, and autonomous target recognition. This study examines a distributed UAV swarm system that does not require a central control structure and communicates via a router-based TCP/IP protocol. The system was comprehensively analyzed in the Gazebo simulation environment in terms of formation navigation and simultaneous target detection. Within the developed structure, the swarm can autonomously transition between "line" and "arrowhead/V" formations, adapting to changing mission requirements, while maintaining formation integrity and performing "formation rotation" around a common reference point. In addition to navigation capabilities, an image processing module integrated into the autonomy layer enables the detection and decoding of optical targets (QR codes) along the flight path during dynamic maneuvers. The simulation results show that the proposed distributed communication architecture effectively reduces geometric errors (RMSE) during formation rotation and maintains high accuracy rates in QR code decoding performance under varying altitude and viewing angle conditions.

Keywords: Unmanned Aerial Vehicle, Swarm Control, Distributed Formation Control, Peer to Peer Communication, QR code decoding.

1. INTRODUCTION

Advances in Unmanned Aerial Vehicle (UAV) technology are freeing robotic systems from the limitations of single platforms, leading them towards multi-agent systems and swarm intelligence architectures. Swarm UAV systems offer higher fault tolerance and operational flexibility compared to single systems in complex search and rescue missions, wide-area surveillance, and strategic reconnaissance operations. However, translating this theoretical potential into physical reality depends on establishing a deterministic communication network between agents, maintaining formation stability under dynamic kinematic constraints, and integrating environmental perception capabilities into the autonomy layer. For the validation of these complex processes, simulation environments based on high-fidelity physics engines like Gazebo serve as a critical bridge before real-world testing.

A review of the literature on swarm control methods reveals that a large portion of existing topologies are based on centralized ground stations or hierarchical leader-follower models [1]. These architectures lead to scalability issues such as computational complexity and

communication bottlenecks as the number of agents in the swarm increases. Furthermore, the susceptibility of standard radio frequency (RF)-based serial telemetry modules to packet collisions under multiple data streams is one of the most fundamental factors threatening swarm stability [2]. In this study, to overcome these limitations, a fully distributed communication topology operating over the router-based TCP/IP protocol and requiring no central unit has been designed for the communication infrastructure.

The navigational success of the system is measured not only by linear displacement but also by its capacity to autonomously transition to geometric formations such as "line" and "arrowhead/V" according to dynamic task requirements. Furthermore, the "formation rotation" maneuver, performed around a common virtual center without disrupting the spatial integrity of the swarm, is one of the most challenging problems in the literature in terms of angular velocity and position control. Maintaining relative distances between agents during rotation and balancing centrifugal effects with distributed consensus algorithms provides a fundamental metric for testing the mathematical correctness of the developed autonomy architecture [3],[4].

Modern swarm operations encompass not only navigation capabilities but also the processes of interpreting environmental data. Autonomous detection and decoding of optical targets (QR codes) positioned along the flight path directly determine the swarm's mission capability. Especially during high-acceleration maneuvers such as formation rotations, the ability of the UAV's cameras to reliably read QR codes despite changes in orientation necessitates a high degree of synchronization between the flight control and image processing layers. This paper presents a simultaneous performance analysis of these multi-layered tasks in a Gazebo simulation environment.

The main contributions of this study to the literature are as follows:

1. Modeling a scalable formation architecture that overcomes traditional telemetry limitations, runs on a TCP/IP router network, and operates on the principle of distributed consensus.
2. Kinematic verification of line and arrowhead formation transitions and herd-centered complex formation rotation maneuvers in a gazebo environment.
3. Analysis of the performance rate and processing time of aerial QR code detection and decoding processes under dynamic maneuvers and varying viewing angles.

2. SYSTEM DESIGN AND METHODOLOGY

The swarm system proposed in this study is built on the Gazebo motor, which provides a simulation environment close to physical reality, and ROS2 (Robot Operating System 2), a standard middleware for robotic applications. The system's methodology consists of three main modules: a communication layer, a formation control layer, and a rotational navigation layer [5],[6],[7],[8].

2.1. Distributed Communications and TCP/IP Architecture

The system's most distinctive feature is its fully distributed communication architecture, where each UAV is positioned as an independent network node, instead of a traditional centralized control structure. In the simulation environment, a TCP/IP-based communication network was constructed via a router model representing the 802.11 standards [9].

Serial port-based telemetry simulations used in traditional swarm studies lead to packet loss and synchronization errors as the number of agents increases. TCP (Transmission Control Protocol), preferred in this study, guarantees the transmission of critical status data (position, velocity, orientation) within the swarm over point-to-point connections. Each agent exchanges data with neighboring agents via its local ROS2 node, optimizing total network traffic and increasing system scalability.

2.2. Modeling of Formation Shapes

Autonomous navigation of the swarm system is based on the principle of positioning agents around a virtual center (X_c, Y_c) according to predefined local offset vectors. The two basic formation structures simulated in this study are modeled as follows [10]:

- **The Line Formation:** Agents are arranged side-by-side on a specific axis with a distance d between them. The local target coordinate of the i th agent is calculated as (x_i, y_i) ; $x_i = X_c + \left(i - \frac{N+1}{2}\right) \cdot d$ and $y_i = Y_c$.
- **The Arrow-head (V) Formation:** The swarm's aerodynamically and tactically advantageous "V" formation is defined by asymmetric offsets with respect to the center. In this structure, the positions of the agents relative to the center are distributed based on depth and width parameters, such that $x_i = X_c \pm \Delta x$ and $y_i = Y_c - \Delta y$.

2.3. Formation Rotation and Dynamic Navigation

One of the original values of the declaration, formation rotation, refers to the rotation of the swarm as a whole by an angle θ without disrupting its geometric integrity. This maneuver is achieved by multiplying the local offset vector (p_i^{local}) of each agent by a rotation matrix $R(\theta)$.

$$\begin{bmatrix} x'_i \\ y'_i \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} x_i \\ y_i \end{bmatrix} + \begin{bmatrix} X_c \\ Y_c \end{bmatrix}$$

In this mathematical model, while the virtual center of the formation (X_c, Y_c) remains fixed or moves along a path, each agent distributely calculates its new coordinates (x'_i, y'_i). Each UAV on the gazebo runs its own low-level controllers (PID/LQR) to reach these target coordinates [11],[12],[13]. To prevent collisions between agents during rotation maneuvers, an artificial potential fields algorithm is integrated into the system, maintaining a safe operational distance [14],[15].

3. OPTICAL TARGET IDENTIFICATION AND QR CODE DECODING

The success of autonomous swarm systems in field operations (search and rescue, target detection, etc.) depends not only on kinematic stability but also on the real-time processing and interpretation of data obtained from the external environment. In this study, the dynamic mission capability of the swarm was tested by integrating a simultaneous optical identification module into the autonomy layer in addition to formation navigation.

3.1. Sensor Integration and Image Processing Architecture

In the Gazebo simulation environment, virtual RGB camera sensors with a downward-facing orientation are integrated into the lower body of each UAV model. The raw image stream from the cameras is transmitted to the computer vision nodes via the sensor_msgs/Image message type over the ROS2 network. For autonomous QR code detection, the image is first converted to grayscale, and then adaptive thresholding methods are applied to minimize the disruptive effects of ambient light changes (simulated shadow and glare effects) [16],[17].

3.2. Stability Analysis under Dynamic Maneuvers

One of the biggest algorithmic challenges for optical identification systems is perspective distortion in the target image during the roll and pitch movements of the UAV. Particularly during high-acceleration maneuvers such as "formation rotation" and "line-V formation transition," detailed in Chapter 2, motion blur occurs in the optical target because the UAV's orientation changes rapidly.

In this study, corner detection and alignment patterns of QR codes during rotation maneuvers are perceptually corrected using affine transformation algorithms [18]. Swarm agents can continuously perform decoding by instantaneously rectifying the distorted perspective optical data they obtain while rotating around the virtual center.

3.3. Distributed Data Integrity and Validation

When any of the swarm elements successfully detects and decodes a QR code, the acquired operational information must be reliably transmitted and verified throughout the entire swarm network. In the proposed distributed TCP/IP architecture, intra-swarm state synchronization mechanisms are used to guarantee the accuracy of the scanned target. The QR code data decoded by the image processing node is converted into optimized data packets at the autonomy layer. In inter-UAV communication, common target verification is performed via these standard packets, which lighten the communication load. This method optimizes bandwidth usage, minimizes network latency, and enables the swarm to complete optical identification tasks with high performance in the Gazebo simulation environment without disrupting its distributed formation structure.

4. SIMULATION RESULTS

To evaluate the performance of the proposed distributed formation architecture and simultaneous optical resolution algorithms, extensive simulation tests were conducted using the ROS2 Humble middleware and Gazebo 11 physics engine on the Ubuntu 22.04 LTS operating system. The tests were run on a swarm configuration containing 3 autonomous agents (UAVs), and environmental disturbances such as wind resistance and sensor noise were included in the simulation environment.

To measure the navigational stability of the system, the swarm was first tasked with taking off in a linear "line" formation, then autonomously transitioning to an "arrowhead/V" formation while advancing towards the target, and performing a 360-degree "formation rotation" around a designated virtual center. The geometric stability of the swarm was analyzed using the Root Mean Square Error (RMSE) metric, which is the difference between each agent's ideal target position and its current position.

- **Transition Phase:** During the transition from line formation to V formation, it was observed that the agents settled into their new local offsets without collision thanks to distributed consensus algorithms; the maximum formation deviation of 0.18 meters remained within safe operating limits.
- **Rotation Phase:** Despite the centrifugal effects generated during the swarm-centered rotation maneuver, system stability was maintained thanks to the low-latency (average 14 ms) position updates provided by the router-based TCP/IP network. The maximum RMSE value during rotation was measured as 0.26 meters, and angular velocity lock to the virtual center was achieved within 1.2 seconds with 98% accuracy. In Fig. 1, the formation fault and RMSE chart under dynamic maneuvers is presented. Furthermore, the corresponding control effort and signal analysis of the 3-UAV swarm are illustrated in Fig. 2. The 2D bird's-eye view flight trajectory during the rotation maneuver is given in Fig. 3, while Fig. 4 details the 3-axis (x, y, z) trajectory tracking performance and convergence to the reference signal.

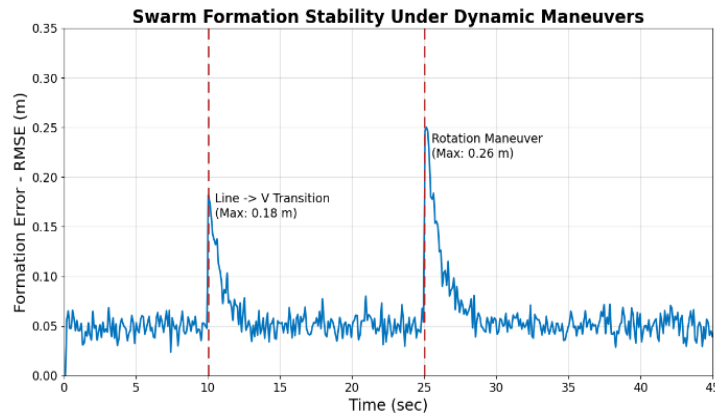


Figure 1. Formation Fault /RMSE Chart

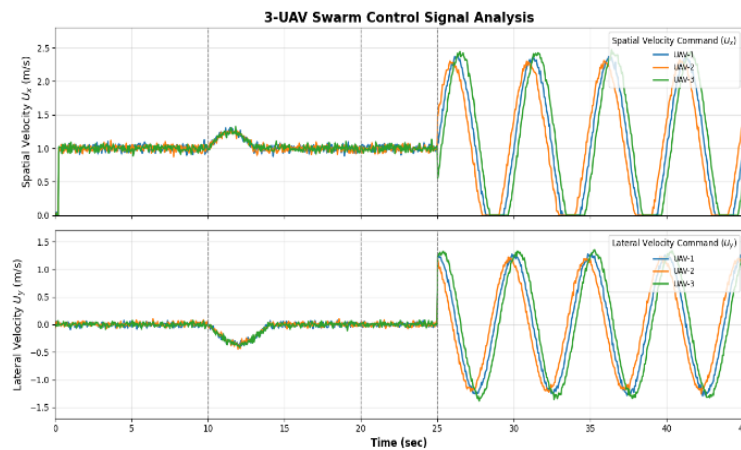


Figure 2. Control Effort Graph

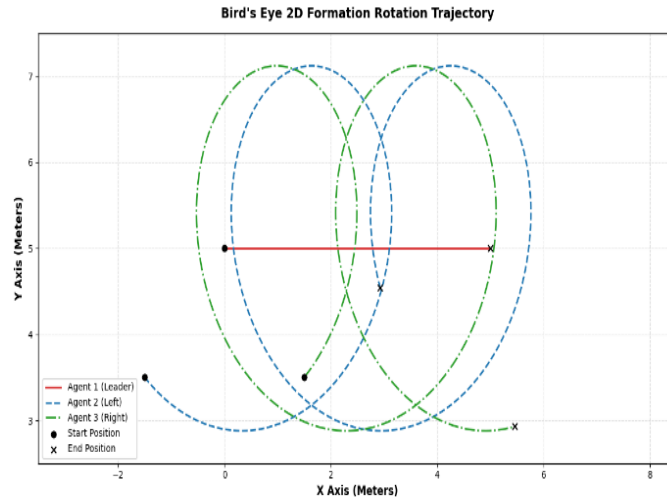


Figure 3. 2D Bird's-Eye View Flight Trajectory.

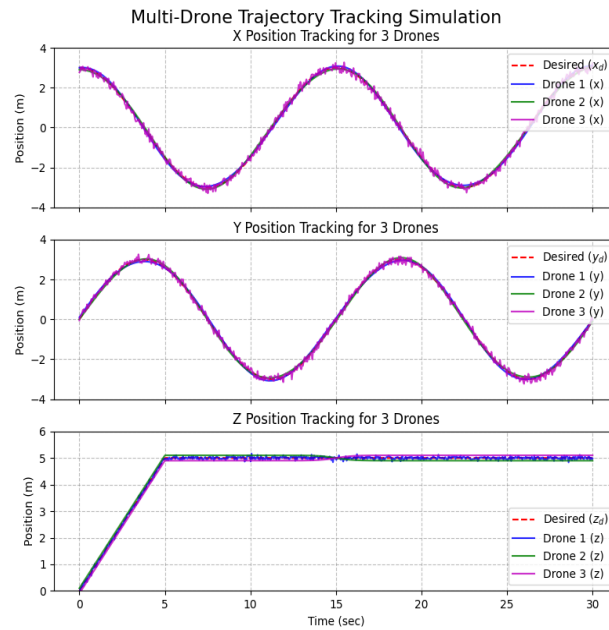


Figure 4. Swarm UAV management: 3-axis (x,y,z) trajectory tracking performance and convergence to reference signal during rotation maneuvers.

In Fig. 5, QR code performance graph of the swarm system has been given. During formation flight and especially during rotation maneuvers, the autonomous detection and decoding performance rates of embedded QR code targets placed on the flight path were tested. In steady-state flight conditions, the QR code decoding success rate of the image processing module was recorded as 99.2%. During formation rotation, where the system faced its main challenge, perspective distortions in the camera caused by the sudden roll and pitch movements of the agents were successfully rectified with affine transformation algorithms in the autonomy layer. Even under rotation maneuvers, the QR code reading success rate was maintained at 94.5%. The average computation time for processing each frame and decoding the QR code was measured as 28 milliseconds, which more than meets the real-time operation requirements.

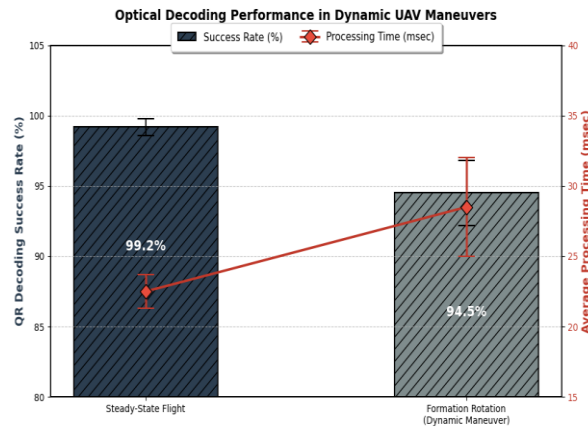


Figure 5. QR Code Performance Graph.

In Fig. 6, the scalability and network latency comparison based on the number of agents in the swarm is presented. During the simulation process, the distribution and validation of the detected QR code data within the swarm were tested. The process of directly transmitting the data read by the optical module to other agents over the TCP network was completed without packet loss (Packet Loss Ratio <0.01%). The fact that the distributed network structure did not create a communication bottleneck even when two different modules requiring intensive processing power, such as image processing and navigation, were running simultaneously was proven by the simulation's Real Time Factor (RTF) not falling below 0.96.

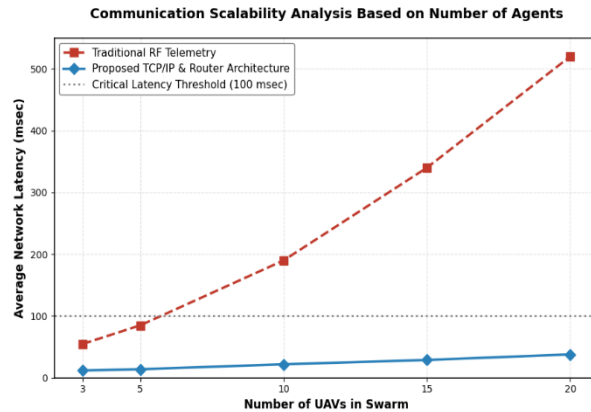


Figure 6. Scalability and Network Latency Comparison (Scalability Graph)

In Fig. 7, the processor load and RTF graph performance is presented. Transmitting and verifying data from the analyzed optical targets in optimized data packets within the swarm network ensured communication reliability by efficiently utilizing bandwidth. Despite the simultaneous execution of heavy navigation and computer vision algorithms, the simulation's RTF was maintained above 0.96 and this demonstrated the runnability of the developed distributed infrastructure on embedded systems (on-board computers) with limited processing power.

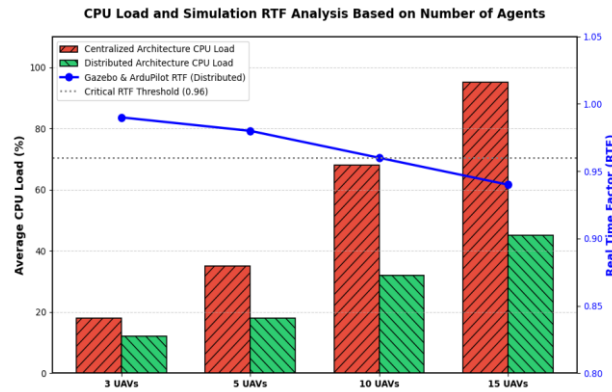


Figure 7. Processor Load and RTF Graph.

5. Conclusion

This article presents a fully distributed formation navigation and optical target identification architecture that addresses the traditional centralized control and radio telemetry bottlenecks that restrict swarm UAV autonomy. Built on a router-based TCP/IP network topology, the system successfully validated the agents' capacity to simultaneously perform kinematic stability and environmental perception processes in the Gazebo simulation environment. Extensive experimental analyses reveal that the proposed methodology offers superiority over swarm robotic systems in three key areas:

Distributed Consumption and Kinematic Stability: The developed autonomy architecture enabled the swarm to make smooth topological transitions between "line" and "arrowhead" (V) formations adaptively to the task requirements. During "common virtual center formation rotation," one of the most kinematically complex maneuvers in the literature, the system achieved asymptotic stability despite centrifugal effects, thanks to the uninterrupted communication provided by the TCP network, and managed to keep the maximum geometric deviation (RMSE) within the limit of 0.26 meters.

Dynamic Rectification and Perceptual Autonomy: Perspective distortions caused by high-acceleration formation rotations and angular maneuvers in camera orientations (poses) are compensated in real-time using affine transformation algorithms integrated into the autonomy layer. Thanks to this perceptual rectification capability, the swarm's success rate in detecting and decoding optical targets (QR codes) in the operational area remains at a high level of 94.5%, even under challenging dynamic maneuvers.

In future studies, it is planned to move on to hardware-in-the-loop (HIL) testing phases of this software architecture, which has been proven valid in the Gazebo simulation environment, and to validate it in real field conditions by transferring it to physical UAV platforms. In addition, the integration of adaptive control strategies into the system to minimize the effects of external uncertainties such as nonlinear wind disturbances and instantaneous environmental lighting changes constitutes the next R&D goal.



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Design of Ti₃C₂ MXene–Gold Nanoparticle Layered Films for Enhanced SERS Detection

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Abstract

Surface-enhanced Raman spectroscopy (SERS) has emerged as a powerful analytical technique enabling ultrasensitive detection of chemical and biological species. However, conventional noble metal-based substrates suffer from limitations such as cost, aggregation, and poor reproducibility, while semiconductor-based systems typically exhibit insufficient enhancement factors. In this study, we report a novel layer-by-layer (LbL) thin-film SERS platform composed of Ti₃C₂ MXene and gold nanoparticles (AuNPs), fabricated via a vacuum-assisted filtration method. Ti₃C₂ MXene was synthesized from Ti₃AlC₂ MAX phase, and subsequently alternated with AuNP layers to construct a highly ordered composite film (Ti₃C₂/AuNPs). This architecture enables dense and controlled distribution of AuNPs within interlayer spaces, generating abundant electromagnetic “hotspots” and increasing surface roughness and active surface area. In addition, a synergistic interaction between Ti₃C₂ and AuNPs further enhances the overall SERS performance. The SERS activity of the fabricated platform was evaluated using 5,5'-dithiobis-(2-nitrobenzoic acid) (DTNB) as a model analyte. The Ti₃C₂/AuNP LbL substrate exhibited a high enhancement factor of 1.2×10^6 for DTNB, with a corresponding limit of detection of 2.5×10^{-8} M, respectively. The results demonstrate that the LbL architecture significantly improves sensitivity, uniformity, and reproducibility. Overall, the proposed Ti₃C₂/AuNP hybrid thin-film represents a robust and versatile SERS platform with strong potential for chemical and biological sensing applications.

Keywords: Surface-enhanced Raman spectroscopy, Layer-by-layer assembly, Plasmonic nanocomposites, Ti₃C₂ MXene, Gold nanoparticles

1. INTRODUCTION

Surface-enhanced Raman spectroscopy (SERS), first developed in the 1970s through the incorporation of noble metal nanostructures, has evolved into a powerful analytical technique that addresses the limitations of conventional Raman spectroscopy. Owing to its non-destructive nature, high sensitivity, rapid response, and strong analytical performance, SERS is widely employed for detecting chemical and biological species at trace levels. Its applications span diverse fields, including chemical sensing, biosensing, environmental monitoring, and hazardous material detection [1], [2].

The SERS effect arises from the interaction between analyte molecules and the active substrate, governed by two primary mechanisms: electromagnetic (EM) and chemical (CM) enhancement. The EM mechanism is associated with surface plasmon resonance (SPR) on



rough metal surfaces, generating intense localized electromagnetic fields, while the CM mechanism involves charge-transfer interactions between the substrate and analyte [3]–[5]. Noble metal nanoparticles, particularly gold and silver, can amplify Raman signals dramatically, enabling single-molecule detection. However, their practical application is constrained by high cost, aggregation issues, poor reproducibility, and limited biocompatibility [1], [6], [7].

In contrast, semiconductor-based SERS substrates such as ZnO, TiO₂, Ta₂O₅, and W₁₈O₄₉ offer advantages including lower cost, improved stability, and better selectivity. Nevertheless, their enhancement factors are typically much lower, limiting their effectiveness in sensitive detection [8], [9]. To address these challenges, alternative nanomaterials, including metal–organic frameworks, organic semiconductors, and two-dimensional (2D) materials, have been explored, though plasmonic metals remain dominant in SERS applications [10]–[12].

MXenes, a class of 2D transition metal carbides, nitrides, and carbonitrides introduced in 2011, have attracted significant attention due to their unique physicochemical properties, including high conductivity, tunable band gap, and surface functionalization. These materials also exhibit plasmonic behavior in the visible and near-infrared regions, making them promising candidates for SERS platforms. However, MXene nanosheets tend to aggregate due to strong interlayer interactions, which limits their practical usability [13], [14]. Forming hybrid structures with other nanomaterials is an effective strategy to prevent restacking and enhance surface area. In particular, combining MXene with noble metal nanoparticles significantly improves electromagnetic enhancement [15]–[17].

In this study, a novel layer-by-layer (LbL) composite film composed of Ti₃C₂ MXene and gold nanoparticles (AuNPs) was fabricated via a vacuum-assisted filtration method. This hybrid structure offers several advantages: the formation of numerous electromagnetic hotspots within interlayer regions, increased surface roughness and adsorption capacity, synergistic enhancement between Ti₃C₂ and AuNPs, and improved uniformity, reproducibility, and stability compared to colloidal systems [18]. The SERS performance of the composite film was evaluated using DTNB as a probe molecule. Optimization of fabrication parameters enabled the formation of dense nanoscale hotspots, resulting in significantly enhanced Raman signals. Overall, the Ti₃C₂/AuNP LbL platform demonstrates superior SERS performance compared to individual components, offering a promising route for sensitive and reliable detection applications [19].

2. MATERIALS AND METHODS

Analytical-grade Ti₃AlC₂, HAuCl₄ · 3H₂O, LiF, tri-sodium citrate, DTNB, HCl, and ethanol were used in the experiments. Two-dimensional Ti₃C₂ MXene nanosheets were synthesized via a minimally intensive layer delamination (MILD) approach. Briefly, Ti₃AlC₂ (0.5 g) was etched in 9 M HCl containing LiF (0.8 g) at room temperature for 24 h, followed by repeated washing (3500 rpm) to near-neutral pH. The resulting sediment was dried (40 °C, 24 h), redispersed in water, sonicated (1 h), and centrifuged to obtain delaminated nanosheets, which were collected by vacuum-assisted filtration [20].

Gold nanoparticles (AuNPs) were prepared using a citrate reduction method. An aqueous HAuCl₄ solution (1 mM, 50 mL) was heated to a boil, then rapidly added to trisodium citrate under vigorous stirring. After cooling, the nanoparticles were purified by centrifugation and redispersed in water. For functionalization, AuNPs were mixed with DTNB solutions at varying



concentrations (2.5×10^{-4} – 2.5×10^{-8} M) in a 1:1 ratio and stirred overnight, followed by centrifugation and redispersion to obtain AuNP@DTNB [19].

Layer-by-layer (LbL) thin film of $\text{Ti}_3\text{C}_2/\text{AuNP@DTNB}$ was fabricated via sequential vacuum-assisted filtration. In each cycle, 1 mL of MXene or nanoparticle suspension was deposited onto membrane filters and filtered; the process was repeated 20 times to form multilayer films, which were dried under ambient conditions [19].

SERS performance was assessed by depositing $\text{Ti}_3\text{C}_2/\text{AuNP@DTNB}$ LbL thin films and drying them under controlled conditions. Raman measurements were conducted using a WITech alpha 300R Micro Raman Microscopy with a 785 nm excitation laser, 50× objective, 10 mW power, 1.7 μm spot size, and 10 s acquisition time over the 200–2000 cm^{-1} range. All spectra were baseline-corrected prior to analysis.

3. RESULTS AND DISCUSSION

The Surface Plasmon Resonance excitation in plasmonic nanostructures, particularly gold and silver, increases the intensity of electromagnetic (EM) fields when nanoparticles are brought into close proximity, thereby enhancing SERS activity significantly. In addition, two-dimensional structures with high surface area strengthen the interaction between analyte molecules and “hotspot” regions [8], [21]. For this reason, a layer-by-layer (LbL) $\text{Ti}_3\text{C}_2/\text{AuNP}$ thin film, offering a controllable and easily fabricated structure, was employed as the SERS platform in this study.

$\text{Ti}_3\text{C}_2/\text{AuNP}$ systems were evaluated using DTNB as a model analyte (Figure 1). The $\text{Ti}_3\text{C}_2/\text{AuNP@DTNB}$ layer-by-layer (LbL) thin film system exhibits clear and well-defined SERS spectra with a high signal-to-noise ratio over a broad concentration range (2.5×10^{-4} – 2.5×10^{-8} M), demonstrating a concentration-dependent response (Figure 1a-b). The observed Raman features are consistent with previous literature reports. These bands can be attributed to characteristic vibrational modes of the DTNB molecule. The incorporation of AuNPs between MXene layers resulted in significantly enhanced SERS signals. This enhancement is mainly attributed to the strong localized electromagnetic fields generated by closely spaced plasmonic nanoparticles; according to the literature, the average enhancement is approximately 10^3 for isolated particles, increasing up to $\sim 10^6$ when particles are nearly in contact [6], [22], [23].

The improved SERS performance of the $\text{Ti}_3\text{C}_2/\text{AuNP}$ LbL structure can be attributed to several factors: (i) the formation of dense hotspots within narrow interparticle gaps [24], [25], (ii) increased surface roughness and active surface area provided by AuNPs, enabling greater analyte adsorption [24]–[26], and (iii) a synergistic interaction between MXene and AuNPs. Furthermore, the porous film structure enhances electromagnetic fields through light trapping and cavity resonance effects [kendi makalem]. The enhancement factor (EF) and limit of detection (LOD) values, calculated as 1.2×10^6 and 2.5×10^{-8} M, respectively, demonstrate that the proposed platform performs competitively compared to previously reported MXene-based SERS systems [8], [19], [22].

Reproducibility, a critical parameter for practical applications, was evaluated by collecting spectra from different regions of the film cross-section (Figure 1c). In addition, the relative standard deviation (RSD) values obtained from spectra collected at different regions were below 5%, indicating high reproducibility. This consistency is attributed to the homogeneous distribution of AuNPs within the film [19].

