NEW | İSTANBUL NİŞANTAŞI ÜNİVERSİTY

1st INTERNATIONAL FOOD SCIENCES AND GASTRONOMY CONGRESS

4-5 December, 2025 / İstanbul, Türkiye/

(Online)

PROCEEDING BOOK

(Abstracts and Full-Texts)

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IFSGC 2025–International Food Science and Gastronomy Congress

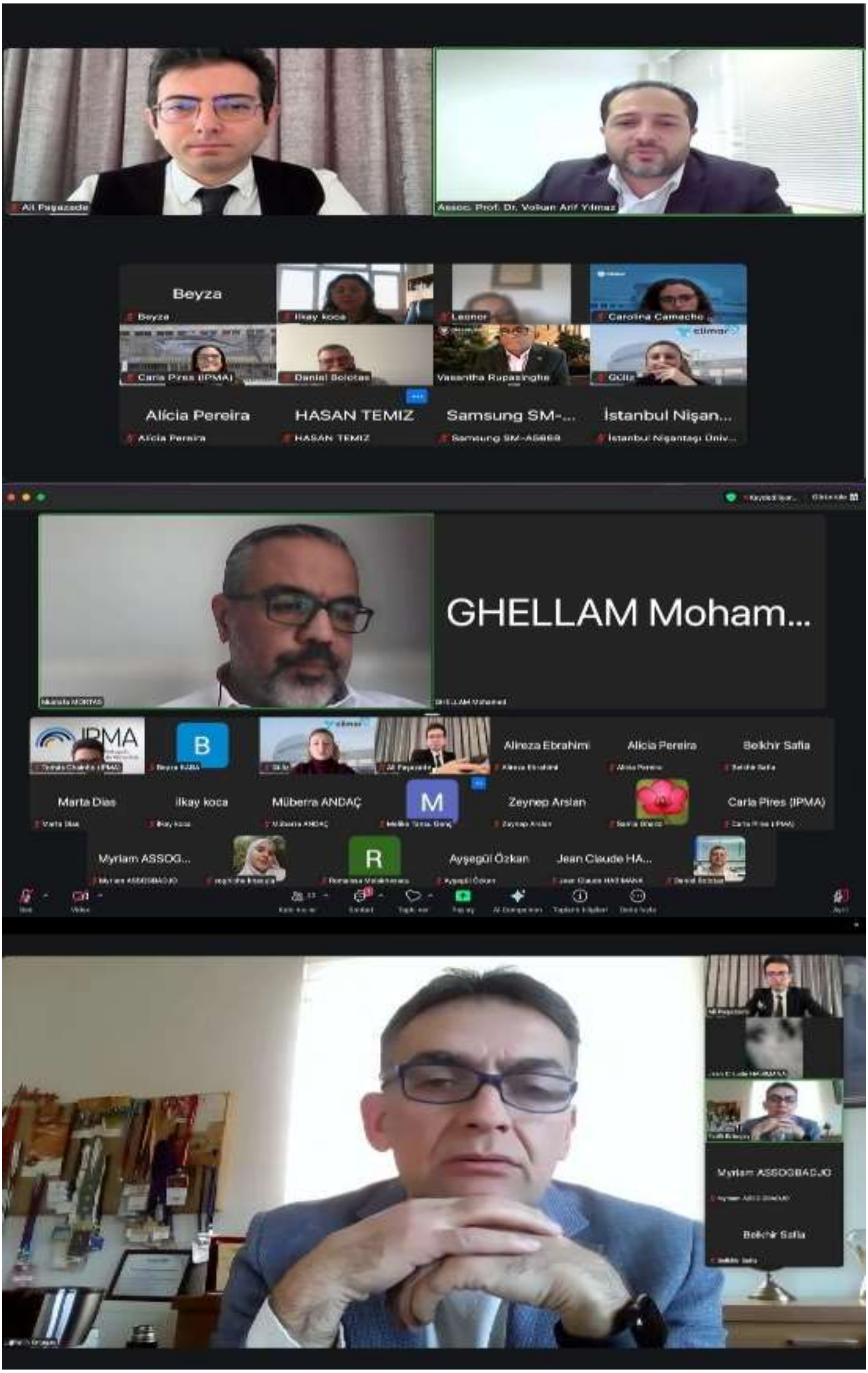
4-5 December 2025-İstanbul, TURKEY

The successful realization of IFSGC 2025–International Food Science and Gastronomy Congress and the preparation of this proceedings book were made possible thanks to the dedicated efforts of a large team. First and foremost, we extend our gratitude to the Rector of Nişantaşı University, Prof. Dr. Ayşegül ÇITIPITOĞLU, for hosting our congress and providing unwavering support. We thank the members of the Scientific Committee, who played a significant role in shaping the scientific quality of the congress, keynote speakers, and our valuable participants who shared their work with us. We are also grateful to the members of the Organizing Committee who dedicated great effort to every stage of the organization.

Finally, we thank Ondokuz Mayıs University, Nişantaşı University and all other stakeholders who contributed to our event, and we hope that this book will be beneficial to the scientific community.

On behalf of the Organizing Committee, Ali PAŞAZADE

KEYNOTE SPEAKERS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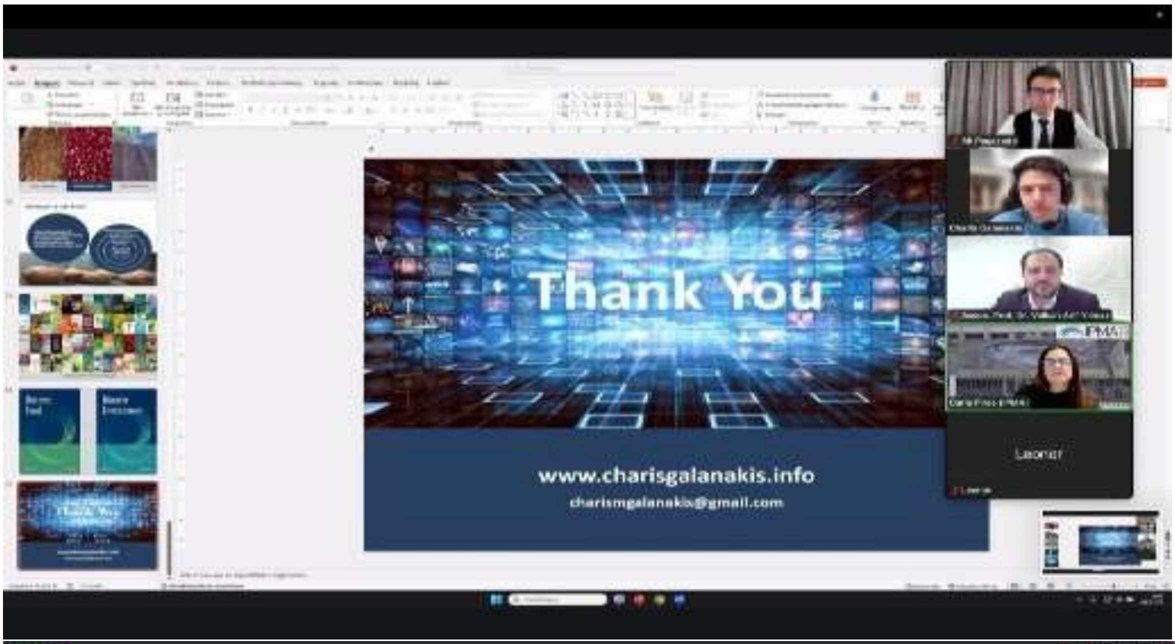
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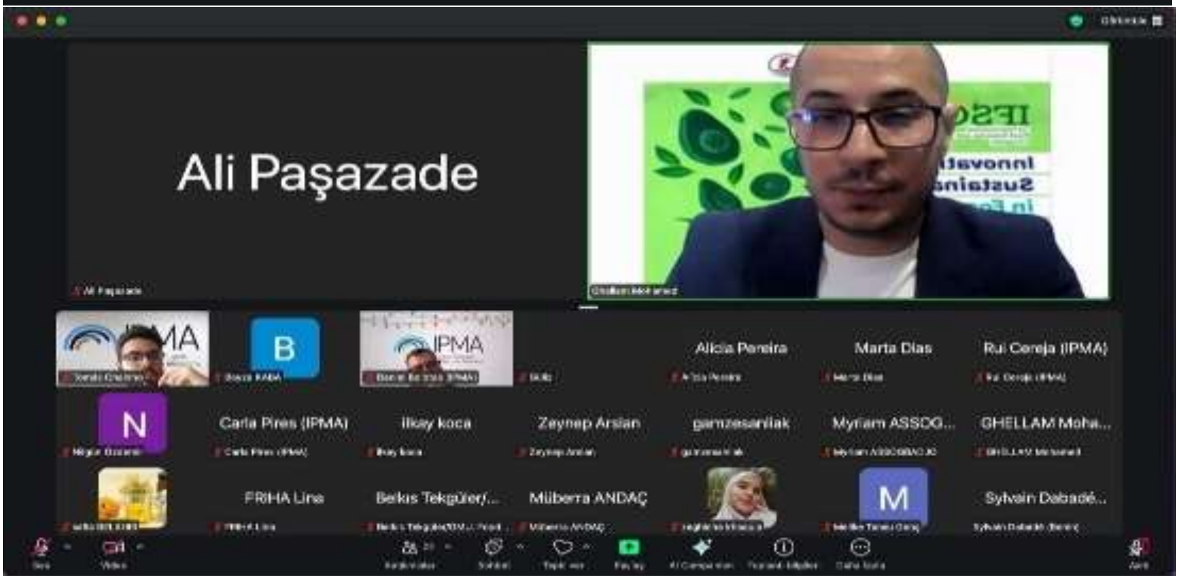
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EVALUATION PROCESS and POLICIES

All applications have undergone double blind peer review process. In addition, each paper was accepted and the process of publishing in the book was carried out through editorial oversight. The published papers were presented and discussed at the meeting. Full texts and abstracts published in accordance with the Congress Policy have been prepared in accordance with ethical rules. Authors of all papers are both ethically and legally responsible.

PARTICIPANTS COUNTRIES: Algeria, Azerbaijan, Benin, Belgique, Iran, Kosovo, Macedonia, Portugal, Rwanda, Türkiye, USA, Yemen, Zimbabwe.

TOTAL ACCEPTED ARTICLES: 59, The Number of Accepted Papers from Türkiye: 14, The Number of Accepted Full Papers from Other Countries: 45

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Editors

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1.International Congress on Food Science and Gastronomy (IFSGC 4-5 December 2025–Fully Online)

Istanbul Nisantasi University
Congress Website: https://ifsgc.net/en/homepage/ Organizing Group Meeting-December 4, 2025

Time	Event	
	Thursday, December 4, 2025	
12:00-13:00	Registration	
Opening IFSGC Ceremony (Keynote Speakers)		
	Main Chair: Assoc. Prof. Dr. Volkan Arif Yılmaz Session 1	
13:00-13:15	Prof. Dr. Ayşegül Komsuoğlu Çıtıpıtıoğlu	The Rector of Istanbul Nisantasi University
13:15-13:45	Prof. Dr. Reza Tahergorabi	North Carolina Agricultural and Technical State University
13:45--14:15	Prof. Dr. H.P. Vasantha Rupasinghe	Functional Foods & Nutraceuticals at Dalhousie University, NS, Canada.
14:15- 14:45	Prof. Dr. Charis M. Galanakis	Taif University, Galanakis Laboratories
14:45-15:15	Assist. Prof. Shahriar Eslamitabar	Smart University of Medical Sciences – Ministry of Health Tahran.
	Chair: Dr. Carla Pires	
15:15-15:45	Prof. Dr. Maria Leonor Nunes	Principal scientist and coordinator of SEAFOOD SAFETY AND PROCESSING Group of CIIMAR
15:45-16:15	Dr. Carolina Camacho	Researcher at the Interdisciplinary Centre of Marine and Environmental Research (CIIMAR/CIMAR- LA)
Session 2		
16:30-18:30	**Chair: Dr. Güliz Akyüz** **12-15 min** of time for each presentation	
	Bioactivity of different macroalgae species from the Portuguese coast	Rui Cereja[1,2,*], Carla Pires[1], Pedro R. Costa[1,3], António Marques[1,4]

	Strategies to reduce sodium in canned Atlantic Horse Mackerel	Helena Oliveira[1,2,*], Alexandre Nabais[1,2,3], Carolina Camacho[1,2], Carla Pires[1,2], H. Lourenço[1], Maria J. Fraqueza[4], Maria H. Fernandes[4], Maria J. Fernandes[4], Carmo Serrano[5,6], Helga C. Augusto[7], Amparo Gonçalves[1,2], António Marques[1,2], Maria L. Nunes[1]
	Nutritional and toxicological profile of edible macroalgae	Tomás Chainho[1,*], Rui Cereja[1,2], Alícia Pereira[3], Vera Marques[1], Sofia Pessanha[4], Inês Oliveira[5], Pedro Reis Costa[1,6], António Marques[1,3]
	Optimization-driven strategies for high-value utilization of food waste	Alev Yüksel Aydar[1,2]
	Comparison of ANN and RSM in predicting SO_2 and quality of dried fruits	Alev Yüksel Aydar[1,2]
	Project GreenFeed4Fish: Turning agricultural waste into nutritious and functional aquafeeds–An eco-Innovative approach to upgrade farmed marine fish welfare and quality	Marta Dias[1,2,3,*], Elsa F. Vieira[4], Valentina F. Domingues[4], Maria João Ramalhosa[4], Cheila Almeida[5], Carla Pires[5], Carolina Madeira[2,3], Cristina Delerue-Matos[4], Ana Luísa Maulvault [2,3,5]
	Microplastics and plastic-derived contaminants in Canned Tuna: Key knowledge gaps and implications for regulatory action	R. Pereira[1*], H. Oliveira[1,2], A. Marques[1,2], M.L. Nunes[1]
	Valorization of pumpkin (*Cucurbita maxima*) in traditional food systems: A case of enhanced pumpkin-based porridge (nhopi) formulation	Juliet Mubaiwa[1,*], Laura J. Mpala[2], Faith A. Manditsera[3]
Organizing Group Meeting – December 5, 2025 **Session 1**		
08:00-09:30	**Chair: Prof. Dr. İlkay Koca** **12-15 min** of time for each presentation	
	Composition of chestnut capsule	Ergin Öztürk[1], İlkay Koca[2], Beyza Kaba[3,*]
	Antioxidant properties of chestnut flower	Ergin Öztürk[1], İlkay Koca[2], Beyza Kaba[3,*]
	Globally popular Turkish dishes: A popularity analysis using AI-Powered Chatbots and Google Trends Data	Efe Kaan Ulu[1,*]
	Evaluation of pesticide properties of nanoparticles obtained from food wastes	Elif Fatma Topkara[1,2,*], Seda Biryol[3]
	The role of new technologies and artificial intelligence in food waste disposal	Mustafa Evren[1,*], Elanur Uzun[1], Melike Tansu Genç[1]
	Antimicrobial potential of plant-derived nanoparticles: A sustainable synthesis approach	Zeynep Arslan[1,*], Güliz Akyüz[2], Müberra Andaç[1,3]
	Menengiç as a functional food and its applications	Hilal Zade Aksakal[1,*], Belkis Tekgüler[1]
	Session 2	
09:30-11:00	**Chair: Assoc. Prof. Dr. Elif Fatma Topkara** **12-15 min** of time for each presentation	
	Recent findings on the metabolic, physiological, and clinical effects of the ketogenic diet	Gamze Şanlı Ak[1,*]
	Gluten-free diet: Updated insights on celiac disease, non-celiac gluten sensitivity, and irritable bowel syndrome	Gamze Şanlı Ak[1,*]
	Aroma recovery under low pressure from tomato plant waste	Aleyna Okutucu[1,*], Hatice Reyhan Öziyci[2], Mustafa Karhan[1]

	Effect of extracts obtained from fruits with antioxidant bioactivity on viral diseases of honey bees	Rafiga Gazi[1,*]
	Health-oriented reformulation of fermented dairy products for children: Strategies for sugar reduction and natural sweetness optimization	Zeynep Öztürk[1,*]
	Utilisation of grape residues processed in the food industry	Ayşegül Özkan[1], Mustafa Evren[1], Deniz Demir[1]
	Mimicking functional roles of sucrose to preserve sensory integrity in food formulations	Pelin Çakır[1,*]
Session 3		
11:00-12:00	**Chair: Dr. Ricardo Pereira** **12-15 min** of time for each presentation	
	Advances in chemical engineering strategies for sustainable food systems: Biorefinery of agro-industrial wastes	Sarhan Mohammed[1,*], Khalid A. A. H. Al-ahdal[2]
	Biogenic synthesis of nanomaterials by plant and their application in food packaging	Amir Pouya Ghandehari Yazdi[1], Elahe Amani[1,2,*], Amin Karimi[1], Arash Soltani[3]
	Alternative proteins and the overlooked barriers in culture, politics, and marketing	Masoumeh Jabbari[1,*], Meisam Barati[2], Arezoo Haghighian-Roudsari[1]
	Lactobacillus plantarum species: An overview with emphasis in bacteriocinogenic, probiotic, biochemical and healthy properties	Abdelmalek Meribai[1,*], Ahmed Bahloul[1]
	Bioactive composition and functional potentials of *Opuntia ficus-indica* for sustainable food Systems	Belkhir Safia[1,*], Abdessemed Dalila[1]
	The gut microbiome: Insights into health benefits and practical dietary tips	Zeghiche Khaoula[1], Tahri Kaouthar[1], Melakhssou Romaissa[1], Menasria hibet el rahmane[1], Ouenas Arij[1], Mekhalfia Nermine Lina[1], Saadaoui Ines[1], Ghellam Mohamed[2]
Session 4		
12:30-14:00	**Chair: Dr. Oscar Zannou** **12-15 min** of time for each presentation	
	Eco-innovative approaches for sustainable food safety: Green nanotechnology in action	Haitham Taleb Salem Mohammed Ali Aldubaei[1*], Sarhan Mohammed[2]
	Green synthesis of nanomaterials via microorganisms: Antimicrobial and antioxidant applications in food science	Elahe Amani[1,2,*], Amir Pouya Ghandehari Yazdi[1], Mohammad Rahmati[1], Arash Soltani[3]
	Bio-based nanocomposite packaging: A sustainable alternative to conventional plastics	Güliz Akyüz[1,*], Zeynep Arslan[2], Müberra Andaç[2,3]
	Comparative evaluation of banana and avocado peel-based biodegradable paper for food preservation and circular economy applications	Marc Antoine Ndisanze[1,2], Fabrice Niyibizi[1,*], Jass Uwera[1], Mary Confidente Nyirahirwa[1]
	Petroleum- and bio-based microplastics during simulated human digestion: Insights into polymer integrity and seafood digestibility	Daniel Bolotas[1,*], Rita V. C. Gomes[1,2], Ana C. Ambrosino[1,3], Clara Lopes[1], Joana Raimundo[1], Mónica V. Loureiro[2,4], Alda S. Pereira[2,4], Pedro Santana[5], António Marques[1,3], Tiago Repolho[6,7], Ana Luísa Maulvault[1,8,9]

	Assessment of antimony migration from PET bottles into water, carbonated beverages, and edible oils under real storage conditions in Benin	Alabi Séfou-Dine Badarou[1,2], Camel Lagnika[1,2,*], Achille Todègnon Gantongbe[1], Abdou Madjid Amoussa[2], Bakary Coulibaly[3], Latifou Lagnika[2]
	Creation of smart systems, based on artificial intelligence, to detect quality and authenticity in bee products	Elnaz Abedini[1], Jafar Abedini[2,*]
Session 5		
14:00-15:30	**Chair: Dr. Mohamed Ghellam** **12-15 min** of time for each presentation	
	Dietary antioxidants and longevity: The impact of nutrition on oxidative stress and healthy aging	Güliz Akyüz[1,*]
	Characterization and quantification of food waste during festive events in Benin, West Africa	D. Sylvain Dabadé[1], Chika J. Kuassi-Péréira[1], Paulin Azokpota[1]
	Reducing the ecological footprint: a solution to achieve food security in line with climate change management	Arezoo Haghighian-Roudsari[1,*], Javad Hassannezhad[2]
	A circular approach for fresh farmed fish waste: functional protein hydrolysates from catfish and tilapia by-products	Alícia Pereira[1, $,*], Busenur Özkan[2,$], Marta Dias[1], M. Leonor Nunes[1], António Marques[1,3], M. João Fraqueza[2], Carla Pires[1,3]
	Research on the geographical indication potential of food/agricultural products in Kaş (Antalya) district	Seda Şenyuva Karaman[1,*], Hojjat Pashazadeh[1]
	Harnessing indigenous probiotic strains from traditional Algerian fermented foods to develop sustainable gut-brain functional supplements	Lina Friha[1,*]
	The effects of preschool children's eating habits on health and development: A case study in Prizren, Kosovo	Cengiz Çesko[1,*], Hyrije Koraqi[2], Belma Gjergjizi Nallbani[2], Loreta Kabashi[1]
Session 6		
15:30-16:30	**Chair: Prof. Dr. Mustafa Fatih Ertugay** **12-15 min** of time for each presentation	
	Challenges and advances in 3D food printing; A focus on measurement techniques and quality evaluation parameters: A comprehensive review	Marc Antoine Ndisanze[1,2*], Leandrine Mushimiyimana[1], Daniel Mukunzi[2], Joseph Flambeau Kayihura[1], Ildephonse Habinshuti[3], Jean Claude Dusabumuremyi[1], Angelique Dusabe[1], Marie Lys Irakoze[1], Gabrielle Ishimwe[2], Ildephonse Habinshuti[3], Valentin Uwishema[1], Daniel Nsengumuremyi[3]
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	Biochemical and anti-nutritional factor: Characterization of pressing cakes from *Ricinodendron heudelotii* kernels	Myriam Assogbadjo[1,3,*], Marius Affonfere[1], Tétédé Rodrigue Christian Konfo[1], Kolawolé Valère Salako[2], Antoine Ide[3], Cathy Debier[3], Flora Josiane Chadare[1], Yvan Larondelle[3]

	Quality and phenolic effects of pectin in blackberry jam across altitudes	Adis Veliu[1], Xhabir Abdullahi[1], Erhan Sulejmani[1,*]
	Migration of antimony from virgin PET bottles into drinking water under various storage conditions: Implications for health and public safety	Alabi Séfou-Dine Badarou[1,2], Camel Lagnika[1,2,*], Achille Todègnon Gantongbe[1], Abdou Madjid Amoussa[2], Latifou Lagnika[2]
	Endogenous knowledge and processing practices associated with *Ricinodendron heudelotii* kernels in Benin and Côte d'Ivoire (West Africa)	Myriam Assogbadjo[1,3,*], Marius Affonfere[1], Tétédé Rodrigue Christian Konfo[1], Ludosky Djomatin[2], Antoine Ide[3], Yvan Larondelle[3], Flora Josiane Chadare[1]
	Dietary habits and health status of primary school children (Grades 1-5) in Prizren	Nora Rrahimi Hasani[1,*], Aulona Sfishta[1], Cengiz Çesko[1], Erëza Krasniqi[1]
	Chair: Assoc. Prof. Dr. Mustafa Mortaş **12-15 min** of time for each presentation	
16:30-17:00	**Prof. Dr. Gianfranco Romanazzi** (Keynote speaker)	Plant Pathology at Marche Polytechnic University Ancona Italy Chair of COST Action CA22134 FoodWaStop
17:00-18:30	The necessity of a zero-waste approach beyond environmentalism	Masoumeh Jabbari[1,*], Arezoo Haghighian-Roudsari[1], Meisam Barati[2]
	Drying kinetics and antioxidant properties of mint leaves (*Mentha spicata* L.)	Mohamed Ghellam[1], Oscar Zannou[2,3], Houda Bezzih[4], Hojjat Pashazadeh[5], İlkay Koca[6]
	Essential oils from *Cupressus sempervirens* L., *Pimpinella anisum* L. and *Rosmarinus officinalis* L.: Physicochemical characteristics, antioxidant and antimicrobial activities	Gharbi Samia[1,*]
	A novel fluorescence platform using aptamer-modified β-Cyclodextrin MOFs for sensitive detection of *Listeria monocytogenes* in tap water and red meat	Alireza Ebrahimi[1,2], Hamed Hamishehkar[3], Ali Ehsani[2,*], Milad Tavassoli[4,*]
	Characterization of local shelling, storage, and processing practices of egusi seeds (cucurbitaceae) in Benin	Bella Virginie Donadjè[1,*], Kotchikpa Justin Ekpo[2], Oscar Zannou[2], M. Vahid Aïssi[1]
	Post-harvest macroalgae processing to mitigate surface-bound contamination withtoxic microalgae	Tomás Chainho[1,*], Miguel Barbosa[1], Rui Cereja[1,2], Maria João Xavier[3], Alícia Pereira[4], Inês Oliveira[5], António Marques[1,4], Pedro Reis Costa[1,6]
	Assessment of key functional traits in lactic acid bacteria isolated from Algerian Makatia goat milk for use in food products	Ahmed Saci[1,*], Samia Gharbi [2], Fatima Djadouni[3], Noureddine Karkachi[1]
	Oils rich in conjugated fatty acids : Methods of Extraction, Preservation and Storage	Massoumoud Arèmou Mochégbolatan Wabi1, Sègla Wilfrid Padonou1, Marcel Houngbédji1,2, Flora J. Chadare1*
	Study of the antimicrobial and antioxidant efficacies of bee products in food and medical industry	Elnaz Abedini[1,*], Hanieh Bagheri Kia[2]
	Design and development of smart wound dressings on the basis of honey and propolis veterans	Elnaz Abedini[1]
Closing Speaker: Congress President		
18:30	Dr. Ali Paşazade	Istanbul Nişantaşı University

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ABSTRACT PROCEEDINGS

Comparative Evaluation of Banana and Avocado Peel-Based Biodegradable Paper for Food Preservation and Circular Economy Applications

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ABSTRACT

Plastic pollution and food waste demand sustainable alternatives that align with circular economy goals. This study comparatively evaluated two agro-waste-derived packaging materials: bioplastic paper from Gros Michel banana peels and biodegradable paper from avocado peels both for food packaging material. Both were processed through drying, grinding, blending with natural binders, and molded into paper. The banana peel bioplastic paper achieved 90% biodegradation within 45 days, exhibited adequate strength for dry food packaging, and maintained structural integrity in cold conditions. It has capability to extend shelf life of roasted peanuts by 7 days. The avocado peel paper showed 87% biodegradability in 45 days, good tensile and barrier properties, and natural antimicrobial activity that extended the shelf life of roasted peanuts by 12 days, outperforming craft and plastic controls. Comparative analysis suggests that while banana-based paper is suitable for low-temperature, single-use applications, avocado peel-based paper provide superior food preservation due to their antimicrobial compounds. These findings demonstrate how agro-waste valorization can reduce pollution, improve food safety, and strengthen circular economy strategies.

Keywords: Avocado peel, banana peel, bioplastic paper.

Advances in Chemical Engineering Strategies for Sustainable Food Systems: Biorefinery of Agro-Industrial Wastes

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ABSTRACT

In a world striving for food sustainability, modern chemical engineering strategies have become a major focus in this frantic race to build sustainable food systems. The term "biorefinery" has become the essential link between modern chemical engineering and sustainability in its broadest sense. The term "biorefinery" encompasses the conversion of agricultural and industrial waste (crop residues, fruit peels, and food processing waste) into value-added products (biofuels, biochemicals, bioactive compounds, and functional food ingredients). In addition to the value conversion, there is another benefit: reducing environmental impact and maximizing resource utilization. This process combines physical, chemical, and biological methods, including thermal treatment and hydrolysis to decompose complex biomass, as well as biological conversions using bacteria or enzymes. A new trend has emerged in biorefinery processes, using modified microbes or specialized enzymes to produce sustainable compounds. Through combined thermal and biological conversion processes, researchers seek to create integrated systems to improve efficiency and achieve flexible operating models. Recent developments and the urgent desire to harness waste as a renewable energy and food source have contributed to greater food security and reduced pollution. Modern efforts and the integration of science represent a fundamental step toward a sustainable bioeconomy that links food production with environmental conservation through the use of innovative engineering techniques that enhance resource efficiency and reduce waste.

Keywords: Chemical engineering, agro-industrial waste, biorefinery, food sustainability, circular bioeconomy.

Harnessing Indigenous Probiotic Strains from Traditional Algerian Fermented Foods to Develop Sustainable Gut–Brain Functional Supplements

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ABSTRACT

The gut–brain axis has emerged as a central pathway linking the intestinal microbiota to emotional and cognitive well-being. Growing evidence supports the role of psychobiotics and neuroactive nutrients in modulating mood, stress, and cognitive performance. However, most formulations depend on imported industrial strains that lack cultural and ecological adaptability. This research introduces an alternative approach based on the isolation and functional characterization of local probiotic strains derived from *M'zeyet,* a traditional Algerian fermented product, aiming to develop a culturally adapted psychobiotic supplement that supports gut–brain communication. The study adopts a multidisciplinary framework combining traditional fermentation microbiology, functional screening, and digital health analytics. Local *M'zeyet* samples were subjected to microbial isolation, morphological and molecular identification, and selection of potential probiotic candidates. The isolates were evaluated for acid and bile resistance, enzymatic activities, and neuroactive potential, particularly their involvement in tryptophan metabolism and neurotransmitter pathways such as serotonin and GABA synthesis—key modulators of mood and cognitive focus. In parallel, an intelligent mobile/web platform was designed to collect multimodal user data, including physiological (BMI, activity, sleep, heart rate) and behavioral parameters (diet and mood surveys). This digital interface aims to bridge biological findings with behavioral data, enabling personalized nutritional recommendations and feedback loops to optimize individual responses. The integration of these data streams supports the emergence of precision nutrition systems tailored for individuals experiencing stress or attention-related challenges. This project pioneers the valorization of Algeria's microbial heritage as a resource for sustainable functional foods and mental health innovation. By merging ancestral fermentation knowledge with modern biotechnology and digital intelligence, it positions traditional fermented foods as strategic assets within the global bio-innovation landscape. Expected findings suggest that *M'zeyet*-derived probiotics possess exceptional gastrointestinal resilience and neuroactive metabolic potential, supporting their application in psychobiotic supplement development. Future work will extend to clinical validation and AI-driven personalization to enhance efficacy and reproducibility. In conclusion, this research establishes a scientific and cultural bridge between traditional food heritage and next-generation nutraceutical technology, highlighting the promise of locally inspired probiotics as sustainable, personalized solutions for mental and cognitive well-being.

Keywords: Psychobiotics, neuroactive metabolites, gut–brain axis, digital nutraceutical innovation, functional food sustainability.

Effect of Extracts Obtained from Fruits with Antioxidant Bioactivity on Viral Diseases of Honey Bees

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ABSTRACT

One of the main causes of recent bee deaths is disease, particularly viral infections, which can lead to complex disease outbreaks and cause severe losses in colonies within a short period. Viral diseases are among the most dangerous threats to honey bees, often reducing productivity. These viruses may remain latent or exhibit visible symptoms, and currently, there are no specific antiviral treatments available for bees. The research was conducted in two stages. In the first stage, honey bee samples were collected from apiaries located in different regions of Azerbaijan-including Guba, Shabran, Astara, Jalilabad, Masalli, Yardimli, Lankaran, and Lerik districts-to investigate the presence of viral diseases. In the second stage, one apiary where viruses were detected was selected as an experimental site. Extracts derived from apple and pomegranate plants were administered to infected bee colonies along with a 1:1 sugar syrup solution for two weeks. A total of seven types of viruses were detected in the collected samples. The highest diversity of viral types was found in Guba and Lerik regions, while the fewest were observed in the Shabran region. Notably, Guba borders Russia and Lerik borders Iran, which may facilitate the spread of pathogens across regions. In the experimental apiary, colonies treated with apple and pomegranate extracts were reanalyzed after treatment. The extracts demonstrated effective antiviral activity, particularly against SBV (Sacbrood Virus) and IAPV (Israeli Acute Paralysis Virus), and the treated colonies also showed improved honey production.

Keywords: Honey bee, viral diseases, antioxidant bioactivity, apple and pomegranate extract, Azerbaijan.

Research on the Geographical Indication Potential of Food/Agricultural Products in Kaş (Antalya) District

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ABSTRACT

The globalizing economy since the nineteenth century has intensified market competition; in this environment, some producers have turned to unfair competition, threatening the production of traditional foods. Against this threat, geographical indication systems, such as "appellation of origin" and "protected geographical indication," which guarantee a product's origin, distinctive characteristics, and link to the geographical area, stand out as a strategic protection tool. Geographical indication registration not only protects the producer and the consumer but also supports rural development by creating local employment and added value, and mediates the transfer of cultural heritage to future generations. Turkey is one of the countries with high geographical indication potential, thanks to its climatic diversity and cultural richness. However, the inadequacy of studies conducted at the local level leads to the ineffective evaluation of the existing potential. The main purpose of this study is to investigate the geographical indication potential of products unique to the Kaş district of Antalya, which has not been able to adequately promote this potential at the national level despite possessing rich agricultural and gastronomic diversity. The study focused on Gömbe tarhana, Gömbe apple, Doğantaş pine honey, and snow sorbet. In addition to the potential economic, social, and cultural contributions of registering these products, the geographical indication awareness level of the local people was also examined. In the literature, there are various academic studies conducted in different provinces of Turkey that examine geographical indication potential and the economic, cultural, or touristic effects of these products. However, these studies have mostly been limited to specific provinces/districts or product groups; no study has been conducted addressing the products specific to the Kaş district. This situation strengthens the originality of the current research and its potential contribution to the field. A mixed-method approach, using quantitative and qualitative methods together, was adopted in the research. A comprehensive literature review was conducted to form the theoretical framework. Primary data were obtained using the face-to-face survey technique. This survey measured participants' demographic structure, consumption preferences, awareness of geographical indication practices, purchase intentions, and opinions on the potential contributions of geographical indications to the region. It shows that the Kaş district has a high geographical indication potential with both its agricultural diversity and cultural accumulation, but the national recognition of these products and the awareness of geographical indications are limited. In conclusion, it has been determined that geographical indication is a multidimensional tool that strengthens the region's gastronomic identity, protects the producer, prevents imitation, and increases tourism potential.

Keywords: Kaş, geographical indication, Doğantaş pine honey, Gömbe tarhana, snow sorbet.

Mimicking Functional Roles of Sucrose to Preserve Sensory Integrity in Food Formulations

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ABSTRACT

Recent advancements in product development within the food industry have increasingly centered on the concept of "less sugar, same taste," reflecting consumers' heightened awareness of health-conscious lifestyles and balanced nutrition. A substantial body of scientific evidence has demonstrated a direct association between excessive sugar consumption and the prevalence of chronic diseases, including obesity, type 2 diabetes, and cardiovascular disorders. Consequently, manufacturers are compelled to innovate formulations that reconcile nutritional adequacy with the maintenance of desirable sensory characteristics. Beyond imparting sweetness, sugar plays multiple crucial roles in determining product quality it influences mouthfeel, aroma release, color development, and flavor perception. Therefore, direct sugar reduction can disrupt sensory equilibrium and potentially lead to consumer rejection. In the present study, a gradual sugar reduction approach was implemented across selected product categories within the company's portfolio. To mitigate losses in sensory attributes, the functional roles of sugar were emulated through the strategic application of flavoring agents. Both natural and nature-identical flavor compounds were meticulously selected and optimized to reestablish the perception of sweetness, restore aromatic harmony, and preserve mouthfeel. Sensory evaluations and consumer acceptance tests were subsequently conducted to assess the interaction effects of flavor components in reduced-sugar formulations. The sensory analysis results revealed that reduced-sugar products enriched with optimized flavor profiles received higher acceptance scores compared to control samples. According to the panelists, well-balanced flavor combinations enhanced the perception of sweetness and maintained a sensation of "natural sweetness." These outcomes indicate that flavoring agents can function not only as taste enhancers but also as functional components that sustain the sensory integrity of food products. In conclusion, this study underscores a novel strategy for sugar reduction that integrates flavor science as a tool to maintain product quality and consumer satisfaction. Such an approach not only supports public health objectives but also contributes to sustainable innovation, nutritional quality, and long-term brand loyalty within the evolving landscape of the food industry.

Keywords: Sugar reduction, flavorings, sensory analysis.

Health-Oriented Reformulation of Fermented Dairy Products for Children: Strategies for Sugar Reduction and Natural Sweetness Optimization

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ABSTRACT

Reducing added sugars in fermented dairy products designed for children, such as yogurts and dairy-based beverages, is a crucial step toward promoting healthier dietary behaviors and preventing nutrition-related chronic diseases. Excessive sugar intake during childhood has been strongly associated with obesity, type 2 diabetes, dental caries, and cardiovascular complications. Moreover, early exposure to high-sugar foods may condition children's palates to prefer overly sweet tastes, fostering unhealthy dietary habits in adulthood. Despite these concerns, sugar remains an essential ingredient due to its multiple functional roles-enhancing sweetness, improving palatability, stabilizing texture, and contributing to microbial stability. Therefore, sugar reduction in fermented dairy matrices presents both technological and sensory challenges. The study involves a systematic evaluation of the sugar content and nutritional profiles of commercially available fermented dairy products targeted at children. Parallel consumer research will identify prevailing consumption patterns and sweetness expectations. Based on these insights, natural reformulation strategies will be investigated, emphasizing enzymatic lactose hydrolysis to generate intrinsic sweetness, the application of natural flavor modulators to enhance perceived sweetness, and the integration of safe, plant-based sugar replacers. Prototype formulations will be developed and subjected to both instrumental and sensory analyses. Sensory evaluations will focus on sweetness perception, flavor balance, texture, and overall acceptability. In addition, nutritional composition and labeling implications of reduced-sugar prototypes will be assessed to ensure compliance with health-oriented product standards. Preliminary analyses are expected to reveal considerable variability in sugar levels among current market products, suggesting a strong need for standardized nutritional improvement. Early sensory trials demonstrated that the combined use of enzymatic lactose hydrolysis and natural flavor modulation can effectively maintain consumer-perceived sweetness while achieving a significant reduction in added sugar. This research highlights the potential of science-based, natural reformulation strategies to achieve sugar reduction in children's fermented dairy products without compromising sensory quality. The findings will contribute to the development of nutritionally improved, clean-label, and consumer-accepted products that align with current health-conscious consumption trends. Ultimately, this study aims to support public health objectives by reducing sugar intake in children's diets while promoting sustainable innovation within the dairy industry.

Keywords: Sugar reduction, fermented products, reformulation, dairy.

Assessment of Antimony Migration from PET Bottles into Water, Carbonated Beverages, and Edible Oils under Real Storage Conditions in Benin

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ABSTRACT

The widespread use of polyethylene terephthalate (PET) bottles for water, beverages, and edible oils has raised concerns regarding the potential migration of residual antimony (Sb), used as a catalyst in PET manufacturing, into food matrices. Despite the importance of this issue, no data were available in the scientific literature regarding Sb migration in products marketed in Benin. This study aimed to evaluate Sb migration from PET packaging into bottled drinking water, carbonated beverages, and edible oils under storage conditions representative of local consumer practices. Samples of locally produced and imported products were analyzed after 0 and 90 days of storage at four temperatures: -18°C, 0-6°C, 22-26°C, and 38°C. Antimony concentrations were determined using an analytical method with a limit of quantification (LOQ) of 0.01 µg/L. The results showed that Sb migration in bottled water remained consistently ≤ LOQ across all conditions, confirming negligible release. In carbonated beverages, Sb levels were also ≤ LOQ except at 38 °C after 90 days, where concentrations reached 4.236 ± 0.018 µg/L in local products and 5.381 ± 0.021 µg/L in imported products, the latter slightly exceeding the European regulatory limit of 5 µg/L. In edible oils, Sb migration was more pronounced, with values of 6.443 ± 0.024 µg/L in local oils and 8.491 ± 0.026 µg/L in imported oils at 38 °C, both surpassing the EU limit. In conclusion, this study demonstrates that Sb migration from PET is strongly dependent on storage temperature and the type of food matrix. While bottled water poses negligible risk, carbonated beverages and particularly edible oils stored under elevated temperatures may lead to Sb concentrations exceeding international safety standards. These findings highlight the need for stricter monitoring of storage conditions and greater regulatory oversight to ensure consumer protection in West Africa.

Keywords: Antimony, PET bottles, migration, storage conditions, food safety.

Migration of Antimony from Virgin PET Bottles into Drinking Water under Various Storage Conditions: Implications for Health and Public Safety

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ABSTRACT

The increasing use of polyethylene terephthalate (PET) bottles for packaging drinking water raises concerns about the potential migration of toxic elements such as antimony (Sb). This study aimed to assess the influence of temperature and storage duration on Sb migration from virgin PET bottles into tap water in Benin. The experiment involved twenty-one new 500 mL bottles filled with tap water and subjected to three thermal regimes (0–6°C, 25°C, and 50°C) over a 90-day period. Analyses were performed on days 0, 60, and 90 using an inductively coupled plasma optical emission spectrometer (ICP-OES, Thermo Fisher iCAP 6500). Each sample was microwave-digested following a standardised protocol and subsequently analysed for Sb quantification at a wavelength of 206.833 nm. The limit of quantification (LOQ) was set at 0.01 µg/L, and the European Union regulatory limit (5 µg/L) was used as the reference value for data interpretation. Results indicated that at 0–6°C and 25°C, no detectable migration occurred over 90 days (≤ LOQ). In contrast, at 50 °C, mean Sb concentrations increased from undetectable levels to 2.319 ± 0.023 µg/L at day 60, and 5.812 ± 0.028 µg/L at day 90, exceeding the EU threshold. These observations confirm a strong temperature- and time-dependent migration pattern, consistent with previous studies describing a diffusion-controlled increase above 50 °C. In conclusion, Sb migration remains negligible under refrigerated and ambient conditions but becomes significant under prolonged thermal stress. The findings support recommendations to avoid extended storage of PET bottles in hot environments and highlight the need for further research on Sb diffusion kinetics under tropical conditions.

Keywords: Antimony, migration, PET bottles, storage temperature, ICP-OES.

Assessment of Key Functional Traits in Lactic Acid Bacteria Isolated from Algerian Makatia Goat Milk for Use in Food Products

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ABSTRACT

While studies on the health aspects of lactic acid bacteria (LAB) may attract more attention from the scientific community, focus on the technological aspects of these bacteria has also become equally important, as they possess physiological traits that make them suitable for various food productions. This study examined some of these traits in 10 LAB isolates from Makatia goat milk in the Wilaya of Mascara in western Algeria. Tests assessed acidifying activity, enzymatic activity, growth at different pH levels, growth in highly salted environments, growth at various temperatures, exopolysaccharide (EPS) production, high-temperature tolerance, antagonistic activity, and antibiotic sensitivity. All isolates lacked amylolytic activity, while proteolytic activity ranged between 14.33 and 32.67 mm of lysis zones, and lipolytic activity ranged between 8.43 and 12.53 mm. Thermotolerance at 63°C for 30 minutes was observed in all 10 isolates, along with varied growth capabilities under different conditions (high and low pH, salted environments, and different temperatures). Significant antagonistic activity ranged from 11.5 to 40.66 mm of inhibition zones against the tested indicator strains. All 10 LAB isolates from goat milk demonstrated notable technological properties that could be useful or detrimental in food technology. For instance, they are desirable in the fermentation industry but could be undesirable in some pasteurization-sensitive products or certain meat food industries.

Keywords: Lactic acid bacteria, technological properties, goat milk, food spoilage.

Endogenous Knowledge and Processing Practices associated with *Ricinodendron heudelotii* KernelSs in Benin and Côte d'Ivoire (West Africa)

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ABSTRACT

In West Africa, *Ricinodendron heudelotii* (Akpi in Baoulé*) is a species with multiple uses but still underutilized. This study aimed at (i) identify products derived from *Ricinodendron heudelotii*, (ii) analyze the associated technological and food practices, and (iii) explore opportunities for their valorization. Surveys were carried out in Benin and Côte d'Ivoire among 62 (30 in Benin, 32 in Côte d'Ivoire) production units. Data were collected on processing techniques, use patterns, and marketing challenges using structured interviews. Descriptive statistics were used to summarize data while Chi-square test was used to assess associations among variables. Results showed that the two main products processed and marketed by the surveyed processing units in Benin and Côte d'Ivoire are oil (48.5%) and dried kernels (48.5%). Ointment (28.5%), spice (25.9%), and powder (24.9%) are also available on the market but are less common. The processing of fruits into kernels is based on techniques including fermentation, cooking and drying. The decantation method is predominantly used by women to extract oil from *Ricinodendron heudelotii* kernels. Sixty percent of processing units in Côte d'Ivoire use an oil extractor to obtain oil after roasting the kernels. Pressed cakes are sometimes processed into Akpi paste used as spices in local sauces. Derived products, criteria to describe high-quality kernels, processing frequency, and commercial practices varied between countries. Our findings suggest that improving the sector's structure and technological processes would enhance both the quality and profitability of this resource and consequently the market penetration of the species derived products.

Keywords: Non-timber forest products, value chain, oil extraction, traditional practices, food processing.

*Baoulé : Local language in Côte d'Ivoire

Biochemical and Anti-Nutritional Factor Characterization of Pressing Cakes from *Ricinodendron heudelotii* Kernels

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ABSTRACT

Wild food resources are a valuable source of nutrients in rural communities of Sub-Saharan and West Africa, offering a sustainable solution to food and nutrition security. *Ricinodendron heudelotii* is one such resource. Its oil-rich kernels are highly prized for food purposes. However, beyond their lipid content, the pressing cakes (residue from oil extraction) have not been characterized. They remain underexplored and underutilized. This study aims to assess the biochemical and toxicological composition of these pressing cakes in view of their potential use in food applications. Fifteen samples of pressing cakes, obtained from kernels extracted from fruits collected in Benin (Zogbodomey, Bantè, Adja-Ouèrè, Pobè) and Côte d'Ivoire (Daloa, Bouaflé, Sinfra, Oumé, Gagnoa, Soubré, Lakota, Divo, Tiassalé, Agboville, Adzopé), were analyzed. Biochemical analyses included: dry matter, total ash, minerals, protein, total and soluble carbohydrates, fat, and crude fiber. Toxicological analysis focused on total and soluble oxalates. Descriptive statistics, correlations, and regressions were performed using R software. The macronutrient composition of the pressing cakes included 10.79 g/100g DM of total carbohydrates, 8.19 g/100g DM of crude fiber, 46.47 g/100g DM of protein, and 20.08 g/100g DM of fat. The cakes were rich in phosphorus (2015.6 mg/100g DM), calcium (1966.79 mg/100g DM), potassium (1358.5 mg/100g DM), and magnesium (1248.8 mg/100g DM). They had a dry matter content of 88.49% and total ash content of 13.14 g/100g DM. Total oxalate content was 39.9 mg/100g DM. The low moisture content and strong nutritional profile make these cakes suitable candidates for food formulations (such as patties and biscuits) adapted to consumer preferences. Valorizing these pressing cakes could enhance rural entrepreneurship and contribute to greater resilience against food insecurity.

Keywords: Non-timber forest products (NTFPs), Akpi, macronutrients, essential minerals, food formulation.

Project GreenFeed4Fish: Turning Agricultural Waste into Nutritious and Functional Aquafeeds-An Eco-Innovative Approach to Upgrade Farmed Marine Fish Welfare and Quality

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ABSTRACT

Transitioning towards sustainable and circular food systems is essential to meet the growing global demand for safe, nutritious, and responsibly produced food. The *GreenFeed4Fish* project contributes to this transition by developing an eco-innovative strategy for the valorisation of agricultural wastes (AWs), converting them into high-value ingredients for aquafeeds that enhance environmental sustainability and food system resilience. By integrating the agriculture and aquaculture sectors, the project promotes resource efficiency, waste reduction, and the establishment of circular agri-food systems aligned with the principles of the Circular Economy and Zero-Waste policies. Within a Mediterranean framework, *GreenFeed4Fish* will: (i) identify and characterize regionally available AWs in terms of biochemical composition, functional properties, and suitability for industrial valorisation; (ii) develop and validate a green extraction methodology to obtain food-grade compounds compliant with EU food-safety legislation; and (iii) formulate and test functional aquafeeds incorporating these extracts to support fish health, welfare and product quality. GreenFeed4Fish project aims to: (1) convert low-value agricultural by-products into safe, high-quality feed ingredients, reducing biomass losses along the food chain; (2) enhance the nutritional and functional quality of food and feed, contributing to improved animal and human health; (3) establish sustainable and traceable valorisation routes for agricultural by-products, thereby minimising waste generation; and (4) promote cross-sectoral innovation between primary production systems, advancing climate-smart, resource-efficient, and socially responsible food production. By transforming agricultural by-products into valuable aquafeed ingredients, *GreenFeed4Fish* provides a scalable model for food sustainability, supporting the global shift towards integrated, low-waste, and resilient circular food systems.