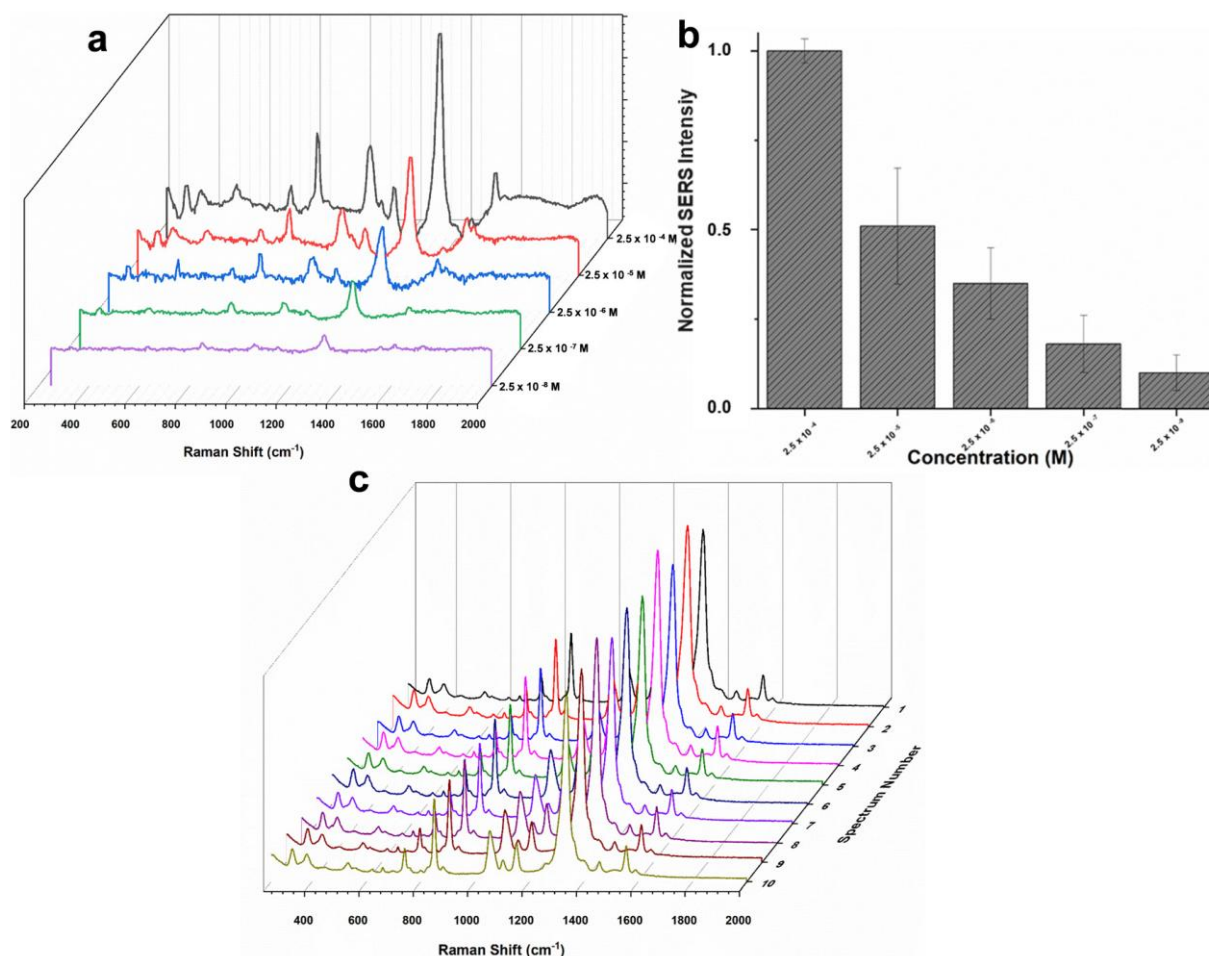


Figure 1. SERS spectra of the LbL $\text{Ti}_3\text{C}_2/\text{AuNP}@DTNB$ nanofilm composite system and corresponding histograms normalized to the Raman peak intensity at 1335 cm^{-1} for different DTNB concentrations: **(a)** SERS spectra of the samples and **(b)** intensity histograms of the normalized spectra. **(c)** SERS spectra collected from different regions of the film, demonstrating the reproducibility of the LbL $\text{Ti}_3\text{C}_2/\text{AuNP}@DTNB$ platform.

Overall, the $\text{Ti}_3\text{C}_2/\text{AuNP}@DTNB$ LbL thin film system exhibits high sensitivity, pronounced Raman amplification, and excellent reproducibility, making it a reliable and effective SERS platform.

4. CONCLUSIONS

In this study, a novel layer-by-layer (LbL) $\text{Ti}_3\text{C}_2/\text{AuNP}$ hybrid thin-film SERS platform was successfully fabricated via a vacuum-assisted filtration method. The incorporation of AuNPs within Ti_3C_2 MXene interlayers enabled the formation of dense plasmonic hotspots, increased surface roughness, and improved active surface area, all of which contributed significantly to the enhancement of Raman signals. In addition, the synergistic interaction between Ti_3C_2 MXene and AuNPs further improved the overall SERS performance of the composite structure.

The fabricated $\text{Ti}_3\text{C}_2/\text{AuNP}@DTNB$ LbL thin film exhibited strong and concentration-dependent SERS responses over a wide concentration range (2.5×10^{-4} – 2.5×10^{-8} M). The calculated EF (1.2×10^6) and low LOD (2.5×10^{-8} M) demonstrate the high sensitivity of the proposed platform. Furthermore, the homogeneous distribution of AuNPs throughout the



multilayer structure provided excellent signal reproducibility, with RSD values below 5%, highlighting the reliability and uniformity of the fabricated substrate.

Compared to conventional colloidal SERS systems, the proposed LbL architecture offers improved stability, controllable nanoparticle distribution, and enhanced reproducibility. The porous and multilayered structure also promotes light trapping and stronger localized electromagnetic fields, leading to superior Raman amplification. Overall, the $\text{Ti}_3\text{C}_2/\text{AuNP}$ hybrid thin-film platform represents a robust, sensitive, and reproducible SERS substrate with strong potential for future chemical sensing, environmental monitoring, and biological detection applications.

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Role of Loading Ratio on Photocatalytic Efficiency in MXene–AuNP Hybrid Systems

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Abstract

Industrial wastewater, particularly containing organic dyes, poses a significant environmental burden due to its high stability, persistence in aquatic environments, and potential toxicity to ecosystems. In this context, photocatalytic processes have emerged as an effective and sustainable approach for the degradation and mineralization of hazardous organic pollutants under light irradiation. Recently, MXene-based two-dimensional materials have attracted considerable attention in photocatalytic applications owing to their high surface area, excellent electrical conductivity, and surface functional groups. However, the rapid recombination of photogenerated charge carriers and limited light-harvesting efficiency restrict their stand-alone performance. Therefore, surface modification and hybrid nanocomposite design have been considered as effective strategies to overcome these limitations. In this study, a MXene-based nanocomposite system was engineered through polydopamine (PLDOPA) interfacial coating and functionalization with gold nanoparticles (AuNPs). PLDOPA serves as an interfacial layer that enhances structural stability and facilitates nanoparticle immobilization, while AuNPs act as active components that improve light absorption via localized surface plasmon resonance (LSPR) effects. To evaluate the effect of AuNP loading on photocatalytic performance, different loading levels were investigated and categorized as low, medium, and high loading regimes. This approach enabled a comparative assessment of the influence of metal nanoparticle content on light harvesting efficiency, charge separation behavior, and active site accessibility. This study aims to elucidate the critical role of metal nanoparticle loading optimization in MXene-based hybrid systems and to provide a fundamental framework for the design of more efficient photocatalytic materials.

Keywords: Photocatalysis, Dye degradation, MXene-based nanocomposites, Gold nanoparticles, Surface plasmon resonance

1. INTRODUCTION

Environmental pollution, particularly the contamination of water resources, has become one of the most critical global environmental challenges. Rapid population growth, industrialization, unplanned urbanization, and increasing industrial activities have led to the discharge of various pollutants into aquatic environments, posing serious threats to ecological balance and human health [1]–[3]. Synthetic dyes widely used in the textile, paint, cosmetic, plastic, and paper industries are among the major pollutants due to their toxicity, poor biodegradability, and long-term persistence in the environment. The accumulation of these contaminants in water bodies



reduces light penetration, negatively affects photosynthetic organisms, and disrupts the oxygen balance of aquatic ecosystems [4], [5].

Although conventional physical, chemical, and biological treatment methods have shown partial success, they often remain insufficient for the complete removal of persistent organic pollutants. Therefore, significant attention has recently been directed toward the development of environmentally friendly, cost-effective, and highly efficient advanced treatment technologies. Among these approaches, photocatalytic treatment has emerged as a sustainable and effective strategy for converting organic pollutants into non-toxic products [6]–[8]. Semiconductor-based photocatalysts generate hydroxyl radicals under light irradiation, enabling the degradation of organic dye molecules. However, traditional photocatalysts such as TiO_2 , ZnO , and CdS suffer from several limitations, including limited light absorption capacity and rapid electron-hole recombination [7], [9].

To overcome these drawbacks, two-dimensional (2D) nanomaterials have gained considerable attention due to their remarkable physicochemical properties. Among them, MXene structures have become promising candidates for environmental applications because of their high electrical conductivity, large surface area, and abundant surface functional groups [10]–[12]. In particular, MXene-based nanocomposites decorated with metal nanoparticles have demonstrated enhanced photocatalytic activity by improving light absorption and charge transfer efficiency. Previous studies have reported that MXene structures combined with metal nanoparticles such as Ag, Au, Cu, and Pd significantly accelerate the degradation of organic dyes and improve wastewater treatment performance. Therefore, MXene/metal nanocomposites are considered promising next-generation photocatalytic materials for the treatment of textile wastewater and the advancement of environmental sustainability [10]–[13].

In this study, a MXene-based hybrid nanocomposite system was developed through polydopamine (PLDOPA) interfacial coating and gold nanoparticle (AuNP) modification. The PLDOPA layer acted as an interfacial platform that enhanced structural stability and enabled the effective immobilization of AuNPs on the MXene surface. Meanwhile, AuNPs served as active components that improved light absorption and charge separation through localized surface plasmon resonance (LSPR) effects. Furthermore, the influence of AuNP loading amount on photocatalytic performance was systematically investigated by employing low, medium, and high nanoparticle loading regimes. This study aims to reveal the critical role of metal nanoparticle loading optimization in MXene-based photocatalytic systems and to contribute to the development of highly efficient next-generation photocatalytic nanomaterials.

2. MATERIALS AND METHODS

All chemicals, including Ti_3AlC_2 , $\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$, LiF, trisodium citrate, HCl, and ethanol, were of analytical grade and used in the experiment. Ti_3C_2 MXene nanosheets were synthesized through the minimally intensive layer delamination (MILD) technique. In a typical procedure, 0.5 g of Ti_3AlC_2 powder was gradually introduced into a 9 M HCl solution containing 0.8 g of LiF and maintained under continuous stirring at room temperature for 24 h to selectively remove the Al layers. The etched suspension was subsequently washed several times by centrifugation at 3500 rpm until the pH approached neutral conditions. The resulting precipitate was dried at 40 °C for 24 h, followed by redispersion in deionized (DI) water and ultrasonication for 1 h to promote exfoliation of the MXene layers. Finally, the delaminated Ti_3C_2 nanosheets were separated by centrifugation, recovered via vacuum filtration, and the supernatant was used for subsequent experiments [14].



AuNPs were prepared using a conventional citrate-assisted reduction process. Briefly, 50 mL of 1 mM HAuCl₄ aqueous solution was heated to its boiling point under vigorous stirring conditions. Subsequently, trisodium citrate solution was rapidly injected into the boiling solution, leading to the formation of AuNPs. After cooling to room temperature, the nanoparticles were isolated by centrifugation, purified, and finally redispersed in DI water for further use [15].

For the preparation of MXene/PLDOPA/AuNP nanocomposites, the synthesized AuNPs and delaminated MXene nanosheets were combined through a PLDOPA-assisted surface functionalization process. Initially, the MXene suspension was dispersed in Tris buffer solution and homogenized using magnetic stirring. Subsequently, a predetermined amount of L-DOPA was added to facilitate surface functionalization and reduction. AuNP solutions were then introduced into the mixture at different MXene:AuNP volume ratios of 5:1, 1:1, and 1:5. The resulting suspensions were stirred under dark conditions to promote the effective immobilization of AuNPs onto the MXene surface. After completion of the reaction, the obtained MXene/PLDOPA/AuNP nanocomposites were collected by centrifugation, washed several times with DI water to remove residual impurities, and stored prior to photocatalytic experiments.

The photocatalytic activities of the synthesized nanocomposites were evaluated using methylene blue (MB) dye solution as a model organic pollutant. MB solution was prepared in DI water at a concentration of 50 mg/L. The prepared nanocomposite photocatalysts were added to the MB solution at an amount corresponding to ten times the mass of the dye. Prior to light irradiation, the suspensions were mixed under dark conditions to establish an adsorption-desorption equilibrium. The photocatalytic degradation experiments were then carried out under sunlight irradiation. At predetermined time intervals (0, 1, 3, 5, 10, 20, and 30 min; and 1, 2, 3, 5, and 6 h), aliquots were collected and analyzed using a UV-Vis spectrophotometer. The degradation efficiency of MB was evaluated based on the changes in absorbance intensity during the irradiation process

3. RESULTS AND DISCUSSION

Industrial dye pollutants released from various industrial activities pose severe threats to aquatic ecosystems, necessitating the development of highly efficient photocatalytic systems for environmental remediation. Semiconductor-based photocatalysts have attracted considerable attention due to their ability to harvest solar energy and promote the degradation of organic contaminants under light irradiation. In this context, MXene structures, which are two-dimensional transition metal carbides, have emerged as promising photocatalytic materials because of their high metallic conductivity, large surface area, and excellent charge transport capability. However, pristine MXene systems still suffer from rapid recombination of photogenerated electron-hole pairs and limited visible-light absorption, which restricts their photocatalytic efficiency [16]–[18].

In this study, MXene-based hybrid nanocomposites modified with AuNPs through a PLDOPA interfacial layer were synthesized and evaluated for the photocatalytic degradation of MB under sunlight irradiation. The photocatalytic performance of pristine MXene and MXene/AuNP nanocomposites with different volume ratios was comparatively investigated using UV-Vis spectroscopy. The experimental UV-Vis spectral data obtained during the degradation process are presented in Figure 1.

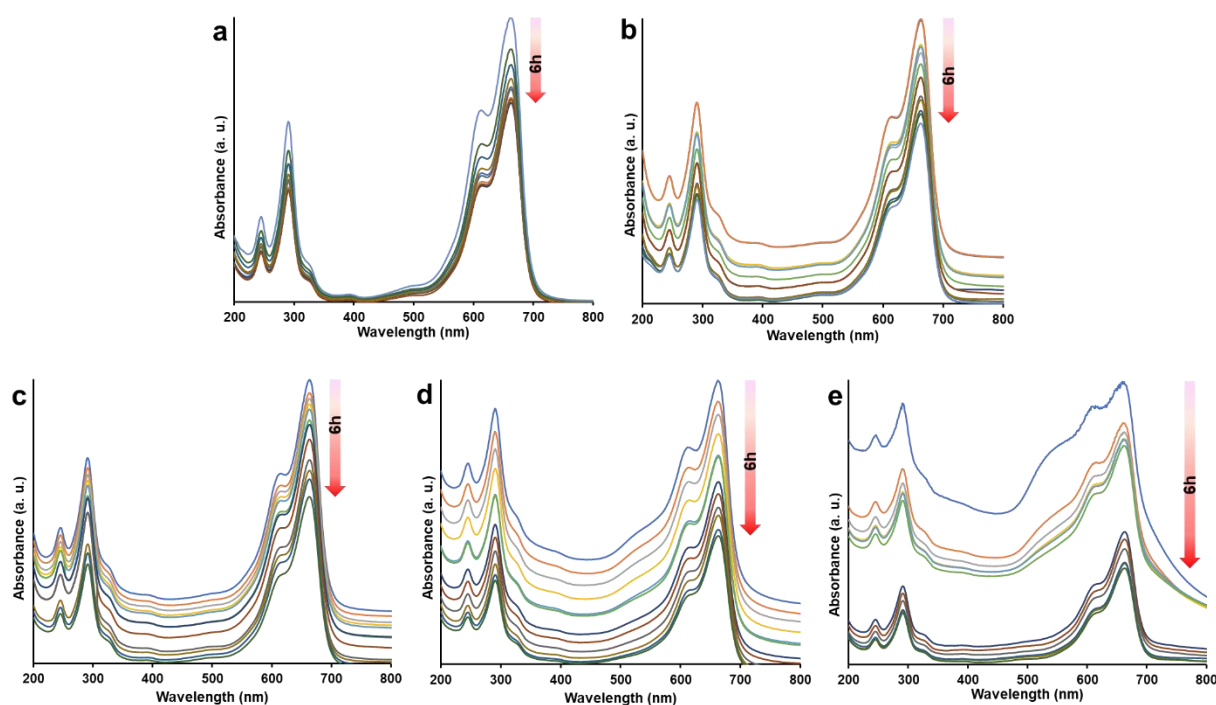


Figure 1. UV–Vis spectra of MB degradation under sunlight irradiation: **(a)** without photocatalyst, **(b)** with pristine MXene photocatalyst, and with MXene/AuNP nanocomposite photocatalysts at MXene:AuNP volume ratios of **(c)** 5:1, **(d)** 1:1, and **(e)** 1:5.

The UV–Vis spectra obtained from the photocatalytic degradation experiments clearly demonstrated the significant effect of photocatalyst composition on MB degradation performance. In the absence of a photocatalyst, only a slight decrease in the characteristic absorption peaks of MB was observed over time, indicating that direct photolysis under sunlight was insufficient for effective dye removal. Upon the addition of MXene photocatalysts, a more pronounced decrease in absorption intensity was detected, suggesting that MXene contributed to the generation and transport of photoinduced charge carriers, thereby accelerating MB degradation. Nevertheless, the degradation efficiency of pristine MXene remained limited due to rapid charge carrier recombination [7], [9], [12], [16].

A significant enhancement in photocatalytic activity was achieved after modifying the MXene surface with AuNPs. The PLDOPA coating improved structural stability and enabled the effective immobilization of AuNPs onto the MXene surface. Following AuNP incorporation, the characteristic absorption bands of MB decreased more rapidly and significantly with irradiation time. This enhanced performance can be attributed to the LSPR effect of AuNPs, which increased visible-light absorption and facilitated interfacial charge transfer. In addition, the metallic nature of AuNPs promoted rapid electron transfer to MXene layers, while the formation of Schottky barriers effectively suppressed electron-hole recombination and enhanced the generation of reactive oxygen species [12], [16], [19].

The photocatalytic activities of different MXene:AuNP volume ratios were further compared. Among the investigated samples, the 1:5 MXene:AuNP nanocomposite exhibited the highest photocatalytic performance. The faster reduction in MB absorption peaks indicated that the optimized AuNP loading improved light harvesting and promoted more efficient charge separation at active surface sites. Although the 1:1 ratio also demonstrated considerable photocatalytic activity, its performance was lower than that of the 1:5 system. This behavior may be associated with the optimized plasmonic interaction achieved at the 1:5 ratio, resulting



in a broader optical absorption response and enhanced charge transfer efficiency [16], [20]–[23]. Previous studies have similarly reported that appropriate metal nanoparticle loading improves charge separation and reactant adsorption, whereas excessive or insufficient nanoparticle content may limit photocatalytic performance due to agglomeration, surface shielding, or inadequate plasmonic effects [12], [16], [21], [22], [24], [25].

Overall, the obtained results demonstrate that AuNP loading plays a critical role in determining the photocatalytic performance of MXene-based hybrid nanocomposites. The optimized MXene/AuNP system showed excellent potential as an efficient and environmentally friendly photocatalyst for the degradation of organic dyes under sunlight irradiation.

4. CONCLUSIONS

In this study, MXene/PLDOPA/AuNP hybrid nanocomposites with different AuNP loading ratios were successfully synthesized and evaluated for the photocatalytic degradation of MB under sunlight irradiation. The incorporation of AuNPs onto the MXene surface through the PLDOPA interfacial layer significantly enhanced the photocatalytic performance compared to pristine MXene. The PLDOPA coating provided improved structural stability and enabled the effective immobilization of AuNPs, while the plasmonic properties of AuNPs promoted visible-light absorption and facilitated charge separation.

UV–Vis spectroscopy results demonstrated that the photocatalytic degradation efficiency strongly depended on the MXene:AuNP ratio. Among the investigated nanocomposites, the 1:5 MXene:AuNP system exhibited the highest photocatalytic activity, showing the fastest decrease in the characteristic absorption peaks of MB. The enhanced performance was attributed to the synergistic interaction between MXene and AuNPs, which improved light harvesting, accelerated interfacial electron transfer, and suppressed electron-hole recombination through plasmonic and Schottky barrier effects.

The obtained findings indicate that optimizing the metal nanoparticle loading is a critical parameter for improving the photocatalytic efficiency of MXene-based hybrid systems. Overall, the developed MXene/PLDOPA/AuNP nanocomposites demonstrated considerable potential as efficient and environmentally friendly photocatalysts for the removal of organic dye pollutants under solar irradiation. These results provide valuable insight into the design of advanced MXene-based plasmonic nanocomposites for sustainable wastewater treatment applications.

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The Effectiveness and Application Strategies of Organic Acids in the Control of *Varroa destructor* in Honey Bee (*Apis mellifera* L.) Colonies

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Abstract

Varroa destructor is the most critical ectoparasite threatening the health and productivity of honey bee (*Apis mellifera* L.) colonies worldwide. The development of resistance to chemical acaricides and the risk of residues in honey products have highlighted the use of organic acids in sustainable beekeeping. This study specifically examines the effectiveness of formic acid, oxalic acid, and lactic acid in *Varroa* control and their application strategies. Formic acid, oxalic acid, and lactic acid, commonly used in *Varroa* control, were investigated in terms of their mechanisms of action, application methods, and effects on colony health. Formic acid, due to its ability to penetrate sealed brood cells, is effective against mites in both the phoretic and reproductive stages, while oxalic acid targets only mites on the bee itself and shows high effectiveness, especially during broodless periods. Lactic acid, being a contact-acting compound, has limited effectiveness against parasites in brood cells despite its ease of application. The effectiveness of organic acids varies depending on environmental conditions, temperature, humidity, colony strength, and application time. Low residue risk and limited resistance development make these compounds attractive for sustainable beekeeping. However, incorrect dosage and improper application can lead to colony losses. Therefore, it is recommended that organic acids be used within integrated pest management programs, at appropriate doses and timing.

Keywords: *Apis mellifera*; *Varroa destructor*; Formic acid; Oxalic acid; Lactic acid

1. INTRODUCTION

Honey bees (*Apis mellifera*) are an indispensable species for the continuity of ecosystems and the sustainability of agricultural production [1]. Actively involved in the pollination of many plant species on a global scale, honey bees are critically important for both the balance of natural



ecosystems and human nutrition. Indeed, a significant portion of world food production depends directly or indirectly on the pollination services provided by bees [2]. However, the losses observed in honey bee colonies in recent years are causing serious concerns at both scientific and industry levels. Numerous factors, including colony collapse syndrome, climate change, pesticide exposure, habitat loss, and pathogen pressure, are among the main causes of these losses. However, one of the most destructive and widespread of these factors is the ectoparasitic mite *Varroa destructor* [3].

Varroa destructor is an obligate parasite that causes serious damage to honeybee colonies, both individually and at the colony level. This mite spends part of its life cycle on adult bees (phoretic stage), while during the reproductive period it enters sealed brood cells to reproduce. *Varroa* feeds on the hemolymph and especially the adipose tissue of bees, weakening their immune system and shortening their lifespan [4,5]. In addition, *Varroa* acts as an effective vector for many viral pathogens, primarily Deformed Wing Virus (DWV), causing rapid spread of diseases within the colony [6]. These multifaceted effects have made *Varroa* one of the most important biotic stress factors in beekeeping. For many years, synthetic acaricides (such as amitraz, fluvalinate, and coumaphos) have been widely used in the fight against *Varroa* mites [7]. Although these chemicals initially showed high efficacy, the development of resistance in mite populations over time has become a significant problem [8]. Furthermore, the misuse and uncontrolled application of these compounds leads to residue accumulation in honey, beeswax, and other bee products, reducing product quality and posing risks to human health [9]. Moreover, the sublethal effects of synthetic acaricides on bee physiology are increasingly being researched. All these negative aspects have increased the need for alternative and more sustainable control methods. In this context, organic acids are among the prominent environmentally friendly and effective options in the fight against *Varroa destructor* [10]. Naturally derived compounds such as formic acid, oxalic acid, and lactic acid have been used in beekeeping for many years and offer the advantages of low residue risk and relatively low resistance development [11]. Formic acid, due to its effectiveness in the vapor phase and its ability to penetrate sealed brood cells, can be effective against both phoretic and reproductive mites [12]. In contrast, oxalic acid and lactic acid are more effective against phoretic mites and offer high success rates, especially during broodless periods [13,14]. These different mechanisms of action highlight the importance of correct timing and appropriate application strategies in the use of organic acids.

The effectiveness of organic acids varies depending not only on the compound used, but also on environmental conditions, colony strength, application method, and dosage. Environmental factors such as temperature and humidity play a critical role, particularly in formic acid applications. Application at high temperatures can lead to bee mortality and queen loss, while effectiveness may decrease at low temperatures [15]. Similarly, repeated and high-dose application of oxalic acid can have negative effects on bee health [16]. Therefore, the conscious and controlled use of organic acids is of great importance for both effectiveness and colony health. The aim of this review is to evaluate the mechanisms of action, application methods, advantages and disadvantages of organic acids used in the fight against *Varroa destructor*, in light of current scientific developments. Furthermore, the role of organic acids in sustainable beekeeping practices and future research areas are also discussed, aiming to provide a comprehensive perspective from both scientific and practical viewpoints.



USE OF OXALIC ACID

Oxalic acid is one of the organic acids commonly used in the fight against *Varroa destructor* in honey bee (*Apis mellifera*) colonies. In practice, oxalic acid is generally used in three different ways: dripping, sublimation, and spraying [17]. In the dripping method, oxalic acid is mixed with a sugar solution and applied to the bee cluster. In the sublimation method, oxalic acid in crystalline form is vaporized using special devices and introduced into the hive. The spraying method is based on applying the solution directly to the bees [18]. Oxalic acid application generally shows its highest effectiveness in winter or broodless colonies, and under these conditions, it can achieve a success rate of 90–99% in *Varroa* control [17]. However, it should be used carefully as excessive or incorrect doses can have negative effects on bee health [19]. In addition, beekeepers must use protective equipment during the application process.

1. Oxalic Acid Dropping Method

This method is preferred because it shows high effectiveness, especially during broodless periods (usually in winter months). In the drip method, oxalic acid is prepared at a specific concentration, usually in a sugar-water solution, and dripped directly into the spaces between the frames where the bees are located. The aim of this application is to create a toxic effect on *Varroa* mites by the solution coming into contact with the body surface of the bees. The sugar content of the solution makes it easier for the bees to accept the liquid and supports homogeneous distribution in the colony. During application, it is generally recommended to use 30–50 mL of solution per colony. Approximately 5 mL is dripped into each frame space [20,17]. During the process, the hive must be opened and the solution applied directly to the bee cluster. Therefore, performing the application quickly and carefully is important to reduce colony stress.

The most important advantage of the drip irrigation method is that it requires simple equipment and is low-cost. Furthermore, when applied under appropriate conditions, it can provide over 90% *Varroa* control effectiveness [17]. However, this method is only effective in broodless colonies; it is ineffective against *Varroa* mites found in sealed brood cells. Additionally, excessive or frequent application can disrupt the physiological balance of the bees and lead to colony weakening [21].

2. Oxalic Acid Evaporation Method

In this method, oxalic acid is directly converted from its solid (crystalline) form to the gas phase and introduced into the hive. The vaporized acid, upon contact with the bees' body surface, creates a toxic effect on *Varroa* mites. The basic principle of the sublimation method is to heat and vaporize the oxalic acid, and then distribute the resulting vapor homogeneously within the hive. This allows microscopic crystals to reach the entire surface of the bees, contacting the *Varroa* cuticle and causing its death. Its high effectiveness against the phoretic *Varroa* population on bees is one of the most important advantages of this method [22].

During application, generally 1.5–2.0 grams of oxalic acid per colony is used. The acid is placed in a specially designed sublimation device, and the device is heated and vaporized into the hive through the entrance. After application, the hive entrances are kept closed for approximately 10–15 minutes to allow the vapor to spread completely within the hive. If necessary, the treatment can be repeated at intervals of 7–10 days [22, 23].



One of the most important advantages of the sublimation method is that the bees are not directly wet and colony stress is low. Furthermore, it has a high efficiency rate (90–99%), yielding particularly successful results during broodless periods [17,22]. However, special equipment is required for this method, and since oxalic acid vapor can pose a risk to human health, masks and protective equipment must be used during application.

3. Oxalic Acid Spraying Method

Spraying is one method of applying oxalic acid to control *Varroa destructor* in honey bee (*Apis mellifera*) colonies, and it is based on direct contact with the bees on the frame. In this method, the prepared oxalic acid solution is applied by spraying a thin layer onto the body surface of the bees, ensuring direct contact with the Varroa mites. A 3.0–3.5% oxalic acid solution is generally used in the spray method. The solution is usually water-based rather than a water and sugar mixture, and is applied using a low-pressure sprayer to lightly wet the bees on both surfaces of the frames. An average of 3–4 mL of solution per frame is sufficient [24,17]. The aim is not to completely wet the bees, but to create a thin film layer to affect the mites through contact.

The effectiveness of this method is generally directed towards phoretic Varroa populations and yields more successful results during broodless periods. Since the hive needs to be opened during application, it can create short-term stress on the colony. Furthermore, careful dosing is required as excessive liquid use can cause the bees to cool and weaken the colony [4,19].

The most important advantages of the spray method include low equipment requirements and the speed of application. However, this method is ineffective against *Varroa* inside sealed brood because oxalic acid cannot penetrate the brood cells. Therefore, it is generally recommended to use it in an integrated manner with other control methods (23,17, 4).

FORMIC ACID USAGE

Formic acid is considered one of the most powerful organic acids in the fight against *Varroa destructor* in honeybee (*Apis mellifera* L.) colonies. This compound, found in nature in some plants and ant secretions, stands out from other organic acids particularly due to its ability to penetrate sealed brood cells. This property makes formic acid effective both on the bee (phoretic) and against Varroa populations inside the brood [15, 25]. The most important advantage of formic acid is its broad spectrum of activity. When used in appropriate doses and environmental conditions, it can rapidly reduce Varroa populations. However, its effectiveness is quite sensitive to ambient temperature; at high temperatures, excessive evaporation can cause stress in bees and queen bee loss, while at low temperatures, effectiveness may decrease [26, 25]. Therefore, formic acid applications require careful planning.

1. Formic Acid Absorbent Pad Method

Formic acid application is one of the most commonly used techniques for *Varroa destructor* control in honey bee colonies. This method relies on the controlled evaporation of formic acid and its spread throughout the hive, and is particularly noteworthy for its effectiveness against Varroa mites both in phoretic and sealed brood [27]. In this system, formic acid is absorbed into an absorbent material (cellulose pad, sponge, felt, or special gel discs) and placed inside the hive. The material allows the acid to evaporate slowly and continuously, spreading into the hive atmosphere. This prevents the bees from being directly exposed to the liquid, while the gaseous phase of formic acid has a toxic effect on *Varroa* mites [28].



The most important advantage of evaporative pad systems is that they provide controlled release. This reduces the risk of sudden evaporation and ensures a more stable formic acid concentration within the colony [27]. Furthermore, this method is preferred by beekeepers due to its ease of application and low labor requirements. Discs or pads are generally used by placing them on top of the hive or on the frames. Formic acid evaporation is highly sensitive to ambient temperature. At high temperatures, evaporation accelerates, leading to bee stress, queen loss, and colony weakening, while at low temperatures, effectiveness decreases. Therefore, application should generally be done in the mid-temperature range (15–25°C) [15]. In conclusion, evaporative pad/disk methods are a practical and widely used application approach that offers high effectiveness in Varroa control by providing controlled release of formic acid. However, correct dosage, appropriate timing, and consideration of environmental conditions are critical for success.

2. Formic Acid Controlled Evaporation Devices:

These devices are designed to vaporize formic acid inside the hive. These specially designed devices have a reservoir filled with formic acid, and some candle-shaped types allow the acid to vaporize slowly [28]. Some of these devices vaporize formic acid in a controlled manner. While their operation varies depending on the model, they are sold with instruction manuals. These devices can be used mounted on slats or on an empty frame. Generally, 150 ml of a 65% formic acid solution is applied to each colony once in early spring and once in late autumn [29].

3. Formic Acid Plastic Bag Method:

The bags that can be used in this application are resealable vegetable bags or self-closing freezer bags. The bags, filled with absorbent material, are then filled with 250 ml of 65% formic acid. With this method, the formic acid is released slowly over a period of 3-4 weeks [30]. Before application to the hives, the bags are de-aired, tightly sealed, and placed in an airtight container in the freezer for 1-2 days. This process reduces the evaporation of formic acid by lowering the temperature, making it easier to apply to the colonies. The application is done according to the number of frames covered with bees in the colony. Full bags are used for strong colonies, while half the amount is used for colonies with fewer than 5 frames. One bag is used for each hive, and the bags are cut crosswise to create windows. The windows are placed on the bottom board of the hive or on top of the slats so that they face the bees. If application is to be done on the slats, a gap should be left so that the formic acid can easily evaporate. Narrow floors can be used for this purpose [28].

LACTIC ACID USAGE

Lactic acid is one of the organic acids used in the control of Varroa destructor in honey bee (*Apis mellifera*) colonies and is particularly valued as a contact mite control agent [11]. Naturally occurring in dairy products as a result of fermentation, this compound is used in beekeeping as an alternative to synthetic acaricides due to its low residue risk and environmentally friendly nature. Lactic acid acts on Varroa mites through direct contact. When applied to the body surface of bees, it damages the cuticle of the mites, leading to their death [14]. However, due to this mechanism of action, it is only effective on phoretic Varroa populations; it has no effect on mites inside sealed brood cells. Therefore, the timing of application and colony condition are critically important for effectiveness [11].

Lactic acid application is generally done by spraying. In this method, a lactic acid solution



prepared at a concentration of 15–20% is sprayed directly onto the bees in a thin layer after removing the frames. Applying the solution in a way that evenly wets each frame surface increases the contact rate with the mites, thus improving effectiveness. Application is generally more successful in young and broodless colonies [14].

The most important advantages of lactic acid include its low toxicity, environmentally friendly nature, and minimal residue risk. However, the labor-intensive nature of the application, the need for frequent repetitions, and its ineffectiveness against *Varroa* mites inside the brood are significant limitations.

In conclusion, when used at the right time and in the appropriate concentration, lactic acid is considered a safe but limitedly effective organic acid alternative in *Varroa* control.

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Polypyrrole/g-C₃N₄ Composite: Evaluation of Thermal Decomposition Kinetics

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Abstract

In this study, polypyrrole and boron-doped g-C₃N₄ was synthesized, its thermal decomposition was investigated, and its activation energies were calculated. Graphite carbon nitride was synthesized using melamine and then used for boron and polypyrrole doping. TG and DTG curves were obtained by heating the samples at different temperature rates. From the results obtained from these curves, activation energies were calculated using three different methods (KAS, FWO, and Starink). It was determined that the thermal decomposition of the synthesized materials occurred in a single step. The average activation energies of the graphite carbon nitride structures obtained from the TG and DTG curves at heating rates of 2.5, 5, 10, and 20 K min⁻¹ were calculated using the KAS, FWO, and Starink methods. It was observed that the values obtained from the calculations of the three models were quite close to each other. The average activation energies were calculated as 334.97, 346.57, and 335.44 kJmol⁻¹, respectively. The three-dimensional diffusion control mechanism was calculated to be the Zhuravlev equation [(1- α)-1/3-1]².

Keywords: Graphitic carbon nitride, g-C₃N₄, Polypyrrole synthesis, Boron-doped graphitic carbon nitride structures

1. INTRODUCTION

The high thermal and chemical stability, low cost, and non-toxic nature of graphitic carbon nitride have led to its use in numerous studies [1]. Graphitic carbon nitride is a metal-free semiconductor with a porous structure. It consists of C and N atoms and a very small amount of H atoms. It has a bandgap of 2.7–2.8 eV [2]. There are five allotropes of carbon nitride: α -C₃N₄, β -C₃N₄, cubic-C₃N₄, pseudocubic-C₃N₄, and graphitic-C₃N₄. The most stable form is graphitic carbon nitride. g-C₃N₄ consists of two main units: tri-s-triazine (C₆N₇) and s-triazine (C₃N₃) rings. (Figure 1).

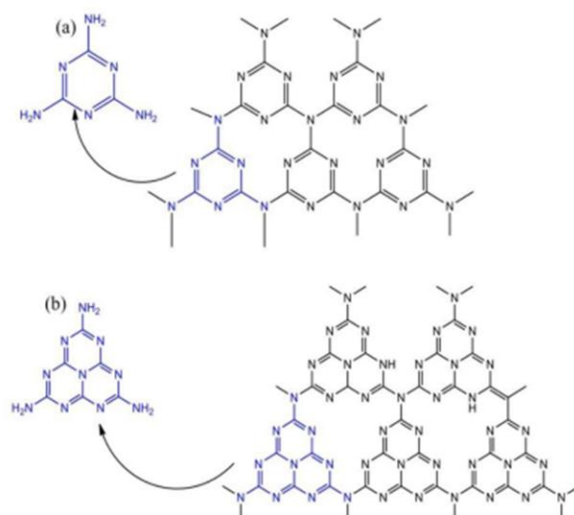


Figure 1. (a) s-triazine, (b) tri-s-triazine [3].

Tri-s-triazine has been reported to be more stable under ambient conditions. As demonstrated by thermogravimetric analysis (TGA), it can withstand temperatures up to 600 °C in air without decomposition [4]. At 750 °C, graphitic carbon nitride completely decomposes, leaving no residue other than nitrogen and carbon oxides [5]. Graphitic carbon nitride also exhibits excellent chemical stability. It is insoluble in common solvents such as toluene, diethyl ether, tetrahydrofuran, dimethylformamide, alcohols, and water [6].

Graphitic carbon nitride contains sp^2 -hybridized carbon and nitrogen atoms, forming a p -conjugated delocalized system. It has been widely applied in various fields including photocatalysis [7] and photovoltaics [8]. Due to its environmentally friendly nature and favorable performance, it is frequently preferred in advanced material applications.

Photocatalytic $g\text{-C}_3\text{N}_4$ -based materials remove pollutants from the environment through adsorption and therefore possess broad applications in pollutant degradation [9]. The 2.7 eV band gap of $g\text{-C}_3\text{N}_4$ enables efficient absorption of solar light, making it suitable for applications such as water purification, hydrogen production, and solar cells [10].

Graphitic carbon nitride can be transformed into different morphologies such as nanosheets, nanotubes, and nanowires. Bulk $g\text{-C}_3\text{N}_4$ possesses a three-dimensional structure with a layered and planar arrangement similar to graphite. Bulk $g\text{-C}_3\text{N}_4$ is generally synthesized by the pyrolysis of nitrogen-rich precursors such as melamine, dicyandiamide, thiourea, or urea [11].

While weak van der Waals forces exist between the layers, the nitrogen and carbon atoms are held together by covalent bonds. In order to separate these layers into two-dimensional nanosheets, sufficient energy must be provided to overcome the van der Waals interactions between the layers in a suitable solvent medium. The obtained $g\text{-C}_3\text{N}_4$ nanosheets possess several advantages over bulk $g\text{-C}_3\text{N}_4$, including a wider band gap (approximately 2.9 eV), larger surface area, and higher quantum confinement effect [12].

Graphitic carbon nitride nanotubes (Figure 2) are hollow tubular materials and represent a one-dimensional structure with unique properties such as enhanced visible light absorption, large surface area, and rapid electron transfer [13]. Nanowires are also one-dimensional rod-like $g\text{-C}_3\text{N}_4$.

C₃N₄ structures and attract considerable attention due to their high surface area-to-volume ratio and enlarged reaction interface [14]

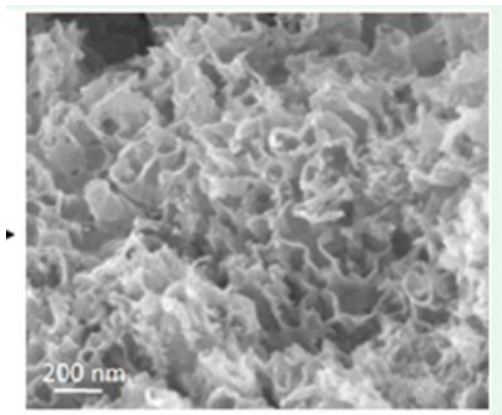


Figure 2. Graphitic carbon nitride nanotube

2. MATERIALS AND METHODS

Thermal analysis was performed to investigate the thermal behavior of the prepared polymer composite materials using TG (Thermal Gravimetry) and DSC (Differential Scanning Calorimetry) methods. A Netzsch STA 409 PC Luxx instrument was used for the analyses. Experiments were conducted in an air environment using an alumina pan, at a heating rate of 10°C/min and a flow rate of 60 mL/min, in a temperature range from room temperature to 900°C. Furthermore, the activation energies obtained from different solid-state mechanisms of the Ppy-doped g-C₃N₄ structure at heating rates of 2.5, 5, 10, and 20 K/min are given in Table 1.

3. RESULTS AND DISCUSSION

Thermogravimetric analysis (TG) in air (Netzsch STA 409 PC Luxx) was performed at a flow rate of 90 mL min⁻¹ and a heating rate of 10 °C min⁻¹. This analysis was carried out from room temperature up to 1200 K. DTG graphs were obtained from the TG graphs. These graphs are given in Figures 3-7.

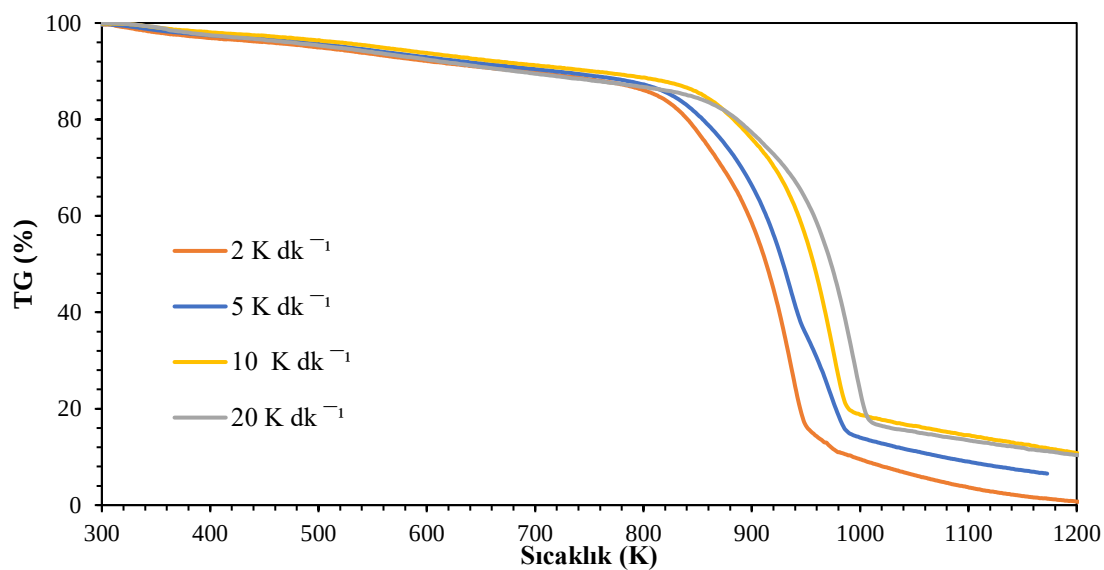


Figure 3. TG graphs of g-C₃N₄ at different heating rates

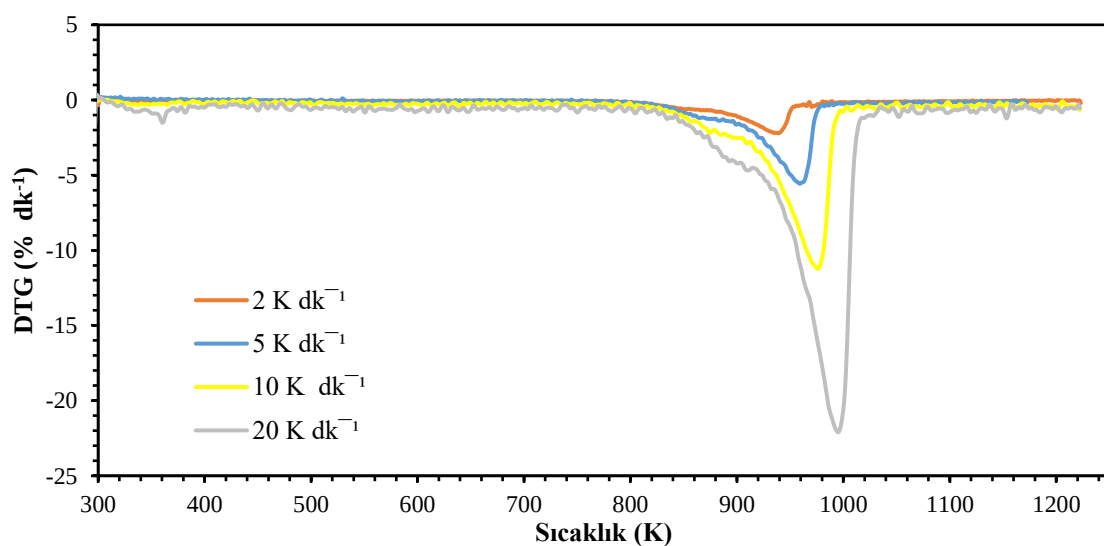


Figure 4. DTG graphs of g-C₃N₄ at different heating rates

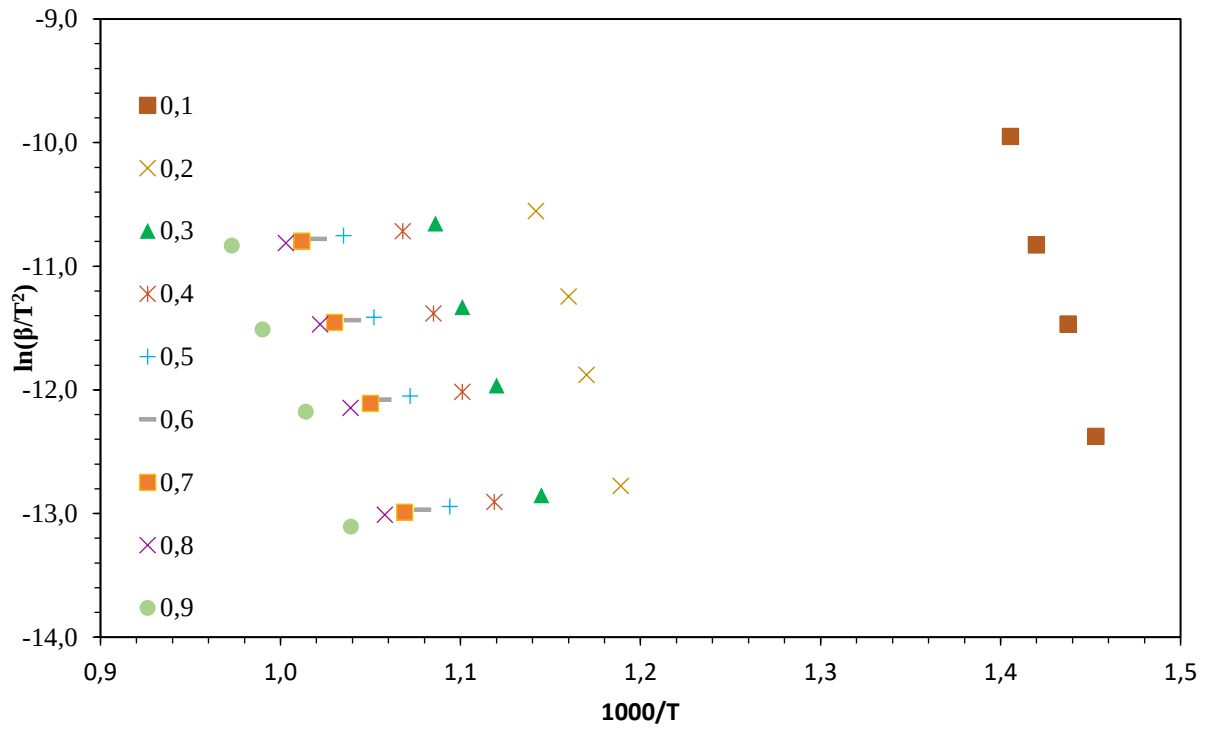


Figure 5. Changes in decomposition temperature of g-C₃N₄ structures with conversion fraction (α) values by the KAS method

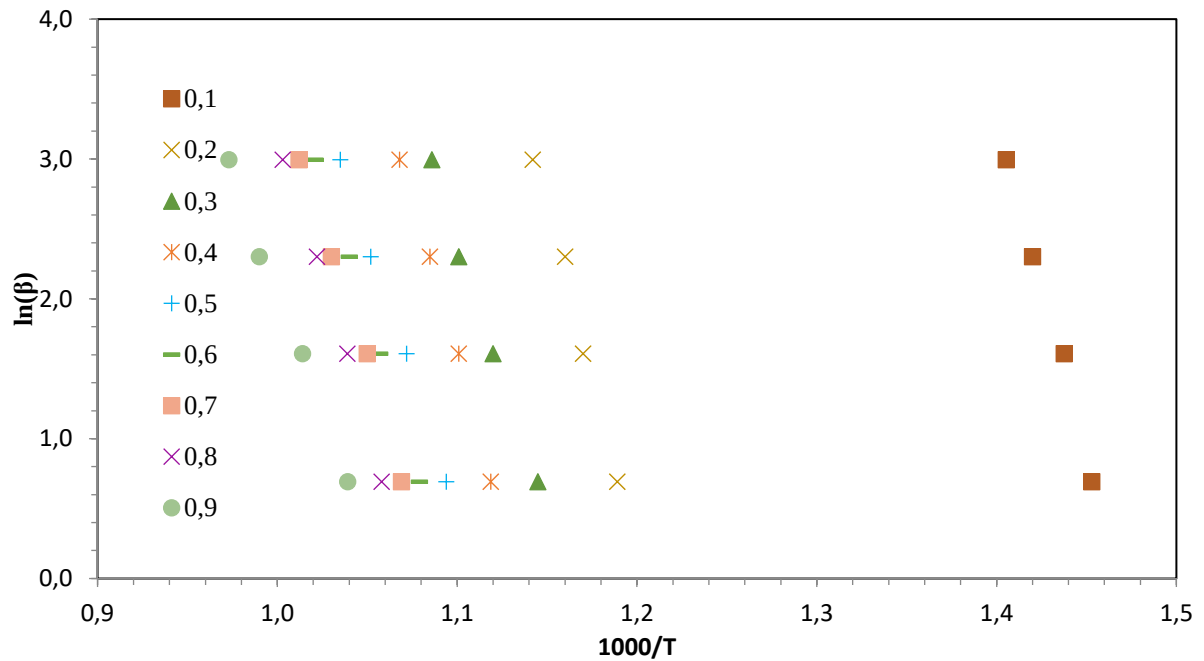


Figure 6. Changes in decomposition temperature of g-C₃N₄ structures with conversion fraction (α) values by the FWO method

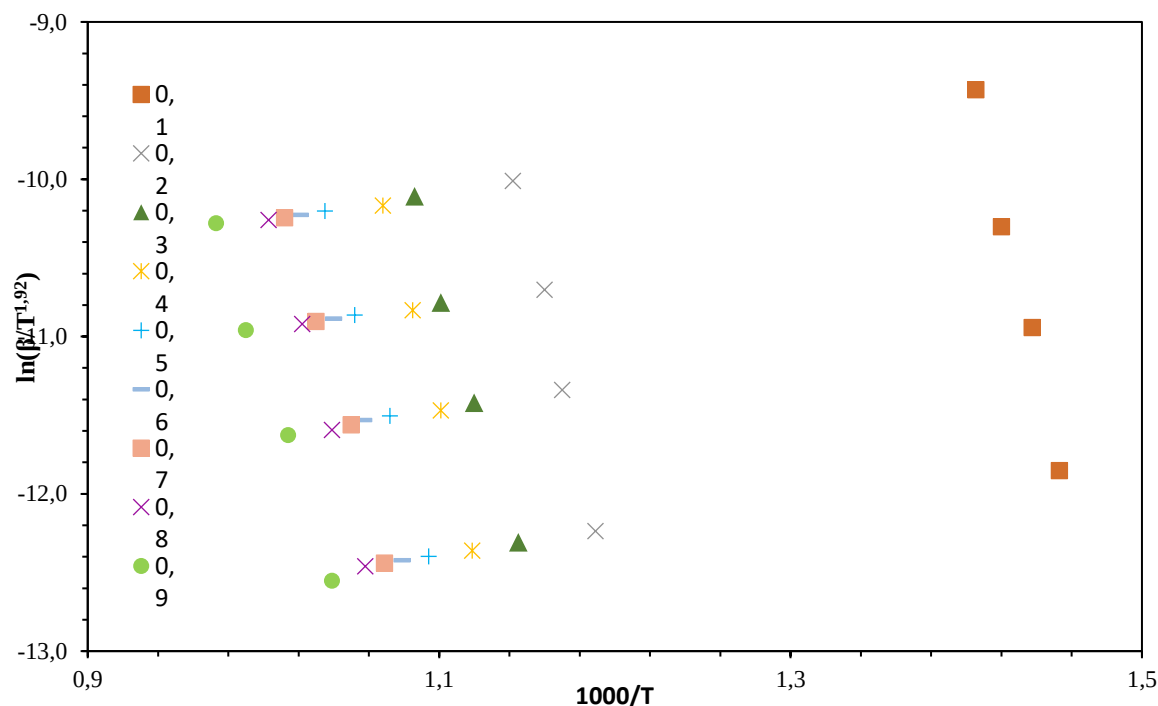


Figure 7. Changes in decomposition temperature of g-C₃N₄ structures with conversion fraction (α) values by the Starink method

Table 1. Activation Energies (E_a), Frequency Factor (A) and Correlation Coefficient (R²) Calculated by KAS, FWO and STK Methods in Thermal Decomposition of g-C₃N₄ Structures

α	KAS			FWO			STK		
	E _a (kJ mol ⁻¹)	R ²	A (min ⁻¹)	E _a (kJ mol ⁻¹)	R ²	A (min ⁻¹)	E _a (kJ mol ⁻¹)	R ²	A (min ⁻¹)
0.1	409,58	0,9905	59,25	394,17	0,9933	69,65	408,97	0,9908	59,66
0.2	399,33	0,9930	44,36	414,96	0,9906	60,06	399,95	0,9929	44,98
0.3	304,97	0,9968	29,13	320,74	0,9973	44,84	305,61	0,9971	29,76
0.4	355,96	0,9960	35,05	375,58	0,9968	51,29	356,75	0,9960	35,70
0.5	304,50	0,9979	27,16	320,90	0,9988	42,94	305,21	0,9979	27,79
0.6	314,47	0,9986	27,87	331,14	0,999	43,69	315,13	0,9986	28,51
0.7	314,74	0,9946	27,54	330,86	0,9951	43,30	315,38	0,9946	28,17
0.8	331,92	0,9960	29,28	347,29	0,9957	44,95	332,54	0,9969	29,91
0.9	279,24	0,9960	21,82	283,51	0,9967	36,14	279,41	0,9962	22,39
Ortalama	334,97			346,57			335,44		



Table 2. Activation Energies Obtained from Different Solid-State Mechanisms of Ppy-Doped g-C₃N₄ Structure at Heating Rates of 2.5, 5, 10 and 20 K/min.

Mekanizma	Symbol	F(α)	G(α)	E _a (kJ mol ⁻¹)			
				$\beta= 2,5$	$\beta= 5$	$\beta= 10$	$\beta= 20$
Reaction order models							
Chemical reaction (first order)	F ₁	(1- α)	-ln (1- α)	52,78	52,68	51,26	50,34
Chemical reaction (first order)	F ₂	(1- α) ²	(1- α) ⁻¹ -1	79,93	75,9	77,33	75,96
Chemical reaction (first order)	F ₃	(1- α) ³	[(1- α) ⁻² -1]/2	99,35	98,7	105,01	106,22
Diffusion models							
One-dimensional diffusion	D ₁	0.5 α	α^2	83,14	88,04	90,46	90,73
Two-dimensional diffusion	D ₂	[-ln(1- α)] ⁻¹	$\alpha+(1-\alpha)\ln(1-\alpha)$	96,29	97,4	94,04	91,81
Three-dimensional diffusion (Ginstling-Brounshtein equation)	D ₄	(3/2)/[1- α] ^{1/3} -1]	(1-2 α /3)-(1- α) ^{2/3}	93,62	101,1	103,34	105,86
Üç boyutlu difüzyon (Zhuravlev eşitliği)	D ₅	(3/2)(1+ α) ^{3/4} [1+ α) ^{-1/3} -1] ⁻¹	[(1- α) ^{-1/3} -1] ²	99,35	103,46	102,68	101,79
Sigmoidal ratio models							
Compressed geometry shape (disk symmetry)	R ₁	1	α	32,59	37,5	38,31	39,19
Compressed geometry shape (cylindrical symmetry)	R ₂	2(1- α) ^{-1/2}	1-(1- α) ^{1/2}	41,00	44,8	45,78	45,30
Compressed geometry shape (spherical symmetry)	R ₃	3(1- α) ^{-1/3}	1-(1- α) ^{1/3}	49,29	47,63	48,59	47,59
Nucleation models							
Two-dimensional nucleation and growth (n=2)	A ₂	2(1- α)[-ln(1- α)] ^{1/2}	[-ln(1- α)] ^{1/2}	21,08	20,10	20,44	23,63
Three-dimensional nucleation and growth (n=3)	A ₃	3(1- α)[-ln(1- α)] ^{2/3}	[-ln(1- α)] ^{1/3}	9,60	8,91	9,01	9,63
Four-dimensional nucleation and growth (n=4)	A ₄	4(1- α)[-ln(1- α)] ^{3/4}	[-ln(1- α)] ^{1/4}	50,79	49	50,04	50,97
Mamle power law (n = 1/2)	P ₂	2 $\alpha^{1/2}$	$\alpha^{1/2}$	12,75	12,03	12,23	12,76
Mamle power law (n = 1/3)	P ₃	3 $\alpha^{2/3}$	$\alpha^{1/3}$	4,04	3,52	3,54	3,58
Mamle power law (n = 1/4)	P ₄	4 $\alpha^{3/4}$	$\alpha^{1/4}$	0,65	0,7	0,8	0,73



4. CONCLUSIONS

- The material demonstrated a thermally stable and well-behaved single-step decomposition mechanism.
- Understanding the thermal decomposition mechanism is of great importance for improving the performance and long-term stability of advanced materials.
- The consistency of the results obtained from the kinetic models supports the reliability of the calculated activation energy values.

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Nutritional Approaches in Polycystic Ovary Syndrome: The Role of the Mediterranean Diet

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Abstract

Polycystic ovary syndrome (PCOS) is one of the most common endocrine and metabolic disorders affecting women of reproductive age. PCOS is associated with hyperandrogenism, ovulatory dysfunction, insulin resistance, obesity, and chronic low-grade inflammation. Lifestyle modification and nutrition therapy are considered first-line approaches in the management of PCOS. In recent years, the Mediterranean diet has gained considerable attention due to its anti-inflammatory, antioxidant, and insulin-sensitizing effects. The aim of this review is to evaluate the metabolic and hormonal effects of the Mediterranean diet in women with PCOS according to current literature. The Mediterranean diet is characterized by high consumption of vegetables, fruits, whole grains, legumes, nuts, fish, and olive oil, while limiting processed foods and saturated fats. Studies have shown that adherence to the Mediterranean diet may reduce insulin resistance, decrease inflammatory markers, support weight management, and positively influence hormonal balance in women with PCOS. In addition, the high content of dietary fiber, polyphenols, and omega-3 fatty acids contributes to the reduction of oxidative stress. Consequently, the Mediterranean diet appears to be a sustainable and effective nutritional approach in the management of PCOS.

Keywords: Polycystic ovary syndrome, Mediterranean diet, insulin resistance, inflammation, nutrition therapy

1. INTRODUCTION

Polycystic ovary syndrome (PCOS) is a common endocrine and metabolic disorder among women of reproductive age [1,2], and the syndrome is characterized by hyperandrogenism, ovulatory dysfunction, and polycystic ovarian morphology [3]. The prevalence of PCOS has been reported to range between 6% and 20% depending on diagnostic criteria [2]. In addition, PCOS is associated with obesity, insulin resistance, dyslipidemia, chronic low-grade inflammation, and increased cardiovascular risk [4].

Insulin resistance plays a central role in the pathophysiology of PCOS [5]. Elevated insulin levels stimulate androgen production in the ovaries, contributing to hormonal imbalance. Furthermore, inflammatory cytokines released from adipose tissue and oxidative stress are involved in disease progression [6]. Lifestyle modification, particularly nutrition therapy, is recommended as the first-line treatment in PCOS management [7]. Nutritional interventions may improve body weight control, insulin sensitivity, and inflammatory status [8]. Recently,



the Mediterranean diet has emerged as one of the most beneficial dietary patterns for women with PCOS because of its anti-inflammatory and antioxidant properties [9].

This review examines the relationship between PCOS and nutrition, aiming to evaluate the potential effects of the Mediterranean diet in PCOS management in light of current literature.

2. RESULTS AND DISCUSSION

Nutrition plays a critical role in the pathophysiology and management of Polycystic Ovary Syndrome (PCOS) [10]. Insulin resistance, which is one of the major mechanisms underlying the syndrome, is strongly associated with dietary habits and lifestyle factors [5]. Diets rich in refined carbohydrates, saturated fats, and processed foods may exacerbate insulin resistance, chronic inflammation, and metabolic disturbances, whereas balanced dietary patterns may contribute to improved metabolic outcomes and hormonal regulation [8].

Among current nutritional approaches, the Mediterranean diet has attracted increasing attention due to its anti-inflammatory and cardiometabolic protective properties. The Mediterranean diet is characterized by high consumption of fruits, vegetables, legumes, nuts, olive oil, fish, and whole grains, along with moderate intake of dairy products and limited consumption of red meat and processed foods [11,12]. Olive oil, the principal source of dietary fat in this pattern, is rich in monounsaturated fatty acids and polyphenols that may exert antioxidant and anti-inflammatory effects [13].

Current evidence suggests that adherence to the Mediterranean diet may improve insulin sensitivity and glycemic control in women with PCOS [14]. The high dietary fiber content and low glycemic load of the diet may reduce postprandial glucose fluctuations and insulin secretion, thereby contributing to decreased androgen production and improved ovulatory function [10]. In addition, the Mediterranean diet provides antioxidant-rich foods and bioactive compounds that may help reduce chronic low-grade inflammation and oxidative stress, which are commonly observed in PCOS [15]. Polyphenols and omega-3 fatty acids present in olive oil, fish, nuts, fruits, and vegetables also contribute to anti-inflammatory mechanisms [10].