Keywords: Upcycling, circular economy, resource efficiency, food resilience, sustainable aquaculture.

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Antimicrobial Potential of Plant-Derived Nanoparticles: A Sustainable Synthesis Approach

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ABSTRACT

Increasing resistance to conventional antimicrobial agents has increased the importance of metal nanoparticles synthesized using environmentally friendly approaches. Green synthesis using plant extracts stands out as an economical and sustainable alternative that reduces the use of toxic chemicals. In this study, silver nanoparticles (AgNPs) were synthesized using quince (*Cydonia oblonga* Mill.) extract and their characterization and antimicrobial activities were evaluated. The color change from light yellow to brown observed during the synthesis process was the first indicator of nanoparticle formation. The surface plasmon resonance band observed around 423 nm in UV-Vis spectroscopy was consistent with the 380-500 nm range reported in the literature for AgNPs synthesized with different fruit extracts. FTIR analyses demonstrated that natural compounds contribute to the reduction and stabilization processes. SEM and STEM studies demonstrated the formation of spherical nanoparticles with a homogeneous distribution in the 20-25 nm size range; these properties are consistent with structural trends reported in similar plant-derived systems. Antimicrobial tests conducted using the agar well diffusion method revealed that the synthesized AgNPs exhibited significant inhibition against Gram-positive (*Staphylococcus aureus* and *Bacillus subtilis*) and Gram-negative (*Escherichia coli* and *Salmonella enterica*) bacteria. These results support the strong antimicrobial effects of AgNPs obtained through green synthesis reported in various biological systems. In conclusion, silver nanoparticles synthesized via quince extract are promising alternative agents that can be used in the pharmaceutical, food, and biomedical fields due to their high antimicrobial activity and environmentally friendly production processes.

Keywords: Quince extract, green synthesis, silver nanoparticle, antimicrobial activity.

Bioactive Composition and Functional Potentials of *Opuntia Ficus-Indica* for Sustainable Food Systems

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ABSTRACT

The prickly pear (*Opuntia ficus-indica*) represents a significant resource for advancing sustainable and nutritious food systems. This species, highly valued for its capacity to grow in both arid and semi-arid conditions, plays a significant role in the conservation of biodiversity and enhancing food security in areas with harsh climatic conditions. What makes it truly unique is its biochemical composition, which has garnered significant interest from scientists and industry alike. The plant's polyphenols, betalains, flavonoids, essential fatty acids, and mucilage are particularly intriguing. The bioactive compounds found in prickly pear cactus exhibit strong antioxidant, anti-inflammatory, and nutritional characteristics, positioning it as a promising option for the development of functional ingredients. This study integrates and synthesizes recent advances concerning the cactus's bioactive composition across its distinct anatomical components (pulp, peel, cladodes, seeds, and mucilage) and explores their diverse applications within the contemporary food industry. These include beverages rich in antioxidants, gels that enhance texture derived from gum polysaccharides, flours high in fiber, biodegradable coatings suitable for consumption, and natural pigments that serve as alternatives to artificial colorings in food processing. The abundance of high-value functional compounds in the prickly pear cactus plays a significant role in addressing the demand for healthy and sustainable food systems from a bioeconomic standpoint. Recent findings have shown the potential for collaboration among food science, technology, and gastronomy in enhancing the application of this plant. Such collaboration can result in a more resilient and resource-efficient food system, reinforcing the connection between sustainable production methods and human health.

Keywords: Antioxidants, polysaccharides, food innovation, bioeconomy, natural pigments.

Nutritional and Toxicological Profile of Edible Macroalgae

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ABSTRACT

Seaweed-derived products are gaining increasing attention as nutrient rich and environmentally sustainable sources of bioactive and functional compounds in the food industry. They supply valuable proteins, essential minerals, and bioactive metabolites, making them highly versatile for use in functional foods and nutraceuticals. Furthermore, their role as sustainable biofertilizers and ingredients for aquafeeds continues to expand, with growing evidence from recent research and industry applications. This research investigated the presence of biotoxins and the concentrations of macro and trace elements in macroalgae collected from Ria de Aveiro (Aveiro, Portugal) and from three aquaculture facilities along the Portuguese coastline (Ria de Aveiro, Matosinhos, and Olhão). In Ria de Aveiro, both wild and cultivated samples were obtained seasonally over a one-year period (2024,2025) to assess temporal variability. Among the factors tested, species identity emerged as the primary determinant of elemental composition, accounting for more than 75% of the variation in major and trace essential elements. The origin (wild versus cultivated) showed no statistically significant effect on the elemental profiles. Seasonal variation, while modest, influenced redox-sensitive elements such as copper and manganese. No regulated marine biotoxins were detected in any samples. All quantified elemental concentrations were below established safety thresholds for human consumption, supporting the overall safety of macroalgae both from Aquaculture and Wild origin. Nonetheless, the inclusion of macroalgae in systematic monitoring programs and the establishment of a clear regulatory framework are recommended to reinforce consumer confidence and to foster the sustainable growth of the national macroalgae aquaculture sector.

Keywords: Seaweeds, food safety, seasonal variation, elemental composition, marine toxins.

This work was financially supported by “Pacto da Bioeconomia Azul” (Project No. C644915664-00000026) within the WP5 Algae Vertical, funded by Next Generation EU European Fund and the Portuguese Recovery and Resilience Plan (PRR), under the scope of the incentive line “Agendas for Business Innovation” through the funding scheme C5 - Capitalization and Business Innovation.We also acknowledge FCT, I.P., for the financial support under the strategic projects (UID/MAR/04292/2020,LA/P/0069/2020) granted to MARE and ARNET.

Post-Harvest Macroalgae Processing to Mitigate Surface-Bound Contamination with Toxic Microalgae

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ABSTRACT

Aquaculture has become a significant component of global food production. For many decades, seaweed products have been traditionally used as food alongside many applications in various sectors. In recent years, the demand for seaweed products has been rising, with the global market expected to increase 9.1% until 2027. New environmental challenges resulting from climate change, such as rising sea temperatures, pose serious food safety risks due, e.g. to the possibility of accumulation of marine biotoxins (e.g., okadaic acid and dinophysistoxins) or deposition of abundant toxic microalgae cells on seaweed surfaces, during blooms of harmful algae. Using the green seaweed *Ulva rigida* as a model and exposed to toxic dinoflagellates *Prorocentrum lima*, this study aims to understand if seaweeds accumulate dinoflagellate toxins or whether toxic microalgae cells attached to the surface may contaminate the seaweed, requiring a post-harvesting strategy. *Ulva rigida* (60 g WW) was maintained in 3 L sterile F/2 medium, with and without addition of approximately 1×10^6 cells/L of *P. lima*. Macroalgae samples were collected at day 0, day 3, and day 7, and subjected to a post-harvest processing method: rigorous processing involving washing with seawater, rinsing and scrubbing with a scalpel. Lipophilic toxin concentrations (okadaic acid [OA] and dinophysistoxins [DTXs]) were quantified by LC-MS/MS analysis. Statistical differences were assessed using ANOVA. LC-MSMS analysis showed high levels of OA (301.45 ± 40.07 ng/g FW) and DTX^{-1} (82.23 ± 12,26 ng/g FW) when *Ulva* was exposed to *P. lima*. At day 7, significantly higher toxin concentrations were observed than in day 3. In contrast, processed seaweed samples exposed to *P. lima* that underwent the post-harvest cleaning method showed no detectable toxin levels. These findings indicating that the toxins were primarily surface-bound and effectively removed by rigorous post-harvest treatment. The toxin levels in unprocessed macroalgae were within or above the maximum limits allowed for OA and related toxins DTXs in shellfish for human consumption, which are established at 160 µg OA equivalents per kg, representing a risk to human health. Importantly, toxins were on algal surface rather than incorporated within the algal tissues, hence enabling an efficient removal through mechanical processing. This study highlights the risks associated with seaweed surface contamination by lipophilic toxins, that are currently overlooked.

Keywords: Aquaculture, food safety, seaweed, marine biotoxins.

This work was financially supported by “Pacto da Bioeconomia Azul” (Project No. C644915664-00000026) within the WP5 Algae Vertical, funded by Next Generation EU European Fund and the Portuguese Recovery and Resilience Plan (PRR), under the scope of the incentive line “Agendas for Business Innovation” through the funding scheme C5 - Capitalization and Business Innovation.We also acknowledge FCT, I.P., for the financial support under the strategic projects (UID/MAR/04292/2020,LA/P/0069/2020) granted to MARE and ARNET.

A Circular Approach for Fresh Farmed Fish Waste: Functional Protein Hydrolysates from Catfish and Tilapia By-Products

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ABSTRACT

The European INNOECOFOOD project contributes to the blue bioeconomy by converting fish filleting by-products, particularly from catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*) into value-added protein ingredients. To ensure resource efficiency within the fish-processing sector, this study explores the valorisation of fish by-products through the production of enzymatically derived protein hydrolysates (FPH), recognised for their safety, functionality and potential applications in the food industry. Hence, this study investigated optimised hydrolysis methods using only Alcalase (A) and a combination of Alcalase and Protana (AP) to produce FPHs from catfish and Nile tilapia by-products and to characterise their properties. Heads and frames from catfish and tilapia were freeze-grinded and subjected to enzymatic hydrolysis at a 1:2 (w/v) ratio of raw material to distilled water. Hydrolysis A was conducted at 60 ºC with stirring at pH 8.5, while the AP treatment was performed at 55 ºC and pH 7. Enzymes were added at 1% (w/w) and the reactions proceeded for 3 hours before being stopped by heating to 90 ºC for 10 min. Mixtures were subsequently cooled and centrifuged and the supernatants filtered, freeze-dried and stored at -80 ºC. Chemical, functional and biological properties of the FPHs were evaluated. The FPH chemical composition showed low fat content (<3%) and a high protein content (70-85%), with the highest levels observed in the AP hydrolysates. Both species' by-products showed low lipid peroxidation (1.39-1.55 mg MDA/kg); however, hydrolysis led to the formation of peroxidation products, resulting in higher TBARS values for all hydrolysates. The degree hydrolysis was higher with AP (47.7-49.3%) than with A (28.5-30.8%). All FPHs exhibited lower water activity (<0.08), with no significant differences between species or enzymes. Tilapia hydrolysates were lighter (L* = 86) than those from catfish (L* 79-82). Regarding functional properties, foaming capacity was low across hydrolysates (<12.5%), though catfish hydrolysates (A and AP) showed high foaming stability (78-83%). FPHs produced with A had higher protein solubility, and catfish hydrolysates demonstrated better emulsifying capacity and stability. Tilapia hydrolysates exhibited stronger antioxidant capacity, with higher DPPH and ABTS radical scavenging activity, while hydrolysates produced with AP from both species showed higher antihypertensive potential (EC_{50} 3.1-3.3%). Overall, these protein hydrolysates add value to fish by-products and support waste reduction in the fish supply chain. Therefore, FPHs may be considered a versatile ingredient for the food industry, due to their ability to increase protein content and potential role in the technological field.

Keywords: Enzymatic hydrolysis, antioxidant activity, functional properties, anti-hypertensive activity.

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Petroleum- and Bio-Based Microplastics During Simulated Human Digestion: Insights into Polymer Integrity and Seafood Digestibility

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ABSTRACT

Plastic pollution has emerged as a critical environmental and human-health fear. Among exposure pathways, ingestion of microplastics through contaminated seafood has become a major concern. However, the extent to which microplastics may influence the human digestive system and the digestibility of seafood remains poorly studied. This study aimed to investigate, for the first time, the influence of a petroleum-based polymer (polyethylene terephthalate, PET) and a bio-based polymer (polylactic acid, PLA) on protein digestibility of three selected seafood species (Gilthead seabream, *Sparus aurata*; Atlantic salmon, *Salmo salar*; Hard clam, *Mercenaria mercenaria*), and evaluate how the human digestive process may affect the integrity of these microplastics. To this end, seafood samples were first contaminated with microplastic particles by adding 10 or 20 particles to 1.5g of homogenised fish fillet or bivalves' edible meat (i.e. 6.7 or 13.3 microplastic particles g^{-1}). Afterwards, contaminated seafood samples were digested following a standardized in vitro human gastrointestinal model. Protein seafood digestibility (i.e. the bioaccessible fraction, which is the fraction of protein becoming available for absorption) was determined via the Dumas method. Microplastic particles were characterized before and after *in vitro* digestion via binocular stereomicroscopy, Fourier transform infrared spectroscopy (FTIR), and scanning electron microscope (SEM) to assess changes in morphology and chemical structure. Protein bioaccessibility was higher in fish fillets (80-95%) and lower in clam edible parts (70-80%); however, no statistically significant differences were found between control seafood edible parts and those containing either PET

or PLA particles, regardless of polymer type or particle number. In contrast, differences were found in microplastics' integrity after digestion. PET particles showed no changes in surface morphology, whereas PLA particles exhibited signs of surface degradation (enhanced pits and pores). Moreover, PLA FTIR spectra suggested hydrolytic alterations after digestion. This highlights that although the co-ingestion of PET and PLA microplastics did not impair seafood protein digestibility, the gastrointestinal environment may alter the physical and chemical integrity of PLA, with the potential release of health-harming plastic additives (e.g. flame retardants, plasticizers, stabilizers, colorants) and smaller fragments. These findings highlight the need for further research of a wider range of polymers, particle sizes and shapes, and seafood matrices, as well as the interaction of microplastics with nutrients and the potential release or adsorption of contaminants and additives, to better assess the potential human health risks associated with microplastic ingestion.

Keywords: PET, PLA, plastics, protein bioaccessibility.

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Strategies to Reduce Sodium in Canned Atlantic Horse Mackerel

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ABSTRACT

Since sodium chloride (NaCl) is widely used in canned fish production as both a technological ingredient and a flavour enhancer, it is common to find products on the market containing 1.5% or more. However, there is increasing pressure to reduce NaCl levels in foods, as excessive sodium (Na) intake is associated with elevated blood pressure and other health problems. Thus, the aim of this study was to evaluate the effect of partial replacement (50%) of NaCl by KCl and microencapsulated spices and aromatic plants extract (ME) (in a light brine) on the stability, sterility, physicochemical and sensory properties of canned Atlantic horse mackerel (*Trachurus trachurus*) prepared with olive oil and stored for up to 4 months at room temperature. Hence, cans were prepared with steamed fillets (65%), refined olive oil, and 5 ml of light brine (14%). Three brine formulations were tested: 100% NaCl (control, CTR), 50% NaCl + 50% KCl (F1) and 50% NaCl + 50% ME (F2). The cans were hermetically sealed and sterilised by heat treatment. After cooling, they were stored at 20 and 40 °C and analysed after 1 month (to simulate a 4-month ageing period). Generally, formulation and accelerated ageing did not affect the proximate composition, pH, or sensory properties (evaluated by a trained panel – e.g., salty flavour, bitterness, firmness, juiciness - or instrumentally, in the case of colour and texture) of the canned fish. All products remained stable and sterile after a 4-month ageing period and can be nutritionally claimed as "source of protein". Na reductions of 43% were observed for F1 and F2 (compared to CTR), allowing the products to be labelled as "reduced in Na content", according to Regulation (EC) No. 1924/2006. Partial replacement of NaCl with KCl also resulted in a product richer in K (504.3 ± 20.6 mg/100 g). On the other hand, total volatile basic nitrogen levels increased in all formulations after 4 months of ageing; however, these values remained within safe limits (<45 mg/100 g) for this product type. All samples were described as having a typical canned flavour ranging from slight-moderate to moderate and a bitter taste from absent to slightly perceptible. In conclusion, the 50% replacements of NaCl by KCl and oleoresin microcapsules proved to be effective solutions to reduce Na levels and also increase K content (in F1) in the canned food industry, while maintaining product quality for at least 4 months at room temperature.

Keywords: Sodium chloride (NaCl), potassium chloride (KCl), microencapsulated spices and aromatic plants extract, *Trachurus trachurus*, quality.

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Aroma Recovery under Low Pressure from Tomato Plant Waste

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ABSTRACT

Post-harvest greenhouse tomato plant waste arising from agricultural production has the potential to be economically valorized due to its volatile organic compound content. In this study, post-harvest plant material from cluster-type tomatoes cultivated in the Antalya region was collected in October 2024. The material was homogenized, the juice and remaining plant parts were combined at a 2:3 ratio to prepare the mash. The mash was then heated at an initial temperature of 60 °C and distilled for 1 hour under constant pressure conditions of 200 and 400 mbar. Different temperature profiles were observed at each pressure level: 47.4 °C at 200 mbar and 54.5 °C at 400 mbar. Aroma recovery was carried out using a fractional distillation setup equipped with a rectification column integrated into the rotary evaporator. The process time was fixed at 1 hour for both pressure conditions, and samples were collected from different sampling ports depending on the temperature reached during distillation. At 200 mbar, samples were taken from the third sampling port at 54 °C, whereas at 400 mbar, the fourth port was sampled at 57 °C. The collected aroma fractions were subjected to comparative analysis. The volatile compound profile was examined using GC-MS after diluting the distillates with acetone at a 1:5 ratio. Compound identification was performed using the NIST and Willey libraries, and calibration curves were applied for quantitative determination of hexanol and phenethyl alcohol. The results indicate that the concentrations of hexanal, hexanol, and phenethyl alcohol-key aroma compounds characteristic of tomato pulp-are markedly higher in the vegetative waste fractions compared with the pulp. For instance, hexanal reached 12.087 ppm in the fraction collected from the third sampling port at 400 mbar, whereas it was only 1.105 ppm in the pulp. Hexanol was 6.93 ppm at 400 mbar and 1.441 ppm in the pulp. Phenethyl alcohol exhibited its highest concentration at 5.201 ppm at 1000 mbar in the fraction taken from the fifth sampling port. Overall, these findings indicate that greenhouse waste derived from tomato stems, leaves, and other vegetative parts can be transformed into value-added products through aroma recovery.

Keywords: Tomato vegetative waste, fractional distillation, HS-SPME-GC-MS, aroma recovery.

Characterization of Local Shelling, Storage, and Processing Practices of *Egusi* Seeds (*Cucurbitaceae*) in Benin

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ABSTRACT

Egusi seeds (Cucurbitaceae) are an excellent source of proteins, unsaturated fatty acids, minerals, and bioactive compounds essential for human health. Widely used in various food products such as sauces, oils, and fritters, they play a crucial role in food security and the cultural heritage of local populations in Benin. However, the value chain remains constrained by rudimentary processing and storage practices, including labor-intensive manual shelling and inefficient preservation methods. This study aimed to characterize local shelling, storage, and processing practices in order to identify constraints and opportunities for improvement. The survey was conducted from October to November 2024 in four representative municipalities (Glazoué, Djougou, Kétou, and Porto-Novo) among 651 stakeholders, 137 producers, 159 traders, 157 processors, and 198 consumers selected through simple random sampling. Data were collected through semi-structured interviews and direct observations, and analyzed using R software to generate descriptive statistics. Results showed that shelling is performed exclusively by hand after seed moistening. This technique, considered laborious and time-consuming, often causes injuries and limits processing capacity. All respondents (100%) expressed willingness to adopt mechanical shellers. Storage practices remain limited: only 18 to 35% of actors store seeds, mainly in undehulled form, sun-dried, and packaged in polyethylene bags. Storage duration ranges from 3 to 6 months, with average reported losses of 10 to 16 kg per year, primarily due to drying difficulties and pest infestations. Regarding processing, the study identified nine major derived products (powder, sauces, fritters, etc.) consumed across all social groups. Their production, entirely artisanal and non-standardized, results in considerable variability in product quality. In conclusion, the egusi value chain in Benin relies on valuable endogenous knowledge but remains hindered by technical and organizational limitations. Mechanization of shelling, improvement of drying and storage techniques, and capacity building for processors emerge as key priorities to enhance the sustainability and added value of this strategic sector.

Keywords: *Egusi*, local practices, shelling, storage, processing, Benin.

Oils Rich in Conjugated Fatty Acids: Methods of Extraction, Preservation and Storage

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ABSTRACT

Conjugated fatty acid (CFA)-rich oils, particularly conjugated linoleic acid (CLA) and conjugated linolenic acid (CLnA), are gaining increasing attention due to their nutritional, functional, and technological properties. However, their high susceptibility to oxidation and thermal degradation represents a major limitation to industrial utilization. This systematic review, conducted in accordance with PRISMA guidelines and based on 1435 references (2015-2025), retained 46 studies addressing extraction, preservation, and storage methods of these oils. The findings revealed a growing research dynamic, dominated by China and Brazil, but with limited representation in Africa despite a high diversity of oil-bearing plants. The most studied extraction methods include Soxhlet extraction (high yields but risk of oxidation), supercritical CO_2 extraction (higher purity and stability but high cost), ultrasound- and microwave-assisted techniques (reduced processing time and improved yields), and cold pressing (better preservation of bioactive compounds but lower efficiency). Preservation approaches relied on innovative technologies such as micro- and nanoencapsulation, spray-drying, Pickering and layer-by-layer emulsions, oleogels, and polymer-based films, which improve oxidative stability. Storage studies highlighted the critical influence of temperature, light, and oxygen, with optimal practices recommending cold storage in dark conditions under vacuum or inert atmosphere. However, only a few studies integrated extraction, preservation, and storage simultaneously, and most focused on short-term stability (30–90 days). Overall, no single method proved universally optimal; instead, the sustainable valorization of CFA-rich oils required a careful combination of eco-friendly extraction, advanced preservation strategies, and strict storage practices to maintain their nutritional and functional quality while enabling industrial scalability.

Keywords: Conjugated fatty acid, oxidative stability, bioactive compounds, nutritional quality, functional quality.

Microplastics and Plastic-Derived Contaminants in Canned Tuna: Key Knowledge Gaps and Implications for Regulatory Action

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ABSTRACT

Canned seafood represents nearly 10% of global fishery production, with its continued expansion driven by nutritional value, affordability, and long shelf life. However, increasing evidence shows that canned fish products may act as vectors for emerging contaminants such as microplastics (MPs) and plastic-derived chemicals, thus raising potential human health concerns. Specifically, recent studies have confirmed the presence of MPs in canned tuna, with reported levels ranging from only a few particles per can to hundreds per 100 g of product. While these particles may originate from environmental exposure, additional contamination can also occur during processing steps such as handling, packaging, and contact with plastic equipment. In addition to MPs, other compounds, such as bisphenols and phthalates, are a growing concern because they are widely used in the production of plastics and can coatings. These substances can migrate into fish matrices during sterilisation and storage, posing a risk to consumers as they are persistent and potentially carcinogenic endocrine disruptors and are associated with metabolic, reproductive and cardiovascular disorders. However, despite their known occurrence and possible synergistic effects with MPs, most of these contaminants are still not routinely monitored by the seafood industry. While MP contamination, as well as associated contaminants, has been thoroughly researched in recent years, many knowledge gaps still plague the tuna canning industry concerning this topic. Indeed, there are considerable knowledge gaps, as well as their dynamics for accumulation during processing, storage, or contact with packaging materials. The few existing studies rarely compare potential differences across brands or market segments, despite variations in tuna species with different bioaccumulation potential, as well as differences in production practices and lots which are often of different geographical origins, and packaging types that could influence contamination levels. Additionally, limited attention has been given to contamination within filling mediums such as oils or brines, or to the physicochemical and nutritional characteristics that may affect contaminant migration within these products. Consumer exposure assessments remain scarce, leaving uncertainty regarding potential health risks for children and adults. Overall, the lack of integrated data hampers the development of evidence-based mitigation measures and regulatory strategies for the canned tuna sector. Thus, the objective is to evaluate the state of the art on microplastic and associated contaminants in canned tuna and outline unresolved questions relevant to consumer safety and regulation.

Keywords: Bioaccumulation, bisphenol, phthalates, food safety, exposure risk.

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Lactobacillus plantarum Species: An Overview with Emphasis in Bacteriocinogenic, Probiotic, Biochemical, and Healthy Properties

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ABSTRACT

Lactobacillus plantarum species matching the features of lactic acid bacteria, mesophilic, facultative heterofermentative, aerotolerant, of ubiquitous ecology, active in fermentations as a starter. Many *Lactobacillus plantarum* strains have safe status GRAS: *Generally Recognized As Safe.* Its dual role; as native colonizing the human digestive tract, as starter of food fermentations, awarded them a preferential choice for their usage in development of new prebiotic plant beverages. *L. plantarum*, subject to considerable data scientific research. Data linked health benifits to this species. *L. plantarum* is at the focus of heated issues. This study aimed to enhance understanding of the species caracteristics, through bibliographic overview of knowledge, critical analysis, data collecting, to examine its different bacteriological, physiological, biochemical, probiotic, genetic features and production of bacteriocins. *Lactobacillus plantarum* is commonly used for the fermentation of foods of animal origin: dairy products (raw milk, fermented milk, yogurt, and cheese), meat sausages, fermented fish. Foods of plants origin: Vegetables: pickles, cucumber, table olives, sauerkraut, green beans, etc… *Lactobacillus plantarum*, having ability to survive human transit through digestive tract, adheres to intestinal epithelial cells. *Lactobacillus plantarum*, *Lactobacillus pentosus* and *L. paraplantarum* are genotypically related, exhibiting similar phenotypes. Plant-derived strains of *L. plantarum* have strong bacteriocinogenic activity and thermostable bacteriocins that are effective across a broad pH range and have a broad bactericidal/bacteriostatic spectrum. *Lactobacillus plantarum,* through its versatile role as a sourdough starter, its ubiquitous ecology, having probiotic virtues, opens up promising perspectives in human nutrition and food technologies.

Keywords: Bacteriocin, fermentation, food industry, *Lactobacillus plantarum*, probiotic.

Evaluation of Pesticide Properties of Nanoparticles Obtained from Food Wastes

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ABSTRACT

Given the negative impacts of chemical insecticide applications on human health, living organisms, and the environment, nanotechnology offers sustainable and environmentally friendly approaches to pest management, which benefits both farmers and ecosystems. The use of nanoparticles synthesized through environmentally friendly methods reduces the negative environmental impact of pesticides. Nanoparticles obtained through green synthesis offer a viable solution by utilizing bio-based materials, such as microorganisms, plants, and agricultural wastes, as environmentally friendly sources for nanoparticle synthesis. Nanoparticles derived from biowaste are emerging as a next-generation material with the potential to transform traditional agricultural practices. Nanopesticides derived from biowaste represent promising, environmentally friendly, sustainable, and economical alternatives to existing synthetic pesticides. In the studies, the pesticidal properties of nanoparticles obtained from wastes obtained from rice husk, *Pongamia pinnata*, cashew nut, *Lantana camara*, hibiscus, and pomegranate, as well as large amounts of biological wastes obtained from poultry and aquaculture sectors, were studied in detail. Assessing the pesticidal properties of nanoparticles derived from food waste provides advantages for the circular economy and sustainable waste management in the food industry. Another advantage is the use of these nanoparticles for food preservation. Assessing the pesticidal properties of nanoparticles derived from waste products will also pave the way for future use of nanoparticles derived from various waste products as pesticides.

Keywords: Biowaste, nanoparticle, nanopesticide.

Quality and Phenolic Effects of Pectin in Blackberry Jam Across Altitudes

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ABSTRACT

The present study aimed to evaluate the influence of pectin concentrations (0%, 0.1%, and 0.5%) on the physicochemical, antioxidant, and sensory properties of blackberry jam (*Rubus fruticosus* L.) produced from fruits harvested at different altitudes (wild: 998 m; cultivated: 500 m and 1090 m). Blackberry samples were processed into jam, and the products were analyzed for phenolic profile, antioxidant capacity (DPPH and FRAP methods), color parameters (*L**, *a**, *b**), texture (spreadability and firmness), and sensory attributes using a 9-point hedonic scale with 50 trained panelists. Results demonstrated that altitude significantly affected the phenolic composition and antioxidant activity of the raw fruits, with wild blackberries at 998 m showing the highest levels of total phenolics (1,248.6 ± 32.4 mg GAE/100 g), flavonoids (428.3 ± 18.7 mg QE/100 g), and anthocyanins (312.5 ± 14.2 mg C3G/100 g). Pectin addition at 0.1% improved gel formation, increased vitamin C retention by 22–28% compared to the control, and reduced perceived bitterness associated with phenolic compounds. Sensory evaluation indicated higher overall acceptance (7.8 ± 0.6) for jams with 0.1% pectin, particularly those from higher-altitude fruits. Higher pectin levels (0.5%) led to excessive firmness and lower spreadability, negatively impacting texture scores. In conclusion, moderate pectin supplementation enhances both functional stability and sensory quality of blackberry jam while mitigating undesirable astringency from high-phenolic fruits. Altitudinal variation in raw material significantly influences final product quality, underscoring the importance of source selection in jam production. These findings contribute to optimizing pectin use in high-phenolic fruit preserves.

Keywords: Pectin levels, altitude variation, blackberry jam, sensory evaluation.

Characterization and Quantification of Food Waste during Festive Events in Benin, West Africa

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ABSTRACT

Food waste is becoming a growing concern because of its economic, environmental, and social impacts. In recent years, especially in developed countries, an increasing number of studies have focused on the characterization and quantification of food waste in osrder to formulate effective policies to reduce it. Unfortunately, in developing countries such as Benin, food waste has been the subject of very little scientific research, even though large quantities of edible food are sometimes discarded, particularly during festive events. The present study aims to characterize food waste during festive events in the large cities of Benin. To that end, a survey was conducted among 300 organizers and guests of festive events in the cities of Abomey-Calavi, Cotonou, and Porto-Novo. Next, food waste was quantified during celebrations using the direct weighing method, focusing on the most frequently discarded meal. The results showed that 70% of guests at festive events do not finish their dishes. The amount of unfinished food can be as high as 10% of the meal served according to 59.9% of respondents, and up to 50% according to 4.6%. Rice was identified as the most discarded dish (78% of respondents). The preparation of exaggerated quantities of meals, the free nature of food service leading to oversized portions, and social perceptions such as the shame of finishing one's dish were among the main factors contributing to food waste. Moreover, 45% of respondents believed that food waste is inevitable during celebrations, as leftover food symbolizes the success of the event. Quantification of food waste on the most discarded dish (rice) revealed that 37.5 ± 8.8% of the rice served was discarded in Porto-Novo, compared to 19.9 ± 6.5% in Cotonou and 20.7 ± 7.8% in Abomey-Calavi. This study provides a basis for developing strategies and policies aimed at reducing food waste during festive events in Benin.

Keywords: Festive celebrations, food waste, rice consumption, cultural beliefs.

The Effects of Preschool Children's Eating Habits on Health and Development: A Case Study in Prizren, Kosovo

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ABSTRACT

A healthy and balanced diet during the preschool years (ages 3-6) is essential for children's physiological growth and cognitive development. This study explored how early dietary habits influence child health and development, emphasizing the benefits of nutritious eating and the risks associated with processed-food consumption. The research involved 100 preschool children, their parents, and educators. Participants were divided into two groups: one with balanced, healthy diets and another consuming primarily processed foods. Data collection included questionnaires, semi-structured interviews, and classroom observations. Findings revealed inconsistent interest in healthy foods among children. While 25% of parents reported consistent interest, 45% noted occasional interest, and ~30% observed little to none. Dietary analysis showed grains made up 40% of daily intake, dairy and bread 30%, fresh fruits 20%, and processed foods 10%. This indicates a dominance of staple carbohydrates and proteins, with insufficient vitamin-rich fruit consumption. Comparative results between the two groups highlighted significant differences. Daily food choices: 75% of healthy eaters consumed fruits and vegetables daily, while 70% of the processed-food group regularly consumed sugary snacks and sodas. Motor skills: 85% of well-nourished children showed age-appropriate motor development, compared to 40% of poorly nourished peers. Attention and participation: 90% of the healthy group demonstrated strong focus and engagement, whereas only 30% of the unhealthy group maintained attention. Allergies and intolerances: Less than 10% of healthy eaters had allergies, versus 25% in the processed-food group. Food intolerances affected 5% of the healthy group and 15% of the unhealthy group. In conclusion, the study confirms that balanced nutrition significantly enhances physical and cognitive development in preschoolers. Children with poor diets face increased risks of obesity, allergies, and developmental delays. The findings stress the importance of fostering healthy eating habits early and call for active collaboration between families and educational institutions to improve nutrition education and standards in preschool environments.

Keywords: Preschool nutrition, child development, healthy eating habits, Prizren case study.

Challenges and Advances in 3D Food Printing; A Focus on Measurement Techniques and Quality Evaluation Parameters: A comprehensive Review

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ABSTRACT

Three-dimensional (3D) food printing is revolutionizing modern food design by enabling precision, personalization, and sustainability through the layer-by-layer fabrication of edible structures. This review explores the fundamental principles of 3D food printing technologies, focusing on measurement techniques and quality evaluation parameters essential for optimizing printability, structural fidelity, and nutritional integrity. Rheological assessments, textural analysis, microstructure characterization, and nutritional evaluations are discussed in detail, alongside methods such as 3D scanning, imaging, and real-time monitoring systems. The paper also highlights emerging tools like artificial intelligence (AI), machine learning, and internet of things (IoT) that enhance automation and predictive control in the printing process. Despite rapid progress, challenges persist in reproducibility, standardization, regulatory clarity, and consumer acceptance. Addressing these challenges through multidisciplinary collaboration, innovation in edible ink formulation, and advanced process control will be key to realizing the full potential of 3D food printing in personalized nutrition, food safety, and sustainable food systems.

Keywords: 3D Food printing, measurement techniques, quality evaluation, printability, sustainable food systems.

Integration of a Customized Weather Forecast Warning System Data into the Meteo Rwanda Weather and Climate Services Platform: A Climate-Smart Approach to Potato Late Blight Disease Management

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ABSTRACT

Late blight, caused by Phytophthora infestans, is a major threat to potato production in Rwanda, severely impacting yields and farmer livelihoods. In response, we adapted and piloted the integration of the potato late blight forecasting model into the existing Meteo Rwanda weather and climate services platforms, inspired by the CARAH model successfully used in Belgium and Sichuan, China. Three automatic weather stations were installed, and disease forecasting was validated on pilot plots in three sites namely Burera, Musanze, and Nyabihu Districts. The yield and the quality of the produced potatoes were analysed. The results from this study revealed that, the application of the model significantly contributed to reduced pesticide use by 40%, increased yields by 54%, and reduced disease severity. This study demonstrates that a climate-smart, data-driven approach can sustainably manage late blight in Rwanda and increase potato yields in small-scale farmers' fields.

Keywords: Potato late blight, forecasting system, climate-smart agriculture, CARAH model.

Reducing the Ecological Footprint: A Solution to Achieve Food Security in Line with Climate Change Management

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ABSTRACT

Climate change is the long-term increase in the average temperature of the Earth's surface and widespread changes in global, regional and local weather patterns. Anthropogenic causes of climate change include deforestation and excessive production of greenhouse gases due to reasons such as industrialization, fossil fuels and the agriculture and livestock sector. Environmental impacts of food production and consumption include "carbon footprint", "material footprint", "land use" and "water footprint". This article aims to examine the foods that contribute to water and carbon footprints and strategies to reduce them. This review of published articles and reports revealed that agriculture is responsible for about 14% of total greenhouse gas (GHG) emissions and has a significant environmental impact in three aspects: requiring large amounts of freshwater, being a major driver of climate change, and land user. Food production accounts for more than a quarter (26%) of global greenhouse gas emissions, half of the world's habitable land, and 70% of global freshwater withdrawals. A further important issue is the relationship between dietary patterns (traditional, green, fast food, high in animal protein), and environmental impacts. Daily beef consumption ranges from 20 (green diet) to 50 g per 10 MJ (beef-rich diet) and accounts for 9–20% of GHG emissions in different dietary patterns. Meat production, and especially beef products, is associated with high greenhouse gas emissions, high water consumption and more cultivated land, while plant-based foods have the lowest carbon and water footprints. This substitution results in a 4–12% reduction in greenhouse gas emissions and a 5–14% reduction in land use. The largest impact on greenhouse gas emissions reduction was achieved with legumes or eggs as substitutes, while the largest impact on land use was achieved with fish or eggs as substitutes. Plant-based diets such as lacto-ovo-vegetarian are environmental-friendly foods compared to meat-based diets. Consumers should be aware of the environmental sustainability of food consumption in order to make environmentally friendly food choices while ensuring food security. Eliminating or reducing these products in the diet without adequate replacement may lead to nutrient deficiencies due to vital macro and micro-nutrients in beef and dairy products. Therefore, defining a sustainable food pattern for future, account the environmental and nutritional sustainability by adjusting the meat-based diet (animal sources) towards a plant-based diet includes: eggs, dairy and plant-based foods, organic foods, seasonal and regional products, eco-friendly packaging.

Keywords: Diet, food footprint, food security, greenhouse gases, sustainability.

The Necessity of a Zero-Waste Approach Beyond Environmentalism

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ABSTRACT

The “Zero-Waste” approach, which was initially proposed with environmental and ethical motives, has today moved beyond simply reducing waste and conserving resources to improving productivity, profitability, and brand differentiation in a competitive market as a new strategy in the restaurant industry. This article reviews the sources related to this concept and aims to redefine this approach, examining three key dimensions of it. First, from an economic perspective, the zero-waste approach is introduced as a business model based on resource optimization. By reviewing the supply chain and operational processes, restaurants can significantly save on purchasing and waste disposal costs by reducing waste at the source. Using technologies such as inventory management systems can lead to smarter purchasing decisions and increased operational efficiency while preventing food spoilage. Furthermore, creating new revenue streams through recycling and composting transforms sustainability from a cost to a profitable investment. The second theme addresses the challenges of consumer perception towards sustainable practices. Although consumers are willing to pay more for sustainability, this willingness is conditional on maintaining the quality, taste, and freshness of the food. Therefore, it is suggested that sustainability be introduced as part of the culinary quality rather than a standalone goal. Using local and seasonal ingredients and showcasing creative techniques such as full utilization of food can link sustainability to the dining experience. Finally, a roadmap for the successful implementation of this approach can be presented, which includes identifying waste sources, responsible sourcing, training employees, investing in sustainable infrastructure and rethinking marketing practices. Overall, the "zero waste" approach is aligned with environmental goals and has the potential to transform the restaurant industry as a comprehensive, profitable, and customer-centric strategy.

Keyword: Culinary quality, dining, sustainable practice, “zero-waste” approach.

Alternative Proteins and the Overlooked Barriers in Culture, Politics, and Marketing

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ABSTRACT

The world's growing population faces the challenge of sustainable protein supply. Alternative proteins (APs)-such as plant proteins, insect proteins, and cultured proteins-have come to light as a promising way to solve this problem. Despite the growth of the food product market, public acceptance of these products has been lower than expected. This article reviews the relevant literature and reports in this area and argues that, contrary to popular belief, the main barriers to the deployment of APs are not technical, but rather psychosocial, regulatory, and marketing. From a psychosocial standpoint, food neophobia, aversion, and cultural rejection constitute significant obstacles to the acceptance of these proteins. Most consumers tend to consume alternative proteins in familiar, processed forms; for example, protein bars containing spirulina powder are more acceptable than spirulina itself. Therefore, the success of APs depends on transforming “unconventional food” into “conventional food” through smart processing and alignment with common dietary patterns. Regional differences in regulation and enforcement are also challenging in APs productions regard. For example, some regions with their passive approach and lengthy safety assessment processes hinder innovation and rapid product market entry. In contrast, the United States, with its proactive and collaborative approach, facilitates the approval path. These differences lead to a vicious cycle in which strict regulations limit consumer exposure to APs and make their adoption difficult. Therefore, there is a need to develop harmonized international standards to facilitate market access and consumer education. Finally, effective marketing plays a key role in overcoming cultural resistance. Strategies such as avoiding identity labels, emphasizing the source of protein, highlighting health benefits, and using pleasant language in advertising can increase consumer acceptance. Focusing on personal desires rather than moral obligations will smooth the path to APs' success.

Keywords: Alternative proteins, food neophobia, unconventional food.

Gluten-Free Diet: Updated Insights on Celiac Disease, Non-Celiac Gluten Sensitivity, and Irritable Bowel Syndrome

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ABSTRACT

This review aims to synthesize and critically analyze recent evidence on the benefits, safety considerations, and limitations of the gluten-free diet (GFD) in the management of celiac disease (CD), non-celiac gluten sensitivity (NCGS), and irritable bowel syndrome (IBS). A comprehensive literature search was conducted through PubMed and related databases to identify clinical trials, systematic reviews, and meta-analyses published between 2000 and 2024. Eligible studies were evaluated with respect to GFD adherence, gluten exposure thresholds, and potential nutritional and psychosocial implications in individuals with CD, NCGS, or IBS. Strict lifelong adherence to a gluten-free diet remains the cornerstone of CD management. Current evidence indicates that maintaining gluten intake below 10 mg per day is generally safe, whereas consumption above 20-50 mg/day may induce intestinal injury, and exposure around 200 mg/day can result in pronounced mucosal damage and symptomatic relapse. NCGS is characterized by gluten-related intestinal and extraintestinal manifestations in the absence of celiac-specific serological or histological markers. Among IBS patients, a combined GFD and low-FODMAP approach has been associated with significant reductions in abdominal pain, bloating, and anxiety, while microbiome-based personalized dietary interventions have demonstrated improved microbial diversity. Conversely, unnecessary adoption of GFD may lead to excessive dietary restriction, nutrient deficiencies, increased financial burden, and psychosocial distress. Additionally, elevated intake of FODMAP- or nickel-rich foods during GFD may exacerbate IBS-like symptoms. Although GFD remains an indispensable therapeutic intervention for celiac disease, its use in NCGS and IBS should be personalized and closely monitored by healthcare professionals. Inappropriate dietary restriction without medical indication may compromise nutritional adequacy and overall quality of life. Therefore, GFD should be implemented only when clinically justified and under the supervision of gastroenterologists and registered dietitians.

Keywords: Gluten-free diet, FODMAP, microbiome.

Recent Findings on the Metabolic, Physiological, and Clinical Effects of the Ketogenic Diet

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ABSTRACT

The ketogenic diet is a nutritional approach that severely restricts carbohydrate intake and derives the majority of energy from fats, thereby inducing a metabolic state known as ketosis. This review aims to evaluate the metabolic foundations, physiological effects, role in weight management, and current clinical findings of the ketogenic diet based on recent literature. Systematic reviews, randomized controlled trials, and clinical studies published between 2020 and 2024 were examined. The ketogenic diet induces physiological ketosis by reducing daily carbohydrate intake below 50 g, leading serum ketone concentrations to exceed 0.5 mM. This metabolic adaptation significantly enhances fat oxidation (~1.5 g/min) and contributes to meaningful weight loss through reductions in body fat mass. However, transient decreases in endurance performance have been observed during the short-term adaptation phase. When combined with SGLT-2 inhibitors, the diet has been reported to improve glycemic control and insulin sensitivity, although it may increase the risk of euglycemic ketoacidosis and bone mineral density loss. In studies involving septic patients, the ketogenic diet was shown to safely achieve ketosis, reduce insulin requirements, and improve metabolic stability; however, no significant difference was observed in survival rates. Long-term adherence, particularly among children and individuals with high levels of physical activity, has been associated with adverse effects on bone health. The ketogenic diet is a nutritional strategy that enhances metabolic flexibility by shifting energy metabolism from glucose toward fatty acid oxidation, supports weight loss, and may provide metabolic advantages in certain clinical conditions. Nevertheless, potential drawbacks such as transient performance reduction, adverse skeletal effects, and interactions with specific pharmacological treatments should be considered. Current evidence suggests that the ketogenic diet should be implemented under professional supervision, with an individualized approach that balances potential benefits and risks.

Keywords: Ketogenic diet, ketosis, weight loss.

Bioactivity of Different Macroalgae Species from the Portuguese Coast

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ABSTRACT

Macroalgae are an important source of bioactive compounds. Their consumption is rising worldwide with aquaculture accompanying this trend. However, they present great interspecific variability that can deeply affect how each macroalgae benefits consumers health. In this work we analyzed the bioactivity (antioxidant capacity, total phenolic compounds (TPC), total flavonoid content (TFC), iron chelating capacity and copper chelating capacity) of eight macroalgae species found in the northern Portuguese coast. The analyzed species were the Chlorophyta *Ulva rigida*, the Ochrophyta *Laminaria ochroleuca*, *Sargassum muticum*, *Fucus vesiculosus*, *Fucus spiralis* and *Himanthalia elongate*, and the Rodophyta *Coralina officinalis* and *Gracillaria* sp. There was great interphyletic variability with Ochrophyta presenting higher antioxidant capacity, TPC and copper chelating capacity. Even so, Rodophyta presented greater iron chelating capacity and Chlorophyta presented higher levels of flavonoids. In terms of species, *L. ochroleuca* presented the highest antioxidant capacity, TPC and chelating capacity, and therefore this species presented the highest potential to benefit consumers. *Ulva rigida* and *Coralina officinalis* revealed the lowest bioactivity with the exception of TFC and iron chelating capacity, respectively. However, the high content of *Ulva rigida* in flavonoids, which have better bioavailability, suggests that Chlorophyta may also be an important source of antioxidants due to their different phenolic composition reenforcing that different macroalgae species may have different contributions to consumers health.

Keyword: Macroalgae, bioactivity, interspecific comparison, phenolic content.

Bio-Based Nanocomposite Packaging: A Sustainable Alternative to Conventional Plastics

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ABSTRACT

The increasing environmental burden associated with petroleum-based plastics has driven growing interest in developing sustainable alternatives for food packaging. Among emerging strategies, bio-based edible coatings reinforced with metal nanoparticles have gained attention for their potential to improve food quality, extend shelf life, and reduce ecological impact. This study highlights recent progress in the design and application of alginate-based nanocomposite coatings incorporating nanoparticles as multifunctional materials for food preservation. Alginate, a naturally derived polysaccharide, offers excellent film-forming ability and biocompatibility, yet its limited mechanical and barrier properties necessitate modification. The integration of green-synthesized nanoparticles has been shown to enhance antimicrobial and antioxidant performance, addressing key limitations of conventional biopolymer coatings. Recent studies report that AgNPs (Silver nanoparticles) synthesized using plant extracts can be uniformly distributed within alginate matrices, forming stable nanocomposites with improved physicochemical characteristics. Characterization techniques such as UV–Vis spectroscopy, FTIR analysis, and electron microscopy confirm the successful formation and stabilization of AgNPs within the polymer network. These coatings demonstrate strong inhibitory activity against a wide range of foodborne pathogens, including Gram-positive and Gram-negative bacteria as well as common spoilage fungi. Moreover, the addition of AgNPs improves oxidative stability and contributes to the maintenance of sensory qualities in perishable foods during storage. Collectively, existing research underscores the potential of alginate-nanoparticle nanocomposite coatings as an eco-friendly and effective alternative to conventional plastic packaging. Their combined antimicrobial, antioxidant, and biodegradable properties position them as promising candidates for next-generation food preservation technologies that align with sustainability goals.

Keywords: Sustainable packaging, alginate nanocomposites, silver nanoparticles, green synthesis, food preservation, antimicrobial coatings.

Dietary Habits and Health Status of Primary School Children (Grades 1-5) in Prizren

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ABSTRACT

This study analyzes the multi-dimensional impact of dietary habits on the physical health, cognitive development, and academic performance of primary school children (Grades 1-5, ages 6-11) in Prizren. A mixed-method approach utilized a structured questionnaire applied to a sample of N=100 students (Grades 3, 4, and 5) from a public school to assess dietary preferences and environmental influences. Results revealed a significant imbalance, with the total preference for low-nutrient, processed foods-including Fast Food/Sandwiches (30%), Chocolates/Sweets (20%), and Soft Drinks (10%)-reaching 60% of choices, sharply contrasting with a low 25% preference for Fruits/Vegetables. Furthermore, 10% of students regularly skipped breakfast, compromising morning concentration. The analysis identified the Family's role as having the strongest influence ("Very High") and Media/Advertising as "High" in shaping these habits. The study concludes that these unhealthy patterns pose a direct threat to long-term health and academic potential, necessitating urgent institutional reforms such as strictly prohibiting high-processed products in school canteens and implementing mandatory nutrition education for caregivers and educators.

Keywords: Child nutrition, primary school children, obesity, processed foods, cognitive development, school performance, family role, dietary habits.

Dietary Antioxidants and Longevity: The Impact of Nutrition on Oxidative Stress and Healthy Aging

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ABSTRACT

Nutrition plays a crucial role in regulating oxidative stress and shaping the biological processes of aging. The equilibrium between reactive oxygen species (ROS) generation and the body's antioxidant defense systems determines the extent of molecular damage and, in turn, affects lifespan. Antioxidants obtained through diet, including vitamins C and E, carotenoids, polyphenols, and selenium, counteract ROS and reinforce the body's intrinsic protective mechanisms. This review aims to outline recent findings on the contribution of antioxidant-rich dietary patterns to longevity and healthy aging. Population-based studies consistently show that individuals who follow diets high in fruits, vegetables, whole grains, and nuts, key features of Mediterranean and plant-based diets, exhibit lower oxidative stress and a reduced risk of chronic diseases. Such dietary habits provide an array of bioactive substances that enhance mitochondrial efficiency, suppress inflammatory pathways, and delay cellular aging. Experimental research using animal models indicates that moderate antioxidant intake may extend lifespan and promote better metabolic adaptation, while excessive supplementation could interfere with essential ROS-mediated signaling processes. Clinical and nutritional intervention studies further suggest that antioxidants are most effective when integrated within a diverse and balanced diet rather than taken as single supplements. The combined action of various nutrients and phytochemicals appears vital for maintaining redox equilibrium. Additionally, emerging data highlight the role of individual differences, such as genetic predisposition, gut microbiome diversity, and lifestyle, in determining the outcomes of antioxidant consumption. Overall, a naturally antioxidant-rich diet supports cellular integrity, mitigates oxidative stress, and contributes to healthier aging and longevity.

Keywords: Diet, antioxidants, oxidative stress, longevity, nutrition, aging.

A Novel Fluorescence Platform Using Aptamer-Modified β-Cyclodextrin MOFs for Sensitive Detection of Listeria monocytogenes in Tap Water and Red Meat

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ABSTRACT

This study investigated a rapid fluorescence-based sensor using a 5-FAM-labeled aptamer immobilized on β-cyclodextrin metal-organic frameworks (β-CD-MOFs) for the detection of *Listeria monocytogenes*. The aptamer fluoresces at 366 nm when bound to β-CD-MOFs, but dissociates and binds to *Listeria monocytogenes,* increasing fluorescence at excitation wavelengths of 448 nm and emission wavelengths of 546 nm. The sensor showed a wide detection range (4.6 to 4.6 × 10^9 CFU/mL) with a low detection limit of 3 CFU/mL.

Keywords: Aptasensor, *Listeria monocytogenes*, metal-organic frameworks, nanomaterials, pathogen detection, molecular recognition.

Eco-Innovative Approaches for Sustainable Food Safety: Green Nanotechnology in Action

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ABSTRACT

Amid rapid developments in all sectors, food safety occupies a significant portion of attention, with its connection to environmental sustainability being a contemporary challenge. The current study focused on gathering evidence related to one innovative alternative: the use of nanotechnology. It is characterized by its ease of use, its economics, and its high effectiveness in improving the biological properties of synthetic nanoparticles. Some of the most important NPs are gold (AuNP), silver (AgNP), zinc oxide (AuNP), and selenium (AuNP). The term "green synthesis" was coined to emphasize the critical need to reduce chemical dependence and transition to biological synthesis, which utilizes sustainable sources like plants and microorganisms as natural reducing and coating agents, thereby improving food safety and quality. Studies have proven that the process of biosynthesis not only reduces reliance on chemical manufacturing but also increases the biological activity of the synthetic particles. The most significant enhanced properties of the synthesized green nanoparticles are antimicrobial and antioxidant. Furthermore, these particles enhance food preservation while adhering to the concepts of green chemistry and the circular bioeconomy. These properties enable their use in food matrices and edible coating systems, assessing their ability to reduce spoilage and pathogen contamination. Our research focuses on integrating sustainable nanomaterials into food systems to promote safer, more sustainable, and environmentally responsible food production.

Keywords: Nanotechnology, green synthesis, food safety, environmental sustainability.

Study of the Antimicrobial and Antioxidant Efficacies of Bee Products in Food and Medical Industry

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ABSTRACT

Much attention has been paid to bee products, such as honey, propolis, royal jelly and beeswax, which contain biologically active substances; they provide a natural and powerful alternative as the food preservative and medicine. The purpose of this review is to present an overview of the antimicrobial and antioxidant activity of these products, the mechanism, and their food and medical applications. A literature review will be performed to identify the studies on the bioactive compounds in bee products and their antimicrobial and antioxidant activity as well as their use in food preservation and medicine. PubMed and Scopus databases were searched to identify the relevant articles. Bee products have phenols, flavonoids, enzymes, and organic acids that interfere with microbial cell membranes preventing bacteria, fungi, and some viruses. The excellent antimicrobial effects of propolis and royal jelly can be attributed to a high level of phenolics. They have antioxidant effects that suppress free radicals, oxidative stress, DNA damage, and inflammation and may prevent the onset of chronic diseases, such as heart disease or cancer. Bee products also serve as a natural alternative food preservative that ensures the food product has a longer shelf life in the food industry and replaces synthetic food preservatives. Its uses include bioactive packaging, nanoencapsulation of antioxidants and edible films. Not just wound dressing, skin creams, pharmaceutical preparation or promising in complementary therapies, they are also found. Nevertheless, it continues to be hindered by obstacles, such as the lack of standardised compositions and other clinical studies to address any possible side effects. In summary, bee products are a sustainable alternative to fight microbial resistance and improve the quality of food because they are antimicrobial and antioxidant. There is enormous potential in their selective use in food preservation as well as in medicine, and standardization and safety studies are required. Results indicate that bee products have some solutions to the problems of global health and food safety as a green (environmentally friendly), health-promoting alternative.

Keywords: Bee products, antimicrobial properties, antioxidant, food industry, medicine.

Creation of Smart Systems, Based on Artificial Intelligence, to Detect Quality and Authenticity in Bee Products

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ABSTRACT

Honey is an economically and therapeutically valuable product, which is predisposed to adulteration, but traditional quality evaluation methods are expensive, laborious, and use complex lab machinery. This research is intended to create an AI-driven smart system that will quickly, precisely, and non-destructively identify the authenticity and quality of honey. A sample of 200 honey samples in different regions in Iran (containing 150 samples of real and 50 samples of adulterated (with high fructose corn syrup, sugar syrup, or manipulations of production processes as adulterants)) was examined by FTIR infrared spectroscopy, Raman spectroscopy, microscopic images, and physicochemical parameters. Data were analyzed by Convolutional Neural Networks (CNN), Support Vector Machines (SVM), Random Forest (RF) and a ResNet-50 deep learning framework. To allow quick quality evaluation a mobile application utilizing smartphone functions to analyze colors and transparency was created. The ResNet-50 architecture reported 97.8 percent accuracy in authentic versus adulterated honey. Accuracy of 99.2 was achieved when spectroscopy data were combined with microscopic images in a hybrid model. The system also recognized the botanical origin of honey with 94.5 percent precision and geographical origin of honey with 89.7 percent precision. The predictive correlation (R2 > 0.91) was made on quality parameters (moisture content, acidity, enzyme activity, and hydroxymethylfurfural levels). The mobile app was 85 percent accurate in recognizing bad samples. Difficulties with natural honey variants and changing adulteration methods were overcome with the help of data augmentation and transfer learning. This AI-based solution can provide a strong way to control the quality of honey and help the company identify adulterants fast, screen imported goods, and protect the consumer rights. It promotes standardization of supply chains and enhances confidence in the market. It may also be used in other bee products such as royal jelly, propolis and pollen in the future.

Keywords: Deep learning, machine learning, artificial intelligence, bee products, adulterated product detection, quality control, image processing, spectroscopy.

Design and Development of Smart Wound Dressings on the Basis of Honey and Propolis Veterans

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ABSTRACT

Antimicrobial resistance contributes to making chronic and infected wounds a serious medical and economic burden. This study aims to develop an antibacterial, antioxidative, and anti-inflammatory honey and propolis-incorporated smart wound dressing that can be applied in the wound healing process. The antimicrobial activity and physicochemical characteristics of clove, thyme and citrus honey of the Abedini apiary were tested. High-Performance Liquid Chromatography (HPLC) was used to determine both phenolic and flavonoid content in propolis ethanol extracts of Baruq, Iran. It consisted of a biodegradable nano-fibrous scaffold of polycaprolactone (PCL)/gelatin produced by electrospinning, with the addition of 5, 10, and 20% of honey and 1, 3, and 5% of propolis extract, separately and in combination. The morphology, mechanical properties and biocompatibility of the scaffolds were characterized by Scanning Electron Microscopy (SEM), tensile testing and human dermal fibroblast (HDF) cell culture. To enhance antimicrobial functionality and to detect an infection by offering a color change (blue to red), pH nanosensors were loaded with silver nanoparticles (0.5%). The scaffold containing 10% clover honey and 3% propolis extract showed the best mechanical strength, 85% porosity, high biocompatibility. It was shown to be very active in antimicrobial effects against *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Candida albicans*. *In vitro* tests showed that fibroblast migration could be increased twofold, and it was also possible to preserve wound moistness. *In vivo* experiments using diabetic rats showed that the healing process is accelerated 35-fold compared to the control group, inflagmatory state is decreased, angiogenesis is increased, and the number of collagen under the microscope increases. Senging Bee products, a biomedical engineering approach produces an intelligent wound dressing delivering effective signals of infection, antimicrobial impact, and tissue repair. It already holds enormous potential in diabetic wound care, pressure ulcer control, and chronic infections and opens the way to additional wound care innovation.

Keywords: Smart wound dressing, chronic wound, honey, propolis, nanofibrous scaffold, nanosensor, antimicrobial, tissue regeneration, biomedical engineering.

Valorization of Pumpkin (*Cucurbita maxima*) in Traditional Food Systems: A Case of Enhanced Pumpkin-Based Porridge (nhopi) Formulation

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ABSTRACT

Pumpkins are an important component of Zimbabwean traditional dishes such as *nhopi*, a pumpkin‑based porridge valued for its high carotenoid content. However, their seasonal availability limits year‑round utilization, particularly in resource‑limited rural areas. This study aimed to develop preservation methods to extend pumpkin availability and to optimize *nhopi* formulation using pumpkin and bambara groundnut (*Vigna subterranea* (L.) Verdc.) flours with enhanced nutritional, functional and sensorial attributes. Pumpkin samples were pretreated prior to drying (oven at 60 °C or under sunlight) and subsequent milling into flour. The pretreatments included soaking for 10 min in either 5% or 10% salt solutions, blanching at 70 °C for 5 min, and a control without treatment. Bambara groundnut flour was produced by soaking the black-eyed seeds for 24 h, drying at 50 °C for 48 hours, and milling. Pumpkin-based porridges were then formulated using 20–25% pumpkin flour and 40–45% bambara groundnut flour. The nutritional composition, functional properties, and sensory characteristics of the individual flours and their blends were investigated. Pretreatments and drying methods significantly affected the nutritional composition and color of pumpkin flour ($p<0.05$). The 10% salt treatment yielded the highest nutrient retention in pumpkin flour. Salt-treated samples exhibited reduced sensory acceptability. Blends with blanched pumpkin flour achieved the highest preference scores due to appealing flavor and visual quality. Optimized combinations of pumpkin and bambara groundnut flours can improve the nutritional, sensory, and functional qualities of pumpkin porridge, supporting value addition and extending the use of pumpkin products beyond their seasonal availability.

Keywords: Pumpkin flour, pre-treatment, pumpkin porridge, traditional foods, nutrient retention, sensory evaluation.

Essential Oils from *Cupressus sempervirens* L., *Pimpinella anisum* L., and *Rosmarinus officinalis* L.: Physicochemical Characteristics, Antioxidant, and Antimicrobial Activities

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ABSTRACT

Essential oils derived from aromatic and medicinal plants are increasingly recognized for their diverse biological activities, including their potential applications in health, food preservation and cosmetic formulations. In this context, the present study aimed to characterize and compare essential oils obtained from *Cupressus sempervirens* L.**,** *Pimpinella anisum* L., and *Rosmarinus officinalis* L., by examining their quality, antioxidant capacity and antimicrobial efficacy. Physicochemical parameters such as density, refractive index and acid value were measured, and results demonstrated full compliance with established ISO standards, confirming the high purity and stability of the oils. The antioxidant potential was evaluated via the DPPH radical scavenging assay, revealing a strong positive correlation between the scavenging activity and the total polyphenol as well as flavonoid contents of the oils. Antimicrobial activity was assessed against a broad panel of microbial strains: bacterial species including *Escherichia coli, Staphylococcus aureus, Streptococcus* sp., *Bacillus* sp., *Pseudomonas aeruginosa* and fungal species such as *Candida albicans, Alternaria* sp., *Ascochyta* sp., *Aspergillus niger, and Fusarium* sp., using both aromatogram and well diffusion methods. The tested essential oils exhibited significant antibacterial and antifungal effects, with variations in inhibition zone sizes depending on the plant species and the assay method. These findings highlight the considerable potential of these essential oils as natural antioxidant and antimicrobial agents, which could be effectively integrated into pharmaceutical, food preservation and cosmetic systems. Looking forward, further studies should focus on *in vivo* validation, detailed safety profiling, and rigorous formulation standardization to facilitate their practical application as safe and effective bioactive ingredients.

Keywords: Aromatic plants, polyphenol content, DPPH assay, antimicrobial efficacy, essential oil quality.

FULL TEXTS

Green Synthesis of Nanomaterials via Microorganisms: Antimicrobial and Antioxidant Applications in Food Science

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ABSTRACT

The conventional synthesis of nanomaterials (NMs) faces significant economic and environmental challenges due to its reliance on hazardous chemicals and high energy consumption. Green synthesis has emerged as a sustainable alternative, leveraging the biochemical capabilities of biological systems. This article reviews the microbial-assisted green synthesis of NMs using bacteria, fungi, algae, and viruses, highlighting the mechanisms of intracellular and extracellular reduction and stabilization. This approach operates under mild conditions, utilizes non-toxic reagents, and produces biocompatible nanoparticles with inherent biofunctionality. A critical focus is placed on the potent antimicrobial and antioxidant properties of these biogenic NMs, which are highly valuable for food science applications and enhancing food safety, shelf-life, and functionality. Despite challenges in scalability and uniformity, green-synthesized NMs represent a good potentional for application in food science.

Keywords: Green synthesis, nanoparticles, microorganisms, antimicrobial activity, antioxidant activity.

INTRODUCTION

Conventional methods for synthesizing nanomaterials (NMs) categorized as top-down (e.g., mechanical milling) or bottom-up (e.g., sol-gel processes) are economically and environmentally unsustainable (Chakraborty *et al*., 2022; Kuppusamy *et al*., 2016). Despite offering control and productivity, these methods are energy-intensive, employ hazardous chemicals, and generate toxic waste, posing significant risks to ecosystems and human health (Kavitha *et al*., 2022; Kumari *et al*., 2023; Mughal *et al*., 2021).

This is a major concern because integrating nanotechnology into food science offers transformative potential by leveraging the unique properties of NMs to enhance food quality and functionality (Jafarzadeh *et al*., 2024; Joudeh & Linke, 2022). The significant drawbacks of conventional synthesis thus necessitate an urgent shift towards sustainable production paradigms.

The critical solution to these challenges lies in green synthesis, an innovative branch of green nanotechnology that synergizes green chemistry and engineering principles (Noah & Ndangili, 2022). The utilization of microorganisms including bacteria, fungi, algae, and viruses for the green synthesis of nanomaterials (NMs) represents a paradigm shift towards sustainable nanotechnology. This approach capitalizes on the innate biochemical capabilities of these biological entities to reduce metal ions into zero-valent nanoparticles and stabilize them using self-produced biomolecules like enzymes, proteins, and metabolites (Koul *et al*., 2021; Mughal *et al.*, 2021). The synthesis can proceed via intracellular mechanisms, where metal ions are transported into the cell for enzymatic reduction, or extracellular mechanisms, where microbial exudates reduce and cap ions in the surrounding medium, with the latter being more favorable for easy extraction and scalability (Huq *et al.*, 2023; Saravanan *et al.*, 2018) (Figure 1).

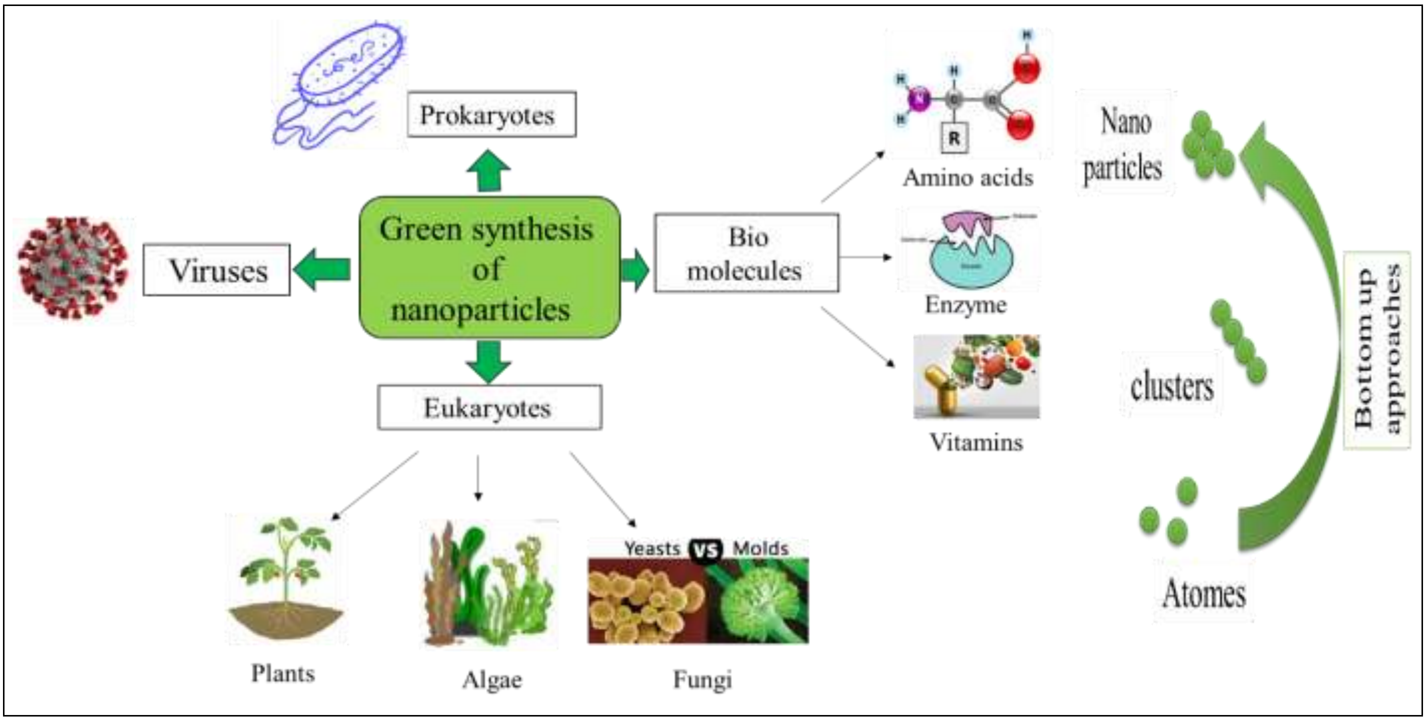

Figure 1. Green synthesis of NMs by different biological systems.

The advantages of this microbial route are profound. It is an environmentally benign, cost-effective, and efficient process that operates under mild conditions (room temperature, neutral pH) without requiring toxic reagents or excessive energy input, significantly reducing the environmental footprint compared to conventional synthesis (Mathur *et al.*, 2018; Saha & Kim, 2022). A key benefit is the inherent biofunctionality imparted to the NMs by the capping biomolecules, which often confer enhanced antimicrobial, antioxidant, and catalytic properties, making them highly suitable for sensitive applications like food technology (Nasrollahzadeh *et al.*, 2019; Osman *et al.*, 2024). Furthermore, the process is highly tunable; critical parameters such as microbial strain, pH, temperature, and incubation time can be strategically manipulated to exert precise control over the size, shape (e.g., spheres, rods, nanoflowers), and monodispersity of the resulting NMs (Mohamed *et al.*, 2019; Rajput *et al.*, 2016).

However, the method is not without its disadvantages and challenges. Intracellular synthesis necessitates additional downstream processing steps for cell lysis and NM purification, which can complicate the process and increase costs (Bharose *et al.*, 2024). Achieving uniform monodispersity on a large scale can be challenging due to the complex and variable nature of biological systems (Iravani *et al.*, 2014). Scaling up microbial cultivation and synthesis from laboratory to industrial levels requires meticulous optimization of bioreactor conditions and processes (Koul *et al.*, 2021). Therefore, the use of certain pathogenic strains requires stringent safety protocols, though this is mitigated by selecting generally recognized as safe (GRAS) organisms.

Bacteria are highly efficient biological factories for NM synthesis, utilizing both intracellular and extracellular mechanisms. Extracellular synthesis, facilitated by secreted reductase enzymes and metabolites, is particularly advantageous for large-scale production and easy extraction. For example, *Paenibacillus* sp. and synergistic cultures of *Lactobacillus* and *Bacillus* species produce spherical silver nanoparticles (AgNPs) with potent antimicrobial activity against pathogens like *Salmonella enteritidis* and *Staphylococcus aureus* (Al-Asbahi *et al*., 2024; Huq *et al*., 2023). Intracellular synthesis, involving enzyme-mediated reduction within the cell, can yield complex structures such as zinc oxide nanoflowers with exceptional photocatalytic properties (Raliya & Tarafdar, 2013). The choice of bacterial species (Gram-positive or Gram-negative) is strategic, dictated by desired nanoparticle characteristics, synthesis route, and scalability requirements (Saravanan *et al*., 2018).

Fungi are valued for their rich reservoir of bioactive compounds, including enzymes, polyphenols, and organic acids, which act as reducing and stabilizing agents. Their superior metal-binding capacity, due to cell wall composition, allows them to process high metal ion concentrations efficiently (Adebayo *et al*., 2021). Synthesis parameters such as pH, temperature, and fungal strain critically influence the morphology and properties of the NMs. The strain-specific nature of synthesis is another critical factor, as evidenced by the production of hexagonal zinc oxide nanoparticles by *Fusarium keratoplasticum* A1-3, while *Aspergillus niger* G3-1 under similar conditions produced nanorods (Mohamed *et al*., 2019).

Algae, including macroalgae and microalgae, utilize bioactive metabolites from processes like photosynthesis to reduce metal ions rapidly, often at room temperature. This method is facile, cost-effective, and highly productive, with parameters like extract concentration, pH, and reaction time allowing precise control over NM properties (Fawcett *et al*., 2017). Species such as *Arthrospira platensis* and *Chlorella vulgaris* produce AgNPs and ZnONPs with significant antimicrobial activity and stability (Obaid *et al*., 2024; Taghizadeh *et al*., 2020). Diatoms and cyanobacteria also contribute to the synthesis of polydisperse AgNPs with broad inhibitory effects against pathogens *pneumoniae* (Mishra *et al*., 2020).

Viruses offer exceptional control over NM morphology and composition through surface proteins (capsids), which facilitate metal ion reduction and nucleation. Genetic engineering can enhance their reducing and structure-directing abilities (Gahlawat & Choudhury, 2019). Plant viruses, non-pathogenic to humans, are stable and easily cultivated, making them attractive templates. For example, cowpea chlorotic mottle virus uses tyrosine residues for AuNP synthesis (Slocik *et al*., 2005), while squash leaf curl China virus enables rapid sunlight-driven biogenesis of metallic NMs for biomedical applications (Thangavelu *et al*., 2020). However, viral synthesis faces challenges in broad applicability and industrial compatibility (Noah & Ndangili, 2022).

Overall, microbial synthesis of NMs is a promising green technology that combines environmental compatibility with high efficiency, producing biocompatible nanoparticles for diverse applications in food science, medicine, and environmental remediation. These nanomaterials that producing by biological approaches also have functional properties such as antimicrobial and antioxidant activities, while minimizing toxic by-products and energy consumption. In this article using of this nanoparticle for encapsulation and naoemusions will be disscoused. Furthermore, they serve as effective nanoencapsulation vehicles for protected and targeted delivery of nutrients, antioxidants, and flavors, enhancing the functionality of food products (Jafarzadeh *et al*., 2024).

Application of Green-Synthesized NMs in Food Industry for Their Antimicrobial and Antioxidant Activity

Antimicrobial activity

The escalating global challenge of antimicrobial resistance (AMR), driven by the widespread use of antibiotics, necessitates the urgent development of innovative and efficient antimicrobial strategies to control pathogenic infections, which is considered a significant threat to humanity.

Therefore, to address these dual challenges, green nanotechnology has emerged as a pivotal field, focusing on the biogenic synthesis and nanoencapsulation of metallic nanoparticles (NPs) as a safe, efficient, and environmentally sustainable alternative to conventional antimicrobial drugs and purification agents (Osman *et al*., 2024) (Table 1). The fundamental antibacterial mechanism of these nanomaterials is multifaceted, encompassing four primary aspects: the delivery of bactericidal substances such as antibiotics, targeting bacterial poisonous substances like toxins, damaging bacterial cell walls and membranes, and destroying bacterial DNA, proteins, and enzymes (Huang *et al*., 2024).

Aqueous extract of the root of *Saussurea costus* serves as a safe and environmentally friendly method for AgNPs biosynthesis, producing nanoparticles with significant potential for organic dye degradation and robust bacterial inhibition activity against *Klebsiella pneumoniae*, *S. aureus*, *S. haemolyticus*, and *Enterococcus faecalis*, as determined by zones of growth inhibition, MIC, and MBC values (Hijazi *et al*., 2024). Similarly, a solution extract of bark from *Solanum tuberosum* (ST) facilitated the biogenesis of spherical silver nanoparticles (size range 3.91-27.07 nm) without involving any toxic bioreducing materials. These NPs, which were crystalline and exhibited good stability (zeta potential: -31.3 mV), demonstrated inhibitory potential against *Escherichia coli*, *Pseudomonas aeruginosa*, *S. aureus*, *Bacillus subtilis*, and the yeast *Candida albicans* (Xu *et al*., 2023). The *Aloe florentinorum* plant extract, containing natural reducing agents, was used to biosynthesize silver nanoparticles (~26.7 nm) that showed antibacterial activity against both Gram-positive (*S. aureus*, *B. subtilis*) and Gram-negative (*E. coli*, *Salmonella typhi*) bacteria (Jamil *et al*., 2024). Beyond plants, intracellular components of the medicinal fungus *Ganoderma sessile* act as ‘bio-factories’ for the biogenesis of metallic NPs. Quasi-spherical copper oxide NPs (2.9 ± 0.9 nm) and silver NPs (14.7 ± 0.6 nm) were highly effective against *Campylobacter jejuni*, with MICs of 10 μg/mL and 6 μg/mL, respectively. Their mode of action involved attachment to the outer cell membrane and subsequent intracellular internalization. The faster inhibitory action of silver NPs is a result of their direct interaction with the bacterial membrane, leading to rapid disruption and cell death, while copper oxide NPs exhibited a slower inhibitory effect, presumably due to the incorporation of copper into bacterial metabolic pathways (Rivera-Mendoza *et al*., 2024).

A key advancement in green nanotechnology is the encapsulation of these biogenic NPs with natural polymers to further enhance their stability and efficacy. A prominent example is the use of fungal chitosan (FCS) from *Cunninghamella elegans* encapsulated with green silver nanoparticles from *Gynura procumbens* (GP-AgNPs), a formulation developed to improve antibacterial activity against *Bacillus cereus*, *S. aureus*, *Listeria monocytogenes*, *E. coli*, and *Salmonella enterica* (Sathiyaseelan *et al*., 2020). Similarly, green AgNPs from *Prosopis juliflora* (PJ) leaf extract encapsulated with chitosan showed a significant inhibition zone against *E. coli*, outperforming the standard antibiotic streptomycin (Malini *et al*., 2020). The synthesis pathway for these chitosan composites impacts their potency; CS-AgNPs synthesized using glucose (G-AgNPs-CS) completely inhibited *E. coli* growth at 100 μg/ml, while a much higher amount (200 μg/ml) of chitosan C-AgNPs-CS and ethylene glycol E-AgNPs-CS were required for the same effect, and *S. aureus* was inactivated by 300 μg/ml of all nanocomposites, with the inhibition induced by an increase in AgNPs concentration (Chen *et al*., 2020).

The application of green nanotechnology extends beyond silver to other metals like zinc. Kombucha extract was used to biosynthesize zinc oxide nanoparticles under optimum conditions (30 °C, pH 9, 25 mM of $Zn(NO_3)_2 \cdot 6H_2O$), resulting in spherical, crystalline ZnO NPs (23 ± 1.5 nm) with a positive zeta potential (19 ± 3 mV). These NPs exhibited potent MIC values against a range of pathogens: 25 μg/ml against *E. coli* ATCC25922, 30 μg/ml against *S. aureus* ATCC25923 and *P. aeruginosa* ATCC27853, 35 μg/ml against *Serratia liquefaciens* and *S. saprophyticus*, and 40 μg/ml against *Lysinibacillus fusiformis* and *K.*

pneumoniae ATCC33495. TEM analysis confirmed their efficient toxic action on the bacterial cell wall, leading to its rupture (El-Fallal *et al*., 2023).

Antioxidants activity

Nanoparticles (NPs) synthesized via eco-friendly, phytogenic methods exhibit potent antioxidant and free radical scavenging activities, crucial for mitigating oxidative degradation in food matrices and enhancing nutritional quality (Table 2). This efficacy is attributed to their unique physicochemical properties, including a high surface-area-to-volume ratio, quantum confinement effects, and the presence of bioactive phytochemicals derived from plant extracts that cap their surfaces, contributing hydrogen atoms or chelating pro-oxidant metals in a natural and non-toxic manner. The single-step, efficient, and environmentally safe phytosynthesis of NPs, such as violet-colored, spherical gold nanoparticles (AuNPs) using halophytic species like *Atriplex halimus* (producing NPs sized 2–10 nm) and *Chenopodium amaranticolor* (producing NPs up to 40 nm), demonstrates this green principle, with the antioxidant and catalytic degradation efficiencies of *A. halimus*-AuNPs being one-fold higher due to the superior efficacy of its stem aqueous extract (Hosny *et al*., 2021).

The antioxidant mechanisms of green-synthesized NPs primarily operate through two pathways: hydrogen atom transfer (HAT) and single electron transfer (SET). In HAT, NPs capped with polyphenols, flavonoids, or terpenoids from plant extracts donate hydrogen atoms to free radicals, neutralizing them into stable species, a process enhanced by electron-donating functional groups (-OH, -COOH) on the NP surface. In SET, the metallic core facilitates electron transfer, reducing their oxidative potential. This is exemplified by platinum nanoparticles (PtNPs) biosynthesized using *A. halimus*, which were characterized as black-colored, spherical particles with an extremely small size of 1-3 nm, a plasmon peak at 295 nm, and a high surface charge of -25.4 mV. Their inhibitory potential against the 1,1-diphenyl-2-picrylhydrazyl radical (DPPH) improved with increasing concentration and surpassed that of both the *A. halimus* extract itself and a standard ascorbic acid control, demonstrating a direct correlation between NP concentration and radical scavenging percentage (Eltaweil *et al*., 2022).

Beyond metallic NPs, biopolymeric systems crosslinked with antioxidant compounds also showcase this principle. For instance, Ahmed *et al.* (2023) utilized the Maillard reaction at high temperatures (120–140 °C) as a crosslinking method between gelatin and fructose to form nanofibers, achieving an antioxidant structure with a high radical scavenging activity of 60% in the DPPH assay (Ahmed *et al*., 2024). Similarly, Karagozlu *et al*. (2021) synthesized gelatin-gum Arabic microparticles crosslinked with the anionic polyphenol tannic acid to enhance the antioxidant activity of the formed system (Karagozlu *et al*., 2021).

The broad applicability of plant extracts for biofabrication is further illustrated by the work of Flieger *et al*. (2021), who used methanol extracts from ten natural products including herbs (*Salvia officinalis, Tilia cordata*), vegetables (*Capsicum baccatum*), marine algae (*Porphyra yezoensis*), and teas (*Camellia sinensis* and *Ilex paraguariensis*) to synthesize AgNPs. Their free radical scavenging activity and reducing power were confirmed via DPPH, CUPRAC (Cupric Ion Reducing Antioxidant Capacity), and SNPAC (Silver Nanoparticle Antioxidant Capacity) assays. Dynamic Light Scattering (DLS) measurements showed hydrodynamic diameters between 99.56 and 119.68 nm and high zeta potentials ranging from -49.8 mV to -56.1 mV. This high negative surface charge, which can increase during storage due to further biomolecule adsorption, ensures colloidal stability and prevents aggregation, maintaining antioxidant efficacy. Among these, green tea extract synthesized the smallest NPs and showed the highest activity in all antioxidant tests, directly linking high phytochemical content to superior NP performance (Flieger *et al*., 2021).

CONCLUSION

The utilization of microorganisms for the green synthesis of nanomaterials represents a cornerstone in the advancement of sustainable nanotechnology for food science. This biological approach capitalizes on the innate metabolic processes of bacteria, fungi, and algae to produce nanoparticles under mild, eco-friendly conditions, effectively circumventing the economic and environmental drawbacks of conventional chemical synthesis.

A key advantage of this microbial route is the formation of nanoparticles capped with bioactive biomolecules, which directly confers enhanced functional properties. These biogenic nanoparticles exhibit potent and multifaceted antimicrobial mechanisms, including cell membrane disruption and enzyme inhibition, offering a powerful, natural solution to combat foodborne pathogens and the growing challenge of antimicrobial resistance. Concurrently, their significant antioxidant activity, through free radical scavenging and metal chelation, effectively mitigates oxidative spoilage in food products, preserving nutritional quality and extending shelf life.

While challenges in scaling up production and ensuring uniform monodispersity remain, the strategic selection of GRAS microorganisms and the optimization of synthesis parameters provide a clear path forward.

Table 1. Antimicrobial activity of biosynthesized NMs.

Green source	Nanoparticles	size (nm)	Morphology	Antimicrobial efficacy/ zones of inhibition (mm)	References
Bacillus vallismortis	Silver	44–70	Spherical	*Escherichia coli, Listeria monocytogenes, Staphylococcus aureus, Bacillus subtilis*	(Das *et al*., 2019)
Citrus sinensis	Zinc oxide	33.1 ± 11.7	Hexagonal	*E. coli, S. aureus, Botrytis cinereal*	(Gao *et al*., 2020)
Proteus vulgaris ATCC-29905	Iron oxide	19.23-30.51	Spherical	*Staphylococcus aureus* (MRSA)	(Majeed *et al*., 2021)
AgNPs	AgNPs	2-47	Spherical	*Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*	(Naaz *et al*., 2021)
Leaf powders of *Centella asiatica and Tridax*	*Lanthanum oxide*	20	Clusters	*Staphylococcus aureus, E. coli, A. fumigatus, Candida albicans*	(Rashmi *et al*., 2022)
Teucrium Parvifolium	Silver	14	Spherical	*Escherichia coli, Enterococcus faecalis*	(Soltani *et al*., 2024)
Penicillium citrinum IBCLP11	Silver	57.5 ± 4	Spherical	*Pseudomonas aeruginosa* IPT322, *Staphylococcus aureus* IPT246, *Klebsiella pneumoniae* IPT412, *Chlorella vulgaris*, *Palaemon pandaliformis*, *Danio rerio*.	(Aguiar *et al*., 2024)
Eclipta prostrata leaf	Zinc Oxide	-	Rod shaped	*Gram-positive bacteria,* gram-negative, *fungi*	(Gnanasekaran *et al*., 2024)

Table 2. Antioxidant activity of biosynthesized NMs.

Green source	Nanoparticles	Particle size (nm)	Morphology	References
Eucalyptus robusta	Zerovalent iron	8	Spherical	(Vitta *et al*., 2020)
Atriplex halimus	Platinum	1-3	Spherical	(Hosny *et al*., 2021)

Crotalaria pallida leaf extract	Zinc	45	Cuboidal	(Chandramouli & Ramasamy, 2024)
Extract of wild olive leaves	Zinc oxide	33	Hexagonal	(Ullah *et al.*, 2024)
Mangifera indica	Titanium dioxide	3-27	Spherical	(Archana Rana *et al.*, 2024)
Azadirachta indica		8-28		
Curcuma longa	Palladium	40-90	Spherical	(Sattar *et al.*, 2024)
Petai peel extract	Cobalt ferrite	36.67	Cubic	(Nadia *et al.*, 2024)
Colocasia esculenta plant	ZnO, (Cu), (Ce)	16-19	Spherical/ irregular shapes	(Verma *et al.*, 2024)
Murraya koenigii	Zinc oxide	7-14	Spherical	(Amisha Rana *et al.*, 2024)
	Yttrium doped ZO			
Euphorbia hitra leaf	Silver	139.5	Quasi-spherical	(Marukurti *et al.*, 2025)

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Biogenic Synthesis of Nanomaterials by Plant and Their Application in Food Packaging

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ABSTRACT

The integration of nanotechnology into food packaging offers transformative potential for enhancing food safety, quality, and shelf life. However, the conventional chemical and physical synthesis of nanomaterials (NMs) raises significant environmental, economic, and safety concerns due to the use of hazardous reagents and high energy consumption. This necessitates a paradigm shift towards sustainable production methods. Green nanotechnology, particularly biogenic synthesis using plant extracts, has emerged as a promising eco-friendly alternative. This approach utilizes phytochemicals as reducing and stabilizing agents to produce a variety of metallic and non-metallic NMs (e.g., Ag, ZnO, Au, Pt, SiO_2 , carbon dots), leveraging plants' abundance, cost-effectiveness, and non-toxicity. The application of these plant-synthesized NMs in food packaging is particularly significant. Their incorporation into biopolymer matrices drastically enhances the functional properties of packaging materials. This includes improved mechanical strength, enhanced thermal stability, and superior barrier properties against oxygen and water vapor. Most notably, they confer potent, broad-spectrum antimicrobial and antioxidant activities, actively protecting against foodborne pathogens and spoilage. Furthermore, their unique optical properties enable the development of intelligent packaging systems for real-time monitoring of food freshness. Despite the considerable advantages, limitations remain. The inherent variability in plant extracts can challenge the precise control over NM size, morphology, and batch-to-batch reproducibility, potentially hindering large-scale standardization. Furthermore, while deemed safer, the long-term human and environmental health impacts of these NMs require more comprehensive toxicological studies. The current lack of robust regulatory frameworks also presents a hurdle to widespread commercial adoption. Future perspectives must focus on standardizing synthesis protocols through rigorous phytochemical identification and process optimization. Interdisciplinary research is crucial to thoroughly elucidate the safety profile of biogenic NMs throughout their lifecycle. Finally, developing clear regulatory guidelines is essential to safely translate this promising technology from the laboratory to the market, enabling the next generation of high-performance, smart.

Keywords: Green synthesis, phytochemical of plants, nanomaterials, food packaging, antimicrobial.

INTRODUCTION

The integration of nanotechnology into food science offers transformative potential for enhancing food safety, quality, and functionality. This potential is unlocked by the unique physicochemical properties such as high surface area, enhanced catalytic activity, and superior mechanical, optical, and antimicrobial characteristics that materials exhibit at the nanoscale (Jafarzadeh *et al*., 2024). However, the conventional synthesis of these nanomaterials (NMs) presents significant economic, environmental, and safety challenges, necessitating a paradigm shift towards sustainable production methods.

Conventional nanomaterial synthesis is broadly categorized into physical (top-down) and chemical (bottom-up) approaches. Top-down methods, such as mechanical milling, laser ablation, electrospinning, and lithography, involve the physical breakdown of bulk materials into nano-sized particles (Pascariu *et al*., 2019). Conversely, bottom-up chemical approaches, including chemical vapor deposition, sol-gel processes, coprecipitation, and microemulsion techniques, construct NMs atom-by-atom through chemical reactions (Chakraborty *et al*., 2022). Despite high productivity and control, these conventional methods are fraught with drawbacks. They often require complex equipment, are energy-intensive, time-consuming, and employ hazardous chemicals that generate toxic by-products, posing substantial risks to ecosystems and human health (Kumari *et al*., 2023).

The critical solution to these challenges lies in green synthesis, an innovative branch of green nanotechnology that synergizes green chemistry and engineering principles (Noah & Ndangili, 2022). This approach utilizes biological systems including like plants their biomolecules (e.g., enzymes, phytochemical components) as sustainable factories for the bioreduction of metal ions into zero-valent NMs (Gupta *et al*., 2023; Osman *et al*., 2024). As a bottom-up process, green synthesis involves the biological nucleation of metal ions, followed by growth and stabilization achieved by bioactive compounds coating the nascent nuclei. This capping action is crucial as it prevents aggregation, ensures monodispersity, and maintains the stability of the resulting nanorods, nanotubes, or nanoparticles (Bhandari *et al*., 2023). The synthesis can occur via intracellular mechanisms, where ions diffuse into microbial cells for enzymatic reduction, or extracellular mechanisms, where plant extracts reduce ions in solution (Mughal *et al*., 2021).

The advantages of this biological route are profound. It is environmentally friendly, cost-effective, efficient, and boast a high metal absorption capacity without the need for toxic reagents or excessive energy input (Saha & Kim, 2022). Consequently, green-synthesized NMs are inherently more biocompatible and present a reduced environmental footprint, making them exceptionally suitable for sensitive applications and health, biological safety, and environmental sustainability (Osman *et al*., 2024), therefore, have a good potentional for using in food packaging.

For the food industry, the implication is significant. The incorporation of these biogenic NMs can enhance food packaging (improving mechanical and barrier properties) (Jafarzadeh *et al*., 2024). Furthermore, the responsible integration of nanotechnology into food science necessitates comprehensive studies on its impact on human health, alongside the establishment of robust regulatory standards and supervision for NM production and use (Osman *et al*., 2024).

Given that, biogenic NMs have emerged as novel, sustainable, economical, and eco-friendly technologies. This review focuses on the production NMs by plant and their implications in food packaging, while critically considering their advantages and potential limitations.

Green Synthesis by Plant

The biogenesis of nanomaterials (NMs) utilizing plant extracts has emerged as a premier green chemistry approach, capitalizing on plants as cost-effective, abundant, non-toxic, and readily available reservoirs of natural phytochemicals (Table 1) (Aslam *et al*., 2021). These phytochemical compounds, which include a diverse array of secondary metabolites generated for therapeutic purposes, function as dual-purpose bioreducing and biostabilizing agents, dictating both the formation and the ultimate morphological and compositional properties of the synthesized NMs (Jadoun *et al*., 2021). The process is governed by a well-defined three-stage mechanism: the initial activation phase involves the phytochemical-mediated reduction of metal ions from their monovalent or divalent oxidation states to a zero-valent nuclear state; during the growth stage, these adjacent nuclei coalesce through ostwald ripening or aggregation to form larger NMs with shapes including spherical, pentagonal, hexagonal, cubic, and triangular geometries, while phytochemicals simultaneously act as capping agents to prevent uncontrolled aggregation; finally, the termination stage sees the accumulation of NMs potentially leading to structures with irregular shapes as the system reaches stability (Sunny *et al*., 2022).

A critical consideration in this approach is the vast variety of active reducing and stabilizing components within a single plant extract can introduce limitations in achieving precise control over morphological properties and size uniformity of the resulting metal NMs (Iravani *et al*., 2014). Therefore, the most crucial step in standardizing this pathway is the rigorous identification and quantification of the phytochemical compounds (Zuhrotun *et al*., 2023).

Compared to microbiological biosynthesis methods, phytosynthesis offers significant advantages, including operational convenience, rapid reaction kinetics (often ranging from 2 to 30 minutes, as opposed to days for microbial systems), a nearly single-step process that obviates the need for complex cell culture maintenance, and superior scalability for industrial production (Saleh & Alwan, 2020). Furthermore, NMs produced using plant extracts exhibit enhanced long-term colloidal stability due to the effective involvement of natural capping agents, which sterically or electrostatically hinder aggregation during storage (Jayaprakash *et al*., 2017).

The efficacy and versatility of this green synthesis route are demonstrated by numerous studies. For instance, the synthesis of gold nanoparticles (AuNPs) from *Persicaria salicifolia* leaf extract is a rapid, one-step process yielding spherical, 5-23 nm particles with a characteristic surface plasmon resonance (SPR) peak at 535 nm and high antioxidant activity (Hosny & Fawzy, 2021). Similarly, extracts from antioxidant-rich sources like blackberry, blueberry, turmeric, and pomegranate have successfully biosynthesized gold and silver NPs; pomegranate extract, in particular, generated more uniform Au and Ag NPs, which were characterized by XRD as having cubic symmetry and sizes between 20-500 nm, indicating potential for anticancer therapies (Nadagouda *et al*., 2014). *Tribulus terrestris* extract, utilizing its oxygenated phytochemicals, produced uniform spherical AuNPs (10–15 nm) with demonstrated antioxidant, anti-leukemic, and anticancer properties (Zhao *et al*., 2021).

The synthesis of silver nanoparticles using *Ferula persica* extract (Fp-NPs) identified chlorogenic acid as a key reducing and stabilizing agent, resulting in uniform spherical particles (~15 nm) with significant antimicrobial efficacy against *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Acinetobacter baumannii* (MIC: 7.8 μg ml^{-1}), as well as anti-leishmanial activity (Hashemi *et al*., 2021). The biosynthesis using *Tibouchina spicata* leaf extract highlighted the influence of parameters like extract purity, metal salt concentration, and pH on NP properties. FTIR analysis confirmed the dual role of phytochemicals like quercetin and rutin in reduction and stabilization, leading to intense SPR bands and producing AgNPs with efficient, reusable catalytic activity (Veisi *et al*., 2018).

Beyond noble metals, this principle extends to other nanomaterials. Tea polyphenols (TPP) served as effective reducing agents for biogenic platinum nanoparticles (PtNPs); XRD confirmed a face-centered cubic crystalline structure, and TEM revealed stable, flower-shaped TPP@Pt particles (30-60 nm) with significant anticancer activity (Alshatwi *et al*., 2015). A green synthesis of nano-silica (SiO_2) NPs using *Rhus coriaria* L. extract and sodium metasilicate under reflux conditions yielded products with enhanced thermal stability and high surface area, attributed to the phytochemical capping (Rahimzadeh *et al*., 2022). Even waste resources like cow dung have been employed in a facile, green synthesis of ZnO NPs with hexagonal wurtzite crystallinity, demonstrating exceptional photocatalytic activity for dye remediation (99.9% removal of MB in 100 min) (Shubha *et al*., 2022). The biosynthesis of ZnO NPs using *Erythrina variegata* leaf extract produced highly crystalline nanoparticles (SPR at 389 nm) with sizes of 15–30 nm (HR-TEM) that exhibited antibacterial, antioxidant, anti-inflammatory, and antidiabetic properties (Velsankar *et al*., 2022). The use of protein biomolecules in Neem extract for PtNP biogenesis further underscores the role of bio-waste (Thirumurugan *et al*., 2016). This methodology is universally applicable, as evidenced by successful NM synthesis using extracts from *Nigella sativa* L. seeds (Aygun *et al*., 2020), saudi dates (Al-Radadi, 2019), coffea Arabica seeds (Bogireddy *et al.*, 2021), and *Xanthium strumarium* leaves (Kumar *et al*., 2019).