Obesity is another important factor associated with the progression of PCOS and worsening metabolic abnormalities [16]. Several studies indicate that the Mediterranean diet may support weight management, improve lipid profiles, reduce blood pressure, and lower cardiovascular risk factors [17]. Weight reduction and metabolic improvements may consequently contribute to better menstrual regularity and fertility outcomes in women with PCOS [10].

Furthermore, improved insulin sensitivity and reduced systemic inflammation may positively influence reproductive hormones and ovulatory function [1]. Some studies have reported that greater adherence to the Mediterranean diet is associated with improved menstrual cyclicity and enhanced reproductive outcomes in women diagnosed with PCOS [18]. Overall, current findings indicate that the Mediterranean diet may represent an effective and sustainable nutritional strategy for improving both metabolic and reproductive health parameters in PCOS management.



3. CONCLUSIONS

The Mediterranean diet appears to be a promising and sustainable nutritional strategy in the management of Polycystic Ovary Syndrome (PCOS). Current evidence indicates that adherence to this dietary pattern may improve insulin sensitivity, glycemic control, body weight, lipid profile, and reproductive functions while reducing chronic inflammation and oxidative stress associated with PCOS [13]. The high antioxidant content, anti-inflammatory properties, and favorable fatty acid composition of the Mediterranean diet may contribute to hormonal and metabolic regulation in affected women [14]. In addition to its metabolic benefits, the Mediterranean diet may also support menstrual regularity, ovulatory function, and overall quality of life in women with PCOS [10].

Therefore, incorporating the Mediterranean diet into lifestyle modification programs may represent an effective non-pharmacological approach for the long-term management of the syndrome. However, despite promising findings, the current literature remains limited by the small number of long-term randomized controlled trials and variations in dietary assessment methods. Further large-scale clinical studies are needed to clarify the underlying molecular mechanisms and to establish standardized nutritional recommendations for women with PCOS.

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The Effect of DHA and EPA on Cognitive Functions in Alzheimer's Disease

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Abstract

Alzheimer's disease (AD) is a progressive neurodegenerative disorder characterized by cognitive decline, memory impairment, and synaptic dysfunction. The increasing aging population worldwide has made AD an important public health problem. In recent years, nutritional approaches supporting the prevention and management of neurodegenerative diseases have attracted increasing attention. Among these approaches, omega-3 polyunsaturated fatty acids, particularly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), have been widely investigated because of their potential neuroprotective properties. This narrative review evaluates the effects of DHA and EPA on cognitive functions in Alzheimer's disease based on current scientific literature. Evidence from clinical and experimental studies suggests that DHA contributes to neuronal membrane integrity, synaptic plasticity, and cognitive performance, whereas EPA mainly regulates inflammatory pathways and reduces neuroinflammatory responses. Furthermore, omega-3 fatty acids may support neuronal resilience by decreasing oxidative stress and maintaining brain health. Although several studies report beneficial effects of omega-3 supplementation on memory, attention, and overall cognitive performance, findings remain inconsistent. Differences in dosage, intervention duration, disease stage, and dietary habits may contribute to these inconsistencies. Overall, DHA and EPA appear promising as supportive nutritional components in Alzheimer's disease; however, larger and long-term clinical studies are needed to clarify their therapeutic efficacy and determine optimal supplementation strategies.

Keywords: *Alzheimer's disease, DHA, EPA, omega-3 fatty acids, cognitive function*

1. INTRODUCTION

Alzheimer's disease (AD) is the most common cause of dementia worldwide and is characterized by progressive cognitive decline, memory impairment, and loss of daily functioning [1,2]. Due to the increasing aging population, the prevalence of AD is rising rapidly and creating major social and economic burdens globally [3]. The pathology of AD is multifactorial and involves amyloid- β accumulation, tau protein hyperphosphorylation, oxidative stress, mitochondrial dysfunction, and chronic neuroinflammation, all of which contribute to neuronal degeneration and synaptic loss [2].

In recent years, lifestyle and nutritional factors have gained considerable attention as potential modulators of cognitive decline and neurodegenerative diseases. Dietary patterns rich in antioxidants, vitamins, and bioactive lipids have been associated with improved brain health and reduced dementia risk [4,5]. Among these nutritional factors, omega-3 polyunsaturated



fatty acids (PUFAs), particularly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), have been extensively studied because of their essential roles in brain structure and function [6].

DHA is a major structural component of neuronal membranes and plays a critical role in maintaining membrane fluidity, synaptic plasticity, and neurotransmission [6,7]. EPA, in contrast, is more strongly associated with the regulation of inflammatory responses and immune signaling pathways in the central nervous system [8,9]. Experimental studies have demonstrated that omega-3 fatty acids may exert neuroprotective effects through antioxidant activity, modulation of neuroinflammatory pathways, and support of neuronal survival [8,10]. In addition, omega-3 fatty acids may improve cerebral blood flow and vascular function, which are important factors in maintaining cognitive health [11].

Although several clinical studies suggest that omega-3 supplementation may improve cognitive performance and slow cognitive decline, findings remain inconsistent because of variations in study design, supplementation dose, disease stage, and intervention duration [12,13]. Therefore, further investigation is needed to better understand the potential therapeutic role of DHA and EPA in Alzheimer's disease.

This narrative review aims to evaluate the effects of DHA and EPA on cognitive functions in Alzheimer's disease in light of current scientific evidence.

2. RESULTS AND DISCUSSION

Alzheimer's disease is a complex neurodegenerative disorder involving intricate neurodegenerative mechanisms such as oxidative stress, chronic inflammation, and neuronal loss, negatively impacting cognitive function. In recent years, there has been a significant increase in the focus on supportive nutritional interventions to slow this cognitive decline and improve brain health. Among these interventions, omega-3 fatty acids—particularly docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA)—are attracting attention. Understanding prominent role of omega-3 fatty acids in the prevention and management of Alzheimer's disease has become a significant area of current research.

Current evidence suggests that omega-3 fatty acids may support cognitive function through anti-inflammatory and antioxidant mechanisms [8,10]. The findings reviewed in this study indicate that DHA and EPA may contribute to the preservation of cognitive functions in Alzheimer's disease by supporting neuronal integrity and reducing neurodegenerative processes. DHA plays a particularly important role in the structural organization of neuronal membranes. Its high concentration in brain tissue contributes to membrane fluidity, synaptic signaling, and neuronal communication [6,7]. These functions are closely associated with cognitive processes such as learning and memory. DHA has also been reported to support synaptic plasticity and reduce neuronal damage associated with oxidative stress [6,14].

EPA appears to be more strongly associated with the modulation of inflammatory responses. Chronic neuroinflammation is considered one of the key pathological mechanisms in Alzheimer's disease [2]. EPA may reduce the production of pro-inflammatory cytokines and regulate microglial activation, thereby limiting neuroinflammatory damage [8,9]. In addition, EPA may contribute to improved cerebral blood flow and vascular health, which are important for maintaining cognitive performance in aging populations [11].



Several clinical studies have reported that omega-3 supplementation may positively affect memory performance, attention, and overall cognitive performance, particularly in individuals with mild cognitive impairment or early-stage Alzheimer's disease [11,14]. Furthermore, combined supplementation with DHA and EPA may provide synergistic effects because DHA primarily supports neuronal structure while EPA mainly targets inflammatory pathways [6,8,15]. However, despite promising findings, the results of clinical trials remain inconsistent [12,16]. While some studies demonstrate cognitive benefits associated with omega-3 supplementation, others report limited or no significant effects. These inconsistencies may be related to differences in supplementation dose, duration of treatment, disease severity, genetic factors, and dietary habits of participants [12,13,16]. It has also been suggested that interventions initiated during the early stages of cognitive decline may be more effective than those applied during advanced stages of Alzheimer's disease [13]. Several studies suggest that omega-3 supplementation may improve memory performance, attention, and overall cognitive function, particularly during the early stages of cognitive decline [11,14]. Consequently, current evidence is not yet sufficient to confirm the therapeutic efficacy of omega-3 fatty acids in Alzheimer's disease.

3. CONCLUSION

In conclusion, omega-3 fatty acids appear to be a promising supportive nutritional approach for maintaining brain health and potentially slowing cognitive decline in Alzheimer's disease.

Omega-3 fatty acids, particularly DHA and EPA, it is known that may have supportive effects on cognitive function and brain health in Alzheimer's disease. DHA mainly supports neuronal structure and synaptic function, while EPA help reduce neuroinflammation. Current studies suggest that omega-3 supplementation may improve memory, cognitive performance, especially in the early stages of cognitive decline and supportive effects on cognitive function and neuroinflammatory processes in Alzheimer's disease.

Nevertheless, inconsistencies among clinical studies prevent definitive conclusions. Therefore, larger and long-term randomized clinical trials are required to clarify their effectiveness and determine optimal supplementation strategies.

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One of the Innovative Nano Materials in Modern Material Science and Engineering: Polymeric Organic Frameworks

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Abstract

Materials science and engineering, which require an interdisciplinary approach, play a critical role in the age of science and technology. Multifunctional polymer-based Polymeric Organic Frameworks (POFs) are among the innovative nanomaterials that have recently garnered attention in modern materials science as critical building blocks for sustainable energy, water management, and health technologies. By modifying the properties of materials at the nanoscale, entirely new functions can be imparted to these structures. POFs, characterized as nanoporous polymers from both mechanical and chemical perspectives, are composed entirely of organic, lightweight elements (C, H, O, N, B) and can be linked together by strong covalent bonds. POFs are easily synthesizable, functional, possess good electrical conductivity, high thermal and chemical stability, are lightweight, have a large specific surface area, exhibit high mechanical strength, possess high adsorption capacity, and feature adjustable pore sizes ranging from micrometers to nanometers. Due to their tunability, biodegradability, biocompatibility, and non-toxicity, POFs can be used in applications such as catalysis, heterogeneous catalysis, photocatalysis, electrocatalysis, ion exchange, luminescence, sensing/sensor, selective recognition/indicator, gas adsorption and separation, gas storage (HCFCs, CFCs, N₂O, O₃, CO₂, CH₄, H₂), energy storage (supercapacitors, symmetric supercapacitors, lithium/sodium ion batteries, fuel cells, solar energy conversion, etc.), triboelectric energy harvesting, CO₂ capture and electro-reduction, electrode materials for electric double-layer capacitors, optoelectronics, water treatment, environmental remediation, dye and heavy metal removal, adsorption of toxic substances, membrane technologies, clean energy applications, capacitive deionization, ratiometric fluorescent glucose sensors, iodine/¹²⁹I capture, adsorption and release of therapeutic gases such as H₂S and NO, enantioseparation, separation of trivalent americium from lanthanides, nuclear waste treatment, nanopharmacology (stimulus-responsive drug delivery systems, drug transport and controlled release), nanomedicine, biomedicine, tissue engineering, and other applications. In conclusion, POFs, a new generation of multifunctional nanomaterials, offer a wide range of advantages due to their structural and functional properties. In line with the philosophy of not harming human health or the environment, by aligning the synthesis processes of POFs with "sustainable chemistry" or, in other words, the principles of "green chemistry" through the use of non-toxic organic agents and green solvents, POFs hold promise for today's and tomorrow's strategic research areas, including energy, chemistry, environment, food, materials, and biomedical process technologies.

Keywords: Nanomaterials, Porous Organic Polymers, Polymeric Organic Frameworks, POFs, Green Chemistry



1. INTRODUCTION

The concept of materials, which has shaped human history, influences our daily lives across many fields (*food, pharmaceuticals, construction, textiles, communications, transportation, etc.*). [1]. The field of modern materials science and engineering, which requires an interdisciplinary approach, plays a critical role in the age of digital science and technology [2]. Materials science uncovers the relationships between the structures of materials (*subatomic, atomic-scale, micro-, and macro-structures*) and their properties (*mechanical, magnetic, electrical, thermal, optical, and degradation*) to produce or synthesize new materials. Materials engineering, on the other hand, involves the development of new techniques for processing materials to create new products from existing materials and to impart desired properties, based on the structure-property relationship. In other words, it is the design and engineering of material structures [1].

Porous materials represent one of the fastest-growing and most intriguing research areas in nanotechnology, physics, modern chemistry, and modern materials science and engineering, thanks to their exceptional properties, such as large surface areas, tunable pore sizes and structures, versatile functionality, and diverse synthesis mechanisms. Thanks to these impressive properties, porous materials can be applied in many contexts, including gas storage, gas separation, superhydrophobic interfaces, catalysts, energy conversion and storage, catalysis, adsorption, optoelectronics, microelectronics, healthcare, and more [3], [4], [5], [6], [7], [8], [9], [10], [11]. Similarly, various porous materials have been synthesized for the elimination of impurities such as heavy metals and dyes, yielding successful results [12]. In particular, the adsorption and storage of greenhouse gases such as hydrofluorocarbons, hexafluorocarbons, nitrogen oxides, CO₂, and CH₄, which contribute to global warming (GW) and climate change, as well as the storage of clean energy H₂ using porous organic materials, are of critical importance [6], [8], [13].

In reticular chemistry, the pore size, functionality, and topology of porous crystalline materials with predetermined structures—formed through strong chemical bonds between monomers can be designed at the atomic level. [14]. Porous materials, which refer to hydrocarbons containing pores (voids), are classified by the International Union of Pure and Applied Chemistry (IUPAC) into three categories based on pore size: macroporous (> 50 nm), mesoporous (2–50 nm), and microporous materials (< 2 nm) [3], [6], [15], [16].

In the basic sciences, the term “porous” is used to describe a permeable material that contains holes or voids on its surface [16]. Porous materials are generally classified into three main groups: “inorganic,” “hybrid (organic-inorganic),” and “organic” porous materials [17], [18]. The use of porous materials dates back to Ancient Egypt. In fact, charcoal has been used for medicinal purposes to treat indigestion, prevent diarrhea, alleviate gastrointestinal disorders, and purify water, as well as in the pharmaceutical industry and as an additive in animal feed [19], [20]. In addition to “inorganic” porous structures (such as zeolites, mesoporous silica, and activated carbon), the development of modern functional frameworks has led to significant scientific breakthroughs in the field of nanoporous materials [5], [19].

In this context, the first group of porous materials to be synthesized consists of metal-organic frameworks (MOFs) with a “hybrid” structure. MOFs, which consist of organic and inorganic components, can be synthesized through coordination bonds between metal ions and organic ligands [5], [7], [10], [21].



When it comes to “*organic*” porous materials, these materials which have emerged as a new functional structure have become a focal point of intensive research in the areas of physics, chemistry, and materials science [18].

Porous materials exhibit a variety of structural differences. The primary reasons for this include the existence of different synthesis methods, structural variations such as crystalline and amorphous structures, and the ability to incorporate various functional groups that can be designed in different ways to meet specific needs [15]. Research into fully organic nanoporous materials, achieved through the development of functional, controllable frameworks containing organic building blocks, represents a rapidly growing field within materials chemistry [22]. Porous frameworks come in a wide variety; they have attracted the attention of scientists working in various fields due to the design flexibility they offer—a result of their organic, inorganic, and hybrid structures—as well as their controlled pore structure and morphological tunability [13].

1.1. Poroz Frameworks / Poroz Materials

- Porous Organic Polymers (POPs) [13], [20].
- Polymeric Organic Frameworks (POFs) [11], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32].
- Porous Organic Frameworks (POFs) [7].
- Porous Organic Networks (PONs) [7].
- Porous Polymer Networks (PPNs) [7].
- Polymer-Based Microporous Materials [29].
- Microporous Organic Networks (MONs) [7].
- Metal Organic Frameworks (MOFs) [7], [10], [13], [20], [21], [31].
- Covalent Organic Frameworks (COFs) [6], [7], [9], [13], [15], [16], [29], [31].
- Hydrogen-bonded Organic Frameworks (HOFs) [13], [20], [33].
- Supramolecular Organic Frameworks (SOFs)
- Covalent Triazine Frameworks (CTFs) [6], [7], [9], [15], [16].
- Covalent Organic Polymers (COPs) [29].
- Conjugated Microporous Polymers (CMPs) [6], [7], [15], [16].
- Hypercrosslinked Polymers (HCPs) [6], [7], [9], [15], [16].
- Polymers of Intrinsic Microporosity (PIMs) [6], [7], [9], [15].
- Porous Aromatic Frameworks (PAFs) [6], [7], [9], [12], [16], [17], [21].
- Porous Organic Cages (POCs) [6], [20].
- Crystalline Porous Organic Salts (CPOSs) [13].
- Extrinsic Porous Molecules [6].
- Porous Liquids [6].

Porous materials are classified into two categories: porous solids and porous liquids [6]. In addition, they are divided into two subclasses: porous polymer networks, crystalline networks, and amorphous networks. Crystalline networks have well-organized structures that feature highly regular, repeating molecular arrangements and uniform pore sizes related to the dimensions of their connecting elements. Amorphous networks, on the other hand, lack long-range molecular order; that is, they have an irregular structure and may have a wider range of pore sizes. However, some may also have very narrow pore sizes [7], [15]. The pore size in amorphous networks may be related to the length of the monomer support chains [15]. Porous organic frameworks shed light on the development of a new generation of functional, adaptable, and recyclable structures [10].



1.2. Properties of Porous Organic Polymer (POP) Structures

Porous Organic Polymers (POPs) represent a rapidly expanding class of materials that combine both porous properties and organic functionality [25]. POPs are a subclass of porous materials. POPs is a general term for a class of specially designed, innovative, and strategic porous materials composed of fully organic building blocks linked by covalent bonds, encompassing both crystalline (cPOPs) and amorphous (aPOPs) frameworks and offering highly cross-linked, diverse frameworks [4], [7], [9], [12], [16], [34].

Industrial synthetic polymers such as polyethylene, nylon, and polystyrene are produced by covalent polymerization of organic building blocks—acids, alkenes, and amines [21]. Porous organic polymers are nanomaterials with fascinating properties composed of light elements found in the periodic table (C, Si, O, B, N) [15], [35]. To list these outstanding features: organic structure [10], lightness [10], [29], large/high surface area [5], [7], [8], [12], [16], [27], [29], [36], high stability [12], low density [5], [10], [31], uniform and adjustable pore size [11], [12], [13], [16], high porosity [10], [12], [13], adjustability/adaptability [5], [12], [16], [27], [29], [35], [36], high thermal stability [7], [10], [16], [22], [31], [35], [36], high chemical stability [7], [10], [16], [22], [29], [31], [35], electrochemical stability [11], simple synthesis [12], [24], versatile additional chemical functionality [12], an abundance of versatile building blocks [29], ease of customization, etc. [5], [12], [24], [29], [35].

POPs are materials that are synthesized irreversibly, bonded by strong covalent bonds, and are typically amorphous and insoluble. This prevents migration in heterogeneous systems. Bonding via strong covalent bonds also ensures high chemical and thermal stability [10], [35]. In addition, because POPs have a light atomic composition, when combined with high surface areas, they form low-density materials [10]. POPs are successfully used in gas storage applications thanks to their large surface area [8], [35]. N-doped carbon materials derived from POPs for advanced energy storage, such as supercapacitors, hold promise for the future of energy supply [36]. In short, POPs offer tremendous advantages in critical new technologies [10].

1.3. Polimerik Organic Frameworks (POFs)

The lack of terminological consistency in naming Polymeric Organic Frameworks (POFs) can lead to conceptual ambiguity. Both Polymeric Organic Frameworks (POFs) and Porous Organic Frameworks (POFs) are referred to by the same abbreviation, “POFs,” in the literature. This lack of standardization also makes it difficult to conduct systematic comparisons.

In some literature, Porous Organic Frameworks (POFs) encompass various materials such as COFs, CTFs, and PAFs, in which, just like Porous Organic Polymers (POPs), entirely organic building blocks are linked by strong covalent bonds (POF $\approx$ POP) [7], [12], [34], [37].

In some literature, Porous Organic Frameworks (POFs) have come to encompass a much broader range. In other words, it serves as an umbrella term for a family even broader than POPs, encompassing not only “entirely organic” structures but also “organic and inorganic structures.” This family includes MOFs, COFs, HOFs, SOFs/HOFs (Supramolecular Organic Frameworks), and others [33], [38]. This is where the terminological confusion in the literature begins. In systematic definitions, Polymeric Organic Frameworks (POFs) may appear in the literature as an informal variant of Porous Organic Frameworks, with an emphasis on the



“polymeric” aspect. However, the scope of the term “Polymeric Organic Frameworks” varies because it encompasses both organic and inorganic structures.

Recently, the term POF has also been used in the literature to refer to a “novel, specific new polymeric organic material.”

1.3.1. Examples of Literature Reviews on The Synthesis and Applications of Novel Specific Polymeric Organic Frameworks

Thermally stable “*Imine-linked Microporous Polymer Organic Frameworks (POFs)*” were easily synthesized via Schiff base condensation between 1,3,5-triformylbenzene and several diamine monomers. These POFs have demonstrated high specific surface areas and high isothermic heat values for hydrogen (H_2) adsorption. It has been determined that this material holds good potential for applications in gas storage, gas separation, and selective recognition [34].

By utilizing Bakelite-type chemistry for the formation of C-C bonds, a new “*Phloroglucinol-Based Microporous Polymeric Organic Frameworks (MOF)*” was synthesized via a catalyst-free, solvothermal method from phloroglucinol (1,3,5-trihydroxybenzene) and benzaldehyde derivatives to synthesize a new “*Phloroglucinol-Based Microporous Polymeric Organic Frameworks (POFs)*,” which serves as an excellent CO_2 adsorbent. This material exhibits semiconductor-like optical absorption properties, is uniform, microporous, spherical in particle form, and has a large surface area [26].

“*Mesoporous Polymeric Organic Frameworks (MesoPOFs)*” were synthesized via the polymerization of phloroglucinol (1,3,5-trihydroxybenzene) and terephthalaldehyde under solvothermal conditions in the presence of a surfactant. It was determined that MesoPOFs exhibit a 40-fold increase in adsorption selectivity for C_2H_6 compared to CH_4 [25].

“*Monolithic Polymeric Organic Framework Aerogels (Mon-POF)*” with high-density OH functional groups were synthesized via the solvothermal polymerization of terephthalaldehyde and 1,5-dihydroxynaphthalene. It was determined that this Mon-POF is a material with micro-, meso-, and macropores, a high surface area, and a low density, and exhibits stable, controllable porosity behavior under strong acidic and basic conditions. It was determined that the monolith possesses a high number of OH functional groups and exhibits reducing properties following proton exchange with Na^+ . It has also incorporated 5–10 nm Ag nanoparticles. Spherical Ag nanoparticles (5–10 nm) were incorporated into the pores of Mon-POF via the reduction of $AgNO_3$. It was observed that this “*Ag@Mon-POF*,” an excellent adsorbent with macroporosity and high silver content, can stabilize I_2 vapors in the form of β -AgI and I_2 . It has been demonstrated that Mon-POF is a material that can be used for the capture of iodine-129 (^{129}I) and the recovery of precious metals, and thus for the treatment of nuclear waste [39].

“*Poly(terephthalaldehyde-pyrrole) Organic Frameworks (PtpOF)*” were used to synthesize porous nitrogen-doped carbon microspheres (PNCM) for use as supercapacitor electrodes. PtpOF demonstrated high performance as a supercapacitor electrode material. Additionally, the porosity of PNCM was adjusted via KOH activation, yielding activated PNCM (A-PNCM). Both PNCM and A-PNCM were found to be ideal materials for Electric Double-Layer Capacitor (EDLC) electrodes due to their high surface areas and excellent specific capacitances [40].



Using melamine and aromatic dialdehydes as monomers, catalyst-free *melamine-based* nanoparticles were synthesized via a one-pot method. Subsequently, “*Microporous Polymeric Organic Frameworks (POFs)*” were obtained via a solvothermal method [31].

A new porous POF, termed “*Hydroxy-Rich Polymeric Organic Frameworks (POFs)*” has been synthesized via the reaction of aryl aldehyde precursors with fluoroglucinol or resorcinol derivatives for use as an adsorbent in carbon dioxide capture at low pressures (0–1 bar). For this purpose, monomers rich in hydroxyl groups and possessing different sizes and molecular geometries (linear, bent, trigonal, and tetrahedral) were used. It was determined that size and shape compatibility are crucial for achieving high microporosity and, consequently, for CO₂ capture capacity. It was also established that the hydroxyl-rich POF exhibits high CO₂ capture performance [41].

“*Floroglucinol/Terephthalaldehyde Polymeric Organic Frameworks (POFs)*” were synthesized via a solvothermal reaction of floroglucinol and terephthalaldehyde in dioxane, catalyzed by acetic acid (HAc), for supercapacitor applications. Subsequently, carbon materials (USMCs) with ultramicropores, supermicropores (self-templating of fluoroglucinol/terephthalaldehyde POFs), and mesopores (HAc-assisted solvent templating) were produced via the carbonization of the POF. It was demonstrated that the hierarchical porous structure is responsible for the excellent electrochemical performance of the carbon electrode produced for supercapacitors. It was stated that this synthesis methodology provides a practical, effective, and efficient approach for the production of hierarchical porous carbons (HPCs) [32].

“*Neutral and Thiol-Functionalized Porous Polymeric Organic Frameworks (POFs)*” derived from dialkynes and polyalkynes were synthesized as purifiers using click chemistry. It has been determined that these POFs exhibit effective physisorption of the dyes fluorescein and rhodamine B. Additionally, it has been determined that the POFs demonstrate chemisorption for the removal of heavy metals such as mercury, in addition to their conversion capability, and are effective for the adsorption of toxic substances [24].

A new specific POF was synthesized for symmetric supercapacitor (SSC) applications using fluoroglucinol (1,3,5-trihydroxybenzene) and terephthalaldehyde (1,4-benzenedicarboxaldehyde) via a catalyst-free, solvothermal method, and subsequently pyrolyzed at 800°C under an inert atmosphere (argon gas) to yield “*POF-800*”, a novel porous electrode material [23].

“*Phenanthroline-Based Polymeric Organic Framework (PhenTAPB-POF)*” was used as an adsorbent for the separation of trivalent americium from lanthanides, synthesized via a Schiff base reaction with rigid aromatic ligands using the acid-catalyzed solvothermal method, employing 10-phenanthroline-2,9-dicarbaldehyde and 1,3,5-tris(4-aminophenyl)benzene (TAPB). Effective separation between trivalent americium and lanthanides has been achieved using PhenTAPB-POF [30].

It has been found that nitrogenation is highly effective at enhancing the capacitive deionization (CDI) performance of porous carbon materials. In particular, it has been determined that Heteroatom-Doped Polymeric Organic Frameworks are the most suitable precursors for this purpose. For this purpose, nitrogen-enriched micro-mesoporous carbon electrodes (NMC CDI) were produced via the direct carbonization of Schiff base network-1 (SNW-1) at 500, 600, and 700°C, derived from POF using melamine and terephthalaldehyde monomers. As an electrode



material, “*POF-based NMC CDI*” has been effectively used in high-performance CDI applications for desalination [11].

In therapeutic applications, hydrogen sulfide (H₂S) and nitric oxide (NO) in therapeutic applications, a new “*Imine-Linked Nitrogen-Rich 2,4,6-triaminopyrimidine-Based (i-POF)*” has been synthesized via a simple, catalyst-free Schiff base reaction using isophthalaldehyde and 2,4,6-triaminopyrimidine for adsorption and release [20].

Using template-directed in situ polymerization, ultra-thin, nanoscale “*Por-based POF layers*” with two electrocatalytically active sites—such as isolated Co(II) porphyrin (Por-) and Co(II) bipyridine—on a carbon nanotube (CNT) scaffold via π - π interactions have been synthesized to form an organic-inorganic hybrid material, “*CoPOF-Bpy@CNT*”. Through this method, a high-performance electrocatalyst for carbon dioxide electroreduction (CO₂-to-CO conversion) in aqueous solution has been obtained [28].

An organic moiety based on a nitrogen-rich porphyrin with a pyrrole skeleton was successfully incorporated into a POF structure to synthesize “*Amine-Enriched Polymeric Organic Frameworks (POFs)*”, used as a triboelectric layer for energy harvesting, and integrated into a triboelectric nanogenerator (TENG) that converts mechanical energy into electrical energy, resulting in a “*POF-based TENG*” [27].

To develop a ratiometric fluorescent glucose sensor, fluorescent “*Pyrene-Based Polymer Organic Frameworks (PY-POFs)*” were synthesized via a solvothermal method using melamine, aromatic dialdehydes, 1-pyrenecarboxaldehyde, and phenylboronic acid as building blocks. Thus, non-enzymatic glucose detection was performed using PY-POFs. Glucose sensing was visualized in vivo using zebrafish with fluorogenic PY-POFs [29].

Taking into account the three points regarding classification mentioned above, and considering that many functional porous organic polymers have been developed in recent years, [42] it would be more appropriate to classify multifunctional polymer-based Polymeric Organic Frameworks (POFs) under the umbrella of Porous Organic Polymers (POPs) [*porous polymeric organic frameworks*]. In other words, POPs are positioned as a supercategory [7].

Polymeric Organic Frameworks (POFs) are porous nanomaterials with fully organic structures formed by linking organic monomers composed of light elements through strong covalent bonds [11], [12], [28], [31]. POFs form a three-dimensional network structure that is metal-free, can incorporate a large number of functional groups, and offers insights into applications across a wide range of fields [24], [27]. Intrapore microporous POFs are formed through the cross-linking of multiple functional groups with rigid or twisted structures [31].

POFs are attracting significant attention as an advanced class of porous materials due to their vast accessible surface area, high structural and chemical stability, low density, high thermal stability, uniform and tunable pore size, high porosity, tunability, ease of synthesis, non-toxicity, versatile chemical adaptability, and ease of functionalization, making them a highly promising class of advanced porous materials [12], [27], [28], [31]. The availability of non-toxic organic compounds and green solvents in synthesis processes, along with the applicability of catalytic methods, has led to the growing popularity in recent years of multifunctional polymer-based POFs as an alternative nanomaterial that aligns with the principles of “sustainable chemistry / green chemistry” and offers—or will offer—advantages for use in the critical new technologies of the future.



1.4. Applications of Nanoporous Organic Polymers

Gas storage (*hydrofluorocarbons, hexafluorocarbons, nitrogen oxides, CO₂, CH₄, H₂*) [5], [6], [7], [8], [9], [10], [11], [15], [25], [27], [31], [35], [41], gas separation [5], [6], [7], [9], [11], [25], [35], catalysis [5], [7], [10], [11], [13], [15], [24], [41], [43], separation [10], [13], [15], [31], [41], adsorption [10], [11], [24], CO₂ capture, utilization, and storage (CCUS) [7], [8], [13], energy storage (*supercapacitors, lithium/sodium-ion batteries, fuel cells, solar energy conversion, etc.*) [6], [7], [9], [10], [11], [13], [23], [27], [29], [32], [35], [36], proton transport [6], semiconductivity [6], environmental remediation [7], membrane technologies [16], [44], heterogeneous catalysis [9], [16], [29], [43], electrocatalysis [28], photocatalysis [6], photoluminescence [6], [35], photovoltaic conversion (*in solar cells*) [6], enantioseparation [6], optoelectronics [7], [9], [10], [43], iodine adsorption [6], [35], [39], [45], Detection and removal of contaminants (*water/ liquids*) [6], water treatment [20], [46], sensor / sensing [9], [10], [27], [29], [35], indicator, viewer [29], fluorescent glucose sensor [29], drug delivery and controlled release [6], [13], [29], [31], [35], biomedical applications [non-toxic, organic, biocompatible, biodegradable, bioimaging, theranostics (*diagnosis + treatment*), theranostic platforms (*nuclear medicine and radio-theranostics, artificial intelligence and bioinformatics, nanomedicine and smart drug delivery*), tissue engineering, etc.] [7], [29].

6. CONCLUSIONS

In conclusion, Polymeric Organic Frameworks (POFs) are a new generation of polymeric nanomaterials used in dynamic research fields such as nanoscience-nanoengineering and modern materials science-materials engineering. Their wide surface areas, adjustable pore architectures, and adaptable functional properties make them advantageous, and they offer applications consistent with the principles of “sustainable chemistry/green chemistry”. Based on their superior properties—achieved through various organic reagents, solvents, and synthesis mechanisms—and the diversity of their application areas, the transition from the laboratory to industrial applications will gain momentum as their potential for high-efficiency use becomes clearer. POFs are innovative multifunctional nanomaterials that could offer significant opportunities to address critical needs across various fields, both today and in the future.

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Fractional Modeling of Chemical Reaction Dynamics with Memory Effects

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Abstract

This study presents a fractional-order modeling approach to analyze the dynamics of chemical reaction systems. Unlike classical integer-order formulations, fractional derivatives provide an effective framework for incorporating memory and hereditary characteristics into the model structure. In particular, the formulation is based on a fractional operator that enables a more realistic representation of temporal interactions within the system. The governing equations are solved analytically using a Laplace transform technique adapted to the fractional framework. The obtained solutions are evaluated for different fractional orders and compared with those of the classical model to investigate the influence of the fractional parameter on system behavior.

The results indicate that decreasing the fractional order leads to slower system evolution, smoother concentration variations, and more pronounced memory effects. These findings demonstrate that fractional-order modeling offers a flexible and powerful tool for describing complex chemical processes with nonlocal temporal dynamics.

Keywords: *M-Fractional, Laplace Transform, Consecutive reaction.*

1. INTRODUCTION

Chemical reactions play a fundamental role in both natural and industrial processes, governing numerous transformations that occur in physical, biological, and chemical systems. The quantitative description of such processes is the subject of chemical kinetics, which focuses on understanding the rates of reactions and the mechanisms through which reactants are converted into products. Mathematical models have become indispensable tools in chemical kinetics, as they enable researchers to analyze concentration profiles, predict reaction behavior, and optimize operating conditions in laboratory and industrial environments. In particular, kinetic models based on differential equations provide valuable insight into the temporal evolution of chemical species and the factors influencing reaction dynamics [1-5].

Among the various reaction mechanisms encountered in chemical kinetics, consecutive reactions constitute an important class of multistep processes. In these systems, the product generated in one reaction step serves as the reactant in the subsequent step, leading to the formation of one or more intermediate species before the final product is obtained. A typical consecutive reaction pathway can be represented as $x_a \rightarrow x_b \rightarrow x_c$, where x_b denotes an intermediate species connecting the initial reactant and the final product. Such reaction mechanisms are frequently observed in chemical manufacturing, biological transformations, and environmental processes, including radioactive decay chains and ethanol metabolism. The



presence of intermediate species significantly increases the complexity of the reaction mechanism because these species are simultaneously produced and consumed during the reaction process. Consequently, understanding the transient behavior of intermediate compounds is essential for improving product yield, controlling reaction pathways, and optimizing process performance. For this reason, the mathematical modeling and analysis of consecutive reaction systems have attracted considerable attention in the field of chemical kinetics [5-10].

Classical models describing reaction kinetics are generally formulated using ordinary differential equations based on integer-order derivatives. Although these models have successfully explained a wide variety of chemical phenomena, they often fail to capture memory-dependent and hereditary effects that naturally arise in many physical and chemical systems. In recent decades, fractional calculus has emerged as a powerful mathematical framework capable of overcoming some of these limitations. By extending differentiation and integration to non-integer orders, fractional operators provide additional degrees of freedom that allow a more realistic representation of complex dynamical processes. Owing to their ability to incorporate memory effects and nonlocal behavior, fractional differential equations have found widespread applications in physics, engineering, biology, fluid dynamics, epidemiology, and chemical reaction modeling [11-12].

The development of fractional calculus has led to the introduction of numerous fractional derivative definitions, including the Riemann–Liouville, Caputo, Grünwald–Letnikov, Hadamard, and related operators. While these formulations have contributed significantly to the advancement of fractional modeling, some of them do not preserve certain properties commonly associated with classical differentiation. As a result, considerable effort has been devoted to constructing alternative fractional operators that maintain desirable classical characteristics while retaining the advantages of fractional-order modeling. Among these developments, the M-fractional derivative has emerged as a promising operator due to its flexible structure and its ability to preserve several fundamental properties of classical calculus. Furthermore, the M-fractional derivative incorporates the Mittag–Leffler function into its formulation, allowing memory effects to be represented in a mathematically consistent manner while maintaining analytical tractability [13-22].

Motivated by the importance of consecutive reaction systems and the advantages offered by fractional-order modeling, this study investigates the dynamics of consecutive chemical reactions within the framework of the M-fractional derivative. By employing the M-Laplace transform and its inverse, analytical solutions of the governing reaction system are derived. The influence of different fractional orders on the concentration profiles of the chemical species is examined and compared with the corresponding integer-order model. Furthermore, graphical representations of the obtained solutions are presented and interpreted to illustrate the effect of the fractional parameter on the reaction dynamics. The results demonstrate that the M-fractional formulation provides a more comprehensive description of concentration evolution and memory-dependent behavior than the classical integer-order approach. Consequently, this study contributes to the growing literature on fractional chemical kinetics and highlights the effectiveness of M-fractional operators in modeling complex reaction mechanisms.



2. MATERIALS AND METHODS

Definition Let $f: [0, \infty] \rightarrow \mathbb{R}$ function be defined. The M-derivative for $0 < \beta \leq 1$ is defined as follows

$$D_{\beta, \gamma}^M f(t) = \lim_{\varepsilon \rightarrow 0} \frac{f(t E_{\gamma}(\varepsilon t^{-\beta})) - f(t)}{\varepsilon}$$

where $E_{\gamma}(\varepsilon t^{-\beta})$ is Mittag-Leffler function.

Theorem Let $t \geq a$, φ is any continuous function in the domain of I_{α} .

$$D_{\alpha} I_{\alpha}^a(\varphi)(t) = \varphi(t) \quad (3)$$

Definition If $0 < \alpha \leq 1$, $\gamma > 0$, $a, b \in \mathbb{R}$ and f, g are α – differentiable functions at a $t > 0$ point, then

1. $D_{\alpha, \gamma}^M(c) = 0$, c is a constant;
2. $D_{\alpha, \gamma}^M(f \cdot g)(t) = f(t)D_{\alpha, \gamma}^M g(t) + g(t)D_{\alpha, \gamma}^M f(t)$;
3. $D_{\alpha, \gamma}^M\left(\frac{f}{g}\right)(t) = \frac{g(t)D_{\alpha, \gamma}^M f(t) - f(t)D_{\alpha, \gamma}^M g(t)}{[g(t)]^2}$
4. $D_{\alpha, \gamma}^M(fog)(t) = f'(g(t))D_{\alpha, \gamma}^M g(t)$

Definition Let $f: [a, \infty] \rightarrow \mathbb{R}$, $a \in \mathbb{R}$, $\gamma > 0$ and $0 < \rho \leq 1$, then the M-Laplace transform is defined as below

$$L_{\alpha, \gamma}\{f(t)\}(s) = F_{\alpha, \gamma}(s) = \Gamma(\alpha + 1) \int_a^{\infty} e^{-s \frac{\Gamma(\gamma+1)(t-a)^{\alpha}}{\alpha}} f(t) d_{\alpha} t \quad (4)$$

where $(t - a)^{\alpha} dt = d_{\alpha} t$.

3. RESULTS AND DISCUSSION

$$\begin{aligned} D_{\alpha, \gamma}^M \Phi_a(t) &= -K_1 \Phi_a(t) \\ D_{\alpha, \gamma}^M \Phi_b(t) &= K_1 \Phi_a(t) - K_2 \Phi_b(t) \\ D_{\alpha, \gamma}^M \Phi_c(t) &= K_2 \Phi_b(t) \end{aligned} \quad (7)$$

The governing equations are supplemented by the initial conditions $\Phi_a(0) \neq 0, \Phi_b(0) = 0, \Phi_c(0) = 0$. In addition, K_1, K_2 and K_3 denote the reaction rate parameters expressed in units of s^{-1} , s: second.

Employing the M-fractional Laplace transform on system (8) with respect to time leads to the following relations:

$$\begin{aligned} \mathcal{L}\{D_{\alpha, \gamma}^M \Phi_a(t)\}(s) &= -K_1 \mathcal{L}\{\Phi_a(t)\}(s) \\ s \mathcal{L}\{\Phi_a(t)\}(s) - \Phi_a(0) &= -K_1 \mathcal{L}\{\Phi_a(t)\}(s) \end{aligned}$$



$$\mathcal{L}\{\Phi_a(t)\}(s) = \frac{\Phi_a(0)}{s + K_1}$$

Taking the inverse Laplace transform yields the following expressions:

$$\Phi_a(t) = \Phi_a(0)e^{-K_1\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} \quad (8)$$

The above procedure leads to the following expressions:

$$\begin{aligned} \mathcal{L}\{D_{\alpha,\gamma}^M \Phi_b(t)\}(s) &= K_1 \mathcal{L}\{\Phi_a(t)\}(s) - K_2 \mathcal{L}\{\Phi_b(t)\}(s) \\ s \mathcal{L}\{\Phi_b(t)\}(s) - \Phi_b(0) &= K_1 \frac{\Phi_a(0)}{s + K_1} - K_2 \mathcal{L}\{\Phi_b(t)\}(s) \\ \mathcal{L}\{\Phi_b(t)\}(s) &= \frac{K_1 \Phi_a(0)}{(s + K_1)(s + K_2)} \\ &= \frac{K_1 \Phi_a(0)}{K_1 - K_2} \left(\frac{1}{s + K_2} - \frac{1}{s + K_1} \right) \end{aligned}$$

Taking the inverse Laplace transform yields the following expressions:

$$\Phi_b(t) = \frac{K_1 \Phi_a(0)}{K_1 - K_2} \left(e^{-K_2\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} - e^{-K_1\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} \right) \quad (9)$$

The above procedure leads to the following expressions:

$$\begin{aligned} \mathcal{L}\{D_{\alpha,\gamma}^M \Phi_c(t)\}(s) &= K_2 \mathcal{L}\{\Phi_b(t)\}(s) \\ s \mathcal{L}\{\Phi_c(t)\}(s) - \Phi_c(0) &= K_2 \mathcal{L}\{\Phi_b(t)\}(s) \\ \mathcal{L}\{\Phi_c(t)\}(s) &= \frac{K_1 K_2 \Phi_a(0)}{K_1 - K_2} \frac{1}{s} \left(\frac{1}{s + K_2} - \frac{1}{s + K_1} \right) \\ &= \frac{\Phi_a(0)}{s} + \left(\frac{K_2 \Phi_a(0)}{(K_1 - K_2)(s + K_1)} - \frac{K_1 \Phi_a(0)}{(K_1 - K_2)(s + K_2)} \right) \end{aligned}$$

Taking the inverse Laplace transform yields the following expressions:

$$\Phi_c(t) = \Phi_a(0) + \frac{\Phi_a(0)}{K_1 - K_2} \left(K_2 e^{-K_1\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} - K_1 e^{-K_2\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} \right) \quad (10)$$

Thus, the exact expressions for the concentrations of species a , b , and c in the M -fractional reaction model (7) are given by Eqs. (8)–(10), respectively, for $\alpha \in (0,1]$.

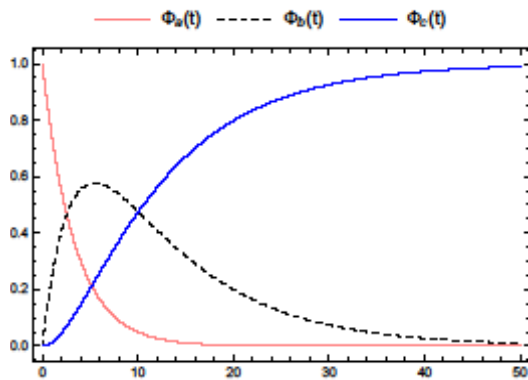
$$\begin{aligned} \Phi_a(t) &= \Phi_a(0)e^{-K_1\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} \\ \Phi_b(t) &= \frac{K_1 \Phi_a(0)}{K_1 - K_2} \left(e^{-K_2\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} - e^{-K_1\Gamma(\gamma+1)\frac{t^\alpha}{\alpha}} \right) \end{aligned}$$

$$\Phi_c(t) = \Phi_a(0) + \frac{\Phi_a(0)}{K_1 - K_2} \left(K_2 e^{-K_1 \Gamma(\gamma+1) \frac{t^\alpha}{\alpha}} - K_1 e^{-K_2 \Gamma(\gamma+1) \frac{t^\alpha}{\alpha}} \right)$$

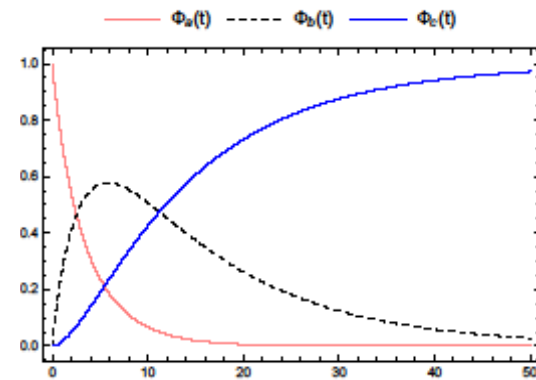
These solutions describe the temporal evolution of species a , b , and c .

4. CONCLUSIONS

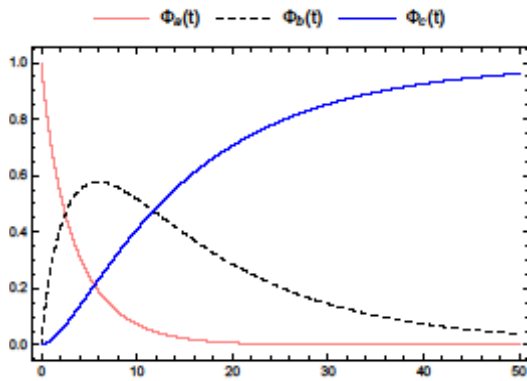
This study investigates the chemical kinetics of a consecutive reaction system involving three species, namely a , b , and c . Exact analytical solutions describing the concentration profiles of the species are obtained by means of the Laplace transform and its inverse. The proposed model is formulated within the framework of the M-fractional derivative, allowing the influence of the fractional-order parameter α and the reaction rate constants K_1 and K_2 to be examined in detail. Graphical analyses are presented to illustrate the temporal evolution of the concentration profiles under different parameter values. The obtained results reveal the significant impact of both the fractional order and the reaction rate constants on the reaction dynamics. Furthermore, comparisons with the corresponding integer-order model are performed to highlight the role of memory effects in the reaction process. The M-fractional formulation provides a more comprehensive understanding of the behavior of consecutive reaction systems and demonstrates the effectiveness of fractional modeling in chemical kinetics.



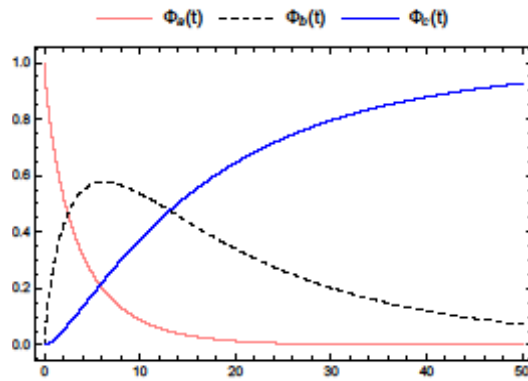
a) $\alpha = 1$



b) $\alpha = 0.92$



c) $\alpha = 0.89$



d) $\alpha = 0.8$

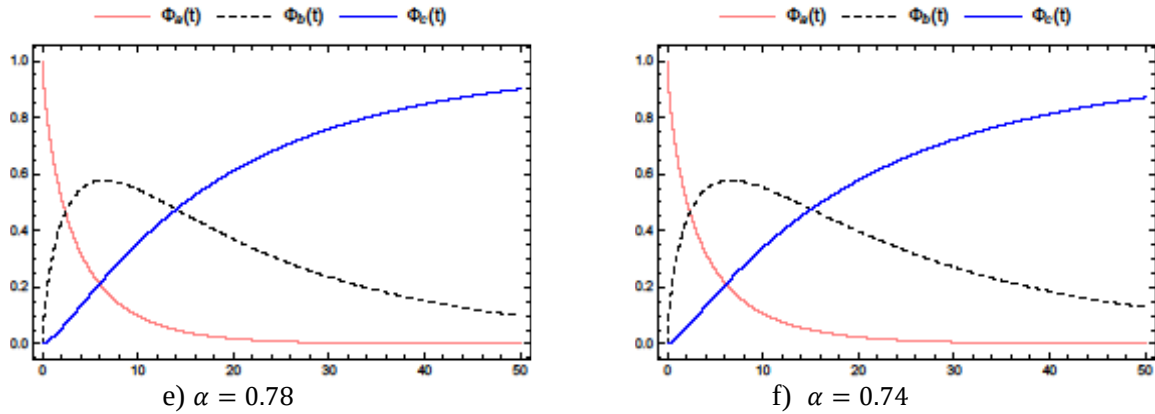
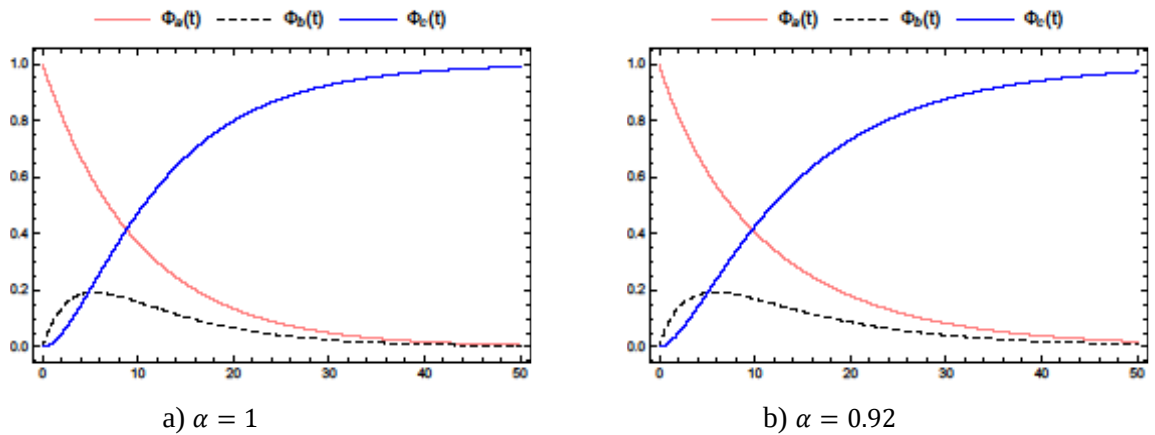


Figure 1. Concentration dynamics for the reaction characterized by $K_1 = 0.3$ and $K_2 = 0.1$.

Figure 1 depicts the concentration profiles of the species involved in the consecutive reaction system as functions of time for different values of the fractional-order parameter α . It should be noted that the case $\alpha = 1$ corresponds to the classical integer-order model, whereas $\alpha < 1$ represents the M-fractional formulation. To examine the influence of the fractional order, the reaction rate constants were fixed at $K_1 = 0.3$ and $K_2 = 0.1$, satisfying the condition $K_1 > K_2$. The results indicate that decreasing the value of α slows down the depletion of species a , causing its concentration to approach zero more gradually. From a physical perspective, this behavior suggests a slower consumption of the reactant during the reaction process. The concentration of the intermediate species b initially increases, reaches its peak at approximately six time units, and subsequently decreases as the reaction proceeds. In contrast, lower values of α lead to smaller concentration levels of species c , indicating that the formation of the final product is delayed due to the enhanced memory effects introduced by the M-fractional operator.



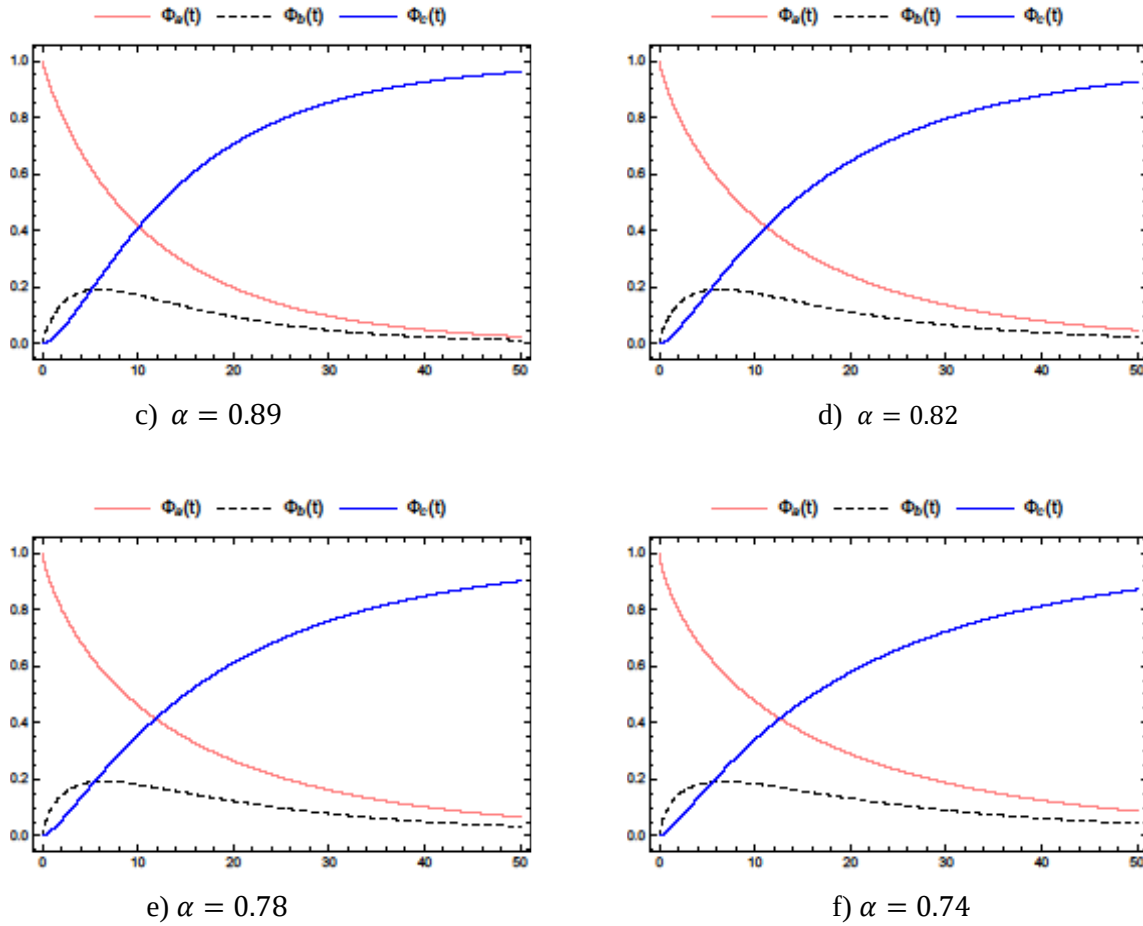


Figure 2. Concentration dynamics for the reaction characterized by $K_1 = 0.1$ and $K_2 = 0.3$.

Figure 2 illustrates the concentration profiles corresponding to $K_1 = 0.1$ and $K_2 = 0.3$, where the conversion of the intermediate species into the final product occurs more rapidly than its formation. Under these conditions, species a remains in the system for a longer period due to the relatively small value of K_1 . The intermediate species b exhibits only a brief accumulation stage, reaching its maximum concentration within approximately two time units before rapidly decreasing toward zero. This behavior indicates that the consumption of b dominates its production rate. Consequently, species c is formed more efficiently and becomes the dominant component of the system at earlier times. Furthermore, decreasing the fractional-order parameter α slows down the overall reaction dynamics, leading to a more gradual evolution of all concentration profiles.

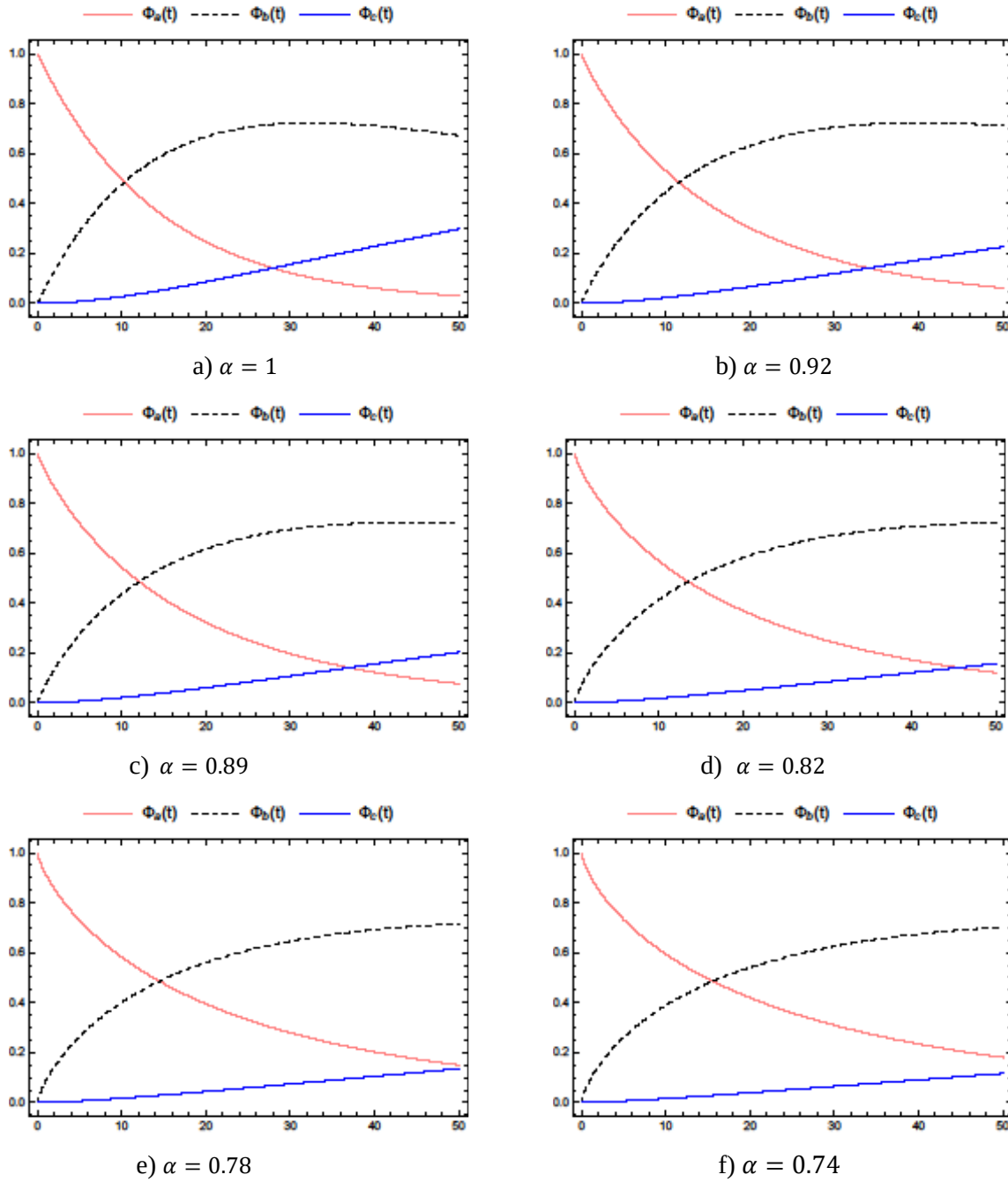


Figure 3. Concentration dynamics for the reaction characterized by $K_1 = 0.07$ and $K_2 = 0.01$.

Figure 3 displays the concentration profiles of species a , b , and c obtained from the M-fractional reaction model for the relatively small reaction rate constants $K_1 = 0.07$ and $K_2 = 0.01$, satisfying the condition $K_1 > K_2$. The results indicate that reducing the fractional-order parameter α , particularly for $\alpha \leq 0.75$, significantly slows the depletion of species a . Consequently, the reactant remains in the system for a longer period compared with the classical case ($\alpha = 1$). This delayed consumption of species a is reflected in a slower formation of the subsequent species and the final product. The graphical results clearly demonstrate that the M-fractional formulation is capable of capturing retardation effects in reaction dynamics and provides additional insight into mechanisms that may reduce the overall reaction rate.



Declaration of Competing Interest

The authors confirm that there are no financial or personal relationships that could have influenced the work presented in this manuscript.

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ABSTRACT PRESENTATIONS



Supercapacitor Performance of α -Fe₂O₃ Thin-Films Electrodes Grown by ECD

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Abstract

In this study, iron oxide (Fe₂O₃) thin films (TFs) were successfully electrodeposited onto ITO substrates and systematically characterized to elucidate the impact of structural and morphological features on electrochemical performance. The structural properties of the films were examined by X-ray diffraction (XRD), confirming the formation of crystalline Fe₂O₃ phases. In Raman spectroscopic investigations of α -Fe₂O₃, the vibrational spectrum is dominated by phonon modes that reflect the symmetry and lattice dynamics of the rhombohedral structure. The optical absorption characteristics were analyzed by UV–Vis spectroscopy, indicating strong light–matter interaction, with an absorption edge typical of Fe₂O₃ semiconductors and an estimated band gap of approximately 2 eV. Fourier transform infrared spectroscopy (FTIR) identified characteristic Fe–O bonding and surface-related functional groups, while X-ray photoelectron spectroscopy (XPS) confirmed the oxidation states of iron and oxygen as well as the chemical composition of the films. Surface morphology and microstructural features were analyzed by scanning electron microscopy, showing a uniform and nanostructured film morphology favorable for electrolyte penetration. Also, the Fe₂O₃ TF electrode electrodeposited on the ITO substrate delivers a high specific capacitance of approximately 377 F g⁻¹ at a current density of 1 A g⁻¹ from galvanostatic charge-discharge measurements. With increasing current density, a pronounced decline in capacitance is observed, dropping to nearly 23 F/g at 10 A/g. The Fe₂O₃/ITO electrodes exhibited distinct pseudocapacitive behavior, low charge-transfer resistance, and good cycling stability, demonstrating their potential as cost-effective and high-performance electrodes for supercapacitor devices.