Application of Green-Synthesized NMs in the Food Industry

Food packaging

The imperative to maintain the freshness, quality, and nutritional value of food products throughout storage is a fundamental driver of innovation in food packaging science. This has led to extensive research focused on enhancing the performance and functionality of packaging materials to mitigate quality reduction and prevent waste across the entire supply chain, from production to consumption (Ali *et al*., 2022). Nanomaterials (NMs) are now widely exploited for roles as diverse as anticaking agents, nanoadditives, antimicrobial agents, and sensors capable of monitoring and recording product history (Biswas *et al*., 2022). A particularly promising approach is their integration into packaging materials to augment the technological properties of both synthetic and biobased polymers. It successfully merges the imperative for environmental sustainability with the urgent need for enhancing functionality, enabling the creation of next-generation active, intelligent, and high-performance packaging systems that significantly extend food shelf life and improve safety (Figure 1).

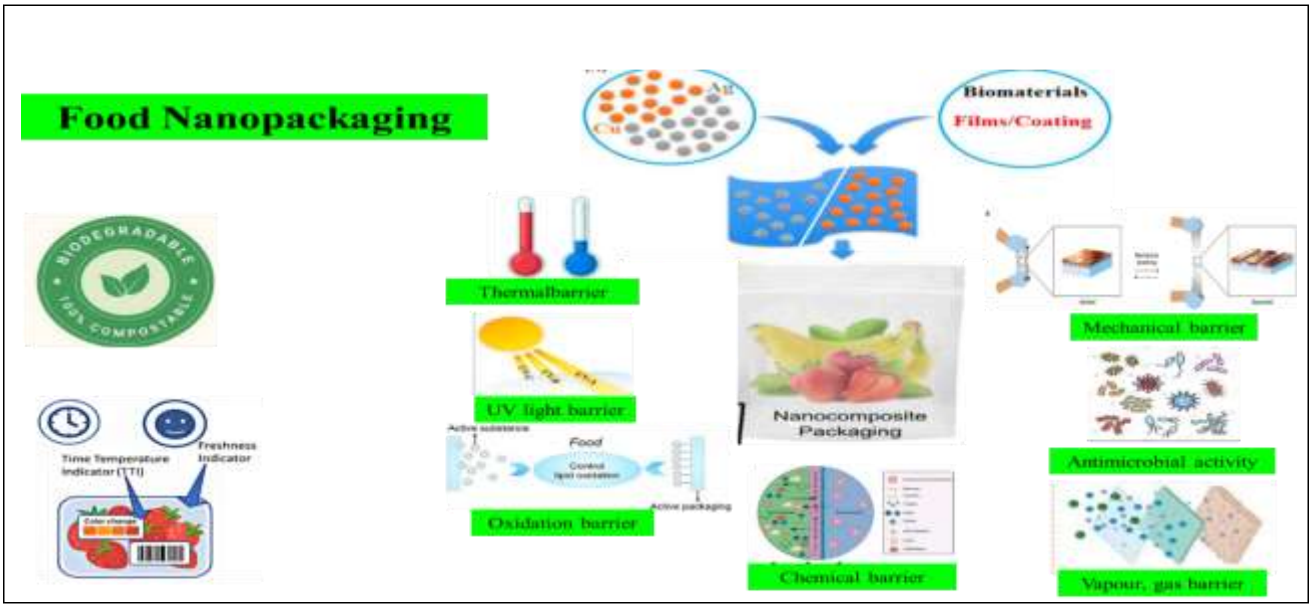

Figure 1. Functional Roles of Nano-Packaging: Active and Intelligent Systems: These composites provide enhanced barrier properties against gases (O_2 , CO_2) and moisture, and improved mechanical strength and thermal stability. Furthermore, nanotechnology enables active packaging, where nanomaterials act as antimicrobial or antioxidant agents to actively extend food shelf-life, and intelligent packaging, where nanosensors detect and signal microbial or biochemical changes in the food product, providing real-time quality and safety monitoring.

The environmental challenges associated with recycling synthetic plastics have intensified the search for sustainable alternatives, leading to a significant research focus on natural hydrocolloids like polysaccharides and proteins. However, the widespread application of these biopolymers is often constrained by their inherently weak functional characteristics, such as poor barrier and mechanical properties. To address these limitations, the incorporation of nanomaterials, especially those synthesized through green principles using biological extracts, has been investigated. This approach aims to improve the physicochemical, barrier, antimicrobial, thermal, and optical properties of packaging (Babaei *et al*., 2022).

The enhancement mechanism is rooted in the fundamental properties of nanomaterials. Their exceptionally high surface energy and surface area enable potent modification of surface interactions and facilitate nano-scale dispersion within biopolymer matrices. This dispersion profoundly alters the material's properties by creating a more tortuous path, which impedes the direct permeation of gas and vapor molecules through the polymer, thereby enhancing barrier properties (Gao *et al*., 2020). The addition of NM fillers can improve the inhibitory properties of homogeneous polymer films by modifying their permeability behavior, increasing mechanical strength and heat resistance, and creating active, intelligent functionalities. These include antimicrobial and antifungal activity, the capacity to sense and signal microbial or biochemical changes indicative of spoilage, and even the promotion of biodegradability (Rendón-Villalobos *et al*., 2017).

The efficacy of green-synthesized silver nanoparticles (AgNPs) is particularly well-documented (Table 2). For instance, AgNPs produced with Enoki mushroom extract (~10 nm) demonstrated strong antibacterial activity against foodborne pathogens like *Listeria monocytogenes* and *Escherichia coli*. When incorporated into starch/agar films, these AgNPs significantly enhanced the water vapor barrier and hydrophobicity, though they did not alter mechanical strength (Roy & Rhim, 2022). Similarly, AgNPs synthesized using propolis extract and microwave heating, then conjugated with *Aloe vera* gel, yielded coatings with high bactericidal and fungicidal activities. The physical properties of these films were highly dependent on plasticizer concentration, with a 2% v/v glycerol content proving optimal for achieving a clear, smooth morphology without defects (Jafari *et al*., 2021). The antimicrobial potency of biogenic AgNPs is a consistent finding, as further evidenced by nanoparticles synthesized from *Nymphaea odorata* extract, which showed excellent inhibitory activity against *S. aureus* and *E. coli* even at low concentrations, a property retained in the resulting sodium alginate films (Gudimalla *et al*., 2021). This application has application to food preservation, as demonstrated by a chitosan film incorporating AgNPs synthesized with *Poria cocos* polysaccharides (PCP-AgNPs), which significantly maintained the quality indices of strawberries during storage compared to control samples (Yang *et al*., 2024).

Beyond silver, other metallic nanoparticles offer versatile functionality. Zinc oxide nanoparticles (ZnONPs) biosynthesized using *Cassia fistula* fruit extract (20-40 nm) improved the thermal stability, elongation at break, and compressive properties of chitosan-gelatin nanocomposites, with a 2-4% loading yielding optimal smooth morphology and significant antimicrobial activity (Kumar *et al*., 2020). A comparative study between ZnONPs from citrus peel extract and commercial nanoparticles (CNP) revealed that both types effectively prevented weight loss and decay in strawberries, with CNP exhibiting slightly greater antifungal activity against *Botrytis cinerea* in some cases (Gao *et al*., 2020). The shelf-life extension capability of ZnONPs is underscored by research showing that agar films functionalized with ZnONPs from *Mimusops elengi* extract extended the freshness of green grapes to 21 days, completely inhibiting the mold growth observed in control samples (Kumar *et al*., 2019). Innovation also extends to bimetallic systems, such as Cu/Zn nanoparticles synthesized from *Hibiscus rosa sinensis* flower extract, which were incorporated into chitosan-pectin matrices to improve overall antimicrobial activity (Singh, 2022).

A frontier in green nanotechnology for packaging is the development of carbon quantum dots (CDs). These sub-10 nm nanomaterials possess a unique suite of advantages, including low cytotoxicity, excellent light stability, biocompatibility, ease of functionalization (Zhu *et al*., 2013), inherent antibacterial and antioxidant activities (Zhao *et al*., 2023), and water solubility. This makes them exceptionally efficient nanofillers for enhancing the physicochemical, thermal, mechanical, and barrier properties of packaging films (Zhao *et al*., 2023). Crucially, their optical properties pave the way for *smart* packaging applications, where they can function as sensors to detect food freshness, spoilage, and quality in real-time (Kilic *et al*., 2022).

Development of cellulose-based wrappers modified with AgNPs synthesized from pomegranate and citrus peels. These wrappers exhibited a remarkable decrease in oxygen permeability, water vapor permeability, and water absorption capacity compared to control wrappers, while also displaying strong antimicrobial activity. Most importantly, they successfully improved the shelf life of bread, demonstrating tangible potential as a substitute for polyethylene-based food packaging (Gopalakrishnan *et al*., 2023).

CONCLUSION

Plant-based synthesis of nanomaterials offers a sustainable and eco-friendly method for creating effective nanoparticles for food packaging. These nanomaterials enhance packaging by improving barrier properties, mechanical strength, and adding antimicrobial and antioxidant activities, which extend food shelf life and reduce effect of physicochemical methods for producing nanomaterials. A key advantage is the use of non-toxic, renewable plant resources. However, a major limitation is the difficulty in controlling the size and shape of the nanoparticles due to the complex nature of plant extracts, which hinders standardization and requires further research for widespread adoption.

Table 1. Biological synthesis of nanoparticles by microorganisms and plant.

Plant	*Stevia rebaudiana*	Leaf	NiO	Spherical	20–50	(Srihasam *et al*., 2020)
	Centaurea behen	Leaf	Au	Spherical	50	(Abdoli *et al*., 2021)
	Mentha longifolia	Leaf	Au	Oval	10.23 ±2	(Rauf *et al*., 2021)
			Ag		13.45 ± 2	
	Salvia hispanica L. (chia)	Seed	Nickel oxide	Spehrical	30	(Sabouri *et al*., 2021)
	Soursop (Annona muricata L.)	Leaf	ZnO	Quasi-spherical	37	(Selvanathan *et al*., 2022)
	Garcinia mangostana	Peel	ZnO	Spherical	25–70	(Cong *et al*., 2023)
	Nigella sativa L.	Seed	Ag	Spherical	30-60	(Ferdous *et al*., 2024)
	Allium cepa L.	waste peel	ZnO	hexagonal	57.38	(Islam *et al*., 2024)
	Chenopodium album	Leaf	ZnO	Wurtzite hexagonal	broad size distribution	(Samar *et al*., 2024)
	Catharanthus roseus	Bark	Ag	Spherical	1–26	(Samar *et al*., 2024)

Table 2. Application of green-synthesized NMs in the food packaging.

Nanoparticles	Green resource	Morphology	Size (nm)	References
ZnO	*Mimusops elengi*	Hexagonal	14-48	(Kumar *et al*., 2019)
Zinc oxide	*Citrus sinensis*	Hexagonal wurtzite	11.2	(Gao *et al*., 2020)
Cellulose nanocrystals	*Sargassum fluitans*	Rod	43.06 ± 8.94	(Doh & Whiteside, 2020)
Carbon dots (CDs)	Enoki mushroom	Lattice fringes	<10, 8.3 ± 1.6	(Roy *et al*., 2021)
Cellulose nanocrystals	Wheat straw waste	Spherical	5	(Nehra & Chauhan, 2022)
Silver	Chickpea *(Cicer arietinum* L.*)* (CA) leaves	Cubic	6.11–9.66	(Baran *et al*., 2022)
Cellulose nanocrystals	Banana peel	Rod-like	209	(Mishra *et al*., 2022)
Chitosan nanoparticles	*Eucalyptus globulus* Labill leaves	Spherical	6.92–10.10	(El-Naggar *et al*., 2022)
TiO_2	*Citrus limon (lemon)* outer peels	Spherical	80-140	(Nabi *et al*., 2022)
Lignocellulose nanocrystals	Pineapple peel	Rod-like	310-460	(Daassi *et al*., 2023)
Lignin nanoparticles	Rice husk	Spherical	260 ± 10	
Zinc oxide	*Cassia fistula*	Polyhedral	20–40	(Daassi *et al*., 2023)
Silver	Turmeric	Spherical	23 ± 0.49	(Alsammarraie *et al*., 2023)

Cellulose nanofibers	*Corn straw*	Rod-like	5-6.5	(Barbash *et al*., 2023)
ZnO	Citrus peel waste	Orthorhombic	10	(Vasiljevic *et al*., 2024)
Fe_2TiO_5			50	
Silver	*Arabinoxylans (AXs) from maize bran*	Spherical and irregular	25	(Raza *et al*., 2024)
Silver	*Dragon* fruit stem extract	Spherical	5.85 ± 0.96	(Ton-That *et al*., 2025)

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Gas Chromatography-Mass Spectrometry (GC-MS) and *in vitro* studies of antioxidant and antimicrobial activities of *Mentha spicata* L. essential oil

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ABSTRACT

The present study aimed to examine the chemical makeup, as well as the antioxidant and antimicrobial properties, of essential oil from *Mentha spicata* leaves against common foodborne pathogenic bacteria (*Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli*) and fungal plant pathogens (*Fusarium sp.*, *Aspergillus niger*, *Ascochyta pisi*, *Alternaria spp.*, and *Candida albicans*). The chemical composition of the essential oil was determined using gas chromatography coupled with a mass spectrometer (GC-MS). The antimicrobial activity was tested through the agar disk diffusion method. GC-MS analysis identified over 300 compounds, with the main components being carvone (47.60%), limonene (4.88%), β-Caryophyllene (4.41%), and terpinen-4-ol (1.51%). The essential oil showed significant antimicrobial effects against all tested microorganisms. Overall, *E. coli* and *Fusarium sp.* were more susceptible to *M. spicata*. Based on these results, the essential oil from the *M. spicata* plant collected in the Oran region of western Algeria has potential as both an antioxidant and antimicrobial agent.

Keywords: *Mentha spicata*, essential oil, GC-MS, antimicrobial activity, antioxidant activity, foodborne pathogens.

INTRODUCTION

In the field of public health and food security promotion areas, such as agricultural and animal production, commercial antimicrobial agents are used in prophylactic chemotherapy, chemotherapy, and growth promoters (Ma *et al*., 2021). However, misuse or abuse of these agents can significantly increase bacterial resistance. Furthermore, antimicrobial resistance is an emerging and serious public health concern due to the reduced effectiveness of drugs used to treat infectious diseases (Farrukh *et al*., 2025).

Medicinal plants are natural resources that can cure various ailments in humans, and in many parts of the world, they are used against bacterial, viral, and fungal infections. These plants are rich sources of bioactive secondary metabolites, including polyphenols and essential oils, which are often obtained from aromatic plants through steam distillation or solvent extraction (Boy *et al*., 2018; Davidova *et al*., 2024). Essential oils contain various chemical compounds with different biological activities, capable of reducing foodborne pathogens and decreasing reliance on synthetic and semi-synthetic antimicrobials (Angane *et al*., 2022).

The genus *Mentha* includes 25-30 species cultivated in tropical to temperate regions across many countries (Mamadalieva *et al*., 2020). *Mentha spicata* is one of the most common and popular mint species worldwide. In Algeria, this species is cultivated throughout the country for culinary and medicinal uses. The leaves are popularly used as flavoring for tea, while the entire plant functions as a carminative. Both fresh and dried plants, as well as their essential oils, are widely used in the food, cosmetic, confectionery, chewing gum, toothpaste, and pharmaceutical industries (Fatih *et al*., 2017). Mentha spicata has also been extensively used to treat various ailments such as nausea, vomiting, and gastrointestinal disorders, as well as a breath freshener, antiseptic mouthwash, and a component of toothpaste (Saqib *et al*., 2022).

The present study aims to analyze the chemical composition of Algerian spearmint essential oil grown in the Oran region and to assess its antioxidant and antimicrobial properties against various human pathogenic bacteria and plant fungal strains.

MATERIALS and METHODS

Plant material

Plant samples for this study were collected from a local farm in Oran, Western Algeria, in April 2025. The collected leaves were cleaned of contaminants and dried in a shaded area for two weeks at a constant ambient temperature of 21 ± 2 °C. They were then manually ground into coarse particles and stored in a dark, well-closed container at ambient laboratory temperature.

Extraction of essential oil

Using a Clevenger-type apparatus, 500 g of desiccated leaves were subjected to 2 hours of hydrodistillation at the boiling point (100 °C) with 1 liter of water. The collected essential oil was measured and stored in 4 mL amber vials at 4 °C until analysis (Aziz *et al*., 2018).

Total contents of phenolics, flavonoids, and tannins

The total phenolic content was estimated using the Folin-Ciocalteu assay. The phenolic content was expressed as gallic acid equivalents (GAE) per gram of dry plant material, based on a standard curve made with different concentrations of gallic acid (Pérez *et al*., 2023).

The total flavonoid content of the sample was measured using the aluminum chloride colorimetric method. Quercetin served as the standard to generate the calibration curve for this measurement. The results were expressed as mg quercetin equivalents per mg Q/g of dry extract (Chandra *et al*., 2014).

The vanillin-HCl method was employed to determine the condensed tannin content, following the procedures outlined by Makkar & Becker (1993). A catechin standard curve was used to express results as mg catechin equivalents per mg of dry extract. All measurements for total phenolic, flavonoid, and tannin contents were conducted in triplicate.

Antioxidant activity (DPPH radical scavenging activity)

The free 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity was evaluated following the method described by Cheng *et al*. (2006). Briefly, in 96-well plates, 0.1 mL of the oil extract (25-500 µg/mL) was combined with 0.3 mL of methanolic DPPH solution (0.1 mM). After incubating in the dark at room temperature for 30 minutes, the absorbance of the reaction mixture was measured at 515 nm and expressed as a percentage to indicate DPPH free radical scavenging activity using the following formula:

$$Scavenging\ activity\ (\%) = \frac{control\ absorbance - oil\ extract\ absorbance}{control\ absorbance} \times 100$$

Ascorbic acid and butylated hydroxytoluene (BHT) were used as positive controls, and the IC50 value was calculated through linear regression analysis using different concentrations (25-500 µg/mL), expressed as mean ± standard deviation (SD).

GC-MS analysis of Mentha spicata L. essential oil

GC-MS analysis of *Mentha spicata* L. essential oil. The analysis. The analysis of the essential oil was performed using a Shimadzu GC-MS-TQ8030trometer (Japan). Following standard parameters, 1 µL of the sample was injected at an injector temperature of 220 °C. Helium (He) served as the carrier gas, injected at a flow rate of 4.55 mL/min under constant flow. The oven temperature program began at 50 °C, held for 3 minutes, then increased at a rate of 5 °C/min up to 220 °C with a total run time of 34 minutes. After reaching 220 °C, the temperature was maintained for an additional 10 minutes. The GC-MS analysis was conducted in triplicate, and the results were reported as the average.

All peaks were analyzed to identify the volatile compounds in the extract through their retention indices. The mass spectra were compared with those in the internal reference mass spectra library, and the authentic chemicals were then confirmed using the NIST Chemistry WebBook 2021 database.

Microorganisms

Antimicrobial activity was tested against three pathogenic bacterial strains: *Staphylococcus (S.) aureus* ATCC 25923, *Pseudomonas (P.) aeruginosa* ATCC 27853, and *Escherichia (E.) coli* ATCC 25922 obtained from the Algerian Pasteur Institute (APT). The antifungal activity of *Mentha spicata L.* essential oil was also evaluated using the phytopathogenic strains: *Fusarium* sp., *Aspergillus niger*, *Ascochyta pisi*, *Alternaria* spp., and *Candida (C.) albicans ATCC 10231* obtained from the laboratory of Rhizobium Biotechnology and Plant Improvement, University of Oran collections.

Screening for antibacterial activity

A disc diffusion assay was performed to evaluate bacterial growth inhibition by EO. A single colony from an overnight bacterial culture plate was inoculated into 5 mL of Mueller-Hinton broth

(MHB). The turbidity of each culture was adjusted to 0.5 McFarland. Using a sterile swab, cultures were evenly spread onto pre-warmed 37 °C MH agar plates. Sterile filter paper disks (6 mm Whatman No. 1) were gently pressed onto the agar surface, and EO was pipetted onto the disks. EO was tested at 100% concentration and at various dilutions (5, 10, 25, 50, and 75%) in DMSO. A pure DMSO control was included in each test to confirm that DMSO alone did not inhibit microbial growth. Chloramphenicol (30 µg/disc; Liofilchem S.r.l., Italy) served as a positive control. Plates were then inverted and incubated for approximately 24 hours at 37°C. The diameter of the inhibition zones was measured in millimeters, including the disc diameter. Sensitivity was classified following Ponce *et al*. (2003) as not sensitive for zones less than 8 mm, sensitive for 9-14 mm, very sensitive for 15-19 mm, and extremely sensitive for zones greater than 20 mm. Each test was performed in triplicate.

Screening for antifungal activity

Fungal suspensions were prepared following De Lira Mota *et al*. (2012) by rinsing the surface of the Malt Extract Agar (MEA) slant culture with 5 mL of sterile saline and shaking the suspensions for 5 min. The resulting mixture of sporangiospores and hyphal fragments was withdrawn and transferred to a sterile tube. After allowing the heavy particles to settle for 3-5 min, the upper suspension was collected and vortexed for 15 s. Final conidia suspensions were adjusted using a Neubauer chamber to 10^6 conidia per mL. Then, 300 µL of each fungal suspension was applied to MEA plates. Filter paper discs (6 mm diameter, Whatman No. 1) were placed on the agar surface of the Petri dishes, and EO, dissolved in DMSO at different concentrations (5, 10, 25, 50, and 75%), was individually added. For each dilution, the same volume as the full-strength sample was placed on the sterile disc. Discs impregnated with 10 µL of DMSO, nystatin (50 µg/mL), and cycloheximide (50 µg/mL) (all from Liofilchem S.r.l., Italy) served as controls. Petri dishes were incubated at 25 °C for 5 days. Inhibition zone diameters were measured in millimeters. An inhibition zone larger than 1 mm was considered a positive effect.

Statistical analysis

The data were expressed as the mean ± standard deviation (SD) of three independent experiments performed in triplicate and analyzed using one-way analysis of variance (ANOVA). Tukey's multiple comparison test was used to identify significant differences with a p-value < 0.05, using GraphPad Prism 9.5.1 (733) software.

RESULTS and DISCUSSION

Extraction yield and measurement of phenolic compounds

The *Mentha spicata L.* essential oil yield based on dry weight was 0.92% (v/w), appearing transparent in color with a pungent perfumery odor and a clear aspect at all tested concentrations. The total phenolic, flavonoid, and tannin contents in the essential oil were determined to be 52.8 ± 0.06 mg/g (GAE), 28.6 ± 0.04 mg/g (CE), and 18.6 ± 0.04 mg/g (QEE), respectively. These findings are consistent with previous investigations on spearmint essential oil. For instance, Abootalebian et al. (2016) reported total phenolic contents ranged from 50.1 to 67.2 mg GAE/g, and El Machrafi et al. (2025)found a flavonoid and tannin content of 19.6 mg QE/g and 16.9 mg TAE/g.

Antioxidant activity (DPPH radical scavenging activity)

Antioxidants are natural compounds that protect against oxidative stress (Chandimali *et al.*, 2025). The antioxidant potential of *Mentha spicata L.* essential oil was evaluated by measuring its free radical scavenging capacity using DPPH assays. The results showed strong activity, with IC_{50} values of 15.26 ± 0.2 µg/mL. The DPPH scavenging ability of the essential oil was stronger than that of ascorbic acid and BHT, which had IC_{50} values of 2.91 ± 0.1 and 10.76 ± 0.1 µg/mL, respectively, in a dose-dependent manner. This promising antioxidant potential is due to the presence of phytochemicals that act as free radical scavengers. Previous investigations confirmed that *Mentha spicata L.* exhibits significant antioxidant effects using DPPH, ABTS, H_2O_2, and FRAP assays (Abootalebian *et al*., 2016; Adli *et al*., 2022; Bardaweel *et al*., 2018). Additionally, hydro- ethanolic extracts of *Mentha spicata L.* leaves showed strong antioxidant activity with a DPPH IC_{50} of 17.08 ± 0.7 µg/mL, and other studies reported antioxidant potential in different parts of the plant grown in Morocco (El Machrafi *et al*., 2025). Furthermore, the main compound, Carvone (2-Cyclohexen-1-one, 2-methyl-5-(1-methylethenyl)), isolated from *Carum carvi*, *Anethum graveolens*, and *Mentha spicata* essential oils, was found to possess prominent antioxidant properties (Das *et al*., 2024).

GC-MS analysis of Mentha spicata L. essential oil

The GC- MS analysis identified over three hundred compounds based on their experimental retention indices compared to those documented in the literature. Ten major phytochemicals were identified and ranked according to their relative abundance (Table 1). Among them, Carvone (47.60%), Limonene (4.88%), β-Caryophyllene (4.41%), Dihydrocarveol (4.38%), cis-Carveol (4.22%), β-Bourbonene (3.50%), Germacrene D (2.90%), and Terpinen-4-ol (1.51%) were the most prevalent components of *Mentha spicata* L. essential oil. These compounds were distributed across various chemical classes, with most falling into oxygenated monoterpene, monoterpene hydrocarbon, and sesquiterpene hydrocarbon categories. This profile aligns with previous studies on *Lamiaceae* species, which often report terpenoid groups (Figure 1). For example, Brahmi *et al.* (2016) found that the chemical profile of *Mentha spicata L.* essential oil was mainly made up of oxygenated monoterpenes (60.11%), with carvone (48.5%) as the main component. This was followed by monoterpene hydrocarbons (26.64%), primarily limonene (20.8%), while sesquiterpene hydrocarbons accounted for a smaller part (11.07%) of the total oil. Abdel-Hameed *et al*. (2024)reported oxygenated monoterpenes as the major class constituent at 93.39% in *Mentha longifolia*. Another study confirmed the presence of trans-Muurola-4(14),5-diene (Sesquiterpene hydrocarbons) as a major component with a percentage of 27.28% in *Mentha spicata L.* essential oil extract (Tewari, 2017).

Table 1. Main compounds found in *Mentha spicata L*. essential oil extract.

Class	**Phytochemicals**	**RT (min)**	**Area%**	**Formula**
Oxygenated Monoterpene	Carvone	13.838	47.60	$C_{10}H_{14}O$
Monoterpene Hydrocarbon	Limonene	3.036	4.88	$C_{10}H_{16}$
Sesquiterpene Hydrocarbon	β-Caryophyllene	10.566	4.41	$C_{15}H_{24}$
Oxygenated Monoterpene	Dihydrocarveol	14.405	4.38	$C_{10}H_{18}O$
Oxygenated Monoterpene	cis-Carveol	16.932	4.22	$C_{10}H_{16}O$
Sesquiterpene Hydrocarbon	β-Bourbonene	8.858	3.50	$C_{15}H_{24}$
Sesquiterpene Hydrocarbon	Germacrene D	13.092	2.99	$C_{15}H_{24}$
Oxygenated Monoterpene	1,8-Cineole	3.129	1.93	$C_{10}H_{18}O$
Sesquiterpene Hydrocarbon	β-Elemene	14.241	1.57	$C_{15}H_{24}$
Oxygenated Monoterpene	Terpinen-4-ol	10.994	1.51	$C_{10}H_{18}$

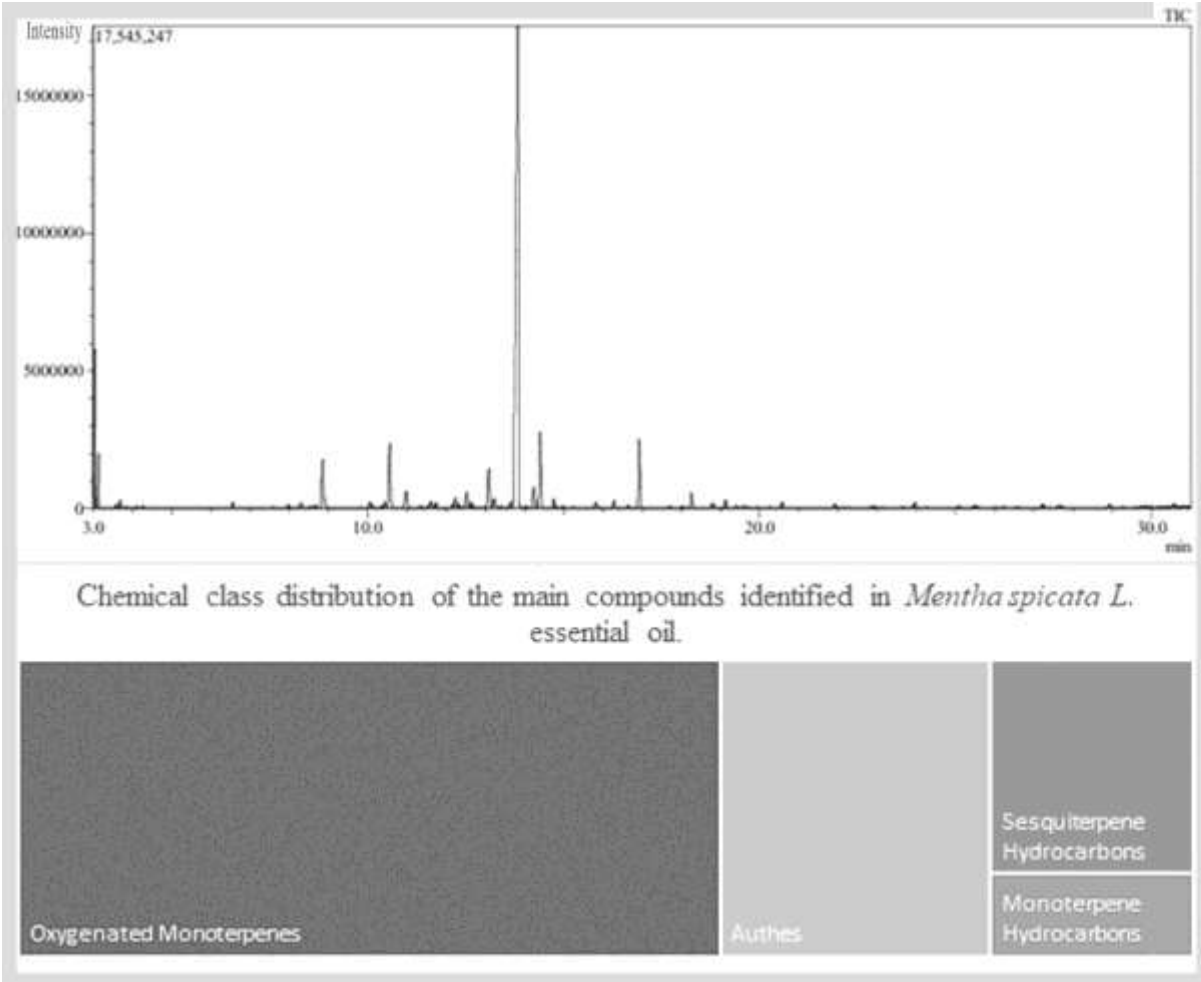

Figure 1. GC-MS chromatogram and the major compound classes identified in *Mentha spicata L.* essential oil extract.

These components are responsible for both the sensory properties and the pharmacological effects of spearmint essential oil, especially 2-Cyclohexen-1-one, 2-methyl-5-(1-methylethenyl) carvone, which has been associated with antioxidant, antimicrobial, and anticancer activities (Bouyahya *et al*., 2021; Chandimali *et al*., 2025).

Screening for antibacterial activity

The essential oil extract of *Mentha spicata L.* exhibited antibacterial activities against *S. aureus*, *P. aeruginosa*, and *E. coli* of 14.53, 18.46, and 22.23 mm, respectively (Figure 2). These results are higher than those reported by Shahbazi (2015), who identified zones of inhibition against *S. aureus* and *E. coli* of 10, 8, 10, and 12, respectively. In another study, Ekhtelat et al. (2019) reported antibacterial activity of *Mentha spicata L.* against *E. coli*, with a zone of inhibition of 10 mm.

Screening for antifungal activity

The different results of the antifungal activity of the essential oil extract of *Mentha spicata L.* against the tested strains are presented in Figure 2. The highest antifungal activity was observed against *Fusarium sp.*, with an inhibition zone diameter of 40.73 mm. In contrast, the lowest was observed against *C. albicans*, with an inhibition zone diameter of 14.26 mm. These results align with several previous studies that have shown Mentha spicata L.'s capacity to inhibit the growth of fungal strains (Crescente et al., 2025; Medjdoub et al., 2019; Piras et al., 2021).

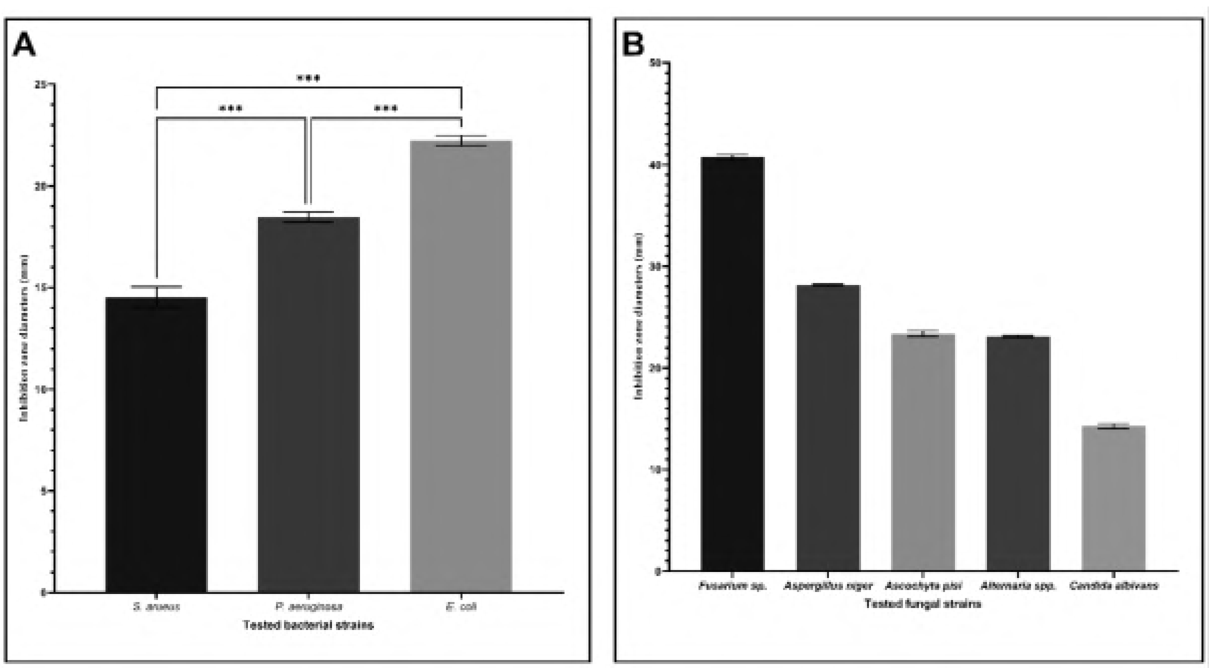

Figure 2. The antimicrobial activity of *Mentha spicata L.* essential oil against (A) selected microbial strains and (B) selected fungal strains.

CONCLUSION

The results of the present study indicate that *M. spicata* L. essential oil has remarkable antioxidant and antimicrobial activity against common food-borne bacteria associated with outbreaks, as well as plant fungal disease strains. The antimicrobial activity of the essential oil could be attributed to the presence of various active compounds. The main components were carvone (47.60%), limonene (4.88%), β-Caryophyllene (4.41%), and terpinen-4-ol (1.51%). Based on our results, the essential oil of the Mentha plant collected from the Oran region, west of Algeria, has the potential to be applied as an antioxidant and antibacterial agent.

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The Gut Microbiome: Insights into Health Benefits and Practical Dietary Tips

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ABSTRACT

The gut microbiota, a complex community of microorganisms residing in the human digestive tract, plays a crucial role in maintaining overall health. A growing number of microorganisms are found in the microbiota, from the stomach to the colon. *Lactobacillus* and *Bifidobacterium* bacteria are among the most beneficial microorganisms and are used as probiotics. The gut microbiota can be influenced by various factors, including genetic and environmental aspects such as diet, geography, lifestyle, pollutants, and the use of medications and antibiotics. Furthermore, immunological and psychological impacts are discussed, focusing on the microbiome's role in the immune system modulation and highlighting the gut-brain axis and it's influences on mental health. Therefore, this review focuses on the relationship between microbiome health, nutrition, prebiotics, probiotics, which is important for maintaining gut health and preventing disease, focusing on personalized nutrition and dietary tips. It has been observed that a varied diet, rich in prebiotics (non-digestible oligosaccharides), promotes the growth of beneficial bacteria and yeasts. Furthermore, consuming fermented or probiotic-enriched products helps support the gut microbiota and maintain intestinal balance. This balance promotes the proper functioning of the body and provides health benefits, notably by helping to fight cancer and various other diseases and reducing their incidence.

Keywords: Microbiota, probiotics, prebiotics, health, nutrition, gastrointestinal tract.

INTRODUCTION

Maintaining general health depends heavily on the human gut microbiome, a huge ecology of bacteria, viruses, fungi, and other microorganisms that live in the gastrointestinal tract (GAOUAR, 2025). The study of the intestinal microbiome has evolved significantly over the centuries. In 1676, Dutch scientist Antonie van Leeuwenhoek first observed microorganisms, which he termed "animalcules," using a single-lens microscope of his own design. His observations laid the groundwork for microbiology as a scientific discipline (Sidebottom, 2023).

In the late 19th century, Theodor Escherich identified a bacterium in the human gut, later named *Escherichia coli*, highlighting the presence of specific microbial species in the intestines (Lewandowska-Pietruszka *et al*., 2022)**.** Around the same period, Henry Tissier isolated *Bifidobacterium* from the feces of breastfed infants, suggesting a link between gut microbes and infant health (Farré-Maduell & Casals-Pascual, 2019). More recently, studies have revealed that certain gut microbes have co-evolved with humans over hundreds of thousands of years, underscoring the deep and intricate relationship between humans and their intestinal microbiota (Suzuki *et al*., 2022).

The composition of the gut microbiota is influenced by various factors, including diet, genetics, age, environment, and the use of medications such as antibiotics (Cantón *et al*., 2024). Furthermore, a balanced and diverse microbiota is essential for maintaining health, while imbalances, known as dysbiosis, have been linked to a range of conditions, including inflammatory bowel disease, obesity, and metabolic disorders (Dupont *et al.*, 2020).

Emerging research have emphasized the interaction between the gut microbiome and systemic physiological systems, including the gut-brain axis and immune system modulation, suggesting new pathways for tailored nutrition recommendations targeted at promoting microbiome health (Dupont *et al*., 2020). This bidirectional communication involves neural, hormonal, and immune pathways, highlighting the microbiome's role in overall well-being (Dupont *et al*., 2020).

Maintaining a healthy intestinal microbiome involves lifestyle choices such as consuming a diet rich in fiber, limiting processed foods, managing stress, and using antibiotics judiciously (Dupont *et al*., 2020). More recently, emerging interventions, including probiotics and prebiotics, are being explored for their potential to modulate the microbiome and promote health (Gerritsen *et al*., 2011).

The purpose of this review is to consolidate current understanding about the interaction between nutrition and the gut microbiome and highlighting the effects of some medications on our microbiota, with a focus on the impact of dietary treatments such as prebiotics, probiotics, and functional foods in maintaining microbial balance and disease prevention.

What is the Intestinal Microbiome?

The intestinal microbiome refers to the vast community of microorganisms residing in the human gastrointestinal tract. This complex ecosystem includes bacteria, viruses, fungi, and protozoa, with bacterial cells alone numbering approximately 10^{13}, comparable to the total number of human cells in the body (Sokol, 2019). The lower bacterial numbers (10^3 to 10^4 bacteria of intestinal content) found in the upper end of GI tract (stomach and small intestine) and highest biodiversity content (10^{10} to 10^{11}) is in the colon (Hillman Ethan *et al*., 2017).

The microbiome is a wider notion that includes not only these microbial communities, but also their genes, metabolites, ecological niches or habitats, and interactions with the host. The microbiota is a subset of the microbiome found in distinct ecological niches throughout the body, with the gut microbiome being the most diverse and well-studied. Other key areas include the genitourinary system, oral cavity, nasopharynx, respiratory tract, and skin, each with their own microbial composition (Alanazi *et al*., 2024). These microbial communities have symbiotic and mutualistic connections with human cells, maintaining vital communication with the immune system and acting as a key "organ" impacting health and disease. Individual microbiomes differ depending on genetic background, food, early environmental exposures, location, and age (Cantón *et al*., 2024) (Figure 1).

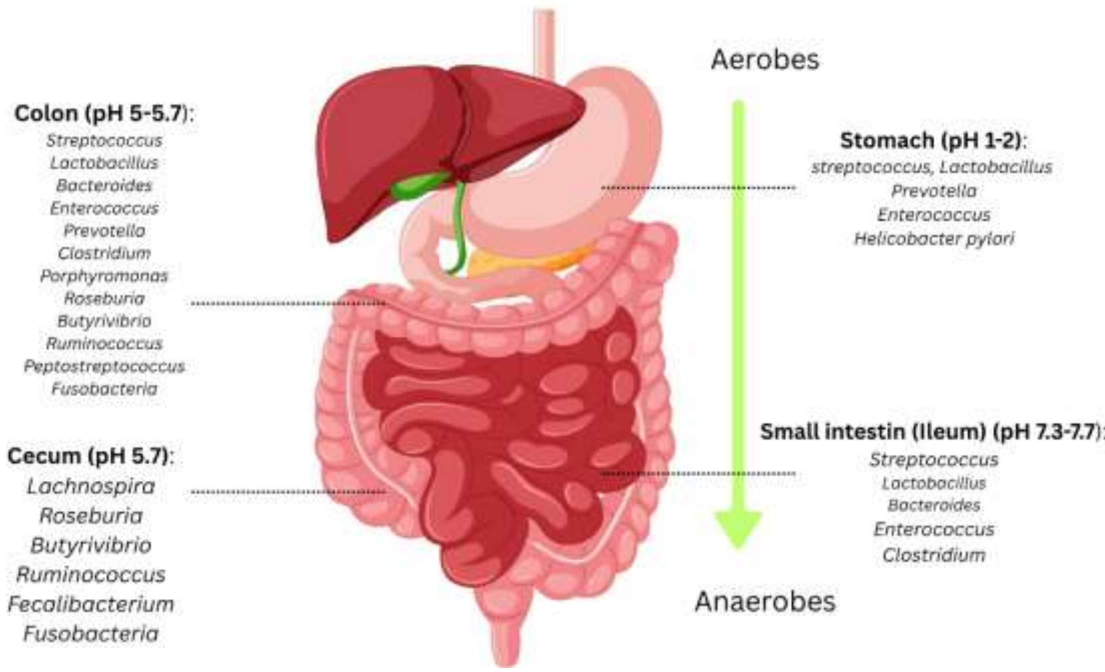

Figure 1. Gut microbiota distribution across different section of the human digestive tract (Kumar *et al*., 2025).

Prebiotics-Probiotics and Gut Health

Prebiotics

It is impossible to talk about probiotics without mentioning prebiotics. Prebiotics are non-digestible substances that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, which improve host health (Obayomi *et al*., 2024). Prebiotics include non-digestible oligosaccharides like fructooligosaccharides (FOS) and galactooligosaccharides (GOS), dietary fibers such as inulin and pectin, plant-derived polyphenols, and polysaturated fatty acids, which are naturally found in foods like asparagus, sugar beet, garlic, chicory, onion, and other vegetables (Yoo *et al*., 2025) (Table1).

Table 2. Prebiotic from food and their benefits.

Prebiotic	**Dietary source**	**Potential benefits**	**References**
Fructans	Chicory root, agave, artichokes	Modulate gut microbiota and improve bodyweight regulation, regulate appetite and energy metabolism	**(**Reimer *et al*., 2024)

Inulin	chicory, asparagus, onions, garlic, banana, rye, barley, and artichokes	Improvement of the metabolic state, increases different *Bifidobacterium* species, reduced inflammation and enhanced overall digestive health and nutrient absorption.	(Alonso-Allende *et al*., 2024)
Fructooligosaccharides (FOS)	Onions, wheat, rye shallots, tomatoes	Prevent colon cancer, immunomodulatory effects, improve mineral adsorption, regulate serum lipid and cholesterol concentration	(Yoo *et al*., 2024)
Galactooligosaccharide (GOS)	Human milk, cow's milk, oats, garlic, fruits, asparagus	Increased bifidobacterial abundance, strengthen the intestinal barrier, inhibit the adhesion of pathogens,	**(**Ambrogi *et al*., 2023)
Xylooligosaccharides (XOS)	milk, honey, fruits, garlic, artichoke, lentils, and barley.	Growth of beneficial intestinal microflora bifdobacteria and lactobacilli	(Kumari *et al*., 2024)
Chitooligosaccharides (COS)	shrimp shells and crab shells	Decreases the number of *Escherichia*/*Shigella* pathogens, enhance intestinal barrier function	(Wei *et al*., 2024)
Pectin	Citrus fruits, and berries	Stimulating the growth of beneficial bacteria, production of SCFA, prevent inflammatory bowel diseases	(de Oliveira *et al*., 2024)
Resistant starch (RS)	Cooled potatoes, rice, wheat, corn	The modulation of microbial communities, the reduction in gallstone formation, increasing satiety, and preventing colon cancer	(Niu *et al*., 2025)
Polyphenols	Berries, nuts, dark chocolate and green tea	Stimulating the growth of beneficial gut bacteria, production of short-chain fatty acids, combating	(Nandha *et al*., 2025)

	oxidative stress and inflammation in the gut.

Prebiotics are important because they support the growth of beneficial gut bacteria (probiotics), leading to increased microbial biomass and more frequent bowel movements, similar to the effects of dietary fiber (Rolim, 2015). The bioactivity of prebiotics empowers the intestinal mucosa, regulates absorption and moderate inflammatory processes, providing not only to gastrointestinal health, but also to the overall health of the host (Sionek & Szydłowska, 2025).

A study showed that Rats supplied with inulin at a level of 10% in the diet showed a decrease in the level of triglycerides and cholesterol void and after a meal (Tomasik & Tomasik, 2003). Another study showed that the ingestion of two prebiotics, galactooligosaccharide (GOS) and polydextrose (PDX), leads to an increase in iron absorption and promotes recovery from anemia in gastrectomized rats (Santos *et al*., 2011). Prebiotics can assist in regulating the overall bacterial diversity of the gut by promoting the growth of useful bacteria, while inhibiting the augmentation of dangerous species(Nadeem *et al*., 2024)**.**

Probiotics

The Russian Nobel laureate Elie Metchnikoff observed that consuming fermented food which containing lactic acid bacteria (LAB), had advantageous effects on human health and leads to longevity (Jang *et al*., 2024).

Microorganism-fermented foods such as bread, beer, kefir, yoghurt, kumis, and cheese have been consumed by humans since the Neolithic period (Álvarez *et al*., 2021). The term "probiotics" is defined by the WHO/FAO as "living microorganisms that, when taken in sufficient quantities, provide health advantage to the host (Meher *et al*., 2024). Most probiotics are Gram-positive bacteria, notably *Lactobacillus* and *Bifidobacterium* (Mazziotta *et al*., 2023). These probiotics support gut health by generating short-chain fatty acids (SCFAs) and preventing the growth of harmful bacteria by competing for nutrients and adhesion sites along the intestinal mucosa (Abeltino *et al*., 2024).

Various *Lactobacillus* and *Bifidobacterium* probiotic strains can boost the production of tight junction proteins, essential for connecting adjacent enterocytes "intestinal cells" (Piccioni *et al*., 2023) (Table 2).

Table 3. Microorganisms used as probiotics.