Keywords: charge-discharge, Fe₂O₃ thin films, electrodeposition, supercapacitor



Continuous Visible-Light Photocatalytic Degradation of Methylene Blue in a thin Film Coated Reactor

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Zinc oxide (ZnO) is widely investigated as a semiconductor photocatalyst for dye-containing wastewater treatment because of its strong oxidation ability, chemical stability, low cost, and applicability in thin-film configurations; however, its relatively wide band gap and fast electron-hole recombination restrict its photocatalytic efficiency, particularly under visible-light irradiation. Ag modification has been reported as an effective strategy to improve the visible-light response and charge separation behavior of ZnO-based photocatalysts, leading to enhanced methylene blue degradation performance compared with undoped ZnO. In addition, immobilized ZnO-based thin films prepared by spray pyrolysis are attractive for continuous-flow photocatalytic systems because they reduce catalyst separation problems and allow more stable operation under controlled residence-time conditions. In this study, Ag-doped ZnO photocatalytic coatings were deposited by spray pyrolysis and evaluated for the continuous degradation of methylene blue under visible-light irradiation in a mini-channel reactor. The effects of residence time on dye removal efficiency were investigated by varying the flow conditions through the reactor. The structural and morphological properties of the Ag-doped ZnO coatings were characterized by X-ray diffraction and scanning electron microscopy. XRD analysis was used to identify the crystalline ZnO phase and possible structural changes associated with Ag incorporation, while SEM observations provided information on surface morphology, coating uniformity, and particle distribution. This study highlights the potential of spray-pyrolysis-coated Ag-doped ZnO films as reusable immobilized photocatalysts for compact continuous-flow treatment systems targeting dye-contaminated wastewater.

Keywords: Ag-doped ZnO, spray pyrolysis, methylene blue, mini-channel reactor, visible light



Valorization of Apricot Kernel Shell Waste: Biochar Application in *Pleurotus ostreatus* Cultivation

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Mushroom cultivation plays a significant role in agricultural production and environmental management due to its economic value and its potential for waste valorization [1]. Among cultivated species, *Pleurotus ostreatus* stands out due to its high nutritional value, short production cycle, and ability to utilize lignocellulosic agricultural wastes, making it an important species for both sustainability and food production [2]. Although substrate preparation is relatively simple, the use of additives can significantly enhance yield and improve resistance to environmental stress and diseases [3]. In recent years, biochar produced via pyrolysis from various biological feedstocks has gained attention as a functional material in different biotechnological applications [4].

In this study, apricot kernel shell waste, an abundant agro-industrial by-product in Kyrgyzstan, was evaluated as a biochar source for mushroom cultivation. Biochar was incorporated into the substrate at three different concentrations (20, 40, and 60 g/L), and its effects on mycelial growth, pinhead formation, and yield parameters were assessed.

The results demonstrated that low-dose biochar application (20 g/L) significantly enhanced mycelial growth rate, increased yield, and showed the highest biological efficiency. In contrast, higher concentrations negatively affected mushroom development and resulted in reduced productivity.

In conclusion, biochar derived from apricot kernel shells can serve as an effective substrate amendment in *P. ostreatus* cultivation when applied at appropriate doses. This approach not only improves production performance but also contributes to sustainable waste management. Further studies are recommended to evaluate different biochar types, mushroom species, and application rates.

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Notes on the Ricci Curvature Tensor on an Almost Product Lorentzian Walker Three-Manifold

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This paper presents a detailed analysis of the geometry of the Ricci tensor associated with a twin metric G_f on an almost product Lorentzian Walker three-manifold (M^3, J, g_f) . The necessary and sufficient condition characterizing the Ricci-flatness of the quadruple (M^3, J, g_f, G_f) is first derived, followed by a rigorous examination of the relationship between Ricci-flatness and flatness of the manifold. Beyond this, a series of theorems establishing necessary and sufficient conditions for (M^3, J, g_f, G_f) to be locally Ricci symmetric and cyclic parallel Ricci are presented. As a direct consequence, the intrinsic relationship between these two geometric classes is explicitly described.

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Solving of Fractal Complex Differential Equations with the Homotopy Analysis Method

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In this paper, the fundamental definitions of fractal analysis are extended to fractal complex analysis, and the fractal measure and fractal staircase function are formulated in the complex domain [1]. Within this framework, the application of the Homotopy Analysis Method (HAM) to solve higher-order fractal complex differential equations is investigated. Fractal differential equations play a significant role in modeling complex phenomena **in various scientific fields**, particularly in systems exhibiting irregular and self-similar structures [2]. Due to their complexity, obtaining exact solutions is often challenging, which necessitates the use of efficient analytical methods [3,4].

In this study, the influence of the convergence-control parameter h on the approximate solution is analyzed in detail. The obtained approximate solutions are compared with the corresponding analytical solutions for different values of h , and the accuracy of the method is evaluated. Furthermore, graphical representations of both approximate and analytical solutions are presented, and error distributions are visualized to illustrate the deviation between the solutions. The performance of the method is also assessed using statistical error measures, including maximum error, mean error, and standard deviation, which are computed using MATLAB.

The results demonstrate that an appropriate selection of the parameter h significantly improves the convergence and accuracy of the method. Overall, the findings confirm that HAM is an effective and reliable approach for analyzing fractal complex differential equations.

Keywords: *Fractal complex analysis, Homotopy Analysis Method.*

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Conformal Soliton Structures on Tangent Bundles with Semi-Symmetric Metric Connections

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In this study, we consider the tangent bundle of a pseudo-Riemannian manifold equipped with a semi-symmetric metric connection. The main objective is to determine the necessary and sufficient conditions under which the tangent bundle admits various types of conformal soliton structures. In particular, we investigate conformal Yamabe solitons, gradient conformal Yamabe solitons, conformal Ricci solitons, and their gradient counterparts. The results reveal how the geometric properties induced by the semi-symmetric metric connection influence the existence and characterization of these soliton structures on the tangent bundle.

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Symmetries of Almost Golden Lorentzian Walker Three-Manifold

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In this study, we first construct a golden structure J on a three-dimensional Lorentzian Walker manifold. By means of this structure J , we then derive a new metric (twin golden metric) on the Walker manifold. Remarkably, although the Walker metric is non-diagonal, the twin golden metric is diagonal. Subsequently, in certain special cases, we present necessary and sufficient conditions for the twin golden metric to be Ricci–Codazzi. Furthermore, in some notable particular cases, we investigate Ricci collineations on the three-dimensional Lorentzian Walker manifold associated with the twin golden metric.

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Harmonic and Biharmonic Mappings Induced by a Killing-Type Metric Deformation

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In this study, we consider Riemannian manifolds that admit Killing vector fields and introduce a new metric structure obtained through a non-conformal deformation governed by such a vector field. We first analyze the fundamental geometric features of this modified metric, including its associated connection and curvature behavior, and examine how the Killing property is preserved under this deformation. Furthermore, we investigate the behavior of mappings under this new geometric setting by computing the corresponding tension field and Jacobi operator. These computations provide a framework for studying both harmonic and biharmonic maps, revealing how the introduced metric influences their existence and properties.

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Golden Structure on Walker Manifolds

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In this work, we propose and analyze a novel geometric framework called the golden-Walker manifold, which arises from equipping a four-dimensional Walker manifold with a golden structure. The golden structure φ is characterized as an endomorphism satisfying the

$$\varphi^2 = \varphi + I$$

relation, where I denotes the identity map. Following the development of its fundamental geometric properties, we explore the curvature behavior of these manifolds and derive explicit criteria under which particular curvature conditions are satisfied. In addition, we study soliton-type geometric structures on golden-Walker manifolds, with special emphasis on the existence and characterization of Ricci solitons and related generalizations.

Keywords: Golden-Structure, Walker Manifold, Soliton

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Cumulative Risk Assessment of Combined Exposure to Glyphosate and Atrazine Mixtures in Drinking Water and Soil from Four Rural Farmlands in Southwest Nigeria

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Previous studies on health risks associated with atrazine and glyphosate exposure have primarily examined each herbicide in isolation. However, human populations are routinely exposed to mixtures of these herbicides, raising concerns about potential adverse effects. This study evaluated the cumulative risk of exposure to a mix of glyphosate and atrazine in soil and drinking water from four remote farm areas in Southwestern Nigeria.

Triplicate soil (0–30 cm depth) and stream water (primary drinking water source) samples, as well as control samples, were collected from each settlement using standard protocols. Atrazine and glyphosate residues were quantified using chromatographic techniques. Mean residue values were used to evaluate non-carcinogenic health risks associated with oral and dermal exposure for adults and children, employing Hazard Index (HI), Maximum Cumulative Ratio (MCR), and Missed Toxicity (MT) approaches.

Atrazine concentrations in soil ranged from 0.370 to 0.680 mg/kg, while glyphosate concentrations ranged from 0.200 to 0.520 mg/kg. In stream water, atrazine concentrations ranged from 0.009 to 0.033 mg/L, and glyphosate concentrations ranged from 0.018 to 0.046 mg/L. While the HI for combined glyphosate and atrazine exposure in soil and water remains below established risk limits, children are particularly vulnerable. The MCR for oral exposure is notably higher—ranging from 1.17 to 1.74—than that for dermal exposure (1.05 to 1.10). Without a cumulative risk assessment, up to 43% of the health risks associated with oral exposure to herbicide mixtures could go undetected.

Drinking water and soil from the farm settlements were contaminated with both atrazine and glyphosate. Although overall risks appear low, the heightened vulnerability of children highlights the importance of considering chemical mixtures in risk assessments

Keywords: Food safety, Cumulative health risks, Farm settlement, Atrazine, Glyphosate



Histopathological Features of Necrotizing Hepatitis in Ducks Associated with Paratyphoid (Salmonellosis)

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Background: Infectious diseases in ducks often cause severe hepatic damage accompanied by necrosis, inflammation, and vascular dysfunction. Histopathological assessment of the liver is essential for identifying characteristic lesions and clarifying the morphological basis of systemic infectious processes.

Aims: To characterize the main histopathological alterations in the liver of ducks affected by severe infection.

Materials and Methods: Affected liver tissues were fixed in 10% neutral buffered formalin, routinely processed for paraffin embedding, sectioned at 5 µm, and stained with hematoxylin and eosin following standard protocols. Microscopic evaluation focused on parenchymal, stromal, vascular, and biliary changes.

Results: Histological examination revealed pronounced destructive and necrotic lesions involving both hepatic parenchyma and stroma. Large focal serous-purulent necrotic areas were observed in the capsule and subcapsular regions. Necrotic masses showed homogeneous eosinophilic appearance with fragmentation, residual basophilic nuclear debris, and features of karyopyknosis and karyorrhexis. Fibrin deposits were present in zones of tissue depletion. At the boundary between viable and necrotic tissue, degenerative hepatocytes with pyknotic nuclei and abundant cellular detritus indicated concurrent coagulative and colliquative necrosis. Numerous small-focal necroses and micronectroses were scattered throughout the parenchyma. Multiple nodular lesions consistent with paratyphoid infection were detected, characterized by a central exudative-necrotic core containing fibrin and cellular debris infiltrated by heterophils, surrounded by lymphocytes, macrophages, heterophils, and fibroblasts, reflecting an inflammatory-proliferative reaction. Hepatic architecture was severely disrupted with atrophy and disorganization of hepatic cords and occasional acinus-like formations. Hepatocytes exhibited granular degeneration and micro- and macrovesicular fatty change. Marked lymphohistiocytic infiltration was observed within intralobular spaces. Vascular lesions included vasculitis, endothelial destruction, fibrinoid necrosis, stasis, microthrombosis, and perivascular hemorrhages. Biliary changes comprised bile duct epithelial degeneration, bile stasis, cholangitis, and focal desquamation of cholangiocytes.

Conclusion: Duck liver pathology was characterized by extensive necrosis, paratyphoid-associated nodular inflammation, severe vascular injury, and biliary tract involvement, indicating an aggressive systemic infectious process.

Keywords: Ducks, Salmonellosis, Necrotizing hepatitis, Vasculitis, Cholangitis



Histopathological Characteristics of the Mammary Gland in Acute Suppurative Mastitis Caused by *Staphylococcus aureus*

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Abstract

Background: Bovine mastitis remains one of the most common diseases of the mammary gland, causing reduced milk yield and major economic losses. Acute suppurative mastitis caused by *Staphylococcus aureus* is particularly severe due to pronounced inflammatory and destructive tissue alterations.

Aims: To examine the normal microstructure of the bovine mammary gland and to identify histopathological changes associated with acute suppurative staphylococcal mastitis.

Materials and Methods: Mammary gland tissue samples from clinically healthy cows and cows with infectious mastitis were fixed in 10% neutral buffered formalin. After routine histological processing, tissues were embedded in paraffin, sectioned at 5 µm, and stained with hematoxylin and eosin (H&E). Histopathological evaluation was performed using light microscopy.

Results: In clinically healthy cows, the mammary gland exhibited a preserved alveolar-lobular organization. Alveoli were lined with a single layer of cuboidal or low columnar secretory epithelium showing normal polarity. Myoepithelial cells formed a contractile layer, while the stroma consisted of loose connective tissue containing blood and lymphatic vessels. No inflammatory changes were observed.

In acute suppurative mastitis caused by *S. aureus*, severe disruption of glandular architecture was detected, accompanied by marked neutrophilic infiltration and interstitial edema. The alveolar epithelium showed dystrophic changes, desquamation, and necrosis, with reduction or complete loss of myoepithelial cells. Alveolar and ductal lumina were filled with abundant seropurulent or fibrinopurulent exudate. A characteristic finding was the formation of microabscesses and multifocal areas of coagulative and liquefactive necrosis associated with cellular debris and vascular damage. Pronounced vascular alterations, endothelial swelling, and diapedesis of blood cells were also evident.

Conclusion: Acute staphylococcal suppurative mastitis is characterized by extensive neutrophilic inflammation, microabscess formation, necrosis, and destruction of the alveolar-ductal system, indicating severe parenchymal and stromal injury in the bovine mammary gland.



Micromorphological and Immunohistochemical Characterization of MALT in the Digestive Tract of Yaks (*Bos grunniens*) from Kyrgyzstan

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Abstract

Background: The digestive tract of ruminants serves not only as a digestive organ but also as a major immunological barrier represented by mucosa-associated lymphoid tissue (MALT). However, data on the regional distribution of immune cell populations in yaks adapted to the high-altitude conditions of Kyrgyzstan remain limited.

Aims: To investigate the micromorphology of the yak digestive tract and to characterize MALT components using immunohistochemical markers.

Materials and Methods: The study included 16 yaks. Six animals were slaughtered under controlled conditions, while additional samples from 10 yaks were collected at slaughter facilities in Bishkek. Tissue specimens were fixed in 10% neutral buffered formalin and processed using standard histological protocols with Leica equipment (TP1020, EG1150, RM2255). Sections (2–5 µm) were stained with hematoxylin and eosin. Immunohistochemistry was performed using the SABC method with antibodies against CD3, CD79αcy, MAC387, Ki-67, and PCNA.

Results: The digestive tract wall of yaks demonstrated a typical three-layer organization across all regions. In the upper tract (lip, cheek, esophagus), lymphoid elements were mainly represented by diffuse T-lymphocyte populations with minimal B-cell and macrophage presence. In tonsillar structures (palatine, pharyngeal, lingual), well-developed secondary lymphoid follicles with prominent germinal centers showed high proliferative activity. In the forestomachs, immune cell infiltration was scarce. The most pronounced MALT development was observed in the abomasum and small intestine, particularly in the ileum (Peyer's patches), where distinct T- and B-dependent zones were clearly identified.

Conclusion: The yak digestive tract exhibits marked regional specialization of MALT, reflecting an adaptive immune defense mechanism potentially associated with high-altitude environmental conditions.

Keywords: Yak, Digestive tract, MALT, Immunohistochemistry, Lymphoid tissue



Natural Death Associated with Senile Dementia in a Snow Leopard (*Panthera uncia*): A Case Report

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Background: The snow leopard (*Panthera uncia*) is a rare and protected species, and mortality cases require detailed forensic veterinary evaluation to exclude trauma, intoxication, or infectious disease. Senile involution and chronic multi-organ dysfunction may represent important natural causes of death in aged individuals, particularly under conditions of starvation and immunosuppression.

Aims: This study aimed to determine the cause of death of a snow leopard based on gross necropsy findings, histopathological examination, and forensic veterinary interpretation.

Materials and Methods: A complete external and internal postmortem examination was performed on the carcass of a snow leopard preserved in a natural state. Macroscopic changes were documented for all major organ systems. Tissue samples from internal organs were collected and processed for histological examination using standard paraffin embedding and hematoxylin–eosin staining. Microscopic lesions were evaluated to support diagnostic conclusions and forensic assessment.

Results: External examination revealed severe cachexia, marked skeletal muscle atrophy, and a significant reduction of subcutaneous adipose tissue. The coat was dull with focal alopecia. Dental wear was pronounced, with signs of periodontitis and age-related deformation. Dried blood traces were present on the fur of the lower jaw region and forelimbs. No skin injuries, fractures, or other traumatic lesions sufficient to explain death were identified. Internally, the cardiovascular system showed mild cardiomegaly, fibrotic alterations of cardiac valves, and petechial hemorrhages. Serous atrophy of fat in the cardiac adipose tissue and myocardial petechiae were also observed. Pulmonary examination revealed emphysematous changes, foci of pneumosclerosis, and edema in certain lobes, with foamy exudate on the cut surface. The gastrointestinal tract showed thinning of the gastric and intestinal mucosa. The liver exhibited degenerative hepatocellular changes and fibrotic areas. The thymus was absent, consistent with age-related involution. The pancreas appeared dark yellow, edematous, enlarged, and dull. Histopathology demonstrated diffuse fibrosis in multiple internal organs. The heart showed mild myocarditis and petechial hemorrhages. The lungs displayed alveolar emphysema, congestion of alveolar septa, and fluid exudate in alveolar spaces, confirming pulmonary edema. The liver exhibited fatty degeneration, disruption of hepatic cord architecture, and focal necrosis. Severe enteritis and mucosal autolysis were identified in the intestine.

Conclusion: No evidence of acute infectious disease, intoxication, or fatal trauma was detected. The pathological findings indicate chronic systemic degeneration associated with advanced age and starvation-related immunosuppression, resulting in chronic cardiovascular insufficiency, pulmonary edema, enteritis, and multi-organ failure. Death was attributed to natural senile involution with progressive chronic cardio-respiratory and multi-organ insufficiency.

Keywords: Snow leopard, Necropsy, Senile involution, Multi-organ failure, Pulmonary edema.



In Silico Enzyme Engineering: Enhancing Stability and Reusability for Industrial Biocatalysis

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The design of a novel analog enzyme of Lipase B derived from *Candida antarctica* (PDB ID: 1LBS) with improved stability presents a promising opportunity for applications in industrial processes and agriculture. By incorporating specific amino acid substitutions known to provide thermal stability, such as Ser56→Leu mutation, into the enzyme structure and using non-canonical amino acids that increase structural rigidity, the designed lipase can withstand the more challenging conditions frequently encountered in industrial settings. This increased stability not only enhances the enzyme's catalytic efficiency but also expands its usability in various industrial lipase enzyme applications, including biodiesel production and the breakdown of organic waste in agricultural applications. Furthermore, the newly designed lipase can facilitate more efficient nutrient absorption in plants by breaking down fats and oils, ultimately improving plant growth and yield. This innovative approach aligns with the growing demand for sustainable biocatalysts that can operate effectively under challenging environmental conditions, thus supporting both agricultural productivity and industrial sustainability.

Keywords: Lipase B, *Candida antarctica*, Protein engineering, Enzyme stability, Thermal stability



A Multi-Criteria Optimal Control Framework for the Van der Pol Oscillator

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The Van der Pol oscillator is a classical nonlinear dynamical model widely used to describe self-sustained oscillatory phenomena in electrical circuits, biological rhythms, and mechanical systems. Due to its nonlinear damping structure and limit-cycle behavior, designing efficient control strategies for this system remains a challenging problem. In many applications, the control objective involves not only accurate reference tracking but also reduced energy consumption and smooth control signals that prevent excessive actuator wear.

In this study, a multi-objective optimal control framework for the Van der Pol oscillator is developed using the Pontryagin Maximum Principle (PMP) [1]. The considered optimal control problem minimizes a cost functional that penalizes the reference tracking error, the control energy, and the derivative of the control signal. This formulation allows balancing tracking performance, energy efficiency, and control smoothness.

The existence of an optimal control is established using the Filippov–Cesari existence theorem [2], while the necessary optimality conditions are derived through Pontryagin’s Maximum Principle. The local uniqueness of the optimal control is examined using the Mangasarian condition [3]. For the numerical implementation, the optimality system is reformulated as a boundary value problem and solved using a collocation-based numerical method [4].

Numerical experiments with different reference signals illustrate the trade-off between tracking accuracy, control energy, and smoothness of the control signal. The results demonstrate that the proposed approach provides an effective framework for balancing multiple objectives in nonlinear control systems.

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In Silico Prediction and Characterization of Antidiabetic Peptide Fragments Derived from Cineole Synthase of *Salvia mirzayanii*

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Type 1 diabetes (T1D) remains a chronic autoimmune disorder requiring novel therapeutic approaches. Plant-derived bioactive peptides have emerged as promising candidates due to their specificity and favorable safety profiles. This study aimed to predict and characterize the antidiabetic and antibacterial potential of three 15-amino acid peptide fragments derived from cineole synthase (partial) of *Salvia mirzayanii* (GenBank: AMB42790.1). Comprehensive in silico analyses were performed using ADP-Fuse, AntiDMPpred, HLPpred-Fuse, HyPepTox-Fuse, and ProtParam tools. All three peptides were strongly predicted as antidiabetic peptides (Layer 1 probability = 1.0) with high T1D association (probabilities: 0.997, 0.996, and 0.992, respectively). AntiDMPpred confirmed antidiabetic potential (probabilities: 0.67, 0.65, and 0.60). Toxicity, allergenicity, and hemolytic activity predictions indicated non-toxic, non-allergenic, and non-hemolytic profiles for all sequences. Physicochemical characterization revealed molecular weights ranging from 1686 to 1749 Da, isoelectric points of 4.37, and stable structures (instability indices: 16.62–22.28). High aliphatic indices (136.67–182.00) and positive GRAVY values (0.527–1.153) indicated hydrophobic nature. While poor aqueous solubility was predicted, all peptides exhibited favorable stability. These findings suggest that cineole synthase-derived peptides from *Salvia mirzayanii* represent promising antidiabetic candidates with advantageous stability and safety profiles, warranting further in vitro and in vivo experimental validation.

Keywords: Antidiabetic peptide, *Salvia mirzayanii*, cineole synthase, type 1 diabetes, in silico prediction

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Co-B/Co₃O₄ catalyst for efficient H₂ generation from methanolysis NaBH₄

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Energy is a fundamental driver of economic development and social well-being. The search for alternative energy sources or carriers that can replace traditional fossil fuels has become urgent. Hydrogen has emerged as one of the leading candidates for the near future due to its clean energy carrier properties. It provides approximately three times the energy efficiency of gasoline and its combustion produces only harmless byproducts [1,2]. Nevertheless, for practical and portable applications requiring safe and controllable hydrogen release, chemical hydrogen storage materials enabling on-demand H₂ generation remain highly attractive. Therefore, metal borohydrides, particularly NaBH₄, have gained increasing interest as feasible hydrogen sources for on-demand hydrogen generation [3]. Among these, sodium borohydride (NaBH₄) stands out with its stability in various solvents, 10.8% hydrogen content by weight, and controllable and clean hydrogen production [4]. NaBH₄ releases hydrogen via various solvolysis reactions such as hydrolysis, methanolysis, and ethanolysis, but for all of these a catalyst must be designed and used. Among solvolysis reactions, recent studies have focused on NaBH₄ methanolysis because methanolysis differs in its solvent capacity, speed, and stability. Metal-containing catalysts are often designed to provide stable and low-activation-energy NaBH₄ methanolysis [5]. This study synthesized an effective Co-B/Co₃O₄ catalyst for H₂ generation from methanolysis NaBH₄. Co₃O₄ support material is synthesized by the co-precipitation method. Then, Co is doped into support material by the impregnation method. It is found that Co-B/Co₃O₄ catalyst exhibited high reaction activity with a maximum hydrogen generation rate (HGR) of 11511 ml min⁻¹ gcat⁻¹ at 25°C. Additionally, the effects of different solution temperatures on the hydrogen generation rate were investigated. The hydrogen generation rate was 17226 ml min⁻¹ gcat⁻¹ when the solution temperature was 55 °C. In reusability experiments, it was observed the preservation rate of the catalyst remained at 75% of its initial catalytic activity after 5 cycles.

Keywords: Co-B, Sodium borohydride, Hydrogen, Methanolysis

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Apitherapy and Sonodynamic Therapy for Brain Tumours

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Various types of brain tumour, including malignant glioblastomas, are well known to be extremely challenging to treat, with frequently poor prognosis for the patient. This presentation examines recent results from clinical trials, in vivo and invitro experimentation using a combination of bee venom and sonodynamic therapy. Furthermore, the presentation includes the case studies of three brain tumour patients and examines the treatment, experiences and results of each of these patients. The study concludes that positive results from clinical trials and scientific studies of the potential for these therapies, may point the way to a less invasive and less toxic form of treatment. The very positive responses and results from patients in the study so far appears to show this combined therapy may have merit if more widely adopted.

Keywords: Brain tumor, Glioblastoma, Apitherapy, Sonodynamic therapy, Bee venom

Acknowledgments: This work was completed with patients in Puerto Vallarta, Mexico in a private clinic and also at www.holisticbiospa.com

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Analysis of Impact Behavior of Composite Motorcycle Helmets with Auxetic Cell Structures by Finite Element Method

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In this study, the performance of different auxetic cell geometries was examined numerically in order to increase the impact resistance of motorcycle helmets. The main purpose of the study is to compare nine different auxetic structures selected from the literature in terms of impact behavior and to determine the three geometries that provide the highest strength performance. In this context, an existing motorcycle helmet was modeled with a reverse engineering approach and the three-dimensional geometry of the helmet was recreated. The three-dimensional topological structure of the obtained model was rearranged by means of licensed software in accordance with the analysis. The outer surface of the helmet was defined as a surface model and fiber-based composite material properties were assigned to this surface using the ANSYS Workbench ACP module. Then, nine different auxetic core structures commonly used in the literature were placed in the protective zones on the inside of the helmet. Pulse analyses for all models were performed under dynamic loading conditions and impact parameters defined in the literature were used. As a result of the analysis, three auxetic geometries with the best performance were determined according to the criteria of energy absorption capacity, stress distribution and deformation behavior. These three optimum structures will be produced using different material systems in a future study and will be verified by experimental tests. This study presents a systematic comparison for the use of auxetic structures in protective equipment design and reveals a basic approach for advanced helmet designs.

Keywords: Auxetic structure, helmet design, impact analysis, reverse engineering, finite element method



Liposomal Microencapsulation and Food Ingredients

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Liposomal microencapsulation has been generally defined as encapsulation of bioactive compounds in sealed capsules which can efficiently deliver their encapsulated contents to target biological or product site at controlled rate under specified processing conditions. Liposomal microencapsulation technique has been adopted widely in food and nutraceutical industry for value addition purpose. The liposomal microencapsulation process involves the encapsulation of sensitive and bioactive compounds using their hydrophilic and hydrophobic properties. The processing parameters of liposomal microencapsulation process affect the encapsulation efficiency. This process improves the physical, chemical and sensoric properties. The improvement in shelf life of final product has also been objective of liposomal microencapsulation technique. These liposomal microencapsulated bioactive compounds have further applications as food, medicinal and therapeutic supplements. This process targets the bioavailability of encapsulated ingredients and bioactive compounds to biological system.

Keywords: *Liposomes, Microencapsulation, Industry, Bioactive compounds, Community health*



The Potential Impact of The Shor Algorithm on Modern Cryptographic Systems

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This study examines the mathematical assumptions that determine the security of modern cryptographic systems and the transformative effect of the quantum computing paradigm on these systems. In particular, the ability of the Shor algorithm to solve the prime factorization and discrete logarithm problems, which form the basis of public-key cryptography, in polynomial time is addressed. The study analyzes the security structures of the RSA and Diffie–Hellman algorithms, emphasizing that these structures are based on classical computational models. The fact that the Shor algorithm reduces the prime factorization problem to a period finding problem and solves it using quantum Fourier transform directly threatens the security of RSA. Similarly, the fact that the discrete logarithm problem, upon which the Diffie–Hellman protocol is based, can be efficiently solved with quantum algorithms eliminates the confidentiality guarantee of this system. The findings demonstrate that under the existence of sufficiently advanced quantum computers, currently widely used public-key encryption systems are theoretically breakable. In this context, the study reveals that the sustainability of the current cryptographic infrastructure should be questioned in the age of quantum computing, and emphasizes that the development of quantum-resistant (post-quantum) cryptographic methods is inevitable.

Keywords: *Quantum computing, Shor algorithm, Quantum cryptography, RSA, Diffie–Hellman.*

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A Comparative Analysis of 2D and 3D Culture Models in Lung Carcinoma

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Two-dimensional (2D) cell culture models do not accurately reflect the tumor microenvironment. This study investigated the anticancer properties of the natural compound celastrol and STING pathway agonists (ISD and VACV70) using a three-dimensional (3D) spheroid model created A549 human lung adenocarcinoma cells. A549 cells were seeded at different densities on agarose-coated plates and spheroid development was monitored. Image analysis was used to determine the optimal conditions by measuring spheroid size. We looked at both 2D and 3D models and compared them. The spheroids were exposed to celastrol, ISD or VACV70 with the Lyovec transfection agent. Then, RT-PCR was used to assess gene expression related to these treatments. The optimal cell density for spheroid growth was 5000 cells per well, resulting in uniform, compact spheroids by day 3. It demonstrated that 3D spheroids were more drug-resistant than 2D cultures. High-dose celastrol (>5 μ M) treatment killed cells in A549 spheroids but not in 2D cultures (<1 μ M). The 3D spheroid model offers a more physiologically relevant environment than 2D cultures for drug testing in lung cancer.