Probiotic (bacteria /yeast)	**Dietary source**	**Potential benefits**	**References**
Lactobacillus	Kefir, pickled vegetables, fermented meat products and cheese, sourdough bread	Anti-pathogenic activities and regulation of immune cells	(Shah *et al.*, 2024)
Bifidobacterium	Yogurt, Cheddar cheese	Improve symptoms of inflammatory bowel syndrome, lactose intolerance, inflammatory bowel disease, antibiotic-associated diarrhea	(Schlienger de Alba & Espinosa Andrews, 2024)
Bacillus	Kimchi, Fermented fruit juice, fermented milk, Fermented tea products	Enhances the flavor and texture of the product, production of organic acids and digestive enzymes	(Liu *et al.*, 2024)
Saccharomyces (*S. boulardii*. *S. cerevisiae*)	Northern Caucasus kefir, feta cheese, sourdough bread,	Neutralizes pathogenic enteric bacteria, reduces the levels of pro-inflammatory cytokines,	(Palma *et al.*, 2015)

Lactobacillus probiotics are found in fermented dairy and plant-based diets but also commensal in humans, they require fermentable carbohydrates, organic nitrogen, vitamins, manganese, and tween 80 to thrive properly. Freeze-drying and encapsulation increase survivability in low-moisture food matrices. To gain probiotic benefits, viable counts should be higher than 7 Log CFU/g or mL (Shah *et al.*, 2024).

Bifidobacterium species are primarily found in fermented dairy products such as yogurt, cheese, acidified milk, and kefir, which serve as the primary probiotic carrier foods. They are also found naturally in the human gastrointestinal tract. *Bifidobacterium* can account for up to 90% of the gut microbiota in babies, with major species including *B. breve*, *B. longum* subsp. *infantis*, and *B. bifidum*. In adulthood, they represent roughly 10-40% of the microbiota, but in the elderly, their prevalence declines to about 5% (Sibanda *et al.*, 2024). *Bifidobacterium* require fermentable carbohydrates (such as glucose and oligosaccharides), nitrogen sources (amino acids and peptides), minerals, and vitamins to function well in anaerobic metabolism. They produce acetic and lactic acid through carbohydrate fermentation, which helps to maintain a gut-friendly environment (Yakoob & Pradeep, 2019). To provide health benefits, *Bifidobacterium* products must have viable probiotic counts of at least 10^6-10^7 CFU/mL, with dairy-based products serving as key carriers. Encapsulation and other protective methods improve survivability against stresses (Shori, 2021).

Bacillus coagulans spores can survive food preparation and storage, resulting in high numbers in probiotic-enriched meals. They are versatile in a variety of food kinds, including dairy, meat, cereal, and plant-based goods. *Bacillus coagulans* has spore resistance, making it a promising probiotic strain (de Almeida Costa *et al*., 2022). *Bacillus* spores are more resistant to heat, pH fluctuations, and gastric conditions, making them strong probiotics with functional benefits in the digestive tract. They may ferment a variety of substrates, including carbohydrates and proteins, adding flavor and nutritional value to fermented meals (Liu *et al*., 2024). *Bacillus* species can germinate and become metabolically active in the gut, offering probiotic health advantages such enzyme synthesis, immunological modulation, and pathogen suppression(Elshaghabee *et al*., 2017).

Saccharomyces boulardii, a strain of *S. cerevisiae*, has been isolated from tropical fruit peels (lychee and mangosteen), kombucha, kefir, and several fermented dairy products. It serves as a probiotic in functional foods such as yogurt and fermented soy products (Ansari *et al.*, 2023). This probiotic yeast thrives in harsh stomach acidic conditions (pH 2-7), neutralizing microbial toxins, preventing pathogen adherence, reducing inflammation, and improving gut epithelial barrier function (Souza *et al*., 2021). *Saccharomyces cerevisiae* var. *boulardii*-enriched yogurt and soy yogurt exhibit higher antioxidant activity, vitamin B complex concentration, and mineral bioavailability. This probiotic yeast can withstand heat, acid, and alkaline stressors, ensuring viability during storage (Mehaya *et al.*, 2023). *S. boulardii* strains from commercial products show excellent survival under gastric conditions, resistance to antibiotics, and compatibility with gut microflora, consolidating their probiotic efficacy and safety (Goktas *et al*., 2021).

What Can Affect the Gut Microbiota?

The human intestinal microbiota is a vast and diverse microbial community. Bacteria, viruses, fungi, archaea, bacteriophages, and protozoans are among the microorganisms that inhabit the intestinal lumen. The composition and function of gut microbiota changes based on location, age, gender, race, environment factors and nutrition (Yang & Yu, 2018). The gut microbiota's composition is extensively controlled by a range of factors, including the microbial species acquired at birth, host genetics, immunological factors, antibiotic use, and dietary impacts (Scott *et al*., 2013) (Figure 2).

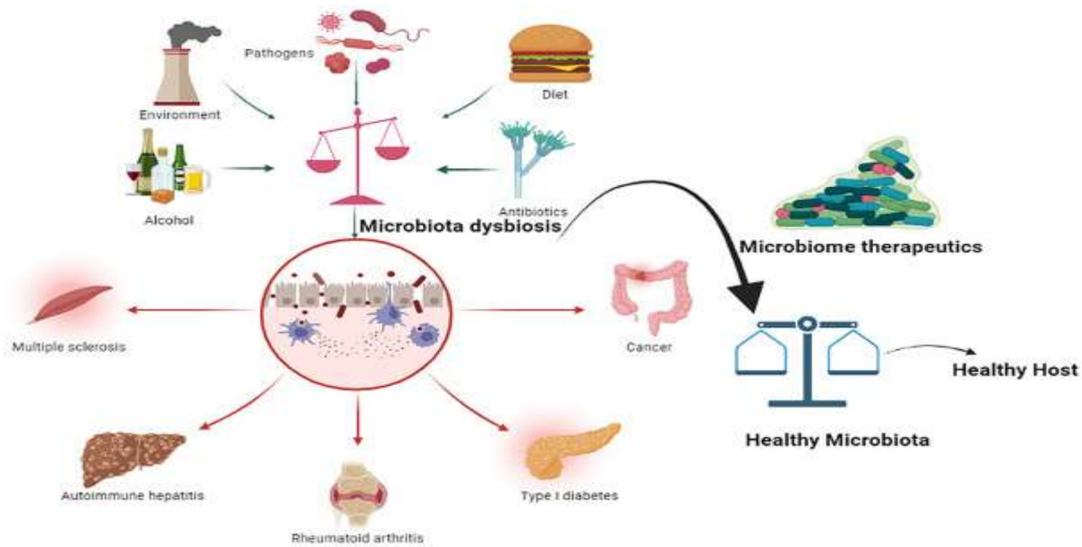

Figure 3. Effects of the gut microbiome (Bhardwaj & Yadav, 2023).

The mode of delivery seems to have an impact on the early-life microbiome (Reyman *et al.*, 2019). Studies have found that there are bacteria and bacterial products, such as DNA, in meconium, amniotic fluid, and the placenta. During birth, the way of delivery influences the gut microbiota's early growth, newborns delivered vaginally have primary gut microbiota dominated by *Lactobacillus* and *Prevotella* derived from the mother's vaginal microbiota, whereas those born via cesarean delivery derive their gut microbiota from the skin, leading to dominance of *Streptococcus*, *Corynebacterium*, and *Propionibacterium* (Hasan & Yang, 2019). Maternal immunity and microbial metabolites during pregnancy, microbial transfer at birth, and transfer of immunological factors, bacteria, and metabolites via breastfeeding all constitute essential sources of early-life microbial and immune training, with important implications for human health (Koren *et al.*, 2024) (Figure 3).

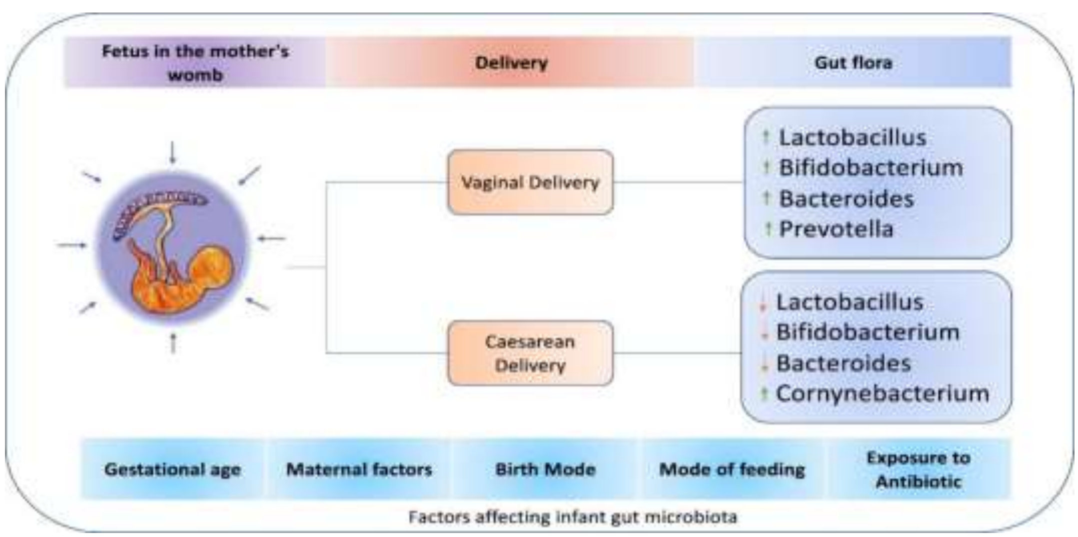

Figure 4. Establishment of early life gut microbiota (Iqbal *et al.*, 2023).

Diet and dietary components have a significant impact on the composition of the gut microbiota and are major contributors to changes in bacterial flora (Beam *et al.*, 2021). A diet lacking in fiber, such as one high in processed foods and low in fruits, vegetables, and whole grains, can starve beneficial gut bacteria, these bacteria ferment fiber, producing SCFAs like butyrate, which are crucial for gut health. Without sufficient fiber, the production of SCFAs decreases, potentially leading to inflammation and increased gut permeability (David *et al.*, 2014). Conversely, a diet high in saturated fats and added sugars can promote the growth of harmful bacteria, such as certain strains of *E. coli*. These bacteria can produce toxins and contribute to inflammation. Additionally, excessive sugar intake can disrupt the gut barrier, making it more permeable and allowing harmful substances to enter the bloodstream (Singh *et al*., 2017).

The Effects of Medications on Gut Microbiome

The consumption of medications, whether antibiotics or other types of drugs, has a significant impact on the composition of our gut microbiome.

Antibiotics (especially broad-spectrum ones), has long-term impacts from prenatal to adulthood, including higher risk of antibiotic resistance, obesity, allergies, asthma, and metabolic changes (Lathakumari *et al*., 2024). Antibiotic therapy, whether short-term or repeated long-term prescriptions, can have a number of negative consequences on the gastrointestinal tract's normal microbiome. Changes in microbiota can take several forms, including decreased species diversity in gut microbiota, altered metabolic activity, and the emergence of antibiotic-resistant bacteria (Dahiya & Nigam, 2023).

Antibiotic use, overuse, and misuse create a low diversity species microbiome, allowing pathogens to flourish and potentially evolve resistance to antibiotics. This, in turn leads to the development of a mechanism such as decreased antibiotic uptake through cell wall modification, producing enzymes to modify or degrade the antibiotic, and actively removing antibiotics using efflux pumps to eliminate the effect of the antibiotic (Dongre *et al*., 2025).

Non-antibiotic drugs such as proton pump inhibitors (PPIs) which used to inhibit acid stomach production are the most associated to a decreased diversity and taxonomical changes in the gut microbiome when used for a long term or irregularly. Changes in the gut microbiota have been linked to lower colonization resistance to enteric diseases such as *Clostridium difficile*, *Campylobacter*, and *Salmonella*, similar to those reported in PPIs users (Weersma *et al*., 2020).

It was found that more than 70% of the pharmaceuticals studied, including common nonantibiotic treatments such as proton pump inhibitors, metformin, and laxatives, affected gut microbiota composition and function (Vich Vila *et al*., 2020). Polypharmacy (the use of numerous medicines) was linked to changes in gut microbial diversity, increased abundance of upper gastrointestinal and nosocomial pathobiont species, decreased short-chain fatty acid metabolism, and enhanced bacterial stress responses. Notably, even nonantibiotic medications were found to induce antimicrobial resistance in the gut microbiome. These data demonstrate that individual and multiple drug exposures have substantial and disruptive effects on gut health, indicating the relevance of evaluating pharmaceutical effects on the microbiota in clinical settings (Nagata *et al*., 2022)

The Main Impact of the Gut Microbiome

The human microbiome, and more specifically the gut microbiota, is often described as an "invisible organ" due to its important and vital contributions to host physiology, including the development and modulation of the immune system, protection and barrier function, as well as metabolic and nutritional functions.

Development and modulation of the immune system

- Induction of immune tolerance: The microbiota promotes immune homeostasis by driving the differentiation of regulatory T cells, which suppress inflammatory responses and help maintain tolerance to both commensal bacteria and self-antigens (Round & Mazmanian, 2009).
- Maintenance of the gut-associated lymphoid Tissue (GALT): The bacteria and their products continuously interact with the GALT, the largest immune organ in the body, stimulating its development and function (Sekirov *et al*., 2010).
- Anti-inflammatory effects: SCFA metabolites, particularly butyrate, exert strong anti-inflammatory effects by inhibiting inflammatory signalling pathways (Andoh, 2016, Round & Mazmanian, 2009).

Protection and barrier function

- Strengthening the intestinal barrier: SCFA are vital for maintaining the physical and functional integrity of the intestinal epithelial barrier, which acts as a selective filter separating the microbial content of the gut lumen from the host's internal tissues (Andoh, 2016).
- Colonization resistance: the established community of commensal bacteria prevents the colonization and overgrowth of invading pathogenic microorganisms by competing for nutrients and adhesion sites (Sekirov *et al*., 2010).

Metabolic and nutritional functions

- Fermentation of indigestible dietary components: The gut microbiota utilizes complex dietary carbohydrates, such as fiber, that the host's enzymes cannot break down, initiating a crucial fermentation process (Andoh, 2016).
- Production of Short-Chain Fatty Acids (SCFAs): The fermentation process yields high concentrations of SCFAs, primarily acetate, propionate (travel via the bloodstream to the liver and other tissues, where they are involved in lipogenesis and gluconeogenesis thus contributing to host energy metabolism), and butyrate is the main energy source for colonocytes (epithelial cells lining the colon), promoting gut barrier integrity and health (Andoh, 2016).

- Vitamin synthesis: Gut microbes are responsible for synthesizing essential micronutrients, including Vitamin K and several B vitamins B1, B9, B12, which can be absorbed and utilized by the host (Valdes *et al*., 2018).
- Regulation of bile acid metabolism: Microbes perform enzymatic transformations (deconjugation and dihydroxylation) of primary bile acids into secondary bile acids, which are important signalling molecules that regulate lipid and glucose metabolism in the host (Ramírez-Pérez *et al*., 2018).

A Psychological Perspective on Microbiota and Mental Health

The gut-brain axis is a complex, bidirectional communication system linking the gastrointestinal tract and the central nervous system via neural, immune, and endocrine pathways (Gershon & Margolis, 2021). Over the past decade, the intestinal microbiota, the trillions of microorganisms residing in the gut, has been recognized as a major regulator of both mental and emotional health, influencing stress responses, cognition, and mood (Cryan *et al*., 2019, Margolis *et al*., 2021). Over the past decade, the intestinal microbiota has been recognized as a major regulator of both mental and emotional health, influencing stress responses, cognition, and mood (Cryan *et al*., 2019, Margolis *et al*., 2021).

Mechanisms of Communication Between the Gut and the Brain

Neural pathways (Vagus Nerve)

The vagus nerve serves as the main neural connection between the gut and the brain. It transmits sensory information from the intestinal wall to brain regions that regulate mood, emotion, and stress responses, such as the amygdala and prefrontal cortex (Breit *et al*., 2018). Studies have shown that stimulation of the vagus nerve can reduce symptoms of depression and anxiety, suggesting a direct neurophysiological link between gut activity and emotional regulation (Bonaz *et al*., 2018).

The enteric nervous system (ENS), often called the “second brain”, operates semi-independently and communicates continuously with the central nervous system to modulate gastrointestinal motility and mood-related behaviors (Gershon & Margolis, 2021).

Importantly, the gut microbiota directly and indirectly affects both the vagus nerve and ENS. Beneficial bacteria produce SCFAs and neuroactive metabolites, such as serotonin and gamma-aminobutyric acid (GABA), which influence vagal tone and neuronal activity (Silva *et al*., 2020). Disruptions in this microbial signalling, caused by stress, poor diet, or antibiotics, can alter vagus nerve function, weaken ENS communication, and contribute to disorders such as irritable bowel syndrome, anxiety, and depression. Thus, the microbiome acts as a neurochemical interface, shaping emotional and cognitive processes through its continuous dialogue with the nervous system (Bonaz *et al*., 2018).

Immune pathways

The gut microbiota interacts closely with the immune system to maintain body-wide balance. When the microbial community becomes disturbed, pro-inflammatory cytokines can be released into circulation and reach the brain, altering neurotransmission and stress responses. Persistent inflammation has been linked to anxiety, depression, and cognitive changes, showing that immune signalling is a key route through which gut microbes affect mental health. A stable microbiota, by contrast, supports anti-inflammatory processes that foster emotional stability and stress resilience (Foster *et al*., 2017).

Endocrine

Microbial metabolites act as key biochemical messengers between the gut and the brain. Among the most influential are SCFAs, acetate, propionate, and butyrate, produced by bacterial fermentation of dietary fibers. These molecules regulate neuroinflammation, neurotransmitter synthesis, and energy metabolism within the brain, influencing emotional and cognitive functions. SCFAs also strengthen the blood–brain barrier and support the production of serotonin from tryptophan, linking microbial metabolism directly to mood regulation and stress resilience (Silva *et al*., 2020) (Figure 4).

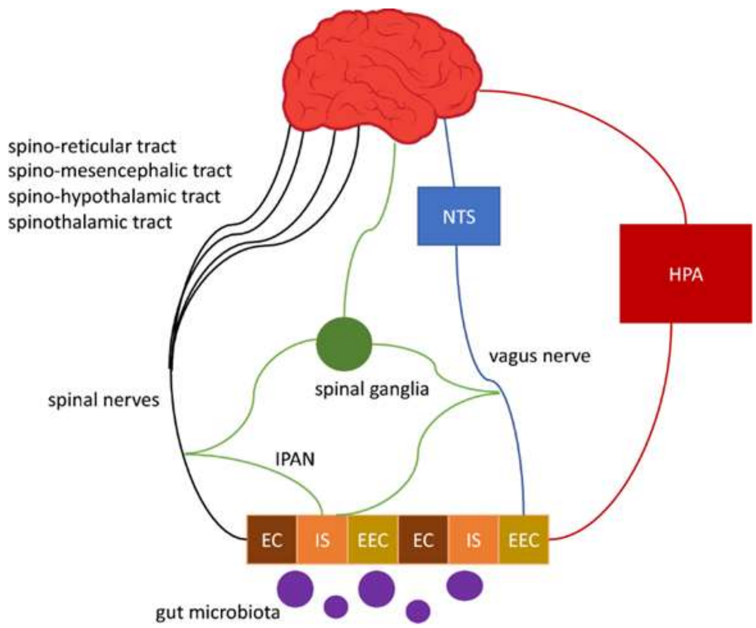

Figure 5. Schematic of neural pathways connecting the gut microbiota with the central nervous system, highlighting the vagus nerve, spinal afferents, and the hypothalamic–pituitary–adrenal (HPA) axis; EC = enterochromaffin cell; EEC = enteroendocrine cell; ENS = enteric nervous system; IPAN = intrinsic primary afferent neuron; NTS = nucleus tractus solitarius; HPA = hypothalamic–pituitary–adrenal axis (Carabotti *et al.,* 2015).

Impact of Dysbiosis on Mental Health

Microbial dysbiosis, defined as an imbalance in the composition or function of the gut microbiota, has been strongly linked to various mental health disorders, particularly depression and anxiety.

Animal studies demonstrate that the absence or alteration of gut microbes disrupts normal stress responses and emotional regulation. Germ-free mice, for example, exhibit exaggerated activity of the hypothalamic–pituitary–adrenal axis, leading to heightened anxiety-like behavior and increased stress hormone release. Remarkably, reintroducing specific bacterial strains or fecal transplants can partially reverse these behaviors, highlighting a causal link between microbial balance and emotional stability (Gershon & Margolis, 2021).

Importantly, this communication is bidirectional: not only can the gut influence mood, but psychological stress and mood disorders can also negatively affect the gut. Chronic stress activates the HPA axis, elevating cortisol levels that alter gut motility, secretion, and permeability. These physiological changes weaken the intestinal barrier, often called the "leaky gut" effect, and disturb the microbial ecosystem, favoring pro-inflammatory bacteria (Foster *et al*., 2017). In individuals with depression or anxiety, this stress-induced dysbiosis increases inflammation and reduces the production of beneficial metabolites such as short-chain fatty acids**,** worsening both gut health and emotional resilience. Thus, mood disorders and gut imbalance form a self-perpetuating cycle, each amplifying the other (Gershon & Margolis, 2021).

Psychobiotics and the Shaping of Mental Health

Recent advances in microbiome research suggest that modulating the gut ecosystem offers new strategies for supporting mental health and emotional balance**.** Probiotics, defined as live microorganisms that provide health benefits when administered in adequate amounts, can restore microbial diversity and enhance the production of neuroactive substances such as serotonin and GABA. Clinical and experimental evidence shows that specific probiotic strains, including *Lactobacillus* and *Bifidobacterium*, may reduce depressive symptoms, anxiety, and perceived stress by influencing neurotransmitter signalling and inflammatory pathways (Wallace & Milev, 2017) (Figure 5).

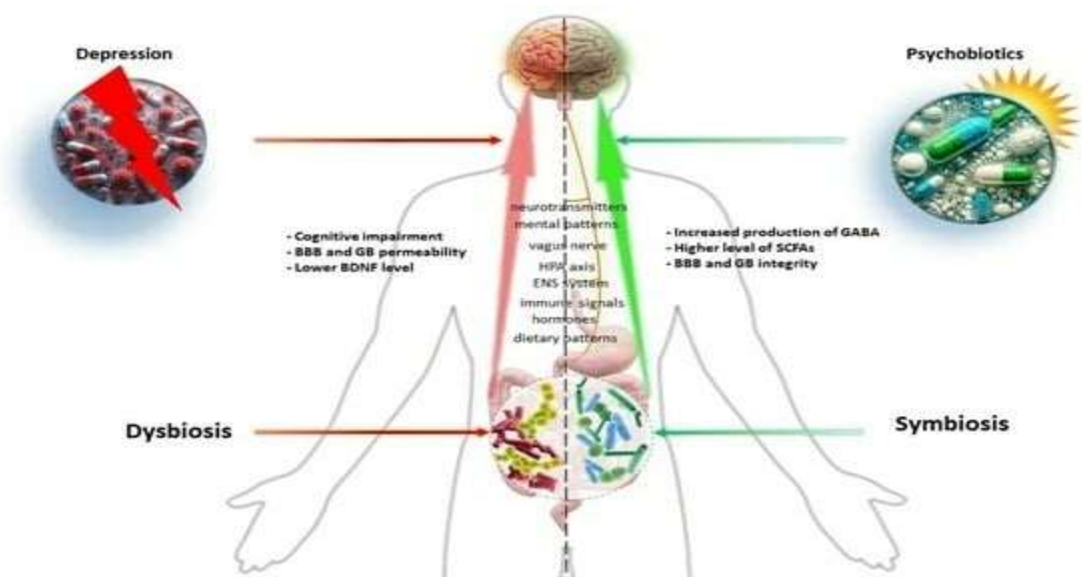

Figure 6. Illustration of the bidirectional relationship between the gut and the brain in depression and recovery through psychobiotic intervention (Dziedzic *et al*., 2024).

Beyond probiotics, psychobiotics, a newer category that includes probiotics, prebiotics, and dietary components with direct effects on the gut-brain axis, have shown promising results in promoting mental well-being. These interventions act through multiple mechanisms: strengthening the intestinal barrier, reducing systemic inflammation, and modulating the HPA axis. Recent reviews emphasize that psychobiotics may serve as adjunct therapies for mood disorders, complementing pharmacological treatments and lifestyle modifications. By improving gut microbial stability and increasing the production of beneficial metabolites such as short-chain fatty acids, psychobiotics help to restore both gut health and emotional resilience (Dziedzic *et al.*, 2024).

From Gut Health to Immune Strength: Understanding the Microbiome's Role in Inflammation

The gut microbiome plays a central role not only in digestion but also in the regulation of immune responses. It trains the immune system from early life, helping it distinguish between harmful pathogens and harmless antigens (Belkaid & Hand, 2014). The microbiota stimulates the development of gut-associated lymphoid tissue (GALT), a key immune structure (Honda & Littman, 2016). This interaction helps shape both innate immunity, which provides rapid defense, and adaptive immunity, which learns and remembers pathogens (Round & Mazmanian, 2009).

When the gut microbiome is in balance, beneficial bacteria produce SCFAs like butyrate, which strengthen the gut barrier and reduce inflammation (Koh *et al*., 2016). These SCFAs also modulate the activity of macrophages, T regulatory cells, and dendritic cells (Smith *et al.*, 2013), keeping the immune system in check. However, disruptions due to antibiotics, poor diet, stress, or infections lead to dysbiosis, a microbial imbalance that triggers pro-inflammatory cytokines (Tilg & Kaser, 2011).

The chronic low-grade inflammation is implicated in autoimmune diseases like Crohn’s disease, type 1 diabetes, and even allergies (Kamada *et al*., 2013, Lynch & Pedersen, 2016) Moreover, the gut microbiota influences systemic immunity, reaching beyond the intestines to affect lungs, brain, and skin (Belkaid & Harrison, 2017).

Diet is a key modulator. High-fiber diets increase microbial diversity, while Western-style diets rich in fats and sugars reduce beneficial microbes (David *et al.*, 2014). Probiotics and fermented foods restore microbial balance and help reinforce immune tolerance (Ouwehand, 2002). Therefore, supporting the gut microbiome through targeted nutrition is not only essential for gut health, but also for preventing immune-related and inflammatory diseases (Figure 6).

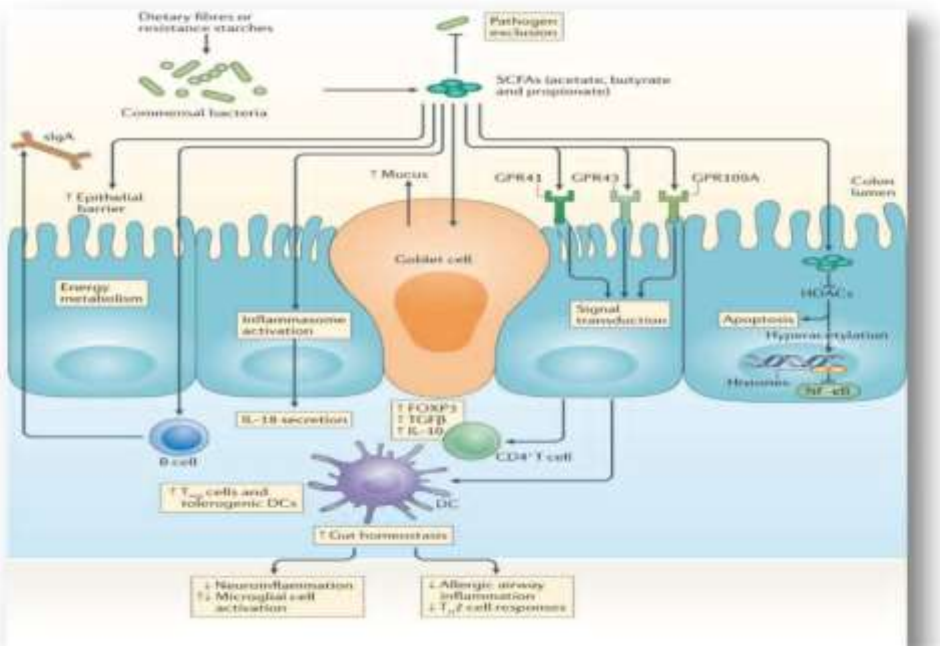

Figure 7. Interaction between gut microbiota and immune system (Rooks & Garrett, 2016).

Personalized nutrition through gut microbiome

Recent developments in science and medicine have led to the understanding that there might not be a single, one-size-fits-all diet and that differential human responses to dietary inputs may rather be driven by unique and quantifiable host and microbiome features (Kolodziejczyk *et al*., 2019). Differences in biochemistry, metabolism, genetics, and microbiota contribute to the dramatic inter-individual differences observed in response to nutrition, nutrient status, dietary patterns, timing of eating, and environmental exposures (Bush *et al*., 2020).

The primary objective of personalized nutrition is to maintain or enhance health by utilizing pertinent individual information to provide tailored nutritional products and services. The idea that individualizing nutritional advice, products, or services is based on two main observations, namely: 1) differential responses to foods/nutrients are dependent on genotypic or phenotypic characteristics, and 2) differential responses in eating behavior are dependent on personal preferences, barriers, and objectives (Vandeputte, 2020).

Although, personalized nutrition can be a valuable tool for shaping the gut microbiome by incorporating functional foods into our diets, they are designed to supply vital nutrients that may offer the host extra health advantages, we can potentially positively influence the growth of beneficial bacteria in our gut so Functional foods typically contain bioactive compounds, such as antioxidants or prebiotics, that have been shown to promote health in different ways (Sangma, 2024).

All things considered, functional foods acquire additional functionalities (generally connected to health promotion or illness prevention) by adding new ingredients or more of the current ingredients, such as probiotics and prebiotics (Tsigalou *et al*., 2020). Prebiotics and probiotics are excellent examples of functional substances added to food matrices for the development of gut health. Prebiotics are substrates that are preferentially used by microorganisms within the host to provide health advantages to the host, whereas probiotics are live microbes that, when administrated in adequate quantities, deliver a health benefit to the host (de Carvalho *et al.*, 2023).

Furthermore, With the almost explosive developments in microbiome research, the intestine, and the role of the diet in intestinal and overall health has gained attention in the academic world and the public domain not seen in decades. In addition, Moreover, alterations in bacterial composition identified using 16sRNA profiling in stool samples have been observed in numerous disorders, leading to the microbiota emerging as a target for intervention or potential treatment (Simon *et al*., 2023).

Dietary Tips for a Healthy Microbiome

A healthy gut microbiome is essential for digestion, immune function, and overall well-being. Diet plays a key role in shaping the balance of gut bacteria. Eating a variety of fiber-rich, plant-based, and fermented foods can promote beneficial microbes, while processed and high-sugar diets may disrupt microbial health (Valdes *et al*., 2018). As microbiome plays a crucial role in digestion, immune function, and even mental health. Table 3 shows some dietary tips to promote a healthy microbiome.

Table 3. Some essential dietary tips for a healthy microbiome.

Dietary Tip	Descriptions & Benefits	Food	References
Eat a variety of fiber-rich foods	Dietary fiber acts as a prebiotic, feeding beneficial gut bacteria and increasing microbial diversity	Vegetables, fruits, whole grains	(Sonnenburg & Sonnenburg, 2019; Makki *et al*., 2018)
Include fermented foods	Fermented foods provide live probiotics that help maintain a balanced gut microbiota	Yogurt, kimchi, sauerkraut	(Marco *et al*., 2017; Hill *et al*., 2014)
Limit intake of processed and sugary foods	Excess sugar and processed foods can reduce beneficial bacteria and promote inflammation	Avoid sugary snacks, sodas	Zmora *et al*. 2019; David *et al*., 2014)

Follow a Mediterranean-style diet	This diet is rich in fiber, healthy fats, and polyphenols, supporting beneficial microbiota and SCFA production	Olive oil, nuts, fish, vegetables	(De Filippis *et al*., 2016; Garcia-Mantrana *et al*., 2018)
Stay well hydrated	Adequate water intake supports digestion and a healthy gut environment	Water, herbal teas	(Chen *et al*., 2022)
Consume diverse plant-based foods	Diverse plant foods encourage a wider variety of gut bacteria, linked to better health outcomes	Legumes, fruits, vegetables	(Johnson *et al.*, 2019; Conlon & Bird, 2014)

CONCLUSION

The gut microbiome has a substantial influence on both health and disease, by affecting our physiological, psychological and immunological systems, as well as it has an essential role in digestion, metabolism and nutritional functions. These microbes can be affected by environment, lifestyle, genetic and diet. Thus, nutrition and dietary treatments such as prebiotics and probiotics are important to modulate gut microbiota and preventing disease. Also, a key finding highlight that the use of medication and antibiotics affected gut microbiome composition and function. Recent studies found that personalized nutrition can be the key of gut health by adding functional foods into our diet to promote gut health.

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Comparison of ANN and RSM in Predicting SO2 and Quality of Dried Fruits

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ABSTRACT

Dried apricots are nutrient-dense foods rich in vitamins, dietary fiber, and antioxidants, with Türkiye ranking first globally in production and export volumes. Sulfur dioxide (SO_2) is commonly added as a preservative to maintain color, prevent microbial growth, and extend shelf life during drying and storage processes. Excessive SO_2 intake can trigger health issues like asthma attacks, necessitating strict regulatory limits and innovative reduction methods without quality loss. In this study, response surface methodology (RSM) and artificial neural networks (ANN) were used for the first time to model and optimize the ultrasonic washing conditions of apricots in order to compare and establish effective prediction models for total phenolic content, L* value and SO_2 content of dried apricots. With this purpose, dried apricots with an initial moisture content of 25 ±2% and containing 458 ± 14 ppm sulfur were sonicated up to 120 minutes using an ultrasonic bath (32 ± 5 kHz). A total of 19 experiments were performed to screen variables. The highest amount of TPC (149.12 mg GAE/100 g DW) and the lowest sulfur dioxide content (229.68 ppm) were obtained under optimal extraction conditions (40 min washing time, and 0.495 g/L solid to water ratio). It has been found that ultrasonic washing causes more color change and higher sulfur removal in apricots compared to conventional washing. The model with the lowest RMSE and the highest R^2 was selected with the "Levenberg-Marquardt" (trainlm) algorithm. Response values were close to the predicted values and indicated that ANN model has higher prediction accuracy than RSM.

Keywords: Neural networks, modeling, prediction methods, food science.

INTRODUCTION

Dried apricots occupy a significant position in global food markets due to their nutrient-dense composition, long shelf life, and broad consumer acceptance. They are rich sources of dietary fiber, minerals, vitamins A and C, and bioactive compounds such as carotenoids and polyphenols, contributing to their functional and health-promoting properties (Hepsağ *et al*., 2016). Türkiye is the world's largest producer and exporter of apricots, making the improvement of dried apricot quality and safety a priority for both domestic consumption and international trade (Poyraz & Gül, 2022).

Sulfur dioxide (SO_2) has long been used as a preservative in dried fruits due to its multifunctional roles: prevention of enzymatic browning, enhancement of color stability, microbial inhibition, and protection of antioxidant capacity. Despite these benefits, SO_2 poses health concerns. Sensitive populations, particularly individuals with asthma, may experience bronchoconstriction, allergic reactions, and gastrointestinal discomfort following high SO_2 exposure (Dordevic *et al*., 2023). Regulatory limits-typically 2,000–3,000 mg/kg for dried apricots-aim to minimize risks while maintaining product quality. However, consumers increasingly demand products with lower chemical preservatives, prompting research into SO_2 reduction strategies without compromising sensory and nutritional attributes.

Ultrasonic washing has emerged as a promising method to reduce surface bound SO_2 through cavitation, microstreaming, and enhanced mass transfer. Cavitation bubbles collapse near food surfaces, disrupting boundary layers and facilitating removal of surface contaminants and residual chemicals. Ultrasonication has also been shown to preserve bioactive compounds and improve antioxidant retention under optimized conditions (Bhargava *et al*., 2021). However, improper conditions may lead to pigment degradation, phenolic leaching, or textural changes, highlighting the need for predictive modeling to identify optimal processing parameters.

Modeling techniques enable the understanding and optimization of food processes. Two widely used approaches include Response Surface Methodology (RSM), a statistical technique that models relationships between independent variables and responses using polynomial equations, is effective for interpreting factor interactions but limited in capturing strong nonlinearity (Moghaddam & Khajeh, 2011) and Artificial Neural Networks (ANN), data-driven models inspired by biological neural networks. ANN excels at describing nonlinear, multidimensional relationships without requiring predefined mathematical structures (Patel & Brahmbhatt, 2016).

Comparative studies have shown ANN to outperform RSM in various food engineering applications, including drying kinetics, enzymatic reactions, extraction processes, and quality prediction. However, limited studies have evaluated their comparative performance in predicting SO_2 reduction in dried fruits, particularly under ultrasonic treatment. The objectives of this study were to (a) investigate the effects of ultrasonic washing time and washing solution concentration on SO_2 reduction and quality parameters (L*, TPC, DPPH), (b) develop predictive models using RSM and ANN, (c) compare the robustness, accuracy, and predictive capability of ANN versus RSM and (d) provide insights for optimizing ultrasonic washing conditions to balance SO_2 reduction and quality preservation.

MATERIALS and METHODS

Sample Preparation

Commercial dried apricots were obtained from local distributors and stored under ambient conditions until analysis. Prior to treatment, samples were inspected for uniformity, free from mold, physical defects, and excessive variability in size and color.

Ultrasonic Washing Treatments

Ultrasonic washing was performed using a 40 kHz ultrasound bath. Two independent variables were tested: washing time (10, 20, 30 and 40 minutes) and washing solution concentration prepared using varying levels (0.100–0.325 kg fruit/L water).

Measurement of Response Variables

SO_2 reduction (%)

Residual SO_2 was measured using the modified Rankine method. Sample extracts were titrated with 0.01 N iodine solution. SO_2 removal percentage was calculated based on initial and residual SO_2 levels (Yamagata &Kim, 1983).

*Color measurement (L)**

Color was quantified using a tristimulus colorimeter calibrated with standard white and black tiles. L* values indicate lightness (0 = black, 100 = white). Color preservation is critical for consumer acceptance (Mello et al., 2021).

Total phenolic content (TPC)

TPC was measured using the Folin-Ciocalteu method. Results were expressed as mg gallic acid equivalents (GAE) per 100 g dried apricot ((Jiskani *et al.*, 2021)

DPPH radical-scavenging activity

DPPH antioxidant capacity was assessed by monitoring absorbance decreases at 517 nm. Results were expressed as percentage inhibition using standard equations (Csepregi *et al.*, 2016).

RSM Modeling

Experimental data were analyzed using Design-Expert 11. A second-order polynomial was fitted:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{12} X_1 X_2$$

ANOVA assessed model significance. Model fit was evaluated using R^2, Adjusted R^2, Predicted R^2, RMSE and Lack-of-fit test. Contour and 3D surface plots illustrated interactions.

ANN Modeling

The ANN model in this study was built using the Box-Behnken Design with 16 experimental runs and three input variables. The experimental data was divided into three sets: for training (12 samples), testing (2 samples), and validation (2 samples). The models' parameters were adjusted by using the training set so the network could perform calculations. The test set was used to evaluate a model's ability to predict unseen data, while the validation set was used to assess network stability and prevent overfitting. To train the network, the Levenberg–Marquardt optimization algorithm was employed in conjunction with the back propagation learning method. The ANN model was developed as a multilayer perceptron using MATLAB software (version R2025b). ANN architecture was designed two input variables, 10 hidden layers of neurons, and one output layer.

Performance metrics included:

$$RMSE = \sqrt{\frac{1}{n}\sum(y_{exp} - y_{pred})^2}$$

$$R^2 = 1 - \frac{\sum(y_{exp} - y_{pred})^2}{\sum(y_{exp} - \bar{y})^2}$$

Epoch limits and stopping criteria prevented overfitting.

RESULTS and DISCUSSION

The result of experimental design is demonstrated in Table 1. Ultrasonic washing significantly influenced SO_2 removal and SO_2 decrease in dried fruits. Longer washing times increased removal rates due to enhanced mass transfer. Higher solution concentrations also improved removal efficiency.

Table 1. Result for experimental design.

Run	Concentration (kg fruit/L water)	Time (min.)	L*	TPC (mgGAE/ 100 g)	% SO_2 decrease	DPPH (%)
1	0.250	40	46.47	127.83	49.43	78.66
2	0.100	20	46.32	140.09	43.66	72.12
3	0.250	30	46.54	131.82	46.45	75.34
4	0.100	10	44.65	153.42	45.01	86.13
5	0.250	20	43.48	154.46	44.78	78.35
6	0.175	30	45.29	128.65	50.71	73.29
7	0.100	30	49.89	123.77	46.11	70.34
8	0.325	40	48.12	130.33	48.55	69.67
9	0.175	40	49.87	125.00	50.03	75.87

10	**0.250**	**10**	40.97	165.45	43.36	**89.47**
11	0.175	10	41.66	146.09	41.70	81.21
12	**0.100**	**40**	50.11	120.55	51.44	67.29
13	0.175	20	45.54	143.99	43.86	72.25
14	0.325	10	42.12	161.12	36.89	84.47
15	0.325	20	43.17	145.20	38.08	76.28
16	0.325	30	46.74	140.21	38.85	73.56

L* values initially increased due to the removal of surface bound SO_2 pigments. Excessive washing caused slight brightness loss. ANN captured these nonlinear behaviors more precisely than RSM. Moderate reductions in TPC occurred due to solubilization. ANN captured the nonlinear relationship between time/concentration and TPC retention. DPPH exhibited similar trends to phenolics. Extended washing caused declines due to bioactive compound diffusion. L* values varied between 40.97 and 50.11, with moderate washing (20–30 min) generally preserving lightness, whereas some extreme combinations led to slight brightness losses, confirming the trade-off between SO_2 removal and color preservation. TPC and DPPH responses followed similar patterns: phenolic content decreased at longer times and higher concentrations, whereas shorter treatments (10–20 min) at moderate concentration retained higher TPC (up to about 165 mg GAE/100 g) and antioxidant capacity (>85% DPPH), reflecting diffusion-driven leaching of bioactives under harsher washing conditions.

Optimum conditions were found 20 minutes and 0.250 for ultrasound time and concentration. According to these optimum conditions validation studies were conducted and predicted values with ANN and RSM models, and observed values were shown in Table 2. Under the selected optimum (0.250 kg fruit/L, 20 min), experimental L* (43.48), TPC (154.46 mg GAE/100 g), DPPH (78.35%), and SO_2 decrease (44.78%) confirmed that this setting achieved a balanced compromise between SO_2 reduction, color stability, and phenolic/antioxidant retention. At these conditions, ANN predictions for all responses were almost identical to the observed values (differences ≤ about 6 units for TPC and <0.15 units or percentage points for L*, DPPH, and SO_2 decrease), whereas RSM systematically deviated more, particularly for TPC and DPPH, demonstrating better point-wise accuracy and robustness of the ANN model.

Table 2. Predicted and observed values at optimum conditions.

		Observed Value	Predicted value ANN	Predicted value RSM
Optimum parameters Concenration;0.250 Time: 20 min	**L***	43.48	43.47	44.27
	TPC (mgGAE/ 100 g)	154.46	160.88	147.14
	DPPH (%)	78.35	78.49	71.96
	%SO2 Decrease	44.78	44.74	43.07

Table 3. Comparison of ANN and RSM.

	RSM		**ANN**	
	R^2	RMSE	R^2	RMSE
L*	0.7817	1.8220	0.9542	0.7581
TPC (mgGAE/ 100 g)	0.8631	6.0671	0.9091	2.4790
DPPH (%)	0.5164	3.6331	0.9855	0.1147
%SO2 decrease	0.8531	1.1661	0.9934	0.2366

Table 3 summarized the ANN consistently achieved lower RMSE, higher predictive power and better generalization, however RSM remained valuable for understanding factor interactions. RSM predicted moderate increases; however, ANN predictions were almost identical to experimental values. Table 3 further highlighted the superiority of ANN, with higher R^2 and lower RMSE for every response: for L*, ANN achieved $R^2 \approx 0.95$ vs. ≈ 0.78 for RSM and reduced RMSE from about 1.82 to 0.76 units; for TPC, R^2 improved from ≈ 0.86 to ≈ 0.91 and RMSE dropped from about 6.07 to 2.48 mg GAE/100 g; for DPPH, ANN dramatically increased R^2 from ≈ 0.52 to ≈ 0.99 and lowered RMSE from around 3.63 to 0.11%; and for SO_2 decrease, R^2 rose from ≈ 0.85 to ≈ 0.99 with RMSE decreasing from about 1.17 to 0.24%. These metrics indicate that ANN not only fits the experimental data more closely but also generalizes better across the design space, especially for highly nonlinear responses such as antioxidant activity and SO_2 removal.

CONCLUSION

In this study, ultrasonic washing proved effective for reducing SO_2 in dried apricots by approximately 40-51% while retaining acceptable color and functional quality, provided that time and fruit-to-water ratio were carefully controlled. The optimum of 0.250 kg fruit/L for 20 min yielded a practical industrial compromise, achieving nearly 45% SO_2 reduction with only moderate losses in TPC and DPPH and without severe color degradation, suggesting that this condition is suitable for cleaner-label processing strategies.

The modeling results showed that ANN clearly outperformed RSM in describing the complex, nonlinear effects of ultrasound time and solution concentration on L*, TPC, DPPH, and SO_2 decrease, as evidenced by consistently higher R^2 and lower RMSE values. While RSM remains valuable for interpreting factor effects and interactions mechanistically, ANN is more appropriate when the primary goal is accurate prediction and process optimization over a multidimensional design space, particularly for quality attributes governed by coupled mass-transfer and degradation phenomena. Taken together, these findings support the integration of ANN-based decision tools with experimentally validated ultrasonic washing protocols to design dried apricot processes that meet regulatory and consumer demands for lower SO_2 levels without compromising product quality.

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Optimization-Driven Strategies for High-Value Utilization of Food Waste

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ABSTRACT

Food waste valorization has emerged as a critical strategy for addressing global challenges related to resource depletion, environmental burden, and food system sustainability. Converting discarded agricultural and food-processing by-products into high-value ingredients, such as bioactive compounds, functional proteins, dietary fibers, and biofuels, offers both economic and ecological benefits. However, the efficiency of these valorization processes depends heavily on selecting optimal processing conditions that maximize yield, functionality, and quality while minimizing cost and energy use. In recent years, mathematical optimization tools, including Response Surface Methodology, Artificial Neural Networks, and multi-objective optimization algorithms, have played a pivotal role in advancing food waste valorization. These techniques enable precise modeling of complex, non-linear systems, support predictive decision-making, and reduce the need for trial-and-error experimentation. By integrating computational optimization with innovative extraction, fermentation, and drying technologies, researchers can significantly enhance process performance and scalability. This approach not only accelerates the development of sustainable value-added products but also supports circular economic principles and promotes cleaner production. Overall, the combination of food waste valorization and advanced optimization offers a promising pathway toward reducing waste, improving resource efficiency, and creating novel opportunities for the food, nutraceutical, and bioenergy industries.

Keywords: Artificial neural networks, modeling, prediction methods, valorization.

INTRODUCTION

Global food waste represents both a critical sustainability challenge and a major opportunity for resource recovery. Estimates suggest that roughly one-third of food produced for human consumption is lost or wasted along the supply chain, corresponding to about 1.3 billion tonnes annually, with fruits, vegetables and processing residues contributing substantially to these losses. Beyond the ethical and economic implications, this waste is associated with significant greenhouse gas emissions, land and water use, and misallocation of energy and inputs (FAO, 2019).

At the same time, food waste streams and byproducts are rich in bioactive compounds, macro- and micronutrients, and structural biopolymers. Fruit peels, seeds, pomace, cereal bran and other residues can provide polyphenols, carotenoids, anthocyanins, dietary fibers, proteins, lipids and fermentable carbohydrates suitable for functional foods, nutraceuticals, natural preservatives, bioplastics and biofuels (Ayala-Zavala *et al.*, 2011). Numerous studies have shown that these materials can be converted into valued ingredients using tailored extraction, drying, bioprocessing and separation technologies, thereby supporting circular bioeconomy concepts and reducing environmental burdens (Teigiserova *et al*., 2020).

However, the efficiency and feasibility of valorization processes are highly sensitive to processing conditions such as temperature, time, solvent composition, pH, pressure, and particle size. Non-optimized conditions often lead to low yields, degradation of heat- or oxygen-sensitive compounds, excessive solvent and energy use, and poor product stability. To overcome these limitations, optimization-driven strategies based on mathematical modeling and experimental design are increasingly used. Statistical tools such as response surface methodology (RSM) and data-driven tools such as artificial neural networks (ANN) can model the complex, non-linear behavior typical of food systems and identify robust operating windows (Kashyap *et al*., 2021; Patel & Brahmbhatt, 2016).

This article provides a focused overview of optimization-driven food waste valorization. First, the role of optimization is discussed in the context of process performance, cost and environmental impact. Second, major categories of high-value products obtainable from food waste are summarized. Third, key valorization technologies are briefly described. Finally, the capabilities of RSM and ANN are compared, and a case study on freeze-drying of olive seeds illustrates their practical application.

The Purpose of Optimization in Food Waste Valorization

Food waste valorization processes typically involve many interacting variables that jointly influence extraction yield, product quality, stability and feasibility. Examples include solvent type and concentration, solid-to-liquid ratio, temperature, time, pH, ultrasound or microwave power, drying temperature and pressure, and airflow rate. These variables often exhibit non-linear effects and interactions; for instance, higher temperature can increase mass transfer but accelerate degradation of phenolics or pigments (Galanakis, 2012, Manousaki *et al*., 2016).

Without systematic optimization, processes may show:

- Reduced recovery of target compounds
- Excessive solvent, water or energy consumption
- Loss of antioxidant activity and color
- Poor texture or functional properties
- Low economic viability and scalability

Optimization methods help identify process conditions that maximize one or more responses (such as phenolic content, antioxidant capacity or oil yield) while simultaneously constraining cost, time or environmental impact. Studies using experimental design and modeling frequently report substantial gains in extraction efficiency when compared with unoptimized or one-factor-at-a-time approaches (Jiskani *et al*., 2021).

In addition, optimization supports scale-up and standardization. By quantifying how process variables influence outputs, models provide a rational basis for adjusting conditions when moving from lab- to pilot- or industrial-scale equipment. This improves reproducibility and facilitates regulatory compliance for food and nutraceutical products derived from waste streams (Mirabella *et al*., 2014).

High-Value Products Derived from Food Waste

Bioactive compounds

Many fruit and vegetable byproducts contain high levels of phenolic acids, flavonoids, tannins, carotenoids, anthocyanins and betalains. These compounds exhibit antioxidant, anti-inflammatory and antimicrobial activities and are attractive as natural preservatives, colorants and functional ingredients in foods, beverages, cosmetics and pharmaceuticals. Efficient extraction and stabilization of these molecules are key goals of optimization studies.

Proteins and bioactive peptides

Seed cakes, legume hulls and cereal byproducts can provide proteins and hydrolyzed peptides with nutritional and bioactive properties such as antihypertensive or antioxidant activity. Optimized enzymatic hydrolysis, membrane separation and drying can convert these wastes into plant protein concentrates or peptide ingredients for supplements and high-protein foods.

Dietary fibers

Peels, pulps and bran fractions are major sources of soluble and insoluble dietary fibers that can improve water- and oil-holding capacity, textural properties and physiological effects such as glycemic control and gut health. Optimized milling, drying and fractionation can tailor particle size and functional properties for incorporation into bakery products, meat analogues, beverages and fiber-enriched supplements.

Pigments

Anthocyanins from berry or grape skins, carotenoids from tomato and carrot residues, and betalains from beet by-products can be recovered as natural colorants with antioxidant activity. Optimization of extraction pH, solvent composition, temperature and light exposure is essential to maximize color intensity and stability.

Oils and lipids

Oils rich in unsaturated fatty acids, tocopherols and phytosterols can be obtained from fruit seeds and pits such as grape, olives, tomato and stone fruits. Process optimization addresses solvent choice, pressing conditions, temperature and refining steps to preserve bioactive lipids and minimize oxidation.

Biopolymers

Pectin, starch, cellulose, hemicellulose and lignin from peels, pomace and cereal residues can be used to produce edible coatings, biodegradable packaging and structured ingredients. The extraction and modification of these polymers depend critically on pH, temperature and enzyme dosage, which are typically optimized to balance yield and functional properties.

Fermentation feedstocks

Carbohydrate-rich wastes serve as substrates for microbial fermentation to produce biogas, organic acids, ethanol, enzymes and single-cell protein. Here, optimization targets pretreatment, nutrient supplementation, inoculum levels, pH and temperature to maximize productivity and substrate utilization.

Valorization Technologies

A wide range of technologies can be applied individually or in combination to convert food waste into valued products. These include:

- **Extraction techniques** such as conventional solvent extraction, ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE) and supercritical CO_2 extraction. Process variables typically optimized are solvent type and concentration, temperature, time, solid-to-solvent ratio and energy input (Arya & Kumar, 2021).
- **Drying technologies** such as freeze-drying, spray-drying, vacuum drying and hot-air drying. Optimization focuses on preserving heat-sensitive bioactives and pigments while achieving adequate moisture reduction and powder properties (Aydar *et al.*, 2025).
- **Thermal and non-thermal processes** including ohmic heating, cold plasma, high-pressure processing and pulsed electric fields, which can enhance mass transfer or inactivate enzymes and microbes with minimal quality loss when properly optimized (Guragain *et al*., 2021).
- **Bioprocessing** such as fermentation and enzymatic hydrolysis, where pH, temperature, substrate concentration, enzyme dosage and time are tuned to generate desired metabolites, peptides or structural modifications (Xie *et al.*, 2022).

In all cases, systematic experimental design and modeling approaches are crucial to identify suitable operating regions and to understand tradeoffs between yield, quality and cost.

Optimization Tools: Response Surface Methodology and Artificial Neural Networks

Response surface methodology is a statistical approach that combines designed experiments with polynomial modeling to describe the relationship between a response and several quantitative variables. Central composite and Box-Behnken designs are commonly used to efficiently explore factor spaces with a limited number of runs. The fitted quadratic models provide estimates of main effects, interactions and curvature, and are readily visualized through contour and surface plots (Refinery & Braimah, 2016). RSM offers several advantages in food waste valorization such as reducing experimental effort compared to full factorial designs, yielding interpretable equations that facilitate understanding of factor effects and supporting multi-response optimization via desirability functions (Aydar, 2018).

However, its performance decreases when system behavior deviates strongly from quadratic forms or when responses exhibit pronounced non-linearities and discontinuities. In such situations, prediction accuracy can be limited and extrapolation risky. Artificial neural networks are data-driven models capable of approximating complex, non-linear mappings between inputs and outputs without specifying an explicit functional form. Multilayer perceptron (MLP) networks with one or more hidden layers are frequently used in food engineering. Model training involves adjusting connection weights to minimize the difference between predicted and experimental data, often using algorithms such as back-propagation with Levenberg–Marquardt optimization (Kaveh *et al.*, 2018; Patel & Brahmbhatt, 2016). Key advantages of ANN include high predictive accuracy even for strongly non-linear, multidimensional systems, ability to handle noisy or incomplete data and flexibility to incorporate additional variables or outputs without redefining model structure (Lukić *et al*., 2019; Singh *et al*., 2021).

Rather than being mutually exclusive, RSM and ANN can be viewed as complementary tools. RSM provides insight and simple equations useful for interpretation and preliminary optimization, whereas ANN excels in predictive tasks and can capture more complex relationships. In some studies, RSM is used to design experiments and define the factor space, while ANN is trained on the resulting data to refine predictions and support robust decision-making (Youssefi *et al*., 2009).

CONCLUSION

Food waste and byproducts represent valuable reservoirs of bioactive compounds, nutrients and structural biopolymers that can be transformed into high-value ingredients and bio-based products. Realizing this potential requires not only appropriate technologies, such as advanced extraction, drying and bioprocessing, but also rigorous optimization of operating conditions. Statistical and computational tools, particularly response surface methodology and artificial neural networks, provide powerful means to model complex systems, improve predictive capability and guide multi-objective process design.

Evidence from valorization studies, including freeze-drying of olive seeds, shows that optimization can significantly increase recovery of antioxidants and other target compounds while reducing resource use and environmental impact. RSM remains a valuable tool for experiment planning and mechanistic interpretation, whereas ANN offers superior predictive performance in non-linear, multi-factor processes. Integrating these approaches within a circular bioeconomy framework can support cleaner production, enhanced resource efficiency and the development of innovative food, nutraceutical and bioenergy products derived from what is currently treated as waste.

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Drying Kinetics and Antioxidant Properties of Mint Leaves (*Mentha spicata* L.)

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ABSTRACT

Mint leaves (*Mentha spicata* L.) are among the most widely used herbs in culinary, traditional medicine, and industrial applications. This plant, with its characteristic green colour, has a considerable content of bioactive compounds and essential oils. These compounds justify its numerous uses and its incorporation into various formulations for therapeutic and well-being purposes. The mint leaves have a high water content (87.16%), which explains their high perishability and the need to dry them. The present study aimed to investigate the effect of drying temperatures (in the shade, at 40°C, 60°C, and 80°C) on the total phenolic compound (TPC) and total flavonoid content (TF), as well as on the antioxidant activity (DPPH, FRAP) of mint leaves. Furthermore, the drying kinetics were modelled and compared to several mathematical models. The TPC content, TF content, and antioxidant activity (DPPH, FRAP) of dried mint leaves were significantly higher in the shade than at 40°C, 60°C, and 80°C. This phenomenon was linked to the effect of increasing temperature on the content and activity of bioactive compounds. It was confirmed by the observed negative linear correlation between the content of bioactive compounds and antioxidant activity. Modelling of the different drying conditions showed that the Midilli model was the most suitable and accurately described the behavior of mint leaves during drying. These findings highlight the importance of selecting a suitable drying temperature to preserve the functional quality of mint leaves.

Keywords: Mint leaves, drying, bioactive compounds, antioxidant activity, kinetics, modelling.

INTRODUCTION

Mint (*Mentha spicata* L.) is an aromatic plant widely valued across culinary, medicinal, and industrial sectors due to its distinctive aroma, vibrant green colour, and richness in bioactive constituents (Ayadi *et al.,* 2014; Karakaplan *et al*., 2019). Traditionally, mint leaves have been used for digestive, antimicrobial, and refreshing purposes, while modern applications extend to cosmetics, pharmaceuticals, and functional foods (Soleimani *et al*., 2022; Tavaszi-Sárosi *et al*., 2025). These diverse uses are largely attributed to the plant's high content of phenolic compounds, flavonoids, and essential oils, which exhibit strong antioxidant properties and contribute to its therapeutic relevance (Soleimani *et al*., 2022; Tavaszi-Sárosi *et al.*, 2025; Hedayati *et al.*, 2025).

Despite its benefits, fresh mint is highly perishable owing to its elevated moisture content, making appropriate post-harvest processing essential for maintaining quality and extending shelf life. Drying remains one of the most common preservation methods; however, the choice of drying temperature plays a critical role in determining the retention of bioactive compounds and the overall functional quality of the final product (Ayadi *et al*., 2014; Kaveh *et al*., 2024). Excessive heat may degrade thermolabile constituents, while inadequate drying may compromise storage stability.

In this context, evaluating the impact of different drying temperatures on the chemical composition and antioxidant potential of mint leaves is crucial for optimizing processing conditions. Additionally, understanding the drying behavior through mathematical modeling provides important insights for designing efficient drying systems and predicting product quality. Therefore, the present study investigates the influence of various drying temperatures on the total phenolic content, total flavonoid content, and antioxidant activity of mint leaves, while also assessing the suitability of different drying models to describe their drying kinetics as well as their rehydration. This work would allow pilot producers or manufacturers to choose the appropriate conditions to obtain a product or ingredient while preserving its bioactivity.

MATERIAL and METHODS

Plant Material and Physical Characterization

Fresh mint leaves were purchased from the local market (Samsun, Turkey) and immediately processed. The moisture was measured at 70°C during 24h, using a drying oven (NÜVE, FN 500P, Turkey). Water activity (a_w), for fresh mint leaves was determined using a calibrated water activity meter at 25 °C ± 0.1 (Aqualab, 4TE, USA). The CIE L*a*b* scale was used to measure leaves colour using a digital colorimeter (Model CR-400, Minolta-Konica Sensing Inc., Japan). The length and width of leaves are measured by digital calliper (TRESNA, Series: EC16, China).

Total Phenolic Content (TPC)

TPC was evaluated by the Folin-Ciocalteu method adopted from Singleton and Rossi (1965) with some modifications. Briefly, 150 µL of samples were mixed with 750 µL of 10% Folin-Ciocalteu reagent (5 min) and 600 µl of 7.5% Na_2CO_3. The mixture was kept in the dark for 2 h and the absorbance was read at 760 nm. TPC was expressed as mg gallic acid equivalent per g (mg GAE/g).

Total Flavonoid Content (TFC)

The TFC was determined using a modified protocol (Lakka *et al*., 2019). 1 mL of the diluted solution was combined with 0.3 mL of 5% $NaNO_2$ and left to stand for 5 min, followed by the addition of 0.5 mL of 5% $AlCl_3$. The mixture was kept for 6 min before adding 0.5 mL of 1 M NaOH. After 10 min, the absorbance was read at 510 nm. The TFC was estimated based on a calibration curve using epicatechin as standard. The results were given as mg epicatechin equivalents (EpE) g^{-1} db.

Determination of the DPPH Radical Scavenging Activity

The DPPH radical scavenging was determined using a modified method (Hossain & Shah, 2015). Briefly, an aliquot of 50 µL sample was added with 1 mL DPPH solution (0.06 mM in 80% methanol). The mixture was shaken and left to stand in dark for 1 h until the reaction completed. Thereafter, the absorbance at 517 nm was recorded. The DPPH solution was used as control. The reduction ratio of DPPH was determined with the following equation:(1) where Ac = Absorbance of control and As = Absorbance of extract. The DPPH radical scavenging activity in each extract was calculated from a calibration curve using Trolox as a standard. The results were given as mmol Trolox equivalent (TE) g^{-1} db.

Determination of Ferric Reducing Antioxidant Power (FRAP)

FRAP assay was performed according to the procedure of Shang *et al*. (2019). Briefly, an aliquot of 50 µL volume of sample was mixed with 950 mM of FRAP solution constituted of 100 mM acetate buffer: 10 mM $FeCl_3$: 10 mM TPTZ (2,4,6-tripyridyl-s-triazine). The assembly was shaken for about 5 min and the absorbance was read at 593 nm against a blank. The FRAP values of the extracts were calculated from the calibration curve using $FeSO_4$ as a standard. The results were given as mmol Trolox equivalent (TE) g^{-1} db.

Drying Techniques and Modelling

Mint leaves were dried to a constant weight using shade drying (≈ 25 °C) and at 40 °C, 60 °C and 80 °C using convective drying (Eksis Makina, Turkey) at 0.75 m/s (air speed) and 3 rpm (rotation of trays).

The drying curves of all dried samples were modelled according to the empirical models in Table 1. The moisture content ratio (MR) versus time (hour) of the experimental data was fitted using the previous models. The MR is dimensionless and is calculated as follows:

$$MR=\frac{M(t)-M_e}{M_0-M_e} \quad (1)$$

Where, M(t) is the moisture content in dry basis at time (hour), M_e is the moisture content in dry basis at equilibrium and M_0 is the initial moisture content (t=0).

Table 1. Empirical models applied to drying curves (Ghellam *et al*., 2022).

	Model name	Model equation
1	Newton	MR=exp(-kt)
2	Page	MR= exp(-kt^n)
3	Modifed Page	MR=exp[(-kt) ^n]
4	Henderson & Pabis	MR=a exp(-kt)
5	Logarithmic	MR=a exp(-kt) +b
6	Two-term	MR=a exp(-kt) +b exp(-gt)
7	Two-term exponential	MR=a exp(-kt) + (1-a) exp(-kat)
8	Wang & Singh	MR= 1+(at) +bt^2
9	Approximation of Diffusion	MR=a exp(-kt) + (1-a) exp(-kbt)
10	Verma et al.	MR=a exp(-kt) + (1-a) exp(-gt)
11	Modified Henderson & Pabis	MR=a exp(-kt) +b exp(-gt) +c exp(-ht)
12	Logistic	MR= b/(1+a exp(kt))
13	Midilli	MR= a exp(-k(t^n)) +(bt)
14	Aghabashlo model	MR= exp(-kt/(1+gt))

MR=moisture ratio (dimensionless); t= time; a, b, c, g, h and k = model constants.

Rehydration and Modelling

Rehydration was performed on dried samples to assess leaf behavior. These dried leaves were immersed in distilled water at 50 °C in a 1:40 ratio. Weighing was performed until a constant weight was obtained. Before weighing, the rehydrated leaves were gently wiped with absorbent paper to remove excess surface water.

$$M(t)=\frac{W(t)-W_0}{W_0} \quad (2)$$

Where, M(t) is the moisture content at t time g/g dry basis (d.b), W(t) is the sample weight (g) at t time, W_0 is the sample weight (g) at t= 0 min, Rehydration fitting curve was modelled according to the empirical models in Table 2.

Table 2. Empirical models applied to rehydration curve (Ghellam *et al*., 2022).

Model name	Model equation
Peleg	$M(t)=M_0+(t/(a+bt)))$
Exponential model	$M(t)= (M_0+((M_e - M_0) exp(-a t^k)))$
Exponential related equation	$M(t)= M_e (1-exp(-a t))$
First-order kinetic	$M(t)= M_e +(M_0 -M_e) exp(- a t)$
Weibull	$M(t)= M_e +(M_0 - M_e) exp(- ((t/b)^a))$
Vega-Gálvez model	$M(t)= a exp(- b/((1+t)^k))$

M(t) = the moisture content at t time g/g d.b; M_0 = the moisture content (g/g d.b) at t =0; M_e = the moisture content (g/g d.b) at equilibrium; t= time; a, b and k = model constants.

The modelling was coded using software MATLAB (2016a). The coefficient of determination (R^2), adjusted coefficient of determination (Adj-R^2), root mean square error (RMSE), sum of square error (SSE) and Chi-square (X^2) were all calculated to show the adequacy of models and the goodness of fitting between experimental data and predicted values. The best models are evaluated according to the highest values of R^2 and Adj-R^2, and the lowest values of RMSE, SSE, and X^2.

Statistical Analysis

Statistical significance ($p < 0.05$) between different drying parameters was analysed through analysis of variance (ANOVA) using SPSS statistics software (Version 23). The comparison of means was evaluated by Duncan test.

RESULTS and DISCUSSION

Physical Characteristics of Mint Leaves

The measured physical characteristics are presented in Table 3. The leaves have a high water content (87.18%) and significant water activity (0.9916). This high water content classifies them among the leafy vegetables with a high risk of spoilage, requiring immediate consumption or processing to minimize post-harvest challenges (Goel *et al*., 2025). Colour measurements revealed that the fresh leaves were dark green. They also show an average leaf length of 57.75 mm and width of 22.73mm.

Table 3. Physical characteristics of fresh mint leaves.

Parameter	
Moisture (n=3) %	87.18 ± 0.16
Water activity (n=6)	0.9916 ± 0.0035
Length (n=12) mm	57.75 ± 6.99
Width (n=12) mm	22.73 ± 2.91
Colour (n=12)	
L*	41.68 ± 1.77
a*	-16.95 ± 0.75
b*	19.76 ± 1.63

Total Phenolic Content, Total Flavonoids, Antioxidant Capacity of Dried Mint Leaves and Their Correlations

The total flavonoid (TFC) and total flavonoid (TF) content, as well as the antioxidant capacity of mint leaves dried at different temperatures, are shown in Figures 1 and 2. It is clear that shade drying preserved the total phenolic compound content, as well as the total flavonoid content, a class of phenolic compounds ($p < 0,05$). The drying temperature of 40 °C had a lesser impact on the phenolic compounds, while the other temperatures (60 °C and 80 °C) had a more pronounced effect.

Similarly, the antioxidant capacity (DPPH and FRAP) of dried mint leaves (Figure 2) was clearly influenced by the drying temperature ($p < 0,05$). Shade drying proved to be the most effective method for preserving high antioxidant capacity after drying, compared to drying at 40°C, 60°C, and 80°C. This is explained by the strong correlation between the content of phenolic compounds and their antioxidant activity.

Figures 3 and 4 show a strong negative linear correlation between the TPC or TF content and the antioxidant activity (DPPH and FRAP) of dried mint leaves. Increasing the drying temperature leads to a marked decrease in TPC and TF, resulting in a corresponding reduction in antioxidant activity. This highlights the importance of phenolic compounds and flavonoids in the antioxidant capacity of mint leaves, as well as their high sensitivity to thermal degradation. Furthermore, the regression equations derived from the graphs allow for the prediction of phytochemical content or antioxidant activity associated with different drying temperatures.

These results are consistent with numerous studies. Fresh mint (*Mentha spicata* L.) exhibits significant antioxidant capacity among the different mint species, thanks to its richness in bioactive phytochemicals (Sfaxi *et al*., 2025). Another study (Kaveh *et al*., 2024) showed that fresh leaves contain a considerable amount of phenolic compounds and exhibit associated antioxidant activity, properties strongly influenced by temperature variations during drying. This loss of bioactivity could be linked to a change in chemical structure or to binding with other compounds.

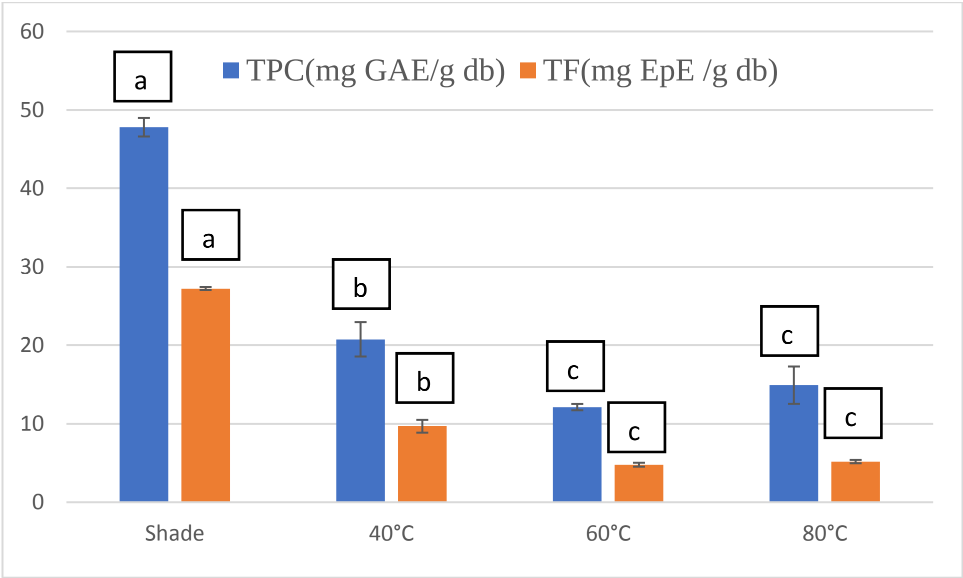

Figure 1. Total phenolic content and total flavonoids of dried mint leaves (in the shade, at 40°C, 60°C, and 80°C). Different letters (a, b, c) in the same color bars are significantly different (Duncan's test, $p < 0.05$).

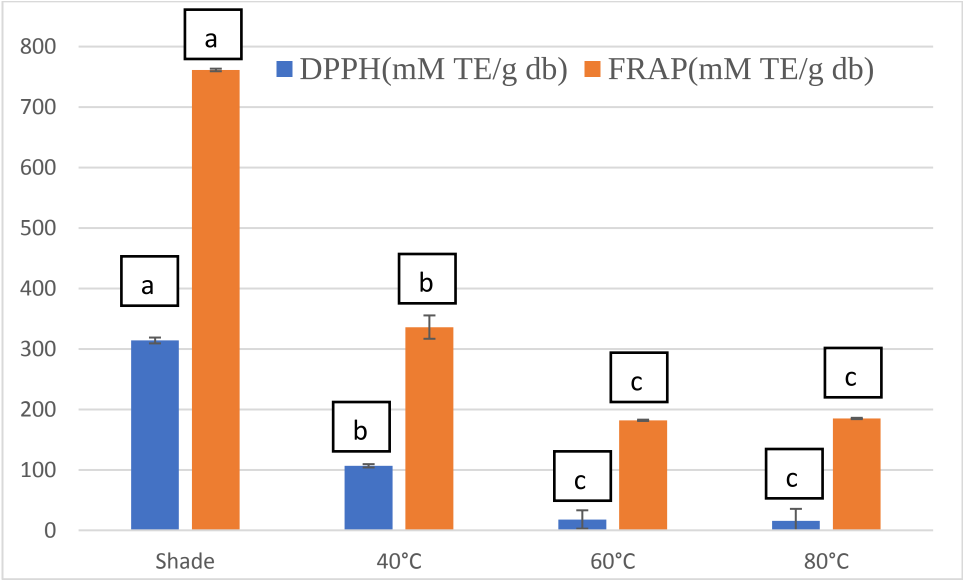

Figure 2. DPPH scavenging capacity and FRAP antioxidant capacity of dried mint leaves (in the shade, at 40°C, 60°C, and 80°C). Different letters (a, b, c) in the same color bars are significantly different (Duncan's test, $p < 0.05$).

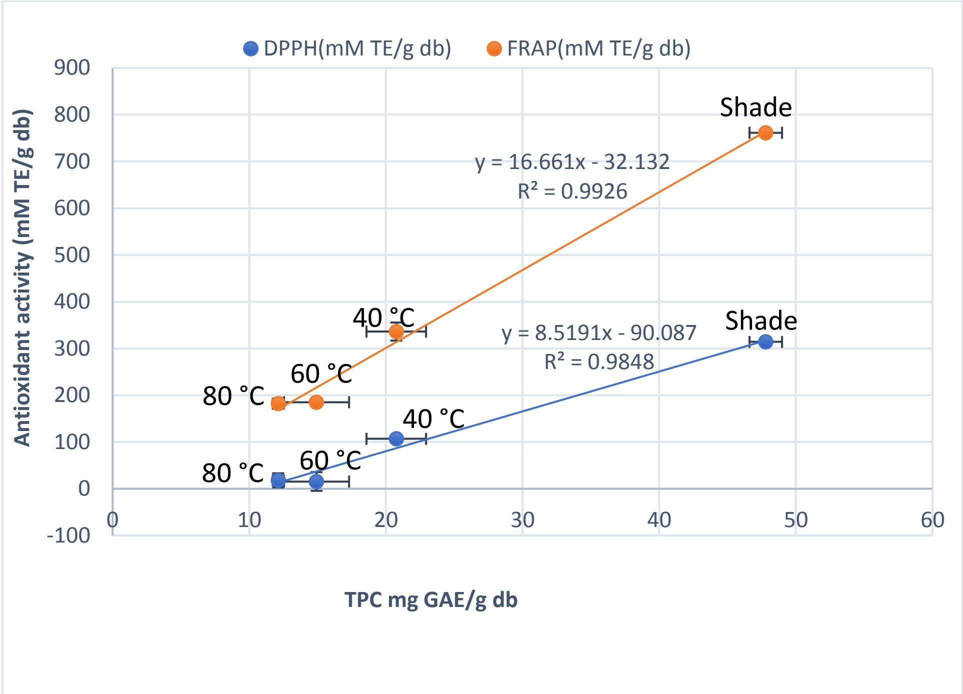

Figure 3. Linear correlation between total phenolic content and antioxidant activity (DPPH and FRAP) of dried mint leaves (in the shade, at 40°C, 60°C, and 80°C).

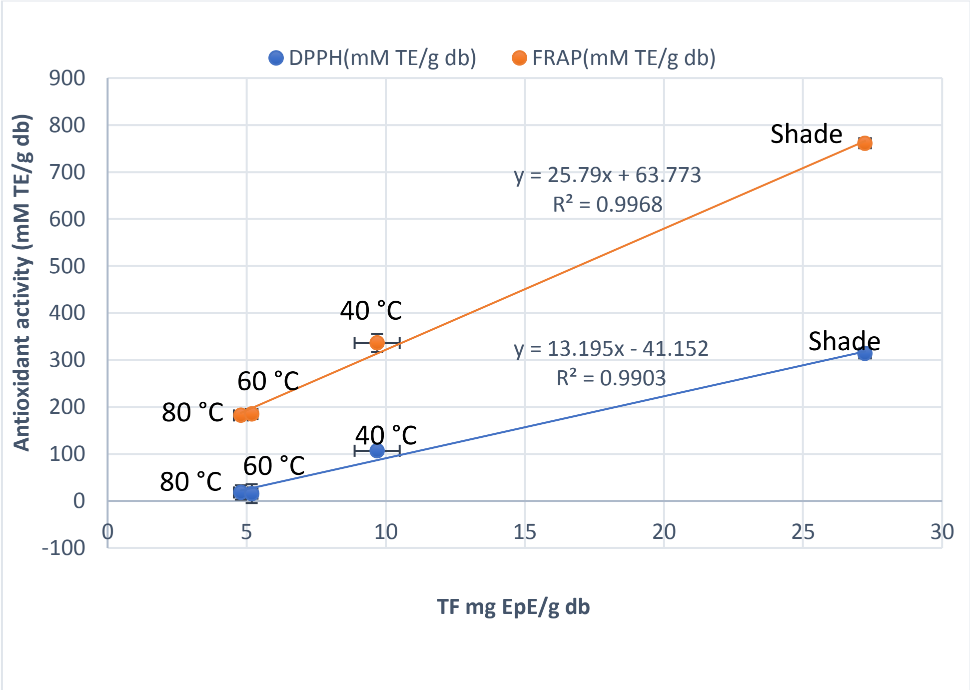

Figure 4. Linear correlation between total flavonoids and antioxidant activity (DPPH and FRAP) of dried mint leaves (in the shade, at 40°C, 60°C, and 80°C).

Drying Kinetics of Mint Leaves at Different Drying Temperatures

The different drying temperatures showed distinct trends (Figure 5). Drying in the shade was very slow and lasted more than two days. In contrast, the curve at 40°C indicated a drying time of less than 12 hours, while the temperatures of 60°C and 80°C exhibited the fastest kinetics (less than 5 hours). The last temperatures exhibited similar drying behaviour. It is clear that an increase in temperature accelerates water desorption. These drying behaviors are observed in many similar studies; on ambang leaves (Eneighe *et al*., 2020), stevia leaves (Kalsi *et al*., 2023) and *Pereskia* sp. leaves (de Alcântara *et al*., 2023).

The modeling of different temperature (in the shade, at 40°C, 60°C and 80°C) with the multiple empirical models, was presented in Table 4. As shown, Midilli model was the best fitted model describing the drying process for all temperatures. This was clear by the highest values of R^2, and the lowest values of RMSE, SSE, and X^2. These results are similar to those of numerous previous studies where the Midilli model proved to be the most representative, such as for savory (Taheri-Garavand *et al*., 2018) and mulberry (Martins *et al*., 2018) leaves.

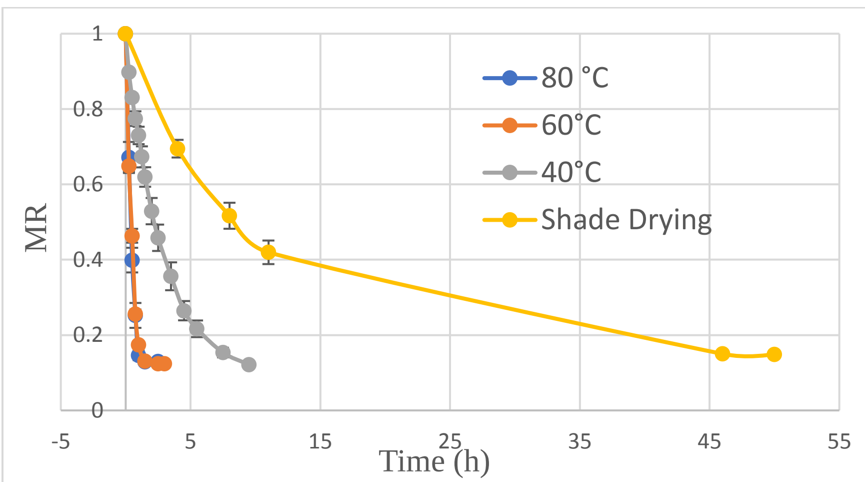

Figure 5. Drying kinetics of mint leaves at different drying temperatures (in the shade, at 40°C, 60°C and 80°C).

Table 4. Modeling results of mint leaf drying in the shade, at 40°C, 60°C and 80°C.

Model Name		Shade	40 °C	60°C	80°C
Newton	R^2	0.9390	0.9900	0.9580	0.9720
	SSE	0.0330	0.0110	0.0300	0.0190
	RMSE	0.0810	0.0290	0.0650	0.0560
	X^2	0.0070	0.0010	0.0040	0.0030

	Model constant	k =0.0761	k =0.2997	k =1.619'	k =1.7361
Page	R^2	0.9950	0.9980	0.9680	0.9730
	SSE	0.0030	0.0020	0.0230	0.0180
	RMSE	0.0270	0.0140	0.0620	0.0600
	X^2	0.0010	0.0000	0.0040	0.0040
	Model constants	k =0.1746 n =0.6273	k =0.3394 n =0.8708	k =1.4333 n=0.7581	k =1.6476 n=0.9055
Modified Page	R^2	0.9950	0.9980	0.9680	0.9730
	SSE	0.0030	0.0020	0.0230	0.0180
	RMSE	0.0270	0.0140	0.0620	0.0600
	X^2	0.0010	0.0000	0.0040	0.0040
	Model constants	k =0.0619 n =0.6273	k =0.2892 n =0.8708	k =1.6077 n =0.7580	k=1.7356 n =0.9055
Henderson and Pabis	R^2	0.9430	0.9940	0.9590	0.9720
	SSE	0.0310	0.0070	0.0290	0.0190
	RMSE	0.0880	0.0240	0.0700	0.0620
	X^2	0.0080	0.0010	0.0050	0.0040
	Model constants	a=0.9507 k=0.0679	a =0.9641 k =0.2814	a=0.9870 k =1.5936	a=1.0012 k =1.7385
Logarithmic	R^2	0.9999	0.9990	0.9920	0.9910
	SSE	0.0000	0.0010	0.0060	0.0060
	RMSE	0.0070	0.0080	0.0330	0.0390
	X^2	0.0000	0.0000	0.0010	0.0020
	Model constants	a=0.8516 b =0.1443 k =0.1043	a =0.8979 b =0.0890 k =0.3534	a =0.9075 b=0.1040 k =2.1300	a=0.9256 b=0.0938 k =2.2274
Two-term	R^2	0.9999	0.9990	0.9400	0.9300
	SSE	0.0000	0.0010	0.0430	0.0460

	RMSE	0.0040	0.0100	0.0270	0.0290
	X^2	0.0000	0.0000	0.0110	0.0150
	Model constants	a =0.2880 b =0.7110 g =0.1282 k =0.0138	a =0.0710 b =0.9151 g =0.34613 k =-0.0219	a =-72.1114 b =73.046 g =0.9868 k =0.9823	a =276.524 b =-275.6412 g =0.8631 k =0.8644
Two-term exponential	R^2	0.9680	0.9980	0.9670	0.9760
	SSE	0.0170	0.0020	0.0240	0.0160
	RMSE	0.0650	0.0130	0.0630	0.0570
	X^2	0.0040	0.0000	0.0040	0.0030
	Model constants	a =0.2456 k =0.2065	a =0.3146 k =0.6684	a =0.3786 k =2.9963	a =0.4415 k =2.7719
Wang and Singh	R^2	0.9780	0.9750	0.9130	0.9470
	SSE	0.0120	0.0270	0.0620	0.0350
	RMSE	0.0540	0.0480	0.1020	0.0840
	X^2	0.0030	0.0020	0.0100	0.0070
	Model constants	a =-0.0651 b =0.0009	a =-0.2467 b =0.01688	a =-1.0569 b =0.2652	a =-1.1840 b =0.3406
Approximation of Diffusion	R^2	0.9999	0.9990	0.9583	0.9899
	SSE	0.0000	0.0010	0.0297	0.0066
	RMSE	0.0044	0.0099	0.0771	0.0408
	X^2	0.0000	0.0000	0.0059	0.0017
	Model constants	a =0.7086 b =0.1095 k =0.1290	a =0.8394 b =0.1308 k =0.3907	a =11.8333 b =0.9958 k =1.5387	a =0.0884 b =339.33 k =0.0063
Verma et al	R^2	0.9999	0.9990	0.9950	0.9950
	SSE	0.0000	0.0010	0.0040	0.0030
	RMSE	0.0040	0.0100	0.0270	0.0290
	X^2	0.0000	0.0000	0.0010	0.0010

	Model constants	a =0.2913 g =0.1290 k =0.0141	a =0.8392 g =0.0512 k =0.3907	a =0.0241 g =1.8247 k =-0.5593	a =0.9916 g =-1.0742 k=1.8634
Modified Henderson and Pabis	R^2	0.9999	0.9960	0.9340	0.9960
	SSE	0.0000	0.0040	0.0470	0.0020
	RMSE	0.0000	0.0230	0.1530	0.0500
	X^2	0.0000	0.0010	0.0230	0.0020
	Model constants	a =0.0427 b =0.1230 c =0.8342 g =-0.0027 h =0.0949 k =4.5052	a =0.1410 b =-0.1429 c =0.9752 g =0.2469 h =0.2514 k =0.6238	a =4.3253 b =0.3200 c =-3.7121 g =0.9904 h =0.8818 k =0.9634	a =-16.8103 b =0.3180 c =17.4979 g =-0.0149 h =0.9605 k =0.8977
Logistic	R^2	0.9990	0.9940	0.9590	0.9720
	SSE	0.0000	0.0070	0.0290	0.0190
	RMSE	0.0130	0.0250	0.0770	0.0690
	X^2	0.0000	0.0010	0.0060	0.0050
	Model constants	a =-1.0105 b =-0.0105 k =0.0012	a =5677.8301 b =5475.05 k =0.2814	a =5471.596 b =5401.7634 k =1.594	a =5561.3012 b =5569.0448 k =1.7387
Midilli	R^2	**0.9999**	**0.9990**	**0.9960**	**0.9990**
	SSE	**0.0000**	**0.0010**	**0.0030**	**0.0010**
	RMSE	**0.0020**	**0.0080**	**0.0260**	**0.0170**
	X^2	**0.0000**	**0.0000**	**0.0010**	**0.0000**
	Model constants	a =1.0000 b =0.0024 k =0.1097 n =0.8919	a =0.9915 b =0.0069 k =0.3326 n =0.9616	a =0.9977 b =0.0440 k =1.9304 n =1.0957	a =1.0009 b =0.0547 k =2.2487 n =1.2016
Aghabashlo model	R^2	0.9999	0.9990	0.9810	0.9800
	SSE	0.0000	0.0010	0.0130	0.0130

RMSE	0.0060	0.0100	0.0470	0.0510
X²	0.0000	0.0000	0.0020	0.0030
Model constants	g=0.0347 k =0.1063	g =0.05321 k =0.35159	g =0.5115 k =2.1994	g =0.3583 k =2.1451

Rehydration Kinetics of Dried Mint Leaves

The results of the rehydration kinetics of dried mint leaves are shown in Figure 6. These leaves were subjected to a rehydration test to evaluate their rehydration capacity, an indicator of the quality of the dried product. Rapid initial absorption was observed, particularly during the first hour. After 5 to 10 hours, this increase was accompanied by a reduction in the rate of water absorption. Finally, after 10 hours, it stabilized and reached an optimal equilibrium after more than 15 hours. This rehydration behaviour was linked to the availability of free capillaries in the product at the beginning of the rehydration process; after several hours, they begin to fill and the absorption rate decreases. Many resembling rehydration findings were found with dried mint leaves (Kaveh *et al.*, 2024), and dried molokhia leaves (Ghellam *et al.*, 2022).

Table 5 presents the modeling of the rehydration kinetics of dried mint leaves using several empirical models. As noted, the Peleg model best fits the rehydration data. It exhibits the highest R^2 and Adj- R^2 , and the lowest values for RMSE, SSE, and X². The Vega-Gálvez model ranks second in performance. These results indicate that the Peleg model is the most appropriate for representing the experimental rehydration kinetics of dried mint leaves. This model has proven representative for many dried leaves, such as dried spinach (Dadali *et al.*, 2008), microwave dried basil (Demirhan & Özbek, 2010), and amaranth leaves (Sultana & Ghosh, 2022).

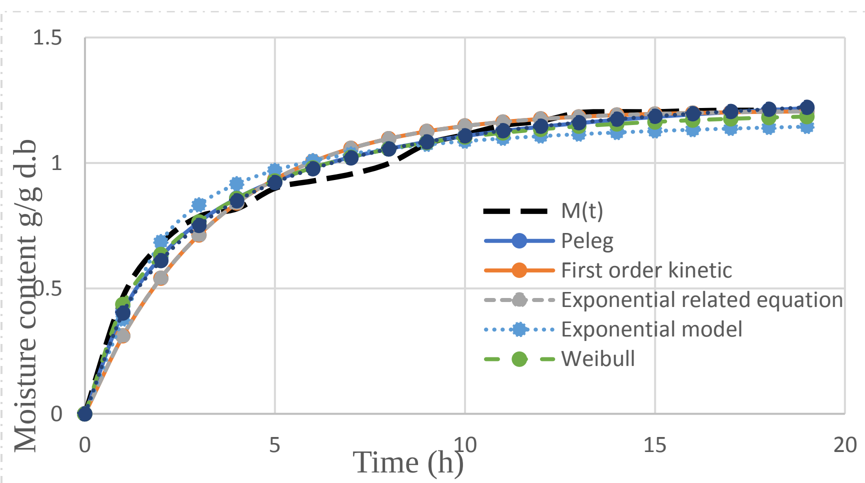

Figure 6. Rehydration kinetics of dried mint leaves.

Table 5. Rehydration fittings result for dried mint leaves.

Model name	R^2	Adj-R^2	SSE	RMSE	X^2	Model constants
Peleg	0.9864	0.9857	0.0249	0.0372	0.0014	a =1.7378, b =0.7293
First-order kinetic	0.9559	0.9559	0.0810	0.0653	0.0043	a =0.2965
Exponential related equation	0.9559	0.9559	0.0810	0.0653	0.0043	a =0.2965
Exponential model	0.9520	0.9494	0.0882	0.0700	0.0049	a =1.1635, k =-1.0347
Weibull	0.9840	0.9832	0.0293	0.0404	0.0016	a =0.7351, b =2.9943
Vega-Gálvez model	0.9794	0.9769	0.0380	0.0473	0.0022	a =1.3701, b =2.5037, k =1.0292

CONCLUSION

This study demonstrates that drying temperature significantly influences the nutritional and physical quality of mint leaves (*Mentha spicata* L.). While the leaves initially high water content (87.18%) necessitates drying for preservation, increasing temperatures from shade-drying (≈25 °C) to 80 °C leads to a marked degradation of bioactive compounds. Specifically, shade-drying proves to be the most effective method for preserving the total content of phenolic compounds, flavonoids, and antioxidant activity (DPPH and FRAP), whereas higher temperatures cause significant heat loss. Kinetic analysis reveals that higher temperatures accelerate water desorption, reducing drying time from over two days in the shade to less than five hours at 80 °C. Among the mathematical models tested, the Midilli model most accurately describes the drying kinetics, while the Peleg model best represents the rehydration behavior. Rehydration reaches equilibrium after approximately 15 hours, a key indicator of the final product's quality. Ultimately, these results suggest that while high-temperature convective drying is faster, lower temperatures are essential to preserve the mint's functional and therapeutic potential.

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The Most Popular Turkish Foods on Global Scale: Popularity Analysis Using an AI-Powered Chatbots and Google Trends Data

Küresel Ölçekte En Popüler Türk Yemekleri: Yapay Zekâ Destekli Chatbot ve Google Trends Verilerini Kullanarak Popülerlik Analizi

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ABSTRACT

In this study, a mixed-methods approach was employed to determine the most popular Turkish dishes worldwide by incorporating an innovative perspective. In the qualitative phase, artificial intelligence models such as Gemini, Deepseek, and ChatGPT were asked the question, "What are the 10 most delicious dishes of Turkish cuisine?", and the obtained data were analyzed. In the quantitative phase, the Google Trends platform was used to examine global search trends from 2004 to the present (February 4, 2025). By interpreting the data from both phases, the most popular dishes of Turkish cuisine were identified. The study's findings revealed the five most popular dishes to be döner, Adana kebap, menemen, künefe, and lahmacun, respectively. The results demonstrate that the combined use of AI models and search trend analysis can provide consistent and comprehensive insights. Notably, kebab and künefe emerged as prominent dishes in both previous literature and this study. The findings suggest that promotional strategies can leverage both widely recognized and lesser-known dishes in different ways to enhance the global recognition of Turkish cuisine. Less popular dishes on digital platforms can be strategically promoted to increase awareness, while highly popular dishes can be emphasized in restaurant menus to enhance tourist satisfaction.

Keywords: Turkish cuisine, ChatGPT, Gemini, DeepSeek, Trends.

ÖZET

Bu çalışmada yenilikçi bir bakış açısı geliştirilerek, Türkiye'nin gastronomi turizmi ve Türk mutfağı tanıtım çalışmalarına katkı sunabilecek içerikler üretmek amacıyla, Türk mutfağının dünya genelinde en popüler yemeklerini belirlemek amaçlanmıştır. Bu doğrultuda yapay zekâ chatbotları ve Google Trends verileri bir arada kullanılmıştır. İlk aşamada, Gemini, Deepseek ve ChatGPT gibi yapay zekâ modellerine "Türk mutfağının en popüler 10 yemeği nedir?" sorusu yöneltilmiş, elde edilen veriler analiz edilmiştir. İkinci aşamada ise Google Trends platformu kullanılarak, 2004'ten günümüze (04.02.2025) kadar olan dönemde dünya genelindeki arama trendleri incelenmiştir. Elde edilen veriler birlikte yorumlanarak, Türk mutfağının en popüler yemekleri tespit edilmiştir. Çalışma sonucunda en popüler beş yemek sırasıyla döner, Adana kebap, menemen, künefe ve lahmacun olarak belirlenmiştir. Bulgular, yapay zekâ ve arama trendlerinin birlikte kullanımının tutarlı ve kapsamlı analizler sunabileceğini göstermektedir. Bu sayede tanıtım stratejilerinde popüler ve daha az bilinen yemeklerin farklı şekillerde değerlendirilebilir ve Türk mutfağının tanıtımına katkı sunabilir. Web ortamında bilinirliği düşük yemekler yeni içerik olarak tanıtım çalışmalarında kullanılırken popülerliği yüksek olan yemeklerin gücünden yararlanılabilir, menüler stratejik olarak bu yemeklerle oluşturulabilir ve dolayısıyla turist memnuniyetinin artırılmasına katkı sağlanabilir.

Anahtar Kelimeler: Türk mutfağı, ChatGPT, Gemini, DeepSeek, trendler.

GİRİŞ

Bir destinasyona ait gastronomik zenginlik, turistlerin seyahat tercihlerinde ve destinasyon marka imajının oluşmasında önemli bir rol oynamaktadır (Harrington ve Ottenbacher, 2010; Lai vd., 2018). Bu sebeple destinasyonlar, ziyaretçileri çekme, seyahat deneyimlerini zenginleştirme ve gastronomi destinasyonları arasında farklılaşmak için yemeğe giderek daha fazla önem vermektedir (Björk ve Kauppinen-Räisänen, 2014; Chaney ve Ryan, 2012; Chang ve Mak, 2018). Gastronomik unsurlar da tıpkı kültürel ve mimari yapılar gibi bir destinasyonu temsil edebilir. Örneğin, Hindistan'daki Tac Mahal veya Barcelona'daki Sagrada Familia nasıl o şehirlerin simgesi haline geldiyse; Napoli'nin pizzası, Brüksel'in midyesi ve Arjantin'in asadosu da bulundukları yerlerin kültürel kimliğini yansıtan birer ikon ve sembol olabilir (Anton Martin vd., 2021) ve ziyaretçileri çekerek onların davranışsal niyetlerini etkileyebilir. Bu yemekler, hangi şehir veya ülkeye ait oldukları belirtilmeden bile tanınan ve ayırt edilen yerel yiyeceklerdir. Eşsiz ve farklı karakterleri sayesinde küresel olarak tanınmış semboller haline gelmişlerdir (Anton Martin vd., 2021). Türk mutfağı da içerisinde çok farklı yemekler, geleneksel ürünler, ritüeller barındıran zengin bir mirasa sahiptir. Tüm bu unsurlar Türkiye'yi önemli bir gastronomi destinasyonu haline getirmektedir. T.C. Kültür ve Turizm Bakanlığı'na ait (gastronomy.gotürkiye.com, t.y.) adresinde kebap, baklava, kahvaltı ve birçok gastronomik ögeler tanıtımlarda öne çıkarılmaktadır. Doğru yemek ve gıdaları tanıtmak için ürünlerin popülerlik durumlarına ait mevcut durumun anlaşılması önemlidir. Bu bağlamda yemeklere yönelik popülerlik analizleri yapabilmek için yapay zekâ modelleri ve Google Trends verileri önemli verilere sahiptir (Masruroh vd., 2024).