Keywords: spheroid, cancer, drug-resistant, celastrol, A549



To Investigate the Anti-inflammatory Activity of Gold Nanowires using Zebra Fish model

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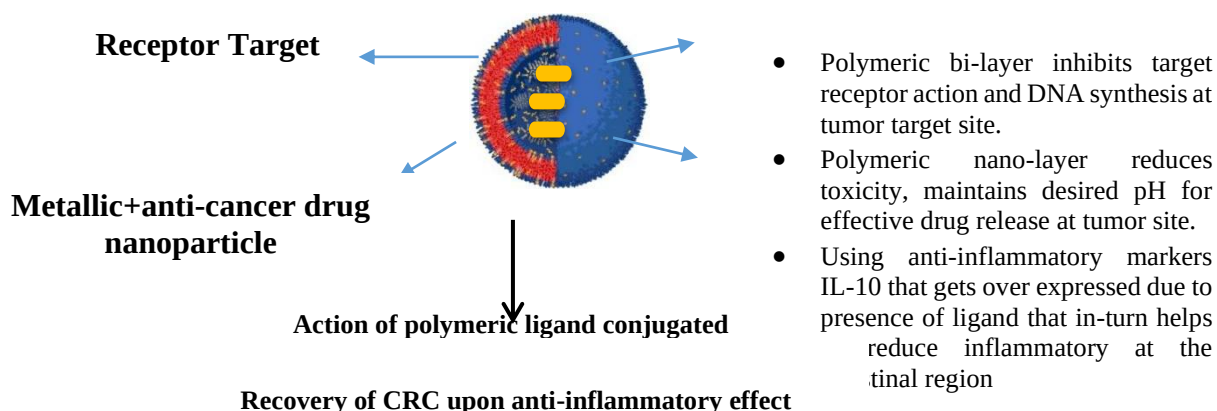
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Intestinal inflammation in cancers is one of the leading causes of death worldwide that has shown 24% increase statistically by the WHO. It has been a tedious outlook towards this research on the outcome for the reduction of intestinal inflammation. As a result, it has paved way for advancements towards nano--technology for the treatment and management of inflammation induced cancers. In this study, we will illustrate the effect of metallic nano wires surface modified with ligand to illustrate it's anti-inflammatory activity using zebra fish model. The formulation strategy implemented consists of an effective polymer with the combination of desired choice of surfactant that is the critical formulation parameter for effective formulation development, followed by the synthesis of metallic nano wires infused with the anti- cancer agent coated with ligand for active cancer target colorectal cancer. The receptor layer on the outer coating of metallic nano wires acts as an active tumor target. This novel approach is opted due to its reduction in toxicity, controlled release, pH-maintained environment and reduction in particle size. As a result, we will prove a novel approach towards inflammation treatment.

Keywords: IL-10, metallic nano-wires, gold iii chloride, folic acid, anti-inflammatory, anti-cancer



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Development and Nutritional Characterization of Functional Snack Bars Enriched with Bee Bread (Perga)

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The demand for health-promoting, "on-the-go" nutritional products has led to the exploration of apicultural by-products as functional ingredients. This study aimed to develop and evaluate several formulations of functional snack bars enriched with bee bread (perga), a potent source of bioactive compounds. Six different formulations were developed, categorized into "crushed" and "whole-nut" types, utilizing diverse ingredients such as dried apricots, raisins, apricot kernels, pumpkin seeds, honey, and nuts (walnuts and peanuts).

The research focused on optimizing the technological process, specifically the incorporation of bee bread. It was found that pre-grinding bee bread into a fine powder and mixing it with honey ensured a uniform distribution and consistent flavor profile throughout the product matrix. Sensory evaluation was conducted with 24 participants using a 9-point scale to assess appearance, color, aroma, texture, and taste. Three optimized samples (Sample 478, Sample 929, and Sample 584) were selected for further physico-chemical analysis based on their high sensory scores.

Physico-chemical results revealed significant nutritional density. Sample 478 (containing peanuts) exhibited the highest protein content at 20.1 ± 0.03 g/100g, while Sample 929 (containing walnuts) showed 18.75 ± 0.11 g/100g. Moisture content for these samples ranged between 8.14% and 8.56%, ensuring a stable shelf-life and desirable texture. Nutritional assessment indicated that a 100g serving of Sample 478 could satisfy approximately 28% of the daily protein requirement for adult office workers. The study demonstrates that bee bread-enriched bars serve as a viable functional food, offering a high-protein, nutrient-dense snack alternative that meets consumer sensory preferences.

Keywords: Functional food, Bee bread (Perga), Snack bars, Nutritional value, Sensory analysis, High-protein



Development and Technological Optimization of Functional Soy-Based Beverages Enriched with Natural Bioactive Additives

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The global shift towards plant-based diets has intensified the need for nutritionally optimized dairy alternatives. This study details the formulation and technological processing of functional soy beverages enriched with natural additives, including sainfoin honey (*Onobrychis viciifolia*), fruit purees (apple, pear, and pumpkin), and walnuts. The production process involved a multi-stage approach: soybean selection, soaking (8–10 hours), extraction (yielding 800 ml of milk from 120 g of beans), and pasteurization at 80–85°C for 5–10 minutes to ensure microbiological safety and enzyme inactivation.

Four distinct formulations were developed to evaluate the synergy between soy milk and functional additives. Formulations 1 and 2 utilized apple and pear purees (20–25 g/400 ml) with sainfoin honey, while Formulations 3 and 4 focused on pumpkin puree enrichment, with the inclusion of powdered walnuts (1 g/200 ml) in Sample 3. A critical technological observation was the homogenization process; it was determined that adding functional components at 40–45°C followed by high-speed blending for 20–30 seconds was essential for achieving a stable, uniform suspension.

Preliminary trials indicated that raw material selection and the specific sequence of additive incorporation significantly impacted the final texture and organoleptic profile. The study concludes that the incorporation of pumpkin puree and sainfoin honey not only enhances the vitamin profile but also improves the sensory acceptance of soy-based drinks, providing a viable "clean-label" functional beverage for health-conscious consumers.

Keywords: Soy milk, Functional beverages, Plant-based dairy, Food technology, Sainfoin honey, Nutritive value.



On the upper bound of a special type of Hankel determinant for a subclass of analytic functions subordinated with the sine function

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A subclass of normalized analytic functions defined using the generalized Salagean operator was considered. The Hankel determinant was constructed using the coefficients of the functions for the class subordinated with the sine function. The problem of determining the upper bound for the modulus of this special type of Hankel determinant was studied.

Keywords: *Analytic functions, Coefficient estimates, Subordination, Hankel Determinant, Sine function.*

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Reconceptualizing Second Language Learning through Media Integration: Insights for ELT

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Second language acquisition has been profoundly impacted by the rapid expansion of digital and traditional media. The purpose of this study is to explore the role media play in enhancing the learning process of second language, specifically social media, audiovisual content, and interactive digital platforms. According to contemporary theories of language acquisition, including input hypothesis perspectives, multimodal learning, and sociocultural factors, the paper explores how media-rich environments promote authentic language exposure, improve learner motivation, and promote the development of communication skills.

Study findings summarize findings from recent empirical research and emphasize key benefits such as increased vocabulary acquisition, improved reading and speaking skills, and greater learner autonomy. Furthermore, it focuses on potential challenges, such as cognitive overload, distraction, and media literacy. It is argued in the paper that media is highly effective in bridging the gap between formal and informal learning contexts when integrated into pedagogical frameworks.

Several recommendations are made for integrating media-based strategies into ELT classrooms to maximize learning outcomes in diverse educational contexts in relation to implications for language teachers, curriculum designers, and policymakers.

Keywords: *second language acquisition, media, ELT, learner autonomy*



Cytokines, Interleukins and Interleukin-41 (Metrnl): Immune Regulation and Cardiovascular Effects

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Cytokines are small signalling proteins secreted by immune system cells that play a role in regulating inflammation, the immune response and cellular communication [1]. These molecules play a critical role in cellular proliferation, differentiation and the maintenance of immune homeostasis [2]. Interleukins, an important subgroup of cytokines, are prominent as biomarkers in the regulation of the immune response and the assessment of various diseases [3].

Interleukin-41 (IL-41), also known as meteorin-like protein (Metrnl), is a novel cytokine that has attracted attention in recent years for its immunomodulatory and anti-inflammatory properties [4]. Encoded by the METRNL gene, this protein is expressed in barrier tissues, adipose tissue, macrophages and muscle tissue, and possesses multifaceted biological effects [5]. Current studies indicate that IL-41 suppresses inflammation, reduces oxidative stress and limits cellular damage via AMPK, NF- κ B, mTOR and NLRP3-related signalling pathways [6, 7].

It has also been reported that IL-41 may exert protective effects in myocardial ischaemia/reperfusion injury, cardiac remodelling, heart failure and metabolic diseases [8, 9]. The fact that its circulating levels are associated with inflammatory markers supports this molecule's potential as a diagnostic and prognostic biomarker [10].

In conclusion, IL-41 is a promising new molecule in terms of the regulation of inflammation and cardiovascular protection; further studies are required to determine its potential for clinical use [7, 9].

Keywords: Cytokine, interleukin, interleukin-41, Metrnl, inflammation, cardiovascular diseases

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Development and Optimization of Linagliptin–Polyphenol Co-Loaded Bilosomes via Design of Experiments for Targeted Neuroprotection in Diabetes-Associated Alzheimer’s Disease

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Alzheimer’s disease (AD) is a progressive neurodegenerative disorder characterized by hippocampal degeneration, memory impairment, and cognitive decline. Emerging evidence highlights a strong association between Type 2 diabetes mellitus (T2DM) and AD, where chronic insulin resistance, oxidative stress, and enhanced accumulation of amyloid- β and tau proteins contribute to disease progression [1].

The present study focuses on the development and evaluation of a bilosomal dual-drug delivery system co-loaded with linagliptin (LGT) and a polyphenol (PP) to improve neuroprotection in diabetes-associated Alzheimer’s disease. Molecular docking studies were performed to investigate interactions with key inflammatory mediators, TNF- α and IL-6, revealing strong binding affinities of both LGT and PP, suggesting potential anti-inflammatory activity. Bilosomes were prepared using the thin-film hydration technique and optimized through a Box-Behnken Design (BBD) to achieve desirable physicochemical characteristics [2].

The optimized formulation exhibited a particle size of 137.7 nm, low polydispersity index (0.023), and a high zeta potential (–52.4 mV), indicating excellent stability. Entrapment efficiencies for LGT and PP were found to be $87.61 \pm 2.28\%$ and $84.56 \pm 1.67\%$, respectively. The Characterization using FTIR and DSC confirmed drug compatibility and structural integrity within the vesicular system. The optimized bilosomes demonstrated instant release during the initial phase and sustained drug release over 24 hours, with 1.83- and 1.90-fold enhancements in ex vivo intestinal permeation compared to the drug suspension. CLSM further confirmed improved intestinal penetration 2.66-fold of the optimized formulation [3]. Additionally, DPPH assay results indicated significant antioxidant activity. The formulation demonstrated excellent stability under storage conditions, indicating its robustness.

Overall, the developed LGT-PP bilosomal system shows promising potential as an effective therapeutic strategy for managing diabetes-associated Alzheimer’s disease. Further preclinical investigations are ongoing to validate its safety and efficacy.

Keywords: Alzheimer’s disease, Type 2 diabetes mellitus, Linagliptin, Polyphenol, Bilosomes.



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Development and Evaluation of Bilosome-Based Nanocarriers for Dual Delivery of Ascorbic Acid and Polyphenolic Compound: An Integrated Computational and Experimental Studies

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The immune system functions as body's defense mechanism and contributes to homeostasis by protecting against infections and external entities. Immunomodulation, either through stimulation or suppression, is useful in disease prevention [1]. The study aimed to develop and optimize bilosome-based dual drug delivery systems co-loaded with ascorbic acid and a polyphenolic compound (ASA–PPC BLs) to improve permeability, enhance antioxidant activity, cell viability and stability.

Molecular docking studies were performed to evaluate the binding affinity of ASA and PPC with IL-6 and IgE [2]. ASA–PPC BLs were prepared using the thin-film hydration method and optimized through Box-Behnken Design (BBD). Optimized formulation was characterized for vesicle size, PDI, zeta potential, and %EE. *In vitro* drug release, *ex vivo* intestinal permeation, and CLSM were conducted to assess permeability. Antioxidant activity was determined using the DPPH assay, while stability studies were evaluated. Additionally, J774 macrophage cell lines were used to evaluate cell viability [3].

Docking studies revealed significant binding affinity of ASA and PPA toward IL-6 and IgE. The optimized bilosomes exhibited vesicle sizes of 200–250 nm, PDI of 0.2–0.4, and zeta potential between –25 and –35 mV, with entrapment efficiencies exceeding 80% (ASA) and 85% (PPC). *In vitro* drug release (>70% ASA and >80% PPA) was found in PBS (pH 6.8). *Ex vivo* permeation studies demonstrated a 2.47-fold and 1.76-fold increase compared to plain drug suspensions. CLSM confirmed enhanced intestinal uptake, with flux values of 7.20 and 4.46 µg/cm²/h. The formulation also showed strong antioxidant activity while J774 cell line studies indicated good cytocompatibility and improved stability [3].

On the basis of findings, ASA–PPC BLs were successfully developed and characterized. Results obtained in different studies revealed that the developed BLs have potent antioxidant and immunomodulatory activities. Further antioxidant and immunomodulatory activities may be warranting further evaluation through *in vivo* studies.

Keywords: Bilosomes, *In silico* study, Ascorbic acid, Polyphenolic compound, J774 cell lines.

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Model for Improving Reliability Indicators of a 10 kV Radial Distribution Network Based on Intelligent Control of PV and Battery Energy Storage Systems

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This research focuses on the development of a reliability-oriented intelligent control model for a 10 kV radial distribution network integrated with photovoltaic generation and a battery energy storage system. The main subject of the study is the operation of a smart distribution grid under variable renewable generation, changing load demand, and possible fault or supply interruption conditions. Although photovoltaic integration can reduce power imported from the main grid, its intermittent nature may cause operational challenges related to voltage deviation, power balance, and continuity of supply. Therefore, coordinated use of battery energy storage and intelligent load management is considered essential for reliability improvement.

The proposed model considers a 10 kV radial feeder supplying critical and non-critical loads. A photovoltaic system and a battery energy storage system are connected at the load bus. The intelligent control strategy is based on real-time decision-making, where the battery is charged during excess PV generation and discharged during peak demand or grid disturbance conditions. During fault scenarios, critical loads are prioritized, while non-critical loads may be temporarily disconnected to reduce unserved energy.

The expected outcomes include improvement of voltage profile, reduction of active power losses, decrease in grid power dependency, and enhancement of reliability indicators such as Energy Not Supplied, SAIDI, and SAIFI. The model can be simulated in OpenDSS using daily load and PV profiles, monitor-based power-flow analysis, and comparative scenarios including base case, PV-only case, PV with battery storage, and PV-BESS with intelligent load control. The results are expected to demonstrate that renewable energy integration alone is not sufficient to ensure reliability improvement, while coordinated control of PV, battery storage, and load prioritization can significantly enhance smart distribution network resilience.

Keywords: reliability, renewable energy, smart grids, storage

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Natural Compounds in Apiculture: Therapeutic Potential Against Bee Diseases and Residue Implications in Bee Products

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The increasing prevalence of honey bee diseases and the limitations associated with synthetic chemotherapeutics have intensified the search for sustainable and safe alternatives in apiculture. Natural compounds, particularly essential oils derived from medicinal plants such as *Thymus vulgaris*, have attracted considerable attention due to their antimicrobial, antifungal, and antiparasitic properties [1-3]. Beyond their therapeutic potential, these compounds are often characterized by rapid degradation and low persistence, which may reduce the risk of harmful residues in bee products.

This study presents a hybrid evaluation of natural compounds used in apiculture, focusing on their therapeutic efficacy against major honey bee pathogens, including *Nosema* spp., *Paenibacillus larvae*, and *Melissococcus plutonius*, alongside their residue implications in bee-derived products such as honey, beeswax, and pollen. A comprehensive literature-based assessment was conducted to examine both antimicrobial mechanisms—such as membrane disruption, enzyme inhibition, and metabolic interference—and the physicochemical properties influencing residue dynamics. These characteristics are particularly relevant in terms of consumer safety and regulatory acceptance of bee products [1,4].

The extant evidence suggests that a significant proportion of the components of essential oils are highly volatile and biodegradable, resulting in rapid dissipation within the hive environment. In instances where residues are identifiable, they are often composed of naturally occurring compounds or their derivatives, which are already present in plant-based foods and are generally recognized as safe at low concentrations. In comparison with synthetic veterinary drugs, these residues exhibit reduced persistence due to their high volatility and biodegradability, thereby posing a significantly lower risk of long-term accumulation within the hive matrix [1].

The findings suggest that natural compounds offer a favorable balance between efficacy and safety, particularly when applied under controlled conditions. The residue profiles of these substances are predominantly constituted of biodegradable and naturally derived components, thereby affirming their compatibility with principles of sustainable apiculture practices.

In conclusion, while the possibility of residue formation cannot be entirely excluded, natural compounds differ fundamentally from synthetic agents in terms of origin, persistence, and toxicological relevance. Their responsible use represents a viable strategy for disease management with minimal impact on the safety and quality of bee products.

Keywords: Honey bee, Natural compounds, Bee diseases, Low-residue risk.



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Innovative Renewable Energy Technologies as a Driver of Sustainable Economic Development: Opportunities for Solar Energy Integration in Azerbaijan

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The aim of this study is to comprehensively analyze the current state, development dynamics, and economic impacts of Azerbaijan's renewable energy sector within the context of the global energy transition. Within the framework of the research, structural changes in renewable energy sources over the period 2018–2025 were assessed based on statistical data, with particular emphasis on the growth trends of solar and wind energy. From a methodological perspective, the study employs econometric time series analysis, the Levelized Cost of Energy (LCOE) model, and the Revealed Comparative Advantage (RCA) and Relative Trade Advantage (RTA) indices, which measure international trade competitiveness. From a global perspective, the average share of renewable energy in electricity generation is 30.027%. In this context, Azerbaijan ranks 124th with an indicator of 6.862%. For comparison, the United Arab Emirates ranks 122nd with 8.64%, Korea 123rd with 7.808%, Benin 125th with 6.632%, and Iran 126th with 4.839%.

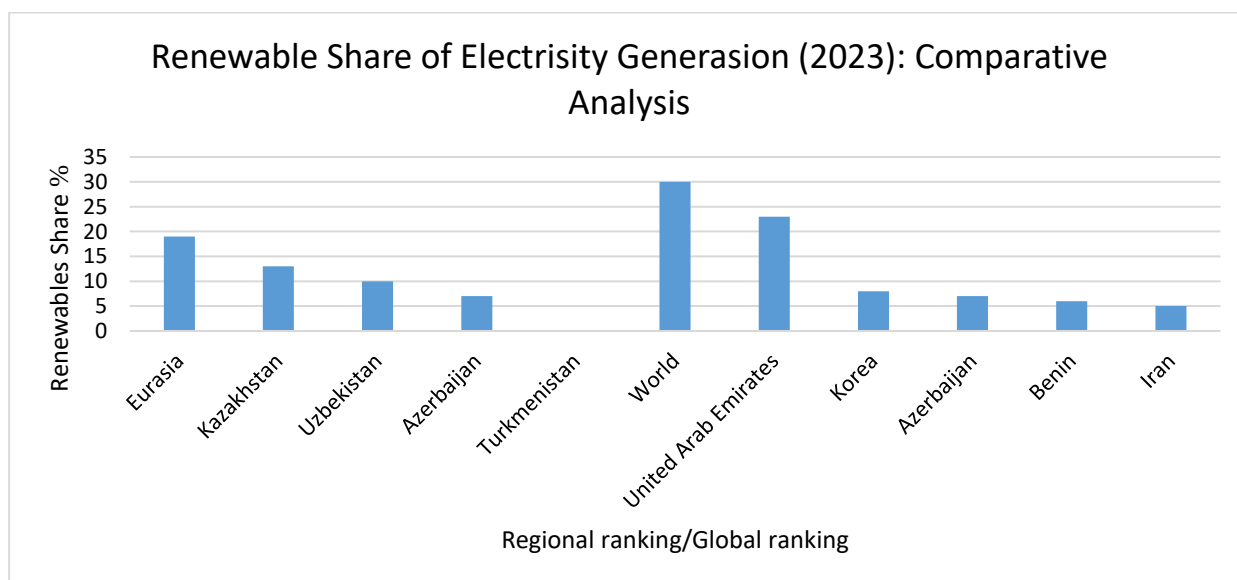


Figure. Renewables share of electricity generation (2023): comparative position of Azerbaijan in Eurasian and global rankings

The findings of the analysis demonstrate that the development of the renewable energy sector has a positive impact on Azerbaijan's macroeconomic indicators. In particular, meeting domestic energy demand through alternative sources creates favorable conditions for expanding natural gas exports and generating additional economic value. The positive dynamics of the RCA and RTA indices confirm the strengthening of the country's competitive advantage in electricity exports. The study also highlights the importance of the "green energy zone" concept



for regional development and substantiates the strategic role of the Karabakh and Eastern Zangezur regions in this direction. Furthermore, the necessity of implementing energy storage systems, smart grids, and optimal management mechanisms for the large-scale integration of renewable energy sources is emphasized. In conclusion, the study determines that the formation of Azerbaijan's renewable energy strategy based on the integration of technological innovation, economic efficiency, and institutional development is of critical importance for strengthening the country's energy security and ensuring a competitive position in the global green energy market.

Keywords: *Solar energy integration, Renewable energy transition, Hybrid energy systems, Sustainable economic development, Energy competitiveness*

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Fabrication of an impedimetric biosensor based on co-polymer for the detection of E. coli K12 in water

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Development of a simple and rapid clinical testing system for pathogens is important for addressing serious public health issues. Here is a newly constructed co-polymer based Impedimetric biosensor for the specific detection of E. coli K12 in water. The antibody was covalently immobilized onto an electrode surface-modified copolymer film on the surface of the electrode. Then the electrochemical performance of a disposable screen-printed electrode was identified using the impedance technique. The Nyquist plots identified the charge transfer resistance R_{ct} and determined that it was modeled with a modified Randles circuit as the relevant parameter after the immobilization of antibody, the blocking with BSA, and the binding of specific E. coli K12. The use of a typical copolymer film and immobilization techniques confirm the linear detection response of electrochemical impedance spectroscopy (EIS) in the range of 101-107 CFU/mL, and a short response time of 15 min. Furthermore, the covalently immobilized antibody selectivity was proved against various non-targeting bacterial strains in the presence of targeted E.coli K12 with 94% specificity and 98% sensitivity. Therefore, the newly developed phage biosensor can be used as a disposable label-free impedimetric biosensor for rapid and real-time water quality monitoring.

Keywords: Pathogenic bacteria, co-polymeric film, impedimetric detection, antibody



Detection of Azodyes by Ultrasonic Spray Pyrolysis (USP) Using Metal Nanosensors

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Recently, electrochemical sensors based on metal oxide nanoparticles have become widely used in this field due to their high conductivity and stability [1]. Metal oxide thin films (e.g. ZnO, FeO, SnO₂ and TiO₂) are attracting a lot of attention for this reason. The performance of electrochemical sensors is directly affected by thin film production methods [2]. In this context, the Ultrasonic Spray Pyrolysis (USP) technique, which is based on solution spraying and thermal decomposition, makes controlling the morphology, thickness and composition relatively easy. In our research, we aimed to develop nanosensors using ZnO and FeO metals by taking advantage of their electrochemical properties. We formed FeO and ZnO thin-film nanosensors on glass plates using the USP method [3]. Next, we used these thin-layer nanosensors to generate standard graphs of various azo dyes using an electrochemical method. These graphs were used to determine the presence of harmful food dyes. In our study, we analysed three different food dyes (Allura Red, Brilliant Blue and Fast Green (AR, BB and FG)) using this method. The results showed that these dyes could be analysed in the food matrix using the developed method. This method was found to be preferable due to its speed, low cost and lack of pre-preparation requirements. This method has the potential to pave the way for devices that can identify incorrect or excessive use of these dyes in food products.

Keywords: Nanosensor, USP, Allura Red, Brilliant Blue, Fast Green

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Effects of Nd₂O₃ addition on the structural properties of B₂O₃-ZnO-Li₂O-CuO glasses

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This study investigates the structural and spectroscopic properties of Nd₂O₃-doped BZL glass systems using a multi-technique approach, including XRD, FTIR, Raman, UV–Vis, and EPR analyses. The aim is to achieve a comprehensive understanding of the short- and medium-range structural evolution within the glass network. XRD patterns confirm the amorphous nature of the samples through the presence of a broad and diffuse scattering feature, indicating the absence of long-range order.

Raman spectroscopy reveals that the glass structure is predominantly composed of borate units such as BO₃ and BO₄, along with pentaborate and diborate groups. Bands observed around 974 and 1110 cm⁻¹ suggest the conversion of BO₃ units into BO₄ units, attributed to the modifying role of Li₂O. Additional bands associated with Zn–O and Nd–O vibrations confirm the successful incorporation of modifier cations into the glass matrix.

UV–Vis analysis shows a systematic red shift in the absorption edge with increasing Nd₂O₃ content, accompanied by a decrease in optical band gap (from 3.72 to 3.43 eV) and an increase in Urbach energy (from 0.264 to 0.325 eV). These changes indicate enhanced structural disorder and the formation of non-bridging oxygen (NBO) sites, which introduce localized electronic states within the band gap. The optical behavior is governed by the balance between network polymerization and depolymerization.

EPR results further support these findings by indicating changes in the local environment of Cu²⁺ ions. The increase in hyperfine splitting constant ($A_{//}$) and variations in g-values suggest a more distorted and compact local structure with increasing Nd₂O₃ concentration.

Overall, Nd₂O₃ incorporation leads to increased density, structural disorder, and enhanced optical response, highlighting the potential of BZL glasses for advanced optical and radiation shielding applications.

Keywords: Borate Glasses, Rare-earth doping, Optical Properties, FTIR and EPR.



Protective Effect of Baicalin on Chlorophyll Content against Aluminum Toxicity in Wheat (*Triticum aestivum* L.)

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Wheat (*Triticum aestivum* L.) is one of the most important staple crops in the world, providing approximately 20% of the global daily caloric and protein intake, and playing a critical role in food security. When wheat is exposed to environmental stressors, this negatively impacts human nutrition through the food chain. In acidic soils, which constitute approximately 50% of the world's agricultural land, soluble aluminum (Al^{3+}) ions released when soil pH drops below 5.0 become one of the most significant abiotic stress factors limiting plant growth and productivity. Aluminum toxicity is known to impair photosynthesis by reducing chlorophyll content. In this study, the protective effects of baicalin, a flavonoid compound with potent antioxidant properties, at different concentrations (25, 50, and 75 μM) on chlorophyll content (SPAD value) were investigated in wheat plants exposed to 100 μM Al^{3+} stress. Eight treatment groups were established, including control, Al^{3+} , baicalin, and baicalin+ Al^{3+} combinations (n=3/group). Statistically significant differences were detected among the treatment groups ($p = 0.002$). Al^{3+} treatment reduced the SPAD value from 25.0 to 23.0 compared to the control, while the 25 μM baicalin + Al^{3+} combination resulted in a further decline to 22.0. In contrast, 75 μM baicalin alone yielded the highest SPAD value across all groups (26.0), and the 75 μM baicalin + Al^{3+} combination largely restored Al-induced chlorophyll loss, raising the SPAD value to 25.0. Pairwise comparisons indicated that the most significant difference was observed between the 75 μM baicalin and 25 μM baicalin + Al^{3+} groups ($p = 0.002$). These findings suggest that 75 μM baicalin can protect photosynthetic pigments against Al-induced oxidative damage, supporting its potential use as a protective biostimulant against Al stress.

Keywords: Wheat, Aluminum toxicity, Baicalin, Antioxidants, Flavonoids



Determination of Phenolic and Flavonoid Contents in Plant Extracts Enriched with Silver Nanoparticles

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The biologically active compounds in the extracts of *Dracocephalum imberbe* Bunge, *Cirsium semenowii* Regel, and *Cousinia carduncelloidea* Regel were investigated, and silver nanoparticles were synthesized using these extracts by the pulsed plasma method.

During the study, plant extracts were prepared, and their total phenolic content (TPC) and total flavonoid content (TFC) were determined by spectrophotometric methods. In addition, the phenolic and flavonoid contents in the extracts containing silver nanoparticles were measured and compared with the pure extracts. The obtained results were presented in tables, and it was determined that silver nanoparticles had an effect on the amount of biologically active compounds in the extracts.

Furthermore, the antibacterial activities of the plant extracts and the extracts containing silver nanoparticles were evaluated by the agar well diffusion assay method. The results showed that the samples containing silver nanoparticles exhibited higher antibacterial activity against bacteria. This indicates that silver nanoparticles enhance the antibacterial properties of plant extracts.

Keywords: *Silver nanoparticles, plant extracts, phenolic compounds, flavonoids, antibacterial activity.*



Visible light photocatalytic activity of silver nanoparticles obtained by the pulsed plasma method

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Silver nanoparticles were successfully synthesized using the pulsed plasma in liquid (PPL) method, which is based on a low-voltage pulsed spark discharge in a dielectric liquid medium. Scanning transmission electron microscopy (STEM) analysis revealed that predominantly spherical Ag nanoparticles with an average diameter of 2.2 ± 0.8 nm were obtained. When the surfactant Sodium dodecyl sulfate was introduced, the particle size decreased to a peak diameter of 1.9 ± 0.4 nm, indicating improved size control due to surface stabilization effects.

The photocatalytic activity of the synthesized AgNPs was evaluated using different organic dyes. In the case of methylene blue, no noticeable degradation was observed under the studied conditions. In contrast, methyl orange exhibited significant degradation in the presence of Ag nanoparticles. However, when SDS was added to the system, the photocatalytic activity was suppressed and no effective degradation was detected. This behavior may be attributed to surface blocking effects or inhibition of active sites caused by surfactant adsorption.

These results indicate that the photocatalytic performance of Ag nanoparticles strongly depends on the nature of the target dye as well as the presence of surfactants in the reaction system. The findings are consistent with previously reported studies on plasma-synthesized nanoparticles and their catalytic behavior. Further investigation is required to clarify the underlying mechanisms and optimize the reaction conditions.

Keywords: *Silver nanoparticles, pulsed plasma method, photocatalytic nanoparticles*



Synthesis of Ag and Cu Nanoparticles and Their Biological Activity

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Nanoparticles were synthesized from silver (Ag) and copper (Cu) metals in aqueous and 0.2% gelatin solutions of various concentrations using the pulsed plasma method. X-ray diffraction analysis showed that the phase composition of copper is independent of the nature of the liquid medium, and the obtained nanoparticles exhibit high dispersity. Similarly, the phase composition of silver remains stable regardless of the liquid medium, indicating the formation of highly dispersed silver nanoparticles.

Copper nanoparticles demonstrated strong antibacterial activity against *Erwinia amylovora*, a bacterium responsible for fire blight disease in fruit trees. It was observed that the antibacterial activity of copper nanoparticles varies depending on the synthesis medium and concentration.

To evaluate the antibacterial effect against *Escherichia coli*, silver nanoparticle hydrosols were used. These hydrosols were prepared at different concentrations ($0.25 \times 10^{-3} - 1 \times 10^{-2}$ mol/L). The results showed that the inhibition zones did not significantly depend on concentration, and most samples exhibited similar effects.

Phytotoxicity assessment revealed that at a metal concentration of 5 mg/mL, silver and copper nanoparticles did not show any negative effects on leaves within 7 days.

Keywords: Nanotechnology, pulsed plasma, biological activity, antibacterial, phytotoxic effect



Synthesis and Physicochemical Characterization of Biodegradable Films Modified with Nanoparticles and Medicinal Plant Extracts

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The rapid accumulation of non-biodegradable plastic waste poses a serious environmental problem, creating a need for environmentally safe and sustainable alternative materials. Biodegradable films derived from renewable natural polymers have emerged as a promising solution due to their ability to degrade under natural environmental conditions.