Son yıllarda haber ve bilgi almak gibi farklı amaçlarla internetin kullanımının artmasıyla arama sorguları giderek önem kazanmaktadır. Google gibi platformlarda insanların ne aradığı, gelecek seyahatlerinde ne yapacaklarının göstergesidir (De Luca & Rosciano, 2024) ve bu sebeple turizm yöneticileri Google aramalarına dayalı analizleri ile proaktif ve başarılı kararlar alabilir. Bu duruma paralel olarak Turizm çalışmalarında Google Trends verilerine başvuran çalışma sayısı giderek artmıştır (Dinis vd., 2019).

Turizm araştırmalarında kullanılabilecek diğer güncel araçlar yapay zeka chatbotlarıdır. Üretken yapay zekâ modellerinden ChatGPT, sohbet arayüzü ve doğal dil işleme ile kullanıcı sorgularına insan benzeri akıllı yanıtlar vererek yapay zekâda yeni bir dönemi başlatmıştır (Gursoy vd., 2023). ChatGPT, ilk lansmanından yalnızca 5 gün sonra 1 milyondan fazla kullanıcıya ulaşmış ve 2023 Ocak ayı itibarıyla 100 milyon aylık aktif kullanıcıyı aşarak, "şimdiye kadar piyasaya sürülen en hızlı büyüyen tüketici uygulaması" olmuştur (Helberger ve Diakopoulos, 2023).

Bilgisayar bilimi bakış açısından ise ChatGPT, sofistike algoritmaları ile geniş bir yazılım modülü yelpazesini kullanan, birçok çevrim içi kaynaktan çıkarılan verilerle önceden eğitilmiş, kullanıcılarla yapılan konuşmalar sırasında toplanan bilgileri, bellek veya geçici veri yapıları aracılığıyla modelin işlem sürecine dinamik olarak ekleyen büyük ve karmaşık bir sistemdir (Mich ve Garigliano, 2023). Dolayısıyla, ChatGPT ve benzeri olan Gemini, Deepseek gibi üretken yapay zekâ modelleri internet ortamında bulunan mevcut dataları kullanarak yanıtlarını oluşturmaktadır. Yemeklerin veya gıda ürünlerinin bir konu hakkındaki popülerliklerini analiz etmek için kullanıldıklarında ise web ortamında en sık kullanılan, en sık aranan, veriler arasından en fazla tekrarlanan sonuçları vermeleri beklenmektedir.

Mevcut literatürde yapay zekâ modelleri ve Google Trends verilerini birlikte kullanarak Türk mutfağına yönelik analiz yapan farklı bir çalışmaya rastlanmamıştır. Bu çalışmada farklı ve yeni bir bakış açısı geliştirilerek dünyada en popüler olan Türk yemeklerinin araştırılması amaçlanmış ve böylece sonuçların Türk mutfağının ve Türk gıda ürünlerinin tanıtım çalışmalarında faydalı olması hedeflenmiştir. Çalışmanın sonuçlarına göre az bilinen yemekler daha çok öne çıkarılabilir veya çok bilinen yemekler için farklı stratejiler geliştirilerek yemeklerin popülerliğinden faydalanılabilir.

YÖNTEM

Bu çalışmada Türk mutfağına ait en popüler yemekleri çevrim içi olarak tespit etmek amaçlanmıştır. Gemini, Deepseek ve ChatGPT, büyük dil modeli (LLM - Large Language Model) temelli, günümüzde en popüler olan ve dünya çapında kullanıcılar tarafından kullanılan yapay zekâ uygulamalarıdır (Rahman vd., 2025). Bu sebeple çalışmanın nitel aşamasında bu üç yapay zekâ uygulamasının kullanılmasına karar verilmiştir. Bu uygulamalar milyarlarca veriden internet tabanlı veri kümeleri üzerinde eğitilmiştir. Bu veri kümeleri kitaplar, haber sayfaları, web siteleri, ansiklopedi siteleri ve akademik makaleler gibi kaynaklardır. Bu modeller dil işleme becerileri sayesinde insan benzeri metin üretimi, bilgi sentezi ve soru-cevap gibi görevleri yerine getirebilmektedir. Çalışmaday apay zekâ chatbotlarının Gemini (1.5 Pro), Deepseek (DeepSeek-V2) ve Chat GPT (GPT-4o) sürümleri kullanılmış, elde edilen veriler doküman analizi yöntemiyle analiz edilmiştir. Döküman analizi yönteminde araştırma bulguları konuyla ilgili kitaplar, dergiler, arşivler, internet siteleri, gazete gibi sürekli yayınlar, sesli ve görüntülü dökümanlar, istatistik raporları gibi doküman türlerinin incelenmesi sonucu elde edilmektedir (Karadaban vd., 2023). Döküman incelemesi yöntemi, "araştırılması hedeflenen konular hakkında bilgi içeren dokümanlar aracılığı ile veri elde etme yöntemi" olarak tanımlanmaktadır (Karadaban et al., 2023).

Çalışmanın ikinci analiz aşamasında da Google Trends platformundan elde edilen sayısal veriler analiz edilmiştir. Google Trends verilerinin indirilebilir ve karşılaştırılabilir olması, derinlemesine araştırmaları kolaylaştırmakta, yöneticiler, planlayıcılar ve akademik çalışmalar için yeni fırsatlar sunmaktadır (Yıldız, 2018). Google'ın arama sıklıkları ve aranan terimler arasındaki ilişkileri açık erişimle paylaşması, araştırmacılara yeni çalışma alanları geliştirme konusunda değerli veriler sunmaktadır (Yıldız, 2018).

Çalışmanın nitel aşamasında ilk olarak Gemini (1.5 Pro), Deepseek (DeepSeek-V2) ve Chat GPT (GPT-4o) yapay zekâ destekli chatbotlarında yeni sohbet açılarak her üç modele de birebir aynı ifade ile "Türk mutfağının en popüler 10 yemeği nedir?" sorusu yöneltilmiştir. Her modelin yanıtları ayrı ayrı metin belgesi olarak ele alınmıştır. Yanıtlarda yer alan yemek adları kodlanarak listelenmiş, tekrar eden yemekler birleştirilmiş ve toplamda 22 farklı yemek belirlenmiştir. Verilerin bir sonraki analiz aşamasında 04.02.2025 tarihinde, Google Trends'in sunduğu en geniş zaman aralığı kullanılarak 2004 yılından günümüze (04.02.2025) yemeklerin popülaritesiyle ilgili olarak dünya geneli yapılmış aramalarla Google Trends'ten elde edilen veriler incelenmiştir. Konu kısmında genel bir sonuç almak amacıyla ‘‘yiyecek ve içecek kategorisi’’ değil, ‘‘tüm kategoriler’’ seçilmiştir. Elde edilen 22 yemeğin isimleri ayrı ayrı analiz edilerek popülerliklerine yönelik sayısal verileri elde edilmiştir. Veriler global sonuçlara göre elde edilmiştir. Platformun sunduğu karşılaştırmalı değerler (CVS – Comparative Value Score) temel alınarak her yemeğe ait değerler toplanmış ve bu puanlar doğrultusunda yemekler en popülerden en az popülere doğru sıralanmıştır. Araştırma sürecinin aşamaları Şekil 1'de gösterilmektedir. Bu analizlerin sonuçları birlikte yorumlanarak, Türk mutfağının çevrim içi ortamda en popüler olan yemeklerini belirlemek için kullanılmıştır.

Şekil 1. Araştırma süreci.

BULGULAR

Veri toplama süreci için ilk olarak yapay zekâ modellerinden olan DeepSeek, Gemini ve ChatGPT'ye ‘‘Türk mutfağının en popüler 10 yemeği nedir?’’ sorusu sorulmuş ve yanıtlar Tablo 1'de listelenmiştir.

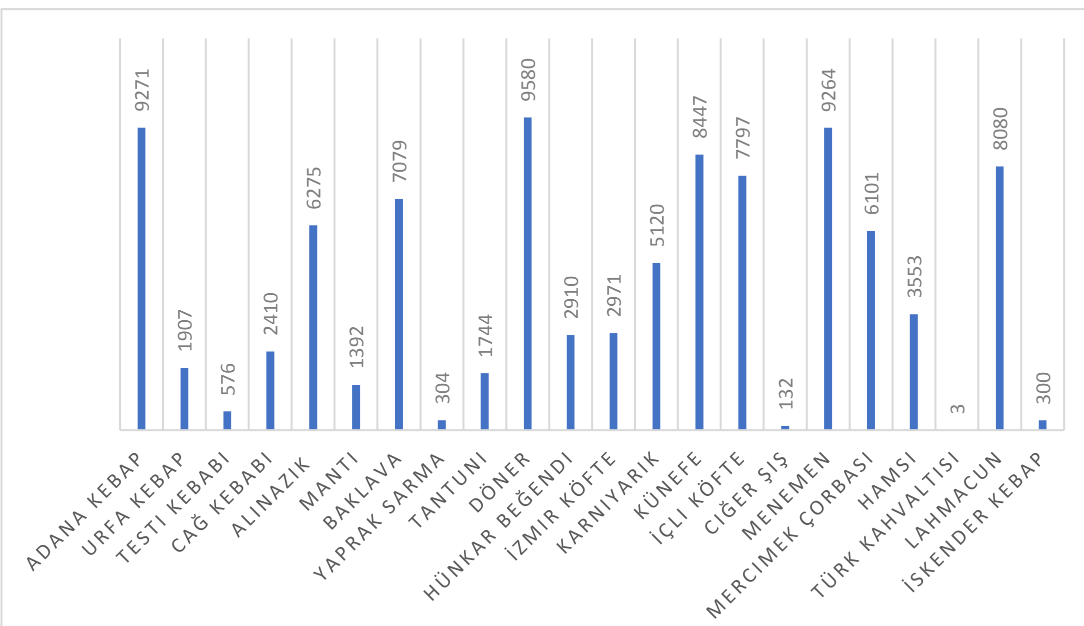
Tablo 1. Türkiye'nin en popüler yemeklerine yönelik Gemini, DeepSeek ve ChatGPT yorumları.

	DeepSeek	ChatGPT	Gemini
1	Adana Kebap: Baharatlı kıyma ile mangalda pişirilir.	İskender Kebap (Bursa): Döner eti, tereyağı, domates sosu ve yoğurt ile servis edilir. Altında kıtır pide parçaları lezzeti tamamlar.	İskender Kebap: Bursa'ya özgü olan bu kebap, pide üzerine yerleştirilmiş döner etinden, tereyağlı domates sosu ve yoğurt ile servis edilir.
2	Urfa Kebap: Daha az baharatlı lezzetiyle öne çıkar.	Testi Kebabı (Kapadokya): Özel testi kabında et ve sebzelerin uzun süre pişirilmesiyle hazırlanan enfes bir Anadolu lezzeti.	Cağ Kebabı: Erzurum'un meşhur lezzeti olan cağ kebabı, yatık şekilde odun ateşinde pişirilen kuzu etinden yapılır.
3	İskender Kebap: Bursa'nın yoğurt ve tereyağlı kebabı.	Alinazik Kebabı (Gaziantep): Patlıcan püresi ve yoğurt yatağında sunulan yumuşacık et parçalarıyla hazırlanan unutulmaz bir kebap çeşidi.	Mantı: Hamur içinde kıymalı harçla hazırlanan mantı, yoğurt ve sarımsaklı sos ile servis edilir. Kayseri mantısı en bilinenlerindendir.
4	Baklava: Gaziantep'in ince yufkalı, fıstıklı tatlısı.	Yaprak Sarma (Ege ve Marmara): Asma yaprağına sarılmış bol limonlu ve zeytinyağlı iç harç; hafif ama müthiş aromatik bir tat.	Lahmacun: İnce hamurun üzerine kıymalı harç yayılmasıyla yapılan lahmacun, genellikle limon ve yeşilliklerle birlikte tüketilir.
5	Lahmacun: Türk pizzası; limon ve maydanozla servis edilir.	Tantuni (Mersin): İncecik kıyılmış et veya tavuk, özel baharatlar ve lavaş içinde sunulan hızlı ve lezzetli bir sokak lezzeti.	Döner: Dikey olarak dönen bir şişe geçirilmiş etin kesilerek servis edilmesiyle yapılan döner, Türkiye'nin en popüler sokak yemeklerinden biridir.

6	Kayseri Mantısı: Sarımsaklı yoğurt ve tereyağı ile sunulur.	Hünkâr Beğendi (Osmanlı Mutfağı): Patlıcan beğendisi üzerinde yumuşak kuzu eti ile hazırlanan, Osmanlı'nın saray mutfağından gelen bir efsane.	Baklava: İnce yufkaların arasına ceviz veya fıstık konularak yapılan baklava, şerbetle tatlandırılır ve genellikle kaymak ile servis edilir.
7	İzmir Köfte: Domates sosuyla patates ve biber eşliğinde.	Karnıyarık (Anadolu Mutfağı): Kıyma, soğan ve baharatlarla doldurulmuş patlıcanın fırında pişirilmesiyle ortaya çıkan enfes bir ana yemek.	Künefe: Kadayıf ve peynirle yapılan künefe, sıcak olarak şerbetle servis edilir ve üzerine genellikle kaymak eklenir.
8	İçli Köfte: Cevizli kıymalı harç ile doldurulmuş bulgurlu lezzet.	Ciğer Şiş (Edirne ve Diyarbakır): Baharatlarla marine edilmiş kuzu ciğerinin şişte pişirilmesiyle elde edilen sokak lezzeti.	Yaprak Sarma: Asma yapraklarının içine pirinç, kuş üzümü ve baharatlarla hazırlanan iç harcının sarılmasıyla yapılan yaprak sarma, zeytinyağlı veya kıymalı olarak hazırlanabilir.
9	Menemen: Domates, biber ve yumurtayla sade bir kahvaltılık.	Kayseri Mantısı (Kayseri): İncecik hamur parçalarının içine kıyma doldurulup yoğurt ve sarımsakla servis edilen geleneksel bir şaheser.	Mercimek Çorbası: Kırmızı veya yeşil mercimeklerle yapılan bu çorba, Türk mutfağının vazgeçilmezlerindendir.
10	Hamsi: Karadeniz'in simge balığı; tavada kızartılır.	Künefe (Hatay): İnce kadayıf, taze tuzsuz peynir ve şerbetle hazırlanan çıtır çıtır bir tatlı. Üzerine fıstık serpildiğinde mükemmel hale gelir.	Türk Kahvaltısı: Türkiye'de kahvaltı, genellikle zengin çeşitlilikte peynir, zeytin, reçel, bal, tereyağı, ekmek ve çaydan oluşur.

Tablo 1'de görüldüğü gibi, Gemini, DeepSeek ve ChatGPT, en popüler Türk yemekleri olarak farklı kebap türlerini önermektedir. Diğer sıralamalarda ise farklı yemekler öne çıkmaktadır. Bazı benzerlikler olsa da, sıralama ve bölgesel lezzetlere odaklanma konusunda belirgin farklar bulunmaktadır. Örneğin, DeepSeek, kendine özgü baharatlı tadı ile Adana Kebap'ı en üst sırada önerirken, ChatGPT ve Gemini İskender Kebap'ı ön plana çıkararak, içeriği ve servis tarzı hakkında detaylı açıklamalar yapmaktadır. Bu farklar, DeepSeek, Gemini ve ChatGPT'nin yapay zekâ teknolojisiyle tasarlanmış olmalarına rağmen kaçınılmazdır. (Drapkin, 2023) tarafından belirtildiği gibi, Gemini internet verilerine gerçek zamanlı olarak erişirken, ChatGPT verilerini Eylül 2021'den önce yayımlanmış bir veri setinden almaktadır. DeepSeek'in en son sürümü olan DeepSeek R1, derin akıl yürütme yeteneklerinin yanı sıra internet bağlantılı arama işlevini de destekler. Bu sayede DeepSeek R1, hem önceden taranmış ve analiz edilmiş verilerle çalışabilen hem de anlık web aramaları yapabilen bir yapıya sahiptir (Lu, 2025). Fakat bu analiz sırasında DeepSeek R1 modeli değil V2 modeli kullanılmıştır.

Tablo 1'deki yanıtların elde edilmesinin ardından bu yemeklerin popülerliği Google Trends kullanılarak incelenmiştir. Tüm yemeklerin popülerliği Google Trends ile analiz edilerek sırasıyla tablolaştırılmıştır. Üç ayrı yapay zekâ chatbotun önerdiği bazı yemekler aynı yemek olduğundan benzer yemekler tek yemek olarak analize dahil edilmiştir. Ayrıca mantı ve kayseri mantısı gibi yanıtlar da tek yemek olarak değerlendirilip Google trends analizinde ‘‘mantı’’ kelimesi ile analiz gerçekleşmiştir. Toplam 22 farklı yemek ile analiz gerçekleştirilmiştir. Google Trends aynı anda en fazla 5 analiz gerçekleştirildiğinden sonuçlar 5 farklı tablo oluşturularak hazırlanmıştır. 22 yemeğe ait 5 farklı kıyaslamanın cvs. dosyaları Google Trend platformu üzerinden indirilmiş ve dosyadaki sayısal veriler toplanarak Şekil 1'de sunulan sütun grafiği oluşturulmuştur.



Şekil 1. En popüler yemeklerin Google Trends popülerlik analizi sonuçları. * 2004 yılından 2024 Aralık ayının sonuna kadar olan arama hacmi verileri. En yüksek sayı ilgili zaman dilimi içinde en fazla aranan yemek olarak kabul edilir.

Şekil 1, Google Trends analiz sonuçlarına göre dönerin küresel olarak en popüler Türk yemeği olduğunu göstermektedir. Google Trends sonuçlarına göre en popüler 10 Türk yemeği sırasıyla Döner, Adana kebap, menemen, künefe, lahmacun, içli köfte, baklava, Alinazik, mercimek çorbası ve karnıyarıktır. Araştırmada kullanılan 3 yapay zekâ modeli sahip olduğu verilere göre (web siteleri, dökümanlar vb.) yemekleri değerlendiren ve sıralayan yapay zekâ modelleriyken Google Trends Google arama verilerine dayalı olarak sonuçlar sunmaktadır. Google Trends verisi, yemeklerle ilgili trendler veya belirli olaylar gibi çeşitli faktörlerden etkilenebilir, bu da daha fazla veya daha az arama yapılmasına yol açarak sonuçları değiştirebilir. Bu nedenle, Google Trends, diğer yapay zekâ sohbet robotlarından farklı sonuçlar sunabilir.

TARTIŞMA

Bu çalışmada yapay zekâ chatbotları ve Google Trends verileri aynı anda kullanılarak Türk mutfağına ait en popüler yemeklerin analiz edilmesi amaçlanmıştır. Gemini, DeepSeek ve ChatGPT'den 10'ar yanıt vermesi istenmiş, elde edilen 30 yanıt içerisinde bulunan aynı yemeklerin silinmesinin ardından 22 yemek ile analizler gerçekleşmiştir. Sonuçlarda 2004 yılından günümüze kadar olan süreçte en popüler 22 yemek listelenmiş ve global aramalarda en popüler 5 yemek sırasıyla döner, Adana kebap, menemen, künefe ve lahmacun olarak saptanmıştır. Türkiye'de 2024 yılı verilerine göre kebapçı ve dönercilerin en çok tüketim yapılan restoranlar olduğu (IPSOS, 2024) göz önünde bulundurulduğunda bu sonuçlar şaşırtıcı değildir. Öte yandan global ölçekte de sevildikleri ve farklı ülkelerden insanların tercihlerine hitap ettikleri anlaşılmaktadır.

Türkiye'ye gelen turistlere yönelik çalışmalarda turistlerin deneyimledikleri ve beğendikleri Türk mutfağı yemeklerini yanıtlamaları istenen çalışmalar ilgili literatürde mevcuttur. Şanlıer'in (2005) çalışmasının sonuçlarına göre Türkiye'ye gelen yabancı turistler en beğendikleri yemekleri domates çorbası, sebze çorbası, tavuk çorbası, kebaplar, güveç, zeytinyağlı sarma, mantı, peynirli börek, hamur tatlılar, çoban salatası ve alkollü içecekler olarak yanıtlamışlardır. Albayrak (2013) turistlerin en sevdiği yemekleri sırasıyla; kebap, lahmacun, pide, hamurlu tatlı ve börek olarak saptanmıştır. Girgin ve arkadaşlarının (2017b) Türk Cumhuriyetlerinden gelen öğrencilerle gerçekleştirdiği çalışmada da çorbalar, dolmalar, sarmalar, mantı ve kebap sırasıyla en beğenilen yemekler olarak öne çıkmıştır. Eser ve Çakıcı'nın (2016) yabancı şeflerle yaptığı çalışmada kebaplar, zeytinyağlı yemekler, salata, humus ve künefe en beğenilen yemekler olarak yanıtlamıştır. Kara (2025) tarafından gerçekleşen çalışmada ise uluslararası öğrenciler Türk mutfağını olumlu olarak değerlendirdiklerini ve en beğendikleri yemekleri çorba kategorisinde mercimek çorbası, et yemeklerinde kebap, etli sebze yemeklerinde fasulye, zeytinyağlı yemeklerde sarma, hamur işlerinde pide, börek çeşitlerinde ise peynirli börek olarak yanıtlamıştır.

Bu çalışmanın bulgularıyla önceki çalışmalar arasında örtüşmeler olduğu görülmektedir. Özellikle kebap ve künefe bu araştırmanın sonuçlarında da popüler olarak öne çıkan yemeklerdendir. Fakat zeytinyağlı sarma, çorba çeşitleri ve bazı hamur işleri geçmiş çalışmalarda turistler tarafından beğenildiği ifade edilmesine rağmen arama trendlerinde düşük sıralarda yer almıştır. Önceki çalışmalar ağırlıklı olarak bireylerin beğenilerine odaklanırken, bu çalışmada küresel çevrim içi arama verileri analiz edilerek nesnel bir popülerlik ölçümü yapılmıştır. Bu yönüyle mevcut araştırma, geleneksel beğeni odaklı yaklaşımlardan farklı ve daha dijital odaklı bir katkı sunmaktadır.

Girgin ve arkadaşlarının (2017a) gerçekleştirdiği, çevrim içi içerikler üzerine yaptıkları analizlere göre Türk mutfağının küresel ölçekte yeterince tanınmadığı ve dijital popülerliğinin düşük olduğu saptanmıştır. Dijital medyada, özellikle ülkelerin web sitelerinde ulusal mutfakların yer alış biçimi, bir ülkenin gastronomik markalaşmasında önemli bir unsurdur (Horng ve Tsai, 2010). Günümüzde Türkiye turizm tanıtım faaliyetlerinde gastronomi temalı içerikleri sıkça kullanmaktadır (Kaman, 2024). 2007 yılında yapılan araştırmalarda Türkiye'nin tanıtım faaliyetlerinde gastronomi temalı içeriklerin arka planda kaldığı, daha çok deniz-kum-güneş turizmine odaklanıldığı saptanmışken, günümüzde Türkiye dijital mecralarda GoTürkiye hesaplarıyla Türk mutfağının zenginliğini yansıtmaya çalışmaktadır (Kaman, 2024; Okumuş vd., 2007). Ancak tanıtım faaliyetleri tek başına yeterli olmayabilir ve hedef kitleye ulaşmada sınırlılıklar gösterebilir. Yapay zekâ, büyük veri ve dijital arama trendlerinin; yemekler gibi turistik ürünlerin popülerlik analizi ve tüketici tercihleri üzerine uygulanması, yeni iş fırsatlarının belirlenmesi, özgün menülerin oluşturulması ve tanıtım stratejilerinin etkinliğinin artırılması için önemli bir potansiyel taşımaktadır (Masruroh vd., 2024).

SONUÇ

Bu çalışmada, dünyada en popüler Türk yemeklerini incelemek üzere farklı ve yenilikçi bir bakış açısı benimsenmiş ve elde edilen bulguların, Türk mutfağının, Türk yemeklerinin tanıtımında katkı sağlaması hedeflenmiştir. Literatürde, yapay zekâ modelleri ile Google Trends verilerinin birlikte kullanıldığı ve Türk mutfağına yönelik analizler sunan benzer bir çalışmaya rastlanmamıştır. Elde edilen sonuçlara göre, daha az bilinen yemekler ön plana çıkarılabilir ya da yüksek bilinirliğe sahip yemekler için farklı tanıtım stratejileri geliştirilerek mevcut popülerlikleri etkili bir şekilde değerlendirilebilir. Ayrıca özgün menülerin oluşturulmasında veya yeni iş fırsatlarının yaratılmasında da Google trends gibi büyük data verileri ve yapay zeka sonuçları yeni bakış açıları sağlayabilir. Çalışmanın sonuçlarına göre 2004 yılından günümüze kadar olan süreçte en popüler 5 yemek sırasıyla döner, Adana kebap, menemen, künefe ve lahmacun olarak saptanmıştır.

En popüler yemek en lezzetli veya en güzel anlamına gelmemektedir. Yemek tercihleri kültür, coğrafya, etnik köken, gelenek gibi çeşitli faktörlerden etkilenen ve bir karar verme sürecidir. Farklı araçlar kullanarak analiz edilen gıdalara yönelik popülerlik farklılıkları, tüketicilerin doğrudan görülemeyen tercihleri hakkında iç görüler sunabilir. Yapay zekânın sonuçları web ortamındaki verilere göre çok beğenilen belirli bir gıdayı gösterse de Google Trend analizinin sonuçları bu gıdalara yönelik düşük popülerlik sonuçları gösterebilir. Çünkü fiyat, bulunabilirlik, evde pişirmeye uygunluk veya yerel tercihler gibi tüketicilerin Google arama tercihlerini etkileyebilir. Yine de yapay zekâ ve Google Trends verilerini kombine ederek sonuçları analiz etmenin tutarlı sonuçlar vereceği düşünülmektedir.

Türk mutfağının tanıtımında yapay zekâ, büyük veri ve dijital arama trendlerinin analizine dayalı yeni yöntemlerin de kullanılmasının önemli olduğu düşünülmektedir. Dijital araçlar aracılığıyla tüketici eğilimlerinin izlenmesi ve stratejik tanıtım kampanyalarında bu verilerin kullanılması tanıtım faaliyetlerinin başarısını artırabilir.

Araştırmanın bazı sınırlılıkları bulunmaktadır. En önemli sınırlılığı Google trends analizi aşamasında yemeklerin sadece Türkçe yazılışları ile analizin gerçekleştirilmesidir. Örneğin Türkçe'de künefe olarak bilinen tatlı Arapça'da knafeh olarak bilinmektedir. Google aramalarında da farklı isimlerle aranabileceğinden bu arama sonuçlarında farklılaşmaya sebep olmaktadır.

Benzer şekilde döner de aynı zamanda döner kebap olarak aranıyor olabilir. Gelecek çalışmalarda yemeklerin diğer dillerdeki isimlerinin de dahil edildiği çalışmalar farklı katkılar sağlayabilir.

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Menengiç as a Functional Food and Its Applications

Fonksiyonel Gıda Olarak Menengiç ve Kullanım Alanları

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ABSTRACT

Menengiç (*Pistacia terebinthus* L.) is a plant species native to the Mediterranean region, belonging to the sumac family (Anacardiaceae), with a strong resinous scent. Menengiç is part of our country's flora and is a tree that grows on its own without the need for cultivation. Menengiç is known by different names in different regions of Turkey, such as çedene, çitlenbik, çıtlık, çitemik, and bıttım. Menengiç (*Pistacia terebinthus* L.) is a natural raw material that attracts attention in the functional food sector thanks to its bioactive components, essential oils, and phenolic profile. Studies in the literature reveal that menengiç fruit, oil, and leaves have significant antioxidant, antimicrobial, anti-inflammatory, and cholesterol-regulating effects. The high oleic and linoleic acid content of menengiç oil offers an important advantage in terms of cardiovascular health; it has been used for many years in folk medicine to treat respiratory tract, digestive system, and urinary tract disorders. Various studies have indicated that extracts from the leaves and fruit of menengiç have a strong antimicrobial effect on gram-positive bacteria; furthermore, their antioxidant power can be close to or even superior to synthetic antioxidants. Coffee and various food products made from menengiç fruit are appreciated for their sensory qualities while also providing nutritional benefits through their functional components. Due to their high oil content, menengiç seeds are also being studied by researchers as a source of oil. Recent studies have revealed the importance of modern extraction and food technology applications aimed at increasing the bioactive component stability and bioavailability of menengiç extracts. In this context, menengiç stands out as a potential food ingredient that can be evaluated as a natural antioxidant and preservative in functional food formulations.

Keywords: *Pistacia terebinthus* L., functional components, bioactive compounds.

ÖZET

Menengiç (*Pistacia terebinthus* L.), Akdeniz bölgesine özgü, sakız ağacı familyasından (Anacardiaceae) bulunan kuvvetli reçine kokulu bitki türüdür. Menengiç, ülkemizin bitki örtüsünün bir parçası olup, tarıma ihtiyaç duymadan kendi kendine yetişen bir ağaçtır. Menengiç, Türkiye'de yörelere göre çedene, çitlenbik, çıtlık, çitemik ve bıttım gibi farklı isimlerle anılmaktadır. Menengiç (*Pistacia terebinthus* L.), sahip olduğu biyoaktif bileşenler, uçucu yağlar ve fenolik bileşen profili sayesinde fonksiyonel gıda alanında dikkat çeken doğal bir hammaddedir.

Literatürdeki çalışmalar, menengiç meyvesi, yağı ve yapraklarının belirgin düzeyde antioksidan, antimikrobiyal, antiinflamatuvar ve kolesterol düzenleyici etkilere sahip olduğunu ortaya koymaktadır. Menengiç yağının yüksek oleik ve linoleik asit oranı, kardiyovasküler sağlık açısından önemli bir avantaj sunmakta; halk hekimliğinde ise solunum yolları, sindirim sistemi ve idrar yolu rahatsızlıklarının tedavisinde uzun yıllardır kullanılmaktadır. Menengiçin yaprak ve meyve ekstraktlarının, gram pozitif bakteriler üzerinde güçlü antimikrobiyal etki oluşturduğu; ayrıca antioksidan güçlerinin sentetik antioksidanlara yakın ya da onlardan daha üstün olabildiği çeşitli araştırmalarda belirtilmiştir. Menengiç meyvesinden elde edilen kahve ve çeşitli gıda ürünleri, duyusal açıdan beğeni toplarken fonksiyonel bileşenleriyle de besinsel katkı sağlamaktadır. Menengiç tohumları yüksek yağ oranına sahip olduğundan, araştırmacılar tarafından yağ hammaddesi olarak da incelenmektedir. Son dönemde yapılan çalışmalar, menengiç ekstraktlarının biyoaktif bileşen stabilitesi ve biyoyararlanımını artırmaya yönelik modern ekstraksiyon ve gıda teknolojisi uygulamalarının önem kazandığını ortaya koymaktadır. Bu bağlamda menengiç, fonksiyonel gıda formülasyonlarında doğal antioksidan ve koruyucu olarak değerlendirilebilecek potansiyel bir gıda olarak öne çıkmaktadır.

Anahtar Kelimeler: *Pistacia terebinthus* L., fonksiyonel bileşenler, biyoaktif maddeler.

GİRİŞ

Menengiç, Pistacia cinsine ait olup, *Pistacia terebinthus* L. subsp. *palaestina* (Boiss.) Engler taksonu içerisinde sınıflandırılan bir meyve türüdür (Dalgıç vd., 2011). *Pistacia terebinthus* L. (Anacardiaceae), Akdeniz bölgesi ve Asya'da yaygın olarak bulunan 20 Pistacia türünden biridir ve birçok biyolojik aktiviteye sahiptir (Dhifi vd., 2012). Menengiçin iki anavatanı vardır. Birisi Anadolu, Kafkasya, İran ve Türkmenistan'ın yüksek kısımlarını içine alan Yakın Doğu gen merkezi, diğeri ise Orta Asya gen merkezidir (Sidar, 2011).

Menengiçin Türkiye'de en çok Kuzey ve Güney Anadolu'nun yanı sıra Marmara ve Akdeniz bölgelerinde doğal olarak yetiştiği belirtilmiştir (Özcan, 2009). Kaya (2012) ise arkeolojik bulguların, menengicin yaklaşık M.Ö. 7000'lerde besin olarak kullanıldığını ortaya koyduğunu aktarmaktadır. Menengiç farklı bölgelerde farklı isimlerle bilinmektedir; örneğin Elazığ'da "çedene", Adana'nın Kozan ilçesinde "çıtımık", Antalya-Akseki yöresinde ise "çöfre" ya da "sakızlak" olarak adlandırılmaktadır (Kaya, 2012). Pistacia türleri, genellikle ağaç ya da çalı formunda gelişen, kış aylarında yapraklarını döken yabani bitkiler olarak tanımlanmaktadır. Yaz sonunda, bu bitki yüksek yağ içeriğine sahip kırmızı-yeşil ila mor renkli yenilebilir meyveler üretir (Orhan vd., 2012). Yoğun reçine kokusuna sahip yapraklara sahiptir. Meyveleri yaklaşık 4–6 mm çapında, küçük, yuvarlağa yakın veya elips biçiminde olup, olgunlaştıklarında mavimsi yeşil bir renk alırlar (Sidar, 2011). Menengiç tohumlarının 1000 tane ağırlığı 150-200 gr arasında değişmektedir (Özçelik, 2016). Menengiçin halk hekimliğinde yüzyıllardır kullanılması, modern gıda bilimini menengicin fonksiyonel gıda ve doğal koruyucu potansiyelinin araştırılması konusunda çalışmalara yönlendirmiştir.

Menengiçin Üretimi, Bileşimi ve Sağlık Üzerine Etkileri

Türkiye'nin doğal bitki örtüsünde yer alan, ekolojik koşullarda kendiliğinden gelişen Pistacia ağacının Mart–Nisan döneminde pembe ile mor tonlarında çiçekleri açarken bu ağaçların tohumları, Ekim ve Kasım aylarında olgunluk evresine ulaşır. Menengiç (*Pistacia terebinthus*), derin kök yapısı ve çevresel koşullara yüksek adaptasyon yeteneği sayesinde hem nemli ve yağışlı hem de kurak ve taşlık alanlarda gelişim gösterebilmektedir (Ekinci, 2021). Menengiçin doğal yollarla kendiliğinden yetişmesi; ekim, toprak hazırlığı ve zirai mücadele gibi üretim giderlerini ortadan kaldırdığı için, diğer yağlı tohum bitkilerine kıyasla ekonomik açıdan avantaj sağlamaktadır (Şahin, 2019). Bitki, özellikle Toros Dağları'ndaki çam ormanlarında, yaklaşık 1600 metre rakıma kadar yayılım göstermektedir (Baytop, 1984). Antep fıstığı (*Pistacia vera*) türünden sonra ülkemizde en yaygın görülen türün menengiç (*Pistacia terebinthus* L.) olduğu ifade edilmektedir (Sidar, 2011). Menengiç, belirgin reçine kokusuna sahip, görece küçük yapılı bir ağaç türüdür (Doğan, 2016). Antep fıstığı, sıklıkla menengiç üzerinden aşılanarak yetiştirilmektedir. Soğuk ve kurak iklim koşullarına karşı oldukça dirençli olan bu ağaç, en iyi gelişimini alkali topraklarda göstermektedir (Kaya, 2012).

Menengiç ağaççıklarından çok yönlü faydalanılmaktadır, bahar mevsiminin gelişiyle beraber, dallardan çıkan ilk filizlere halk tarafından 'ışkın' denilmektedir. Bu ağaççıkların gövdesinden çıkan sıvılar 'günlük' adıyla halk hekimliğinde kullanılmaktadır (Eytemiş, 2016).

Pistacia türleri içinde sadece *Pistacia vera* L. (Antep fıstığı) ekonomik açıdan ticari değer taşırken, halk arasında menengiç veya çedene olarak bilinen *Pistacia terebinthus* L. türünün meyvesi, sınırlı kullanım olanağına sahiptir. Bazı bölgelerde, özellikle Elazığ yöresinde "çedene kahvesi" adlı yerel bir içecek üretiminde kullanılmaktadır (Kaya, 2012). Menengiç kahvesi, öğütülmüş kahve gibi tortu görünümündedir ve sindirim için mükemmel bir yardımcı olarak tüm tatlılardan sonra içilmesi önerilir (Orhan vd., 2012). Menengiç, geleneksel olarak farklı şekillerde değerlendirilmekte olup, farklı oranlarda menengiç yağı içeren ve yöresel adıyla 'menengiç sabunu' veya 'bıttım sabunu' olarak bilinen ürünler, türün ticari anlamda kullanıldığı en önemli ürünlerden biridir (Dalgıç vd., 2011). Taze sürgünlerinin toplanıp konserve haline getirilerek yemeklerde kullanılması, türün bilinen diğer yöresel değerlendirme biçimlerinden biridir. Menengiç meyveleri ise iştah açıcı olarak, yöresel ekmeklerin yapımında ve kahve ya da çay formunda tüketilmektedir. Bu kullanımlarının dışında son zamanlarda gelişmiş kök sistemleri nedeni ile vejetatif bitki üretiminde aşı altlığı olarak bitki ıslahında kullanılmaktadır (Sidar, 2011). Ayrıca menengiç meyveleri kavrularak, besleyici bir atıştırmalık olarak insanlar tarafından tüketilmektedir (Gülsoy vd., 2013).

Yüksek protein ve yağ içeriği ile hoş aroma ve lezzete sahip olması, menengiç tohumlarının gıda sektöründe kullanılabilmesini mümkün kılmaktadır (Tablo 1). Ayrıca, doğal ürünlere olan küresel ilginin artmasıyla menengiç tohumlarının tüketimi de giderek yükselmektedir (Sidar, 2011).

Tohumların yağ miktarı ve diğer özellikleri, iklim koşulları, olgunluk evresi, çekirdeklerin hasat zamanı ve ekstraksiyon yöntemleri gibi faktörlere bağlı olarak değişkenlik gösterebilir. Yağlı tohumlarda bulunan yağ, dokuların veya hücrelerin içinde sıkıştığından, öğütme ya da kavurma gibi ön işlemler yapılsa bile basit filtrasyon veya dekantasyon yöntemleriyle kolayca elde edilemez. Bu nedenle endüstride yağ çıkarmak için genellikle presleme, çözücü ile ekstraksiyon ya da bu yöntemlerin birlikte uygulandığı ön presleme-ekstraksiyon teknikleri kullanılmakta olup genellikle presleme tercih edilmektedir. Menengiç tohumları yüksek yağ oranına sahip olduğundan, araştırmacılar tarafından yağ hammaddesi olarak incelenmektedir (Sidar, 2011). Tohumdan elde edilen bu yağın yağ asidi kompozisyonunda başlıca oleik, linoleik palmitik, palmitoleik ve stearik asitler bulunurken; toplam yağ asitlerinin yaklaşık %75'ini doymamış yağ asitleri, %25'ini doymuş yağ asitleri oluşturmaktadır (Tablo 2).

Tablo 1. Menengiç tohumunun kimyasal bileşimi (% kuru maddede).

Ham yağ	Ham protein	Ham lif	Kül	Kaynak
38.74	9.67	10.90	3.10	(Özcan, 2004)
47.00	9.10	17.52	5.08	(Kaya ve Özer, 2015)
40.21	12.35	11.24	3.23	(Köten ve Satouf, 2019)
46.05	9.49	24.56	2.40	(Bulut, 2019)

Tablo 2. Menengiçteki temel yağ asitleri (%).

Palmitik asit	Palmitoleik asit	Stearik asit	Oleik asit	Linoleik asit	Linolenik asit	Kaynak
21.3	3.4	2.0	52.3	19.7	0.6	(Özcan, 2004)
24.28	3.78	1.70	45.82	23.93	0.47	(Kaya ve Özer, 2015)
23.05	3.85	1.68	43.5	22.9	0.39	(Şahin, 2019)
23.40	-	2.19	48.02	23.03	0.71	(Özcan, 2004)

P. terebinthus L. meyvelerinin yeşilden siyaha doğru olgunlaştıkça, yağ içeriğinin arttığı; bu süreçte oleik ve palmitik asit seviyeleri yükselirken, linolenik asit seviyelerinin azaldığı bildirilmiştir (Ahmed vd., 2025).

Yapılan birçok çalışmada menegiçin uçucu aromatik bileşenlerden ve fenoliklerden oluşan biyoaktif bileşenleri, mineral maddeleri ve bazı vitaminleri içerdiği belirtilmiştir (Tablo 3).

Menengiç, kimyasal bileşenleri bakımından zengin bir tür olup özellikle tanenler, reçineli maddeler ve uçucu yağlar yönünden dikkat çekmektedir. Menengiç türlerinin farklı organlarında (meyve, kabuk, reçine-benzeri salgılar, sürgün ve çiçek dokuları) uçucu yağ bileşimlerinin ayrıntılı şekilde incelendiği çok sayıda çalışma bulunmaktadır (Kıvçak vd., 2004).

Tablo 3. Menengiçin yapısında bulunan biyoaktif bileşenler, mineral maddeler ve bazı vitaminler.

<table>
<tr><th>Bileşenler</th><th colspan="2">Belirlenen Maddeler</th><th>Kaynak</th></tr>
<tr><td rowspan="19">Biyoaktif bileşenler</td><td colspan="2">Terpenler* (Monoterpenler, tetrasiklik triterpenoitler, diğer triterpenoitler)</td><td rowspan="19">(Amanpour vd., 2019)*
(Özcan vd., 2020)**</td></tr>
<tr><td colspan="2">Diğer uçucu bileşenler* (alkoller, aldehitler, asitler ve ketonlar)</td></tr>
<tr><td>Fenolik bileşikler**</td><td>mg/kg</td></tr>
<tr><td>Gallik asit</td><td>4.27</td></tr>
<tr><td>Protokateşuik asit</td><td>3.86</td></tr>
<tr><td>(+)-Kateşin</td><td>5.58</td></tr>
<tr><td>1,2-Dihidroksibenzen</td><td>3.8</td></tr>
<tr><td>Sirinjik asit</td><td>0.95</td></tr>
<tr><td>Kafeik asit</td><td>0.48</td></tr>
<tr><td>Rutin trihidrat</td><td>0.51</td></tr>
<tr><td>p-kumarik asit</td><td>0.08</td></tr>
<tr><td>trans-Ferulik asit</td><td>0.24</td></tr>
<tr><td>Apigenin-7-glukozid</td><td>0.46</td></tr>
<tr><td>Resveratrol</td><td>0.36</td></tr>
<tr><td>Quersetin</td><td>129.09</td></tr>
<tr><td>trans-sinnamik asit</td><td>0.15</td></tr>
<tr><td>Naringenin</td><td>0.87</td></tr>
<tr><td>Kaempferol</td><td>2.50</td></tr>
<tr><td>Isoramnetin</td><td>1.75</td></tr>
<tr><td>Vitamin içeriği</td><td colspan="2">D_2 vitamini (2.5 µg/ g)
D_3 vitamini (9.95 µg/ g)
K_1 vitamini (21 µg/ g)
Retinol (25.65 µg/ g)</td><td>(Ciftci vd., 2009)</td></tr>
</table>

<table>
<tr><td rowspan="14">Mineral içeriği</td><th>Mineral</th><th>mg/kg</th><th>Mineral</th><th>mg/kg</th><td rowspan="14">(Özcan, 2004)</td></tr>
<tr><td>K</td><td>1364.19</td><td>Se</td><td>6.20</td></tr>
<tr><td>Ca</td><td>924.39</td><td>Li</td><td>5.97</td></tr>
<tr><td>Na</td><td>906.64</td><td>Cr</td><td>3.91</td></tr>
<tr><td>S</td><td>897.83</td><td>Zn</td><td>3.09</td></tr>
<tr><td>P</td><td>801.88</td><td>Ag</td><td>2.57</td></tr>
<tr><td>Mg</td><td>318.39</td><td>Co</td><td>2.07</td></tr>
<tr><td>Fe</td><td>41.78</td><td>Cd</td><td>1.98</td></tr>
<tr><td>Pb</td><td>30.15</td><td>Ti</td><td>1.88</td></tr>
<tr><td>B</td><td>29.90</td><td>Cu</td><td>1.28</td></tr>
<tr><td>Al</td><td>16.96</td><td>Mn</td><td>1.23</td></tr>
<tr><td>As</td><td>10.12</td><td>Ni</td><td>1.05</td></tr>
<tr><td>Bi</td><td>9.59</td><td>V</td><td>0.87</td></tr>
<tr><td>Sr</td><td>7.29</td><td>Ba</td><td>0.54</td></tr>
</table>

Literatürde genel olarak Pistacia türlerinin uçucu yağlarının monoterpen hidrokarbonlarca zengin olduğu, bitki organına göre bazı oksijenli terpenler ile seskiterpenlerin de önemli oranlara ulaşabildiği bildirilmektedir. Amanpour vd. (2019) menengiç uçucu aroma bileşenleri içerisinde toplam terpen miktarını 255 mg/kg (toplam aromanın %93,3'ü) olarak belirlemişlerdir. Terpenler içerisinde de *α*-Pinene (108.29 mg/kg) başlıca bileşen olmuş, bunu *D*-Limonene (26.99 mg/kg), Ocimene (25.78 mg/kg), *ß*-Myrcene (21.18 mg/kg), (*Z*)-*ß*-Ocimene (14.54 mg/kg) takip etmiştir. Terpenler haricindeki diğer uçucu bileşenleri ise alkoller (1.44 mg/kg), aldehitler (2.16 mg/kg), asitler (10.78 mg/kg) ve ketonlar (3.20 mg/kg) olarak belirlemişlerdir.

Papageorgiou vd. (1999), *P. terebinthus* reçinesinin uçucu yağında temel bileşenlerin α-pinen, β-pinen, sabinen ve terpinen-4-ol olduğunu belirtmişleridir. Bu çeşitlilik, menengiç uçucu yağının gıda endüstrisi, parfümeri ve farmasötik uygulamalar için önemli bir doğal aroma ve biyolojik aktivite kaynağı olarak değerlendirilmesini mümkün kılmaktadır.

Menengiç uçucu bileşenlerinden mirsen (myrcene) ise hem aromatik karakteri hem de biyolojik etkileri nedeniyle dikkat çeken bir monoterpendir. (Şahin, 2019) ezilmiş menengiç tohumlarında mirsen oranının %8.76 ile uçucu bileşenler içinde en yüksek değerlerden biri olduğunu bildirmiştir. Mirsenin doğal bir kas gevşetici olarak etki gösterdiği, antiinflamatuvar özellik sergilediği ve antimikrobiyal aktivitesi nedeniyle kozmetik ürünler, sabunlar, deterjanlar ile çeşitli gıda ve içeceklerde kullanım potansiyeli taşıdığı belirtilmektedir.

Günümüze kadar yapılan çalışmalar, Pistacia türlerinin önemli doğal antioksidan kaynaklar olarak kullanılabileceğini, standart antioksidan bileşikler olarak kullanılan kuersetin ve α-tokoferol gibi fenolikler ve flavonoidler içerdiğini göstermiştir. (Topçu vd., 2007). Sür (2017) çalışmasında süperkritik karbondioksit ekstraksiyonu ile farklı süre, sıcaklık ve basınçlarda elde ettiği menengiç ekstraktlarında kuersetini 12.19-268.75 ppm, kateşini 0-49.89 ppm gallik asiti 0-29.11 ppm, α-tokoferolü 0.48-153.34 ppm, ß-tokoferolü 0 -205.57 ppm, γ-tokoferolü ise 0.40-13.42 ppm aralığında bulmuştur. Özcan vd. (2020) α-tokoferolü 44.43 mg/100g, ß-tokoferolü 8.38 mg/100g, γ-tokoferolü 102.96 mg/100g, δ-tokoferolü ise 2.15 mg/100g aralığında bulmuştur.