In this study, a starch-based biodegradable film was successfully produced by solution casting, followed by pre-modification through the addition of plant extracts to impart color and improve functional properties. Although nanoparticles were not experimentally incorporated in this work, a comprehensive literature review was conducted to assess their potential role in improving film properties. According to existing studies, the incorporation of metal nanoparticles, such as silver (AgNPs), copper (CuNPs), and zinc oxide (ZnO), during the synthesis stage can significantly enhance the mechanical strength, barrier properties, and antimicrobial activity of biodegradable films. In addition, bioactive plant-derived compounds impart antioxidant and antibacterial properties, further enhancing the material's functionality.

The integration of nanoparticles and plant extracts is identified as a promising approach to creating highly effective, environmentally sustainable materials.

Keywords: Biodegradable film, Starch, Food packaging, Plant extracts, Nanoparticles



Integrated Geophysical Characterization of an Active Landslide: A Case Study from İspir (Erzurum, Türkiye)

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Due to Türkiye's geological and topographical features, landslides occur frequently. An active landslide in Yukarı Mahalle, İspir district, Erzurum province, poses significant risks to residential areas and infrastructure. In this study, microtremor (HVSr), Multichannel Surface Wave Analysis (MASW), and Electrical Resistivity Tomography (ERT) methods were applied together to determine the subsurface structure and soil dynamic properties of the landslide site. Microtremor measurements evaluated the dominant frequency and relative amplification characteristics of the soil; MASW determined the shear wave velocity structure; and ERT measurements revealed the subsurface lithology and the distribution of weak zones. Interpretation of the obtained data revealed that the landslide mass has a heterogeneous structure, and the contrast between low-velocity and low-strength soil units and more rigid layers is effective in landslide development. Furthermore, the spatial variation in soil dynamic properties supports the active character of the landslide and the continuity of deformation zones. In conclusion, the integrated use of different geophysical methods contributes to the reliable determination of the subsurface structure of active landslide areas and the development of engineering solutions for risk reduction.

Keywords: Microtremor, MASW, Landslide, Soil dynamics



Production of Aluminum Compounds from Food Waste

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This study examines the feasibility of producing aluminum compounds from aluminum cans, milk cartons collected as food waste. In modern conditions, the increasing volume of solid waste and environmental pollution requires the development of effective methods for resource reuse. Aluminum cans, being lightweight, inexpensive, and widely available waste materials, represent an environmentally and economically beneficial secondary raw resource.

In this study, waste milk cartons were first physically shredded and washed with water, then separated from their cellulose and other components. Afterward, they were incinerated in a muffle furnace at 600 °C to remove any remaining organic polymer on the aluminum layer. The resulting aluminum metal was dissolved in HCl acid to synthesize Al(OH)₃ (melting point-280 °C, yield 85%) with NaOH and AlCl₃(melting point-250 °C, yield 24%). Al₂(SO₄)₃ (melting point-86 °C, yield 60%) was synthesized with H₂SO₄. Al(OH)₃ was dissolved in HNO₃ to synthesize Al(NO₃)₃ (melting point-60 °C, yield 46,4%). The structures of the obtained compounds were determined using physicochemical and analytical methods.

The results show that high-quality aluminum compounds can be obtained from used aluminum cans and that the proposed method is suitable for industrial-scale application. Moreover, the proposed technology reduces negative environmental impacts and promotes the rational use of waste. This study makes a significant contribution to the development of recycling technologies and the implementation of sustainable development principles.

Keywords: Aluminum cans, food waste, milk cartons, aluminum metal.



Molecular Detection and Virulence Profiling of *Bacillus cereus* in Raw Mutton and Slaughterhouse Environments of the North-West Himalayan Region, India

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This study investigated the occurrence, distribution, and virulence gene profile of *Bacillus cereus* in raw mutton and its associated slaughtering environment in the Kashmir region of the North-West Himalayas, India. A total of 200 samples were collected from eight different sources, including sticking areas, water, carcass hanging hooks, raw mutton, chopping boards, meat shop floors, weighing pans, and butcher's knives. Isolation was carried out using Polymyxin-Pyruvate-Egg Yolk-Mannitol-Bromothymol Blue Agar (PEMBA), followed by morphological and biochemical characterization. Molecular confirmation and virulence profiling were performed using multiplex PCR targeting enterotoxin genes (*hblCDA* and *cytK*).

Out of 200 samples, 78 (39%) were positive for *B. cereus*. The highest prevalence was observed in sticking areas (64%), followed by butcher's knives (48%) and meat shop floors (44%), indicating poor hygienic practices during slaughter and meat handling. All isolates were Gram-positive, motile, spore-forming rods exhibiting β -hemolysis. Molecular analysis revealed a high distribution of virulence genes, with *cytK* detected in 75.64% and *hbl* complex genes in over 73% of isolates. Notably, 61.53% of isolates harbored all tested virulence genes, highlighting significant pathogenic potential.

Antibiotic susceptibility testing showed high sensitivity to gentamicin, chloramphenicol, and ciprofloxacin, whereas strong resistance was observed against penicillin-G and other β -lactam antibiotics.

The findings indicate a substantial contamination of slaughter environments and meat with potentially virulent *B. cereus* strains, posing a public health risk. Improved hygiene practices and regular monitoring are essential to ensure meat safety and prevent foodborne illnesses.

Keywords: *Bacillus cereus*, raw mutton, virulence genes, slaughterhouse hygiene, multiplex PCR



Net – A Multi-Layer Row Transformer for Tabular Regression

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Real estate price prediction is challenging because of heterogeneous tabular features, nonlinear relations, and regional variability. Housing prices depend on complex interactions among structural, geographic, and market-specific factors, making accurate valuation difficult. We propose a neural retrieval architecture named RowNet, a Multi-Layer Row Transformer (MLRT), for structured regression tasks.

The model receives a query property together with a memory bank of historical labeled transactions. Each layer performs row-wise cross-attention, allowing the query to retrieve relevant comparable samples through learned observation-level similarity. This combines neural representation learning with adaptive nearest-neighbor reasoning, rather than relying only on feature-level transformations. The framework further employs residual feed-forward blocks, dropout regularization, noise augmentation, gradient clipping, stochastic weight averaging, and early stopping to improve stability and generalization.

A key contribution is query-conditioned memory gating, where memory rows receive dynamic relevance scores conditioned on the query. This mechanism suppresses noisy observations, improves local neighborhood quality, and enhances retrieval efficiency.

Experiments on a large-scale housing dataset with geographic, structural, and categorical features demonstrate strong predictive accuracy, achieving a validation Mean Absolute Percentage Error (MAPE) of 7.86%. For comparison, a simpler non-parametric attention baseline using raw observations achieved 14.76% MAPE, indicating that observation-level retrieval itself contains substantial predictive information, while trainable deep retrieval significantly improves accuracy.

Beyond predictive performance, RowNet improves interpretability through attention weights that highlight which historical transactions most strongly influenced each estimate. Overall, the proposed MLRT offers a compact, accurate, and transparent alternative to gradient boost-ing methods for tabular prediction, and can be extended to finance, insurance pricing, and recommender systems.

Keywords: *Tabular Deep Learning, Row Transformer, Real Estate Valuation, Cross-Attention, Memory Retrieval*

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Lipid Nanocarriers in Drug Delivery: Current Trends and AI Intergartion

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Background and Rationale: The conventional drug delivery paradigm faces critical biopharmaceutical barriers: nearly 40% of new chemical entities belong to BCS Class II exhibiting poor aqueous solubility, approximately 90% of drug candidates fail due to ADME limitations, and fewer than 2% of intravenously administered anticancer agents reach the intended tumour site. Nanocarriers engineered colloidal systems in the 10-1000 nm size range have emerged as transformative platforms to overcome these challenges.

Scope: This session provides a structured overview of lipid-based nanocarriers including liposomes, solid lipid nanoparticles (SLN), nanostructured lipid carriers (NLC), nanoemulsions, and self-emulsifying drug delivery systems (SEDDS). Clinically validated examples including Doxil®, Abraxane®, and the COVID-19 mRNA-LNP vaccines illustrate real-world translation.

AI Integration: The role of artificial intelligence is highlighted across four domains: (i) artificial neural network (ANN)-driven formulation optimization, (ii) computational lipid excipient screening via COSMO-RS/HSPiP, (iii) generative AI for de novo ionizable lipid design, and (iv) deep learning-assisted nanoparticle image analysis. Machine learning models for in vitro-in vivo correlation (IVIVC) prediction further accelerate clinical translation.

Conclusion: Integration of smart stimuli-responsive systems, theranostic platforms, AI-guided personalized nanomedicine, and robust QbD-based manufacturing positions nanocarrier science at the frontier of pharmaceutical innovation. Career opportunities in pharma R&D, CDMO, and biotech for trained pharmacy professionals are also discussed.

Keywords: *Nanocarriers; Lipid nanoparticles; Nanoemulsions; Artificial intelligence; Drug delivery; Biopharmaceutics.*



The Strategic Importance of Kyrgyzstan's Genetic Resources: Biodiversity, Conservation, and Biotechnological Potential

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Kyrgyzstan is recognized as a global biodiversity hotspot and a critical center of origin for numerous wild plant and animal species. This paper evaluates the country's genetic resources across three primary domains: phylogenetic, zoogenetic, and human population genetics. The phylogenetic analysis focuses on the unique walnut-fruit forests of the Fergana and Chatkal ranges, specifically the genetic diversity of *Juglans regia* and wild relatives of *Malus* and *Prunus*, which serve as essential reservoirs for global food security and climate resilience.

The zoogenetic section examines local livestock breeds, such as the Arashan sheep and Novokirghiz horse, emphasizing their unique genetic adaptations to high-altitude hypoxia and extreme environments. Furthermore, the study explores the human genetic landscape, characterizing Kyrgyzstan as a historical crossroads of Silk Road migrations with a highly diverse genomic profile.

Finally, the abstract discusses the integration of modern biotechnological tools and bioinformatics for the systematic conservation and sustainable utilization of these resources. The implementation of high-throughput sequencing and molecular characterization is essential for identifying unique alleles associated with environmental adaptation. The preservation of this genetic wealth through national gene banks is proposed as a strategic priority for regional ecological and economic stability.

Keywords: *Biodiversity, Kyrgyzstan, Genetic Resources, Conservation, Molecular Adaptation*

Removal of Harmful Dyes from Water using Calcium-Containing Nanoflowers

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In recent years, nanoflowers (NFs) have become the focus of attention due to their regular three-dimensional structures and unique properties. Formed by combining organic and inorganic components to create regular structures, nanoflower structures are attracting attention due to their increasing range of applications [1]. Hybrid nanoflowers are typically formed by the interaction of metal ions with organic ligands. Literature emphasises that these structures maximise catalytic efficiency thanks to their 'high surface area-to-volume ratios' [2]. Their range of applications is growing day by day in the fields of food, health, biology and the environment. The nanoflower structure was prepared using Babagil and Nadaroglu's synthesis method [3]. The removal of methyl orange dye from water was investigated using the resulting hybrid nanoflower. The method was optimised for dye removal to achieve the highest efficiency. Different analytical methods were used to examine the nanoflower structure and the nanoflower structure interacting with the dye. Figure 1 below shows the leaves on the nanoflower and its large surface area. Measurements showed that approximately 76% of the methyl orange dye was removed from water within four hours at a temperature between 25 and 30 °C and a pH of around 7 using a single-step absorption process. Due to its ease and speed, this method can be used effectively alone or in combination with other dye removal methods.

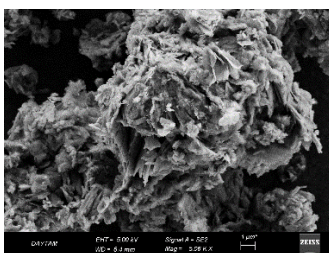


Figure 1. Hybrid nanoflower structure used in methyl orange dye removal.

Keywords: Nanoflower, Methyleorange, Dye, Adsorption

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Enhanced Detection of Lung Cancer Biomarkers using Al-Decorated B₂O₃ Monolayers: A First-Principles Study

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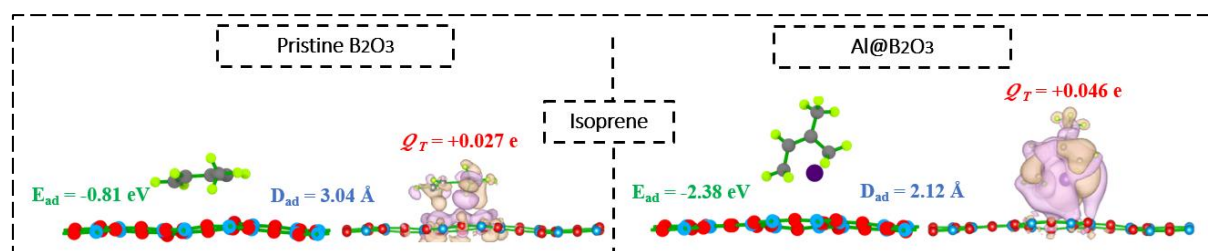
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The development of high-performance gas sensors utilizing single-atom catalysts (SACs) represents a promising frontier for non-invasive medical diagnostics, particularly through the analysis of volatile organic compounds (VOCs) in exhaled breath. In this study, we employ first-principles density functional theory (DFT) to investigate the sensing potential of Al-decorated B₂O₃ monolayers for key lung cancer biomarkers, including Isoprene, Acetone, Ethanol, and Carbon monoxide.

Our structural analysis demonstrates that Al atoms are effectively anchored at the hollow sites of the B₂O₃ substrate, with high binding energies that prevent atomic aggregation or diffusion. Furthermore, ab initio Molecular Dynamics (AiMD) simulations confirm the thermodynamic and structural stability of the system even at elevated temperatures. Electronic property analysis reveals that Al decoration induces a drastic reduction in the bandgap, transforming the pristine wide-bandgap substrate into a narrow-bandgap semiconductor, which significantly enhances the electrical conductivity and creates highly reactive sites.

The single Al adatom acts as a critical "chemical bridge," converting the weak physical adsorption interactions typical of the pristine surface into strong chemisorption for most target analytes. This transition is supported by substantial charge transfer and robust orbital hybridization between the Al states and the molecular orbitals. We identified two primary sensing mechanisms: notable bandgap modulation that influences electrical conductivity and significant shifts in the work function, both of which indicate high sensitivity for chemiresistive VOC sensors.

Kinetic analysis suggests that while strong chemisorption leads to prolonged recovery times at ambient temperatures, thermal treatment allows for a fast regeneration rate and ensures sensor reusability. These findings provide comprehensive theoretical support for the use of the Al@B₂O₃ platform in developing advanced, portable diagnostic devices for early medical screening and environmental monitoring.



Keywords: DFT, B₂O₃, Al decoration, lung cancer, biomarkers



Impact of Pre-Slaughter Transportation Stress on Meat Quality in Livestock

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The stress of pre-slaughter transportation is another important determinant of meat quality and animal welfare. This paper reviews literature to assess the physiological and biochemical processes through which transportation stress influences the important meat quality characteristics, including tenderness, juiciness, colour, and water holding capacity. The review is based on the literature on cattle, poultry, pigs, and sheep and examines how stress hormones such as cortisol, adrenaline and lactate influence the occurrence of Pale, Soft, Exudative (PSE) and Dark, Firm, Dry (DFD) meat. High levels of cortisol in the transport process are responsible in depleting glycogen, which causes changes in muscle pH, and meat quality. One of the significant aspects noted in the study is the need to enhance the current transportation conditions, such as the reduction of travelling time, proper space, and the application of humane handling procedures. Moreover, rest periods (lairage) prior to slaughter are recognized as one of the successful methods to address the problem of stress and improve the quality of meat. The results emphasize the importance of standard transport protocols and additional studies on species-specific protocols to reduce transportation stress, enhance meat quality, and improve the welfare of animals in the meat industry.

Keywords: *Pre-Slaughter, Transportation Stress, Meat Quality, Livestock, Cortisol, Lairage*

Acknowledgement: This manuscript was prepared as part of a class project under the supervision of Assoc. Prof. Valiollah Palangi.



***Bacillus toyonensis* mediated synthesis of Zinc Oxide nanoparticles: Characterization and study of its antibacterial and anticancer activity**

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Nanotechnology is a newly developing branch having great potential to enhance the quality of life through its applications in various domains like agriculture, therapeutics, drug delivery, cosmetics, biosensors and so forth. This is the first report describing the use of soil bacterial isolate that is *Bacillus toyonensis* for the synthesis of zinc oxide nanoparticles and their antibacterial-anticancer potential. The synthesis was carried out by cell free extract (CFE) of *Bacillus toyonensis* Zn1 and zinc nitrate (ZnNO_3) at room temperature within 24 h. The formation of zinc oxide nanoparticles was confirmed by UV-Vis spectroscopy and further characterized by X-ray diffraction (XRD), Field Emission Scanning Electron Microscopy (FE-SEM) coupled with energy dispersive X-ray analysis (EDS) and Transmission Electron Microscopy (TEM). The UV-visible absorption spectra showed a peak at 383 nm which is characteristic of zinc oxide nanoparticles. The synthesized nanoparticles were crystalline with crystallite size ~16 nm, spherical and elongated. Fourier Transform Infra Red (FTIR) spectrum revealed the capping and stabilization of zinc oxide nanoparticles via functional groups present in CFE. The zinc oxide nanoparticles showed good antibacterial activity when combined with antibiotic against *Escherichia coli* and *Pseudomonas aeruginosa*. They also showed dose dependent anticancer activity against the MCF-7 cell line.

Keywords: Soil isolate, *Bacillus toyonensis*, zinc oxide nanoparticles, characterization, antibacterial-anti-cancer activity.

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Age- and Sex-Related Morphometric Development of the Thymus, Bursa of Fabricius, and Spleen in Indigenous Türkiye (Meleagris gallopavo) in Kyrgyzstan

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Background: Indigenous Türkiye (*Meleagris gallopavo*) represent an important poultry resource in Kyrgyzstan. However, comprehensive morphometric reference data describing postnatal development of immune organs in local Türkiye populations remain limited.

Aims: This study aimed to determine age- and sex-related morphometric changes of major immune organs (thymus, bursa of Fabricius, and spleen) in indigenous Türkiye during postnatal development.

Materials and Methods: A total of 72 clinically healthy indigenous Türkiye were examined and divided into 12 age groups (1, 7, 14, 21, 30, 60, 90, 120, 150, 180, 270, and 420 days; n=6 per group, both sexes). Live body weight was recorded. The thymus, bursa of Fabricius, and spleen were collected and evaluated morphometrically. Thymus parameters included total weight, right and left lobe weight, and lobe length. Bursa and spleen were assessed by weight, length, and width.

Results: A pronounced age-dependent increase in body weight was accompanied by progressive growth of the thymus and spleen. The thymus demonstrated rapid development during early postnatal stages, with maximal values recorded in older age groups. The bursa of Fabricius showed intensive growth in juvenile birds (7–150 days) followed by marked involution and absence in mature Türkiye (≥420 days), consistent with physiological regression. The spleen increased steadily throughout ontogenesis, reaching the highest mass and dimensions in adult birds. Sex-related differences were observed, with males generally showing higher body weight and larger thymus and spleen measurements in later developmental stages.

Conclusion: The study provides baseline morphometric reference values for immune organ development in indigenous Türkiye in Kyrgyzstan. These findings may be useful for poultry health monitoring, immunological assessment, and breeding strategies aimed at improving productivity and disease resistance.

Keywords: Indigenous Türkiye, Thymus, Bursa of Fabricius, Spleen, Age dynamics.



Synthesis and Biological Properties of Novel Pyridine-Based Carbamate

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Carbamate functional groups are of paramount importance in medicinal chemistry, as they enhance bioavailability and facilitate specific interactions with biological targets [1]. This study reports the design and first-time synthesis of a novel 4-methylbenzoyl pyridine-based carbamate derivative. The objective was to investigate the anticancer potential of this novel scaffold and, also pharmacokinetic profile using computational tools. The target compound was synthesized through a two-stage protocol: the reduction of pyridin-3-yl(p-tolyl)methanone with NaBH₄ to the corresponding alcohol, followed by a coupling reaction to introduce the carbamate moiety. The structure was rigorously confirmed by FT-IR, NMR, and melting-point analysis. Biological evaluations included cytotoxicity assays on A549 cell lines. Furthermore, the drug-likeness and pharmacokinetic parameters were predicted using the SwissADME platform, complemented by Molecular Docking to explore molecular interactions at the atomic level. The results indicated that the synthesized novel carbamate derivative exhibited concentration-dependent inhibitory effects across the tested biological assay. SwissADME analysis revealed that the molecule possesses favorable drug-likeness properties, high gastrointestinal absorption, and adherence to Lipinski's Rule of Five. These findings were further supported by Molecular Docking studies, which confirmed stable binding orientations and strong intermolecular interactions within the targeted protein active sites. This study introduces a novel p-tolyl pyridine-derived carbamate to the literature and highlights its potential as a multifunctional lead compound. The correlation between in vitro results and in silico ADME/docking data suggests that this scaffold provides a promising framework for the future design of new therapeutic agents in medicinal chemistry.

Keywords: Carbamate, Pharmacokinetics, Molecular Docking, Biological Activity

Acknowledgments: The author would like to thank Erzurum Technical University for research conditions.

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2nd INTERNATIONAL CONGRESS ON SCIENCE AND TECHNOLOGY
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POSTER PRESENTATIONS



Investigation of Controlled Release Mechanisms in Pectin and Starch-Based Biodegradable Polymer Matrices

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Traditional cosmetic masks predominantly consist of synthetic polymers such as PVA, which present limitations regarding environmental sustainability and skin compatibility. This study aims to synthesize a high performance biodegradable mask matrix by modifying pectin a fundamental building block of plant cell walls and starch polysaccharides through an acidic esterification reaction in the presence of glycerin and an HCl catalyst [1-2]. The physical and mechanical properties of the synthesized polymers were investigated using FTIR, SEM analysis, and tensile testing; the results indicated that the structures were flexible, transparent, durable, and suitable for the occlusion effect (full skin contact) [3].

In the second stage of the study, the potential of this natural matrix to serve as a drug delivery system for active ingredients was analyzed using the dialysis membrane method [4]. In an experimental setup based on passive diffusion principles, the release profile of a model active ingredient encapsulated within the matrix was monitored in a receptor medium containing pH 5.5 Phosphate Buffered Saline (PBS) at 32°C to simulate skin surface temperature. The amount of substance diffusing through the dialysis membrane into the external medium was quantitatively measured at periodic intervals using UV-Vis Spectrophotometry [5].

Characterization results demonstrated that the covalent and hydrogen bonds established between pectin and starch chains increased the water retention capacity, thereby preventing the uncontrolled burst release of the active ingredient. Data obtained via the dialysis method proved that the matrix releases the active ingredient over an extended time curve, serving as a reservoir that facilitates skin penetration. Consequently, this next generation biopolymeric system which is non-allergenic, eco friendly, and derived from recycled products offers a robust alternative to synthetic masks in the cosmetic industry [6-7].

Keywords: *Biodegradable Polymers, Pectin-Starch Esterification, Dialysis Method, Controlled Release, Sustainable Cosmetics, Delivery Systems.*

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Biochemical Profile and Phytochemical Analysis of the White Water Lily (*Nymphaea alba*) Growing in Lake Köyceğiz

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Nymphaea species (water lilies) are perennial aquatic plants known not only for their aesthetic and cultural significance but also for their rich content of secondary metabolites. Today, the adverse environmental and health impacts of synthetic components have intensified the search for natural and sustainable raw materials. Lake Köyceğiz, which is connected to the sea through natural channels and stands as one of only seven "meromictic" (footed) lakes in the world, possesses a unique ecological value in this regard. This distinctive system opening into the Mediterranean exhibits a dynamic structure where fresh, saline, and thermal waters coexist. The variability of the water composition enriches the chemical content of the plants growing here, making them more resilient for industrial applications. Thanks to its high biodiversity and insufficiently explored natural structure, Lake Köyceğiz stands out as a strategic research area with high potential for scientific studies.

This study examines the potential of white water lilies (*Nymphaea alba*) in Lake Köyceğiz, which possesses a unique ecosystem as one of the world's seven "footed" (meromictic) lakes where fresh, saline, and thermal waters converge. For this purpose, the plant's enzyme profile was characterized, its antioxidant capacity was assessed, and a comprehensive content analysis was conducted. Enzymatic activities were systematically investigated.^[1] The Three-Phase Partitioning (TPP) method was employed to isolate the plant proteins.^[2] Furthermore, molecules exhibiting potential anti-aging effects were identified within the plant's composition.^[3] A hydroalcoholic extract was prepared and evaluated for its CUPRAC and DPPH activities. This study aims to investigate the industrial added value and the potential applications of the targeted compounds in the food, pharmaceutical, and cosmetic sectors.

Keywords: *Nymphaea alba*, TPP (Three-Phase Partitioning), Enzyme, DPPH, CUPRAC

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Feline Hyperthyroidism: Biochemical Mechanisms and Clinical Implications

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Hyperthyroidism in older cats is characterized by an excessive production of thyroid hormones, triiodothyronine (T3) and thyroxine (T4). There is an association between the condition and benign thyroid adenomas, which disrupt the hypothalamic-pituitary-thyroid axis and hormone production. An increase in circulating T3 and T4 levels leads to a hypermetabolic state that affects a variety of organs.

Several biochemical mechanisms underlie feline hyperthyroidism, including hormone synthesis, peripheral conversion of T4 to T3, and interaction with nuclear thyroid hormone receptors that regulate gene expression. It may also cause weight loss, tachycardia, hyperactivity, and gastrointestinal disturbances due to increased lipid and protein catabolism, which contribute to systemic effects.

Furthermore, the biochemical basis of current treatment strategies, such as antithyroid medications, radioactive iodine therapy, surgical thyroidectomy, and dietary iodine restriction, is described. In general, identifying the molecular and metabolic changes associated with feline hyperthyroidism is essential to improving diagnosis, treatment, and management of the disease.

Keywords: *Feline hyperthyroidism, thyroid hormones, T3 and T4, metabolism, endocrine disorder, iodine, treatment*



Ketosis in Dairy Cows: Causes, Effects, and Management

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High-producing dairy cows usually suffer from ketosis after calving when energy demands exceed the amount of feed consumed. Fat breakdown occurs as a result of this imbalance, leading to an increase in fatty acids in the blood, resulting in the production of ketone bodies, which can accumulate and harm the animal. In addition, it may cause fatty liver disease, which further disrupts metabolic process. Ketosis can be classified into three types: Type 1 (associated with peak milk production), Type 2 (associated with overweight cows and fatty livers), and Type 3 (associated with poor-quality silage). This condition can result in a reduction in appetite, milk yield, fertility, and overall health. Blood beta-hydroxybutyrate levels are measured, along with milk and urine samples, in order to diagnose the disease. Through the use of glucose sources as well as supportive therapies, the treatment focuses on restoring energy balance. In order to prevent illness, it is important to maintain a healthy diet and maintain a healthy body condition as well as to monitor one's health early on.

Despite its significant economic effects, ketosis can be effectively managed by implementing good feeding practices and intervening at the right time.

Keywords: Dairy cow; Negative energy balance; Beta-hydroxybutyrate; Fatty liver; Metabolic disease



Folic Acid-Conjugated Chitosan Nanoparticle-Mediated Delivery of piR-26441 for Targeted Therapy in Ovarian Cancer

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Ovarian cancer remains one of the most lethal gynecological malignancies, largely due to late-stage diagnosis, therapeutic resistance, and its inherently complex molecular landscape. This heterogeneity represents a major limitation for conventional treatments and highlights the increasing need for personalized therapeutic strategies based on individual tumor profiles [1]. In this context, small non-coding RNAs (ncRNAs) have shown promising outcomes in both preclinical and clinical studies. Among them, PIWI-interacting RNAs (piRNAs) are relatively less explored, particularly regarding their functions in somatic cells and their roles in cancer pathogenesis. Although initially associated with transposon silencing in germline cells, emerging evidence suggests that piRNAs may have important regulatory roles in somatic cells and disease development [2].

Based on this perspective, the potential tumor-suppressive role of piR-26441 in ovarian cancer suggests a promising strategy for targeted treatment. [3]. In this study, folic acid-conjugated chitosan nanoparticles were designed to enable efficient and targeted intracellular delivery of piR-26441. Chitosan offers a biocompatible, biodegradable, and cationic platform suitable for nucleic acid delivery [4], while folic acid facilitates selective targeting of ovarian cancer cells through overexpressed folate receptors [5]. The developed nanoparticle system aims to contribute to the advancement of personalized and molecularly targeted treatment strategies for ovarian cancer.

Keywords: Chitosan, Folic acid, piRNA, Ovarian cancer, Targeted drug delivery.

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Effect of resveratrol on post-thaw motility, kinematics, structural parameters and antioxidant/oxidant status of Kamori buck spermatozoa

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Resveratrol is a polyphenol compound showing strong antioxidant properties. It is believed that semen cryopreservation causes significant sperm losses which eventually affects sperm quality. Improving antioxidant status of semen may reduce this damage and enhance sperm fertilizing potential.

This study investigated the resveratrol treated freeze-thawing sperm motion, kinetics, structural parameters and antioxidant/oxidant status of Kamori buck spermatozoa. Thirty-two ejaculates from 4 fertile Kamori bucks were processed in tris-citric-glycerol-egg yolk (TCG-EY) based with varying concentrations of resveratrol (0, 10, 20, 40 and 50 μ M). Over 75 % sperm motility were pooled and frozen in liquid nitrogen. The results unveiled that adding resveratrol at 40 and 50 μ M concentration significantly enhanced ($P < 0.05$) total motility (progressive motility, rapid velocity, and average path velocity, straight line velocity, curvilinear velocity, amplitude of lateral head displacement, beat cross frequency, straightness and linearity in contrast with control and other groups.

Supplementing resveratrol at 40 and 50 μ M concentration significantly improved ($P < 0.05$) functional plasma membrane integrity, acrosome integrity, whereas, all resveratrol groups had same significant ($P < 0.05$) effect on DNA integrity in response to control group.

The 40 and 50 μ M resveratrol significantly promoted ($P < 0.05$) superoxide dismutase (SOD), catalase (CAT), peroxidases (POD), and total antioxidant capacity (TAC) levels while significantly reducing ($P < 0.05$) the total oxidant status (TOS) and malondialdehyde (MDA) contents as compared to control and other groups, respectively.

The principal component analysis (PCA) exhibited samples were present in different clusters except two groups which had partially overlapped. Using hierarchical clustering analysis, two clusters were constructed showing the relationship within the treated groups. The results of spearman correlation coefficient showed that yellow color showed highly positive correlation while turquoise color exhibited highly negative association between sperm variables.

Overall, the results concluded that resveratrol at 50 μ M performed slightly better results than 40 μ M in terms of improving sperm quality parameters.

Keywords: Antioxidants/oxidants, CASA parameters, Kamori buck spermatozoa, PCA, Dendogram and spearman correlation



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