Kavak vd. (2010) yaptığı araştırmada, menengiç bitkisinin farklı kısımlarından elde edilen ekstraktların antimikrobiyal ve antioksidan özellikleri incelenmiştir. Çalışma sonucunda, menengiç yapraklarından %80 etanol ile elde edilen saf ekstraktın antioksidan aktivitesinin 85.06 mmol Trolox/g olduğu belirlenmiştir. Ayrıca bu ekstraktın *Staphylococcus aureus*'a karşı minimum inhibisyon konsantrasyonu ≤ 1.53 mg/mL olarak tespit edilmiş; buna karşın *Escherichia coli* üzerinde herhangi bir antimikrobiyal etki gözlememiştir (Kavak vd., 2010).

Bir başka çalışmada, yaprak ekstraktının içeriğinde görülen flavonoid sayesinde fenolik ekstraktın ve alkoloid antioksidanın yüksek antioksidan kapasiteye ve serbest radikal hasarını azaltarak kanser riskini azaltabilecek potansiyele sahip olduğu sonucuna ulaşılmıştır. Yaprak ekstraktı gram pozitif bakterilere karşı antimikrobiyal etki göstermiş, ancak gram negatif bakterilere karşı etkisiz kalmıştır. *E.coli* tarafından üretilen *β*-glukoronidaz enzimi üzerinde yüksek bir inhibisyon etkisi gösterdiği belirlenmiştir. Bu inhibisyon, bitki ekstraktının insan bağırsak florasında deglukuronidasyonu azaltabileceği ve bu sayede kanser riskini düşürebileceği anlamına gelmektedir (Kavak vd., 2010).

Menengiç meyve kabukları luteolin bakımından zengindir. Luteolin, bitkilerde yaygın olarak bulunan doğal bir flavonoid ve önemli bir ikincil metabolittir. Güçlü antikanser ve antiinflamatuvar özellikleri nedeniyle bilimsel açıdan büyük ilgi görmektedir (Kızılyıldırım, 2024). Bulut (2019) yaptığı çalışmasında menengiç kahvesindeki fenolik bileşiklerden luteolin ellajik asit, gallik asit, fumarik asiti ağırlıklı olarak bulmuştur.

Bu bulgular birlikte değerlendirildiğinde, menengicin hem uçucu yağ hem de fenolik bileşikler bakımından oldukça zengin bir fitokimyasal kaynak olduğu; luteolin ve mirsen gibi biyolojik etkisi yüksek bileşenlerin varlığı sayesinde gıda, sağlık ve kozmetik alanlarında önemli uygulama potansiyeli taşıdığı görülmektedir.

Menengiç tohumlarının kavrulmasıyla elde edilen ve "çedene kahvesi" (menengiç kahvesi) olarak bilinen içeceğin, halk hekimliğinde çeşitli tedavi edici özellikleriyle kullanıldığı bilinmektedir. Bu geleneksel içeceğin; balgam söktürücü, solunum ve idrar yolları antiseptiği, göğüs yumuşatıcı, vücut içi yaraların iyileşmesini destekleyici, ayak terlemesini azaltıcı, kolesterol düşürücü veya önleyici, regl düzenleyici ve böbrek taşı atılımını kolaylaştırıcı etkiler gösterebildiği belirtilmiştir (Kaya, 2012). Halk arasında, menengiçin kurutulmuş yapraklarından hazırlanan dekoksiyonun mide rahatsızlıklarına iyi geldiği söylenmektedir. Meyveleri dışarıdan kullanımla gastralji ve romatizma tedavisinde, içeriden kullanımla ise öksürüğe karşı uyarıcı, öksürük kesici ve idrar söktürücü özellikleri nedeniyle kullanılmaktadır. Ayrıca güneş çarpmasına karşı da menengiç yapraklarının faydalı olduğu ifade edilmektedir (Sidar, 2011). Menengiçin cilt ve saç sağlığını desteklediği, ağız kokusunun giderilmesine yardımcı olduğu ve anne sütü üretimini artırıcı etki gösterebildiği bildirilmektedir. Ayrıca biyolojik yapısında kafein bulundurmaması ve doymamış yağ asitleri bakımından zengin olması, menengiçi doğal bir sağlık kaynağı haline getirmektedir (Ekinci, 2021).

Menengiçin kan parametreleri üzerinde olumlu etkiler gösterdiği bildirilmektedir. Yapılan araştırmalarda, menengiç tüketiminin toplam kolesterol ve LDL-C düzeylerini düşürdüğü, buna karşın HDL-C seviyesini artırdığı belirlenmiştir. Ayrıca lipit profillerinde görülen bu iyileşmenin, koroner kalp hastalığı riskinin azalmasına katkı sağlayabileceği de ifade edilmiştir (Şahin, 2019).

Uyar ve Abdulrahman (2020) diyabetik sıçanlara *P. terebinthus* ekstraklarını uygulamışlar, ekstrakt uygulanan sıçanların kan şekeri, aspartat aminotransferaz, alanin aminotransferaz, alkalin fosfataz, laktat dehidrogenaz, glikoz, toplam trigliserit, toplam kolesterol, yüksek ve düşük yoğunluklu lipoprotein düzeylerinde azalma meydana geldiğini, karaciğer, böbrek ve pankreas üzerinde koruyucu bir etki gösterdiğini, ekstraktın antioksidatif etkisi sayesinde serum enzimleri ve lipid oksidasyonu seviyeleri üzerindeki zararlı etkilerini azaltarak antidiyabetik aktivite gösterdiğini belirlemişlerdir.

Menengicin Kullanım Alanları ve Değerlendirilmesi

Menengiç ağacının genç yaprakları sıcak suda kaynatılarak çay olarak içilmekte ve sebze olarak değerlendirilmektedir. Ağacın kabuğuna yapılan kesiklerden ise reçine (terebentin chia otica veya sakız) elde edilir ve bu reçine geleneksel tıpta kullanılmaktadır. Hoş aromalı ve uçucu yağ içeren bu reçine, bal kıvamında, açık sarı ve şeffaf renge sahip olup alkolde çözünme özelliği taşır. Bitkinin kabuğunda yaklaşık %25 oranında tanenler (bitki polifenolleri) acı ve buruk bir tada sahiptir (Şahin, 2019).

Menengiç meyvesi antepfıstığını andıran tadı ve aromatik uçucu profilleri, biyoaktif bileşenleri, yüksek yağ içeriği nedeniyle oldukça değerlidir. Soğuk pres yöntemiyle elde edilen menengiç yağı, Akdeniz mutfağında yaygın olarak kullanılmakta; kendine özgü lezzeti sayesinde salatalara, peynir çeşitlerine ve marine soslara sıkça eklenmektedir (Batovska, 2025).

Diğer tüketim şekillerine kıyasla menengiçin kahve olarak tüketimi daha yaygındır (Dalgıç vd., 2011). Tıbbi ve aromatik özelliklerinin yanı sıra, son yıllarda tüketimi artan "menengiç kahvesi", yumuşak aroması ve kendine özgü kokusuyla yöresel olarak tüketilen popüler bir üründür. Kahve üretiminde kullanılan menengiç taneleri, önce gölgede kurutulup kavrulmaktadır. Kavurma işleminin ardından öğütülerek elde edilen ezme, kahve olarak kullanılmaya hazır hale gelir. Menengiç kahvesi, tercihe bağlı olarak su veya sütle hazırlanabilmektedir (Şahin, 2019).

Yapılan bir çalışmada menengiç kahvesine tam yağlı süt ilavesinin toplam biyoerişilebilir flavonoidleri önemli ölçüde artırdığını, yağsız süt ilavesinin ise önemli bir değişikliğe yol açmadığını ortaya koyulmuştur. Dahası, menengiç kahvesine tam yağlı sütle şeker veya tatlandırıcı ilave edilmesi biyoerişilebilir flavonoidlerin miktarını daha da artırdığı gözlenmiştir. Genel olarak, menengiç kahve + tam yağlı süt + şeker formülasyonunun en yüksek miktarda biyoerişilebilir flavonoid ve flavonoid olmayan bileşikleri içerdiği bulunmuştur (Kamiloglu vd., 2022). Menengiç ezmesi, bazı bölgelerde çeşitli baharatlarla karıştırılarak "zahter" adı verilen karışım biçiminde değerlendirilebildiği belirtilmiştir (Ekinci, 2021).

Bir araştırmada, ceviz, Antep fıstığı ve badem kabuğu ile menengiç meyvesinin antimikrobiyal ve antioksidan özellikleri incelenmiş ve bu materyallerden elde edilen hidrosol ekstraktlarının meyveli yoğurt üretiminde kullanılabilirliği değerlendirilmiştir. Çalışmada farklı meyvelere ait ekstraktlar, yoğurt üretiminde tek başına uygulanmış ve özellikle son ürünün raf ömrü ile tat ve aroma özellikleri üzerindeki etkileri incelenmiştir. Sonuçlar gıda ürünlerinde raf ömrünü artırma, fermente ürünlerde fermantasyonu sınırlama ve bitkisel yağ sanayisinde oksidasyona bağlı bozulmaları önleme gibi alanlarda ileri çalışmalar için potansiyel taşıdığını göstermiştir (Doğan, 2016).

Farklı oranlarda menengiç ilavesinin dondurmanın fiziksel, kimyasal ve duyusal özellikleri üzerindeki etkilerinin incelendiği bir araştırmada, menengiç katkısının dondurmanın pH değerini düşürdüğü; buna karşılık toplam kuru madde, yağ ve kül miktarlarını artırdığı belirlenmiştir. Ayrıca menengiç ilavesi, ürünün erime süresini uzatmış ancak vizkozite üzerinde anlamlı bir değişiklik oluşturmamıştır. Menengiç oranındaki artışa paralel olarak dondurmaların toplam fenolik madde miktarı ve antioksidan aktivitesi de yükselmiştir. Ancak duyusal olarak %1 menengiç içeren örnekler daha çok beğenilmiştir (Ergenekon, 2018).

Ünüvar (2013) tarafından yürütülen araştırmada, menengiçin kuvvetli un, zayıf un ve tam buğday unu ile yapılan ekmek formülasyonlarına eklenmesi sonucunda, kontrol gruplarına kıyasla daha iyi bir tekstür profili ve daha yüksek ekmek hacmi elde edilmiştir. Menengiç katkılı ekmeklerde 1. ve 3. gün ölçülen sertlik ve katılık değerlerinin genel olarak kontrol örneklerine göre daha düşük olduğu görülmüştür.

Menengiçin şekerleme üretiminde kullanılma potansiyelin değerlendiren bir çalışmada, kavrulmuş menengiçlerin kavrulmamış örneklere göre daha yoğun bir şeker kaplaması oluşturduğu görülmüştür. Araştırma sonuçları, menengiç içeren şekerlemelerin genel olarak yüksek tüketici beğenisi aldığını ve özellikle kavrulmuş menengiç kullanılarak hazırlanan ürünlerin daha fazla tercih edildiğini göstermiştir. Ayrıca menengiçin şekerleme alanında kullanılmasıyla, antioksidan kapasitesi yüksek ve fonksiyonel nitelik taşıyan bu ürünlerin yaygınlaştırılmasının hem ürün çeşitliliğini zenginleştireceği hem de ekonomik açıdan ilave değer yaratacağı vurgulanmıştır (Hayoğlu ve İzol, 2010).

Buğday ununun kısmen yerine kullanılmak üzere menengiç (*Pistacia terebinthus*), susam (*Sesamum indicum*) ve keten tohumu (*Linum usitatissimum*) gibi yağlı tohumların farklı oranlarda (%0, 5, 10, 15, 20, 25) bisküvi formülasyonlarına dâhil edildiği bir çalışmada, üretilen bisküvilerin teknolojik, besinsel ve duyusal özellikleri kapsamlı şekilde değerlendirilmiştir. Genel sonuçlar, bu yağlı tohumların bisküvi formülasyonlarına dahil edilmesinin hem teknolojik performansı hem de besinsel kaliteyi iyileştirdiğini göstermektedir (Karakoç, 2021).

Menengiç, fonksiyonel gıda formülasyonları ve gıdalarda koruyucu olarak doğal bir kaynak olma potansiyeli ile öne çıkmaktadır (Batovska, 2025).

SONUÇ

Sonuç olarak menengiç, hem geleneksel kullanımı hem de bilimsel veriler ışığında modern gıda teknolojisi için önemli bir doğal kaynak olarak öne çıkmaktadır. Ancak ticari kullanımlarının yaygınlaştırılabilmesi için standardizasyon, toksikolojik güvenlik, endüstriyel ölçekli üretim ve raf ömrü üzerine daha kapsamlı çalışmalara ihtiyaç duyulmaktadır. Gelecek araştırmaların menengiçin ekstraksiyon yöntemlerinin iyileştirilmesi, fonksiyonel ürün geliştirme ve biyoaktif bileşenlerinin biyoyararlanımının artırılması üzerine yoğunlaşmasıyla menengiç, sadece yöresel bir ürün olmanın ötesinde, sürdürülebilir gıda üretiminde ve fonksiyonel gıda tasarımında stratejik bir değer kazanabilecektir.

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Antioxidant Properties of Chestnut Flower

Kestane Çiçeğinin Antioksidan Özellikleri

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ABSTRACT

Chestnut (*Castanea sativa* Mill.) flowers are a rich botanical source exhibiting strong antioxidant potential due to their high content of phenolic and flavonoid compounds. This study aimed to determine the phenolic content and antioxidant capacities of extracts obtained from male chestnut flowers collected in Ordu Province (40°59′9.6972″, 37°9′41.9472″). Samples were transported to the laboratory, prepared for analysis, and extracted under specific conditions (60 min, 1:100 solid-to-liquid ratio g/mL, 60 °C). The obtained extracts were analyzed for total phenolic content (TPC) and total flavonoid content (TFC), as well as antioxidant activities determined by DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging, ferric reducing antioxidant power (FRAP), and ABTS (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) assays. On a dry matter basis, the mean TPC and TFC values were found to be 96.58 mg GAE/g and 15.24 mg ECE/g, respectively. Antioxidant capacity results were FRAP 947.06 mmol TE/g, ABTS 2615.26 mmol TE/g, and DPPH 1052.63 mmol TE/g. The results demonstrated that chestnut flower extracts possess strong reducing power and free radical scavenging capacity. A significant positive correlation was observed between total phenolic content and antioxidant activity parameters, suggesting that the phenolic compounds are mainly responsible for the biological activity of the flowers. These findings highlight the potential of chestnut flowers as a natural antioxidant source for improving oxidative stability in food formulations, as well as their applicability as biological protective agents in cosmetic and pharmaceutical industries.

Keywords: Antioxidant activity, waste, polyphenol.

ÖZET

Kestane (*Castanea sativa* Mill.) çiçekleri, içerdiği yüksek düzeyde fenolik ve flavonoid bileşikler sayesinde güçlü antioksidan potansiyel sergileyen bitkisel bir kaynaktır. Bu çalışma, Ordu ilinde (40° 59’ 9.6972’’, 37° 9’ 41.9472) yetişen kestane erkek çiçeklerinden elde edilen özütlerin fenolik içeriği ve antioksidan kapasitelerinin belirlenmesini amaçlamaktadır. Örnekler laboratuvara getirilip analize hazırlanmış, belli koşullarda (60 dakika, 1:100 katı:sıvı oranı g/mL, 60 °C) ekstrakte edilmiştir. Elde edilen ekstraktlarda toplam fenolik madde (TP), toplam flavonoid (TF) içerikleri ile DPPH (2,2-difenil-1-pikrilhidrazil) serbest radikalini giderme etkisinin belirlenmesi, demir indirgeme antioksidan gücü FRAP ve ABTS (2,2'-azino-bis(3-etilbenzotiyazolin-6-sülfonik asit) radikal süpürücü kapasite tayini yöntemlerine dayalı antioksidan aktivite analizleri gerçekleştirilmiştir. Kuru madde bazında ortalama TP değeri 96.58 mg GAE/g, TF değeri ise 15.24 mg ECE/g olarak saptanmıştır. Antioksidan kapasite değerleri FRAP 947.06 mmol TE/g, ABTS 2615.26 mmol TE/g ve DPPH 1052.63 mmol TE/g olarak belirlenmiştir. Analiz sonuçları, kestane çiçeği özütlerinin yüksek indirgeme gücü ve serbest radikal giderme kapasitesine sahip olduğunu göstermiştir. Toplam fenolik madde içeriği ile antioksidan aktivite parametreleri arasında anlamlı pozitif korelasyon tespit edilmiştir. Bu da çiçeğin biyolojik etkisinden, büyük ölçüde fenolik bileşenlerin sorumlu olduğunu göstermektedir. Bu bulgular, kestane çiçeğinin doğal antioksidan kaynağı olarak gıda formülasyonlarında oksidatif stabiliteyi artırma, kozmetik ve farmasötik uygulamalarda ise biyolojik koruyucu ajan olarak kullanılma potansiyeline sahip olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Antioksidan aktivite, atık, polifenol.

Bu araştırma, TÜBİTAK tarafından desteklenen “TOVAG 123O056” numaralı proje kapsamında elde edilen veriler doğrultusunda hazırlanmıştır.

GİRİŞ

Kestane (*Castanea sativa* Mill.), Fagaceae (kayıngiller) familyasına ait, Türkiye’nin Karadeniz ve Marmara bölgelerinde yaygın olarak bulunan ve hem orman ekosistemi hem de kırsal ekonomi açısından önemli bir türdür (Pandey, 2018; Silva vd., 2020). Geleneksel olarak meyvesi ile tanınmakla birlikte, bitkinin yaprak, kabuk ve özellikle çiçek kısımlarının biyokimyasal potansiyeli son yıllarda giderek daha fazla dikkat çekmektedir (Silva vd., 2020; Filippelli vd., 2024). Kestane meyveleri ve yapraklarında fenolik bileşiklerin varlığı uzun süredir bilinmesine rağmen, kabuk ve çiçekleri gibi diğer bitki parçalarının antioksidan özellikleri hakkındaki bilgiler daha sınırlıdır (Barreira vd., 2008). Kestane ağacında erkek ve dişi çiçekler aynı ağaç üzerinde bulunur. Erkek çiçekler Mayıs–Haziran döneminde uzun kedicikler hâlinde gelişir ve polen üretimi bakımından zengin yapılarıyla arıcılık açısından önemli bir nektar–polen kaynağı oluşturur. Bu nedenle kestane balı, fenolik bileşik içeriği ve kendine özgü aromatik profiliyle dikkat çeken bir üründür (Carocho vd., 2014). Kestane çiçekleri aynı zamanda endüstriyel kestane işleme süreçleri sırasında ortaya çıkan değerli yan ürünlerdendir. Özellikle *Castanea mollissima* çiçeklerinin flavonoidler açısından zengin olduğu ve geleneksel tıpta solunum bozuklukları da dahil olmak üzere çeşitli hastalıkların tedavisinde kullanıldığı bildirilmektedir (Peng vd., 2022). Modern araştırmalar, kestane çiçeği ekstraktlarının yüksek düzeyde toplam polifenoller ve flavonoidler içerdiğini, buna bağlı olarak belirgin antioksidan aktivite gösterdiğini ortaya koymaktadır (Barreira vd., 2008; Xie vd., 2025).

Kestane çiçeğinin kimyasal kompozisyonu yalnız fenolik bileşiklerle sınırlı olmayıp, terpenler, fenolik türevler ve aldehitler gibi uçucu bileşikleri de içermektedir. Bu uçucu bileşenler çiçeğe karakteristik aromasını kazandırmakla kalmayıp antimikrobiyal etkileriyle bitkinin çevresel streslere karşı adaptasyonunda önemli rol oynamaktadır (Filippelli vd., 2024). Bu kimyasal çeşitlilik, kestane çiçeğini ekolojik açıdan değerli kılması yanında yüksek biyolojik aktivitesi nedeniyle gıda ve kozmetik endüstrilerinde de ilgi gören doğal bir bileşen hâline getirmiştir.

Nitekim son yıllarda kestane çiçeği ekstraktları, doğal antioksidan ve fonksiyonel katkı maddesi olarak değerlendirilmekte ve çeşitli gıda ürünlerinin fenolik içeriğini, besin değerini ve raf ömrünü iyileştirme potansiyeli taşımaktadır (Carocho vd., 2015; Caleja vd., 2020). Özellikle potasyum sorbat gibi sentetik koruyuculara doğal bir alternatif olarak kullanım potansiyeli üzerinde durulmaktadır (Carocho vd., 2015). Ayrıca, çiçeklerden elde edilen esansiyel yağların benzil alkol, nerol, 3-hekzen-1-ol ve asetofenon gibi bileşenlerce zengin oluşu, bu yağlara antiseptik, antioksidan ve anti-inflamatuar gibi ek biyolojik etkiler kazandırmaktadır.

Bu çalışmada, kestane çiçeği ekstraktlarının antioksidan özellikleri incelenmiştir. Elde edilen sonuçlar, literatürde yer alan diğer sonuçlarla karşılaştırılmıştır.

MATERYAL VE METOT

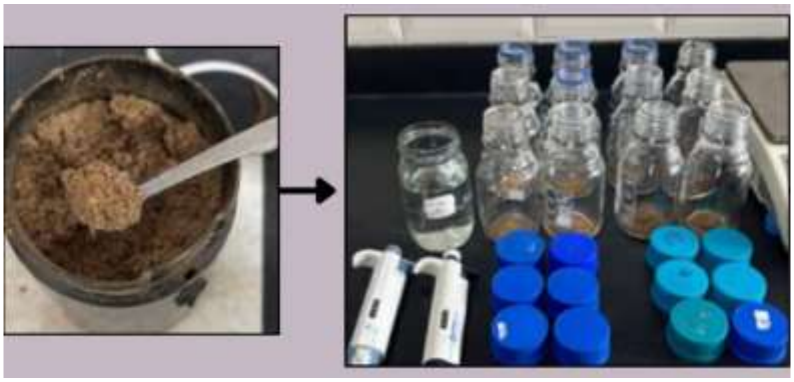
Materyal

Kestane çiçekleri, Ordu ilinde (40°59’9.6972’’, 37°9’41.9472’’) yer alan kestane bahçelerinden, aynı çeşit ve yaş grubuna ait sekiz ağaçtan toplanmıştır. Toplanan örnekler laboratuvara taşındıktan sonra 40°C’de kurutma işlemine tabi tutulmuştur. Kurutulan çiçekler, analiz ve ekstraksiyon işlemleri gerçekleştirilinceye kadar +4°C’de saklanmıştır. Analiz öncesi, kestane çiçekleri, mini bir mutfak değirmeninde öğütülmüştür (Şekil 1).

Şekil 1. Kestane çiçeklerinin öğütülmesi.

Kestane Çiçeği Ekstraktının Hazırlanması

Kurutularak öğütülen kestane çiçekleri, her bir ağacı temsil edecek şekilde eşit oranlarda birleştirilmiştir. Ön denemeler sonucunda belirlenen koşullar (ekstraksiyon süresi (60 dakika), numune/çözücü oranı (1:100, g/mL) ve sıcaklık (60°C)) sabit tutularak toplam fenolik madde (TP), toplam flavonoid (TF) ve antioksidan aktivite (DPPH, FRAP ve ABTS) analizleri gerçekleştirilmiştir (Şekil 2).



Şekil 2. Kestane çiçeklerinin ekstraksiyonu.

Toplam Fenolik Madde Analizi

Toplam fenolik madde içeriği, Folin-Ciocalteu yöntemi kullanılarak belirlenmiştir. Bu amaçla 150 µL seyreltilmiş örnek, 750 µL %10'luk Folin-Ciocalteu çözeltisi ile 5 dakika reaksiyona bırakılmış, ardından 600 µL %7.5 Na_2CO_3 ilave edilmiştir. Karışım, 2 saat boyunca karanlıkta bekletildikten sonra 760 nm dalga boyunda absorbans değerleri ölçülmüştür. Elde edilen sonuçlar, mg gallik asit eşdeğeri/g (mg GAE/g) olarak ifade edilmiştir (Hassan vd., 2022).

Toplam Flavonoid İçeriği (TFC) Tayini

Toplam flavonoid (TFC) içeriğini belirlemek için seyreltilmiş örnekten 1 mL alınmış ve üzerine 0.3 mL %5'lik $NaNO_2$ eklenerek 5 dakika reaksiyona bırakılmıştır. Daha sonra 0.5 mL %5'lik $AlCl_3$ ilave edilmiş ve karışım 6 dakika boyunca bekletilmiştir. Ardından 0.5 mL 1 M NaOH eklenmiş ve 10 dakika sonra 510 nm dalga boyunda absorbansı ölçülmüştür. TFC hesaplamaları, epikateşin standardı ile oluşturulan kalibrasyon eğrisine dayanılarak yapılmış ve sonuçlar mg epikateşin eşdeğeri (ECE) g^{-1} olarak rapor edilmiştir (Hassan vd., 2022).

DPPH Serbest Radikal Giderme Aktivitesinin Belirlenmesi

Seyreltilmiş örnekten 50 µL alınarak 1 mL DPPH çözeltisi (0.06 mM, %80 metanol) ile karıştırılmıştır. Karışım çalkalanmış ve reaksiyonun tamamlanması için 1 saat boyunca karanlıkta bekletilmiştir. Ardından, absorbans değeri 517 nm'de ölçülmüştür. Metil alkol, kontrol olarak kullanılmıştır. DPPH radikal giderme aktivitesi aşağıdaki formül ile hesaplanmıştır:

$$\text{İndirgeme (\%)} = \left(\frac{A\,kontrol - A\,örnek}{A\,kontrol}\right) x\ 100 \quad (1)$$

Ekstraktın DPPH radikal giderme aktivitesi, Trolox standardı ile oluşturulan kalibrasyon eğrisine dayanarak hesaplanmış ve sonuçlar mmol Trolox eşdeğeri (TE) g^{-1} olarak ifade edilmiştir (Bacchetti vd., 2020).

Demir İyonu İndirgeme Antioksidan Gücü (FRAP) Tayini

50 µL ekstrakt, 950 µL FRAP çözeltisi ile karıştırılmıştır. FRAP çözeltisi 100 mM asetat tamponu, 10 mM $FeCl_3$ ve 10 mM TPTZ (2,4,6-tri-piridil-s-triazin) içermektedir. Karışım yaklaşık 5 dakika boyunca çalkalandıktan sonra 593 nm dalga boyunda absorbans ölçümü yapılmıştır. Ekstraktların FRAP değerleri, Trolox standardı kullanılarak hazırlanan kalibrasyon eğrisine göre hesaplanmış ve sonuçlar mmol Trolox eşdeğeri (mmol TE/g) olarak rapor edilmiştir (Pashazadeh vd., 2021).

ABTS Radikal Süpürücü Kapasite Tayini

Ekstrakt (0.2 mL), 2 mL $ABTS^{+}$ radikal katyon çözeltisi ile karıştırılmıştır. Karışım 2 saat boyunca karanlık ortamda bekletildikten sonra absorbans değeri 734 nm dalga boyunda ölçülmüştür. Elde edilen sonuçlar, mmol Trolox eşdeğeri (mmol TE/g) cinsinden rapor edilmiştir (Irondi vd., 2017).

SONUÇLAR ve TARTIŞMA

Kestane çiçeklerine ait antioksidan özellikler Tablo 1'de sunulmuştur.

Tablo 1. Kestane çiçeklerinin fenolik madde ve antioksidan aktivite sonuçları (kuru madde).

	Ortalama	**Minimum**	**Maksimum**	**Std. Hata**	**Std. Sapma**
Toplam fenolik madde, mg/g	96.58	61.85	108.08	5.570	15.754
Toplam flavonoid, mg/g	15.24	12.36	17.10	0.608	1.720
FRAP, mmol/g	947.06	689.30	1117.40	46.499	131.520
DPPH, mmol/g	1052.63	633.61	1318.94	85.995	243.230
ABTS, mmol/g	2615.26	1821.62	3284.33	173.173	489.806

Tablo 1'den de görüldüğü gibi, çiçeklerin toplam fenolik madde miktarı ortalama 96.58 mg GAE/g olup, minimum 61.85 ve maksimum 108.08 mg GAE/g arasında değişmiştir. Bu değer, örnekler arasındaki fenolik madde içerik farklılığının belirli bir düzeyde olduğunu (standart sapma: 15.75 mg/g) göstermektedir. Toplam flavonoid içeriği ortalama 15.24 mg/g olarak tespit edilmiş, düşük standart sapma (1.72 mg/g) değerleri örnekler arasında homojen bir dağılıma işaret etmiştir. Bu durum, kestane çiçeklerinin fenolik bileşikler yanında flavonoid açısından da dikkate değer bir kaynak olduğunu göstermektedir.

Antioksidan aktiviteye ilişkin üç farklı test sonucunda da yüksek değerler elde edilmiştir. FRAP değeri ortalama 947.06 mmol/g ile güçlü bir indirgeme kapasitesi ortaya koyarken, ABTS değeri 2615.26 mmol/g ile örneklerin radikal giderme gücünün yüksek olduğunu göstermektedir. Özellikle ABTS testinde elde edilen yüksek ortalama ve geniş dağılım (SD: 489.81) fenolik bileşiklerin çeşitliliğine ve bazı örneklerde yüksek antioksidan kapasiteye işaret etmektedir. DPPH değeri, ortalama 1052.63 mmol/g olup, minimum ve maksimum değerler (633.61–1318.94 mmol/g) arasındaki fark, çiçek örnekleri arasında belirgin farklılıklar bulunduğunu göstermektedir. DPPH testinde gözlenen daha yüksek standart sapma (243.23 mmol/g), testin serbest radikal türlerine karşı duyarlılığının ve reaksiyon kinetiğinin fenolik yapıya göre değişkenlik gösterdiğini düşündürmektedir.

Genel olarak, fenolik madde ve flavonoid miktarlarının yüksekliği ile antioksidan aktivite arasında pozitif bir ilişki bulunduğu, özellikle FRAP ve ABTS testlerinin bu ilişkiyi daha güçlü yansıttığı anlaşılmaktadır. Bu durum, kestane çiçeklerinin antioksidan kapasitesinin büyük ölçüde fenolik bileşiklerden kaynaklandığını göstermektedir. Elde edilen sonuçlar literatürde kestane çiçeği ekstraktlarının yüksek fenolik içeriğe ve güçlü antioksidan aktiviteye sahip olduğunu bildiren çalışmalarla uyumludur. Bu bulgular, kestane çiçeğinin doğal antioksidan kaynağı olarak gıda, kozmetik ve farmasötik alanlarda değerlendirilebileceğini göstermekte; ancak gözlenen varyasyonların genetik farklılıklar, yetişme koşulları ve çevresel etmenlerden kaynaklanabileceği dikkate alınmalıdır.

Barreira vd. (2008), radikal giderme, indirgeme gücü, β-karoten ağartılmasını önleme, eritrosit hemolizini inhibe etme ve lipid peroksidasyonu testleri uygulamışlardır. Sonuçlar, kestane çiçeği ekstraktının yüksek fenolik madde (298 mg/g) ve flavonoid (160 mg/g) içeriğine sahip olduğunu, buna bağlı olarak da güçlü antioksidan aktivite gösterdiğini ortaya koymuştur. Özellikle çiçek, yaprak ve kabuk ekstraktları yüksek antioksidan kapasite sergilerken, meyve ekstraktı düşük aktivite göstermiştir. Araştırıcılar, kestane çiçeği ve diğer bitki kısımlarının doğal antioksidan kaynağı olarak değerlendirilebileceğini ve gıda ile sağlık alanlarında sentetik antioksidanlara alternatif oluşturabileceğini vurgulamışlardır.

Sapkota vd. (2010), kestane çiçeği (*Castanea crenata* var. dulcis) ekstraktlarının antioksidan ve melanin oluşumunu engelleyici özelliklerini araştırmışlardır. Çiçeklenme öncesi dönemde elde edilen etanol ve metanol ekstraktlarının en yüksek fenolik ve flavonoid içeriğe sahip olduğu ve buna bağlı olarak güçlü antioksidan aktivite gösterdiği belirlenmiştir. Ayrıca, bu ekstraktların ultraviyole ışınlarına karşı koruyucu etki sağladığı ve tirozinaz enzimini inhibe ederek melanin üretimini azalttığı rapor edilmiştir. Araştırmacılar, kestane çiçeği ekstraktlarının yüksek polifenol içeriği sayesinde doğal bir antioksidan ve cilt açıcı ajan olarak kozmetik, gıda ve ilaç sanayinde potansiyel kullanım alanına sahip olduğunu belirtmişlerdir.

Carocho vd. (2015), kestane çiçeği (*Castanea sativa* Mill.) ilavesinin geleneksel "económicos" keklerinin besinsel ve fonksiyonel özelliklerini nasıl etkilediğini araştırmışlardır. Çalışmada, kuru kestane çiçeği ve çiçek dekoksiyonlarının hamura eklenmesiyle ürünlerin toplam fenolik içeriği, antioksidan aktivitesi ve besin değerinin belirgin biçimde arttığını tespit etmişlerdir. Özellikle bu doğal ilavenin oksidatif bozulmayı yavaşlatarak ürünün raf ömrünü uzattığı, ayrıca lif, mineral (özellikle potasyum ve sodyum) ve E vitamini (α-tokoferol) miktarlarını artırdığı vurgulanmıştır. Araştırıcılar, kestane çiçeğinin sahip olduğu fenolik bileşikler sayesinde hem besin değerini zenginleştirdiğini hem de antioksidan ve antimikrobiyal özellikleriyle gıdalarda sentetik katkı maddelerine doğal bir alternatif oluşturabileceğini belirtmişlerdir.

Caleja vd. (2020), kestane ağacının (*Castanea sativa*) erkek çiçeklerinden elde ettikleri özütü, Portekiz'in geleneksel tatlısı "pastel de nata" üretiminde potasyum sorbata doğal alternatif olarak kullanmışlardır. Çalışmada su-etanol (33:67) karışımıyla hazırlanan özütün yüksek antioksidan aktivite gösterdiği, özellikle β-karoten ağartma testinde EC_{50} = 32 µg/mL ve TBARS inhibisyonunda EC_{50} = 13 µg/mL değerlerine ulaşıldığını bildirmişlerdir. Ayrıca, özütün bazı bakterilere karşı 0.075–0.45 mg/mL aralığında MIC değerleri sergilediği, antifungal etkisinin ise ketokonazole kıyasla daha yüksek olduğu belirlemişlerdir. Ürüne 0.54 g kestane çiçeği özütü eklendiğinde, antioksidan kapasitenin potasyum sorbatlı örneklere göre %10–20 oranında daha yüksek olduğu ve fenolik bileşiklerin depolama süresince stabil kaldığı rapor edilmiştir. Bu sonuçlar, kestane çiçeği özütünün hem etkinliği hem de güvenliği açısından potasyum sorbata güçlü bir doğal alternatif olabileceğini göstermiştir.

Alaya vd. (2021), kestane (*Castanea sativa* Mill.) erkek çiçeklerinden fenolik bileşiklerce zengin doğal bir koruyucu ekstrakt geliştirmek amacıyla ultrason destekli ekstraksiyon yöntemini optimize etmişlerdir. Çalışmada ekstraksiyon süresi, çözücü oranı ve ultrason gücü değişkenleri olarak değerlendirilmiş ve yanıt yüzey metodolojisi (RSM) kullanılarak optimum koşullar 24 dakika, 259 W ve %51 etanol olarak belirlenmiştir. Elde edilen ekstraktın başlıca fenolik bileşikleri, pentagalloyl glukozit ve trigalloyl-HHDP-glukozit olarak saptanmıştır. Optimum koşullarda elde edilen ekstraktın güçlü antioksidan, antiinflamatuvar, antitümör ve antimikrobiyal aktiviteler gösterdiği, buna karşın sitotoksik ve hepatotoksik etki sergilemediği belirlenmiştir. Sonuç olarak araştırıcılar, kestane çiçeği ekstraktının biyolojik olarak aktif, toksik olmayan bir doğal antioksidan koruyucu olarak gıda endüstrisinde sentetik katkı maddelerine alternatif olabileceğini vurgulamışlardır.

Peng vd. (2021), kestane çiçeğinden elde edilen saflaştırılmış flavonoidlerin yorgunluk önleme aktivitelerini kapsamlı şekilde değerlendirmiş ve bu flavonoidlerin farklı yorgunluk modellerinde belirgin iyileştirici etki gösterdiğini rapor etmişlerdir. Elde edilen bulgular, kestane çiçeği flavonoidlerinin yalnız geleneksel tıptaki kullanımını desteklemekle kalmayıp, fonksiyonel gıdalar ve yeni nesil farmasötik ürünler için yüksek potansiyel sunduğunu göstermektedir.

Üreyen Esertaş vd. (2022), kestane çiçeği (*Castanea sativa*) ekstraktlarının fenolik bileşik, antioksidan aktivite ve antimikrobiyal özelliklerini incelemişlerdir. Çalışmada sulu ve etanollü ekstraktlarda toplam fenolik madde miktarı sırasıyla 97.17 mg GAE/mL ve 55.55 mg GAE/mL, toplam flavonoid miktarı ise 2.36 mg QUE/mL ve 6.08 mg QUE/mL olarak bildirilmiştir. FRAP değeri sulu ekstrakt için 1.10 mmol $FeSO_4 \cdot 7H_2O$/mL, DPPH değeri ise yaklaşık 40 µg/mL SC_{50} olarak belirlenmiştir. Kromatoğrafi analizlerinde ellagik asit başta olmak üzere gallik asit, rutin, sirinjik asit, t-sinamik asit, ramnetin, crisin ve pinosembrin gibi çeşitli fenolik bileşikler tespit edilmiştir. Mevcut çalışma sonuçları (toplam fenolik madde 96.58 mg/g, flavonoid 15.24 mg/g, FRAP 947.06 mmol/g, ABTS 2615.26 mmol/g, DPPH 1052.63 mmol/g) literatürde bildirilen kestane çiçeği değerlerine büyük oranda benzemektedir. Özellikle toplam fenolik madde miktarı Üreyen Esertaş vd. (2022)'nin sulu ekstrakt verilerine oldukça yakın bulunmuştur. Buna karşın, flavonoid miktarı ile antioksidan kapasite değerleri (FRAP, ABTS, DPPH) daha yüksek sonuçlar vermiştir. Bu durumun ekstraksiyon yöntemi, kullanılan çözücü tipi, sıcaklık ve bitki materyalinin yetişme koşulları gibi değişkenlerden kaynaklanabileceği düşünülmektedir. Genel olarak, her iki çalışmanın sonuçları kestane çiçeğinin fenolik bileşiklerce zengin, yüksek antioksidan kapasiteye sahip ve doğal antioksidan kaynağı olarak değerlendirilebilecek bir bitki olduğunu ortaya koymaktadır.

Liu vd. (2024), kestane çiçeği uçucu yağının (CFEO) kitosan esaslı biyofilm içerisine eklenmesiyle geliştirilen biyobozunur ve antibakteriyel gıda ambalaj filmlerini tanımlamışlardır. CFEO'nun temel bileşenleri geraniol ve mentol olup, bu bileşikler filmlerin UV engelleme, antioksidan ve antibakteriyel özelliklerini belirgin düzeyde artırmıştır. En uygun formülasyonda film UV ışığını neredeyse tamamen bloke etmiş, *Staphylococcus aureus*, *Escherichia coli* ve *Colletotrichum musae* üzerinde güçlü antibakteriyel ve antifungal aktivite göstermiştir. Ayrıca, CFEO katkısı filmin ısı dayanımını artırmış ve muzların raf ömrünü uzatmıştır. Bu sonuçlar, kestane çiçeği uçucu bileşiklerinin çevre dostu, doğal koruyucu ajanlar olarak kullanılabileceğini ortaya koymaktadır.

Sun vd. (2025), kestane çiçeği polisakkaritlerinin (CFPs) kimyasal özellikleri ve biyolojik aktivitelerini altı farklı ekstraksiyon yöntemiyle karşılaştırmışlardır. Kestane çiçeklerinin fenolik asitler, flavonoidler, uçucu yağlar, proteinler ve polisakkaritler bakımından zengin bir biyolojik kaynak olduğu, özellikle polisakkaritlerin doğal antioksidan ve hipoglisemik ajanlar olarak öne çıktığı belirtilmiştir. Sıcak su ekstraksiyonuyla elde edilen CFP'ler en yüksek antioksidan aktiviteyi, enzim destekli ekstraksiyonla elde edilenler ise en yüksek hipoglisemik aktiviteyi göstermiştir. Tüm ekstraktların biyouyumlu bulunması, CFP’lerin fonksiyonel gıdalarda doğal antioksidan ve antidiyabetik bileşenler olarak değerlendirilebileceğini göstermektedir. Bu çalışma, kestane çiçeği araştırmalarında polifenoller ve flavonoidlerin yanı sıra polisakkaritlerin de önemli bir biyoaktif bileşen grubu olduğunu ortaya koymuştur.

Xie vd. (2025), kestane çiçeği ekstraktının *Fusarium graminearum* üzerindeki antifungal etkisini incelemişlerdir. LC-MS analizine göre ekstraktın başlıca bileşenleri fenolik asitler (gallik, protokateşuik asit) ile flavonoidler (kersetin ve kaempferol türevleri) olarak belirlenmiştir. Kestane çiçeği ekstraktı, misel gelişimi ve spor çimlenmesini güçlü biçimde inhibe etmiş; hücre zar bütünlüğünü bozarak ergosterol düzeyini azaltmış ve protein ile nükleik asit sızıntısına neden olmuştur. Ayrıca ATP üretimini ve enerji metabolizmasında görevli enzim aktivitelerini düşürdüğü bildirilmiştir (Xie vd., 2025). Bu bileşiklerin serbest radikalleri nötralize etme, oksidatif zincir reaksiyonlarını durdurma ve hücresel dokuyu oksidatif hasardan koruma özellikleri literatürde de vurgulanmaktadır (Martínez vd., 2022; Filippelli vd., 2024). Modern gıda, ilaç ve bitkisel ürün uygulamalarında, sentetik antioksidanların sağlık riskleri sorgulandıkça doğal antioksidan kaynaklarına ilgi artmaktadır (Carocho vd., 2014; Filippelli vd., 2024).

Yapılan çalışmalarda, kestane çiçeğinin esansiyel yağlarının kimyasal içeriğinin çeşide göre değişmekle birlikte, kozmetik, deterjan ve parfüm gibi endüstriyel uygulamalar için yüksek bir potansiyel taşıdığı gösterilmiştir (Hu vd., 2017).

SONUÇ ve ÖNERİLER

Bu çalışmada, Ordu ilinden toplanan kestane (*Castanea sativa* Mill.) çiçeklerinden elde edilen ekstraktların toplam fenolik madde, flavonoid içeriği ve farklı antioksidan testleri (DPPH, FRAP, ABTS) ile antioksidan potansiyelleri değerlendirilmiştir. Elde edilen bulgular, kestane çiçeklerinin önemli düzeyde fenolik bileşik içerdiğini ve buna bağlı olarak yüksek antioksidan aktivite sergilediğini göstermiştir. Kuru madde bazında ortalama 96.58 mg GAE/g toplam fenolik madde ve 15.24 mg ECE/g toplam flavonoid değerleri, çiçek materyalinin biyoaktif bileşikler açısından zengin olduğunu ortaya koymaktadır. FRAP, ABTS ve DPPH analizlerinde tespit edilen yüksek radikal süpürme ve indirgeme kapasiteleri, kestane çiçeği ekstraktlarının oksidatif stres mekanizmalarına karşı etkili bir doğal antioksidan kaynağı olduğunu doğrulamaktadır. Çalışmadan elde edilen sonuçlar, literatürde kestane çiçeklerinin fenolik bileşiklerce zengin, güçlü antioksidan, antimikrobiyal ve biyolojik olarak aktif bir bitkisel materyal olduğunu bildiren çalışmalarla uyumludur.

Bu kapsamda kestane çiçeği, sentetik antioksidanların kullanımının azaltılması yönündeki güncel eğilimle uyumlu şekilde, gıda formülasyonlarında doğal koruyucu, fonksiyonel gıdalarda biyolojik değer artırıcı, kozmetik uygulamalarda antioksidan ve antiinflamatuvar ajan, farmasötik alanlarda destekleyici doğal bileşen olarak değerlendirilebilecek önemli bir bitkisel hammaddedir. Sonuç olarak, bu çalışma kestane çiçeğinin yüksek fenolik içeriği ve güçlü antioksidan kapasitesi ile doğal bir biyoaktif kaynak olarak büyük potansiyele sahip olduğunu ortaya koymaktadır.

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Composition of Chestnut Capsule

Kestane Kapsülünün Bileşimi

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ABSTRACT

The capsule enclosing the chestnut (*Castanea sativa* Mill.) fruit is a part that serves as the external protective organ of the plant, undertaking an important defensive function in the biological cycle and is generally not utilized industrially. This waste has a remarkable chemical composition in terms of nutritional fiber, mineral substances and bioactive compounds. This study aimed to reveal the chemical composition of capsules obtained from natural chestnut populations in the Black Sea Region and to establish a scientific basis for the different uses of this material. In this context, capsules collected from eight trees of the same age and variety (40° 59' 9.6972'', 37° 9' 41.9472) were analyzed after drying and grinding processes. The findings show that the analyzed chestnut capsules have low water (3.55±0.98%), crude protein (3.95±0.47%) and crude oil (1.94±0.80%) contents. On the other hand, Neutral Detergent Fiber (NDF) (57.75±3.53%) and Acid Detergent Fiber (ADF) (41.06±2.59%) values indicate the structure's high fiber content. Mineral analysis revealed that potassium (5750.63±949.37 mg/kg), calcium (5127.50±786.52 mg/kg), and sodium (1297.50±226.62 mg/kg) levels were significantly high. The results show that chestnut capsules are a plant source with a balanced mineral content and a rich fiber content. Therefore, they can be utilized in a wide range of applications, from animal feed additives to biocomposite production, from organic fertilizer to soil improvement formulations. In addition, the high fiber and mineral content of the capsule structure stands out as an innovative biomass alternative in environmentally friendly production approaches, especially in areas such as biodegradable packaging, filling material, and compostable polymer production. This research sheds light on the chemical structure of chestnut capsules, which have been studied only sparsely in the literature, and provides the scientific basis for new utilization methods that can create added value in the chestnut production chain.

Keywords: Waste, mineral matter, chemical.

ÖZET

Kestane (*Castanea sativa* Mill.) meyvesini saran kapsül, bitkinin dış koruyucu organı olarak görev yapan, biyolojik döngü içerisinde önemli bir savunma fonksiyonu üstlenen, endüstriyel olarak genellikle değerlendirilmeyen bir kısımdır. Bu atık kimyasal bileşimi, besinsel lif, mineral madde ve biyoaktif bileşenler açısından dikkate değer bir potansiyele sahiptir. Bu çalışmada Karadeniz Bölgesi'nin doğal kestane popülasyonlarından elde edilen kapsüllerin kimyasal bileşimini ortaya koymak ve bu materyalin farklı kullanım alanlarına yönelik bilimsel bir altyapı oluşturmak amaçlanmıştır. Bu bağlamda aynı yaş ve çeşitteki sekiz ağaçtan (40° 59' 9.6972'', 37° 9' 41.9472) toplanan kapsüller, kurutma ve öğütme işlemlerinin ardından analiz edilmiştir. Bulgular, analiz edilen kestane kapsüllerinin düşük su (%3.55±0.98), ham protein (%3.95±0.47) ve ham yağ (%1.94±0.80) içeriğine sahip olduğunu göstermektedir. Buna karşın Nötr Deterjan Lif (NDF) (%57.75±3.53) ve Asit Deterjan Lif (ADF) (%41.06±2.59) değerleri, yapının yoğun lif içeriğine işaret etmektedir. Mineral madde analizleri sonucunda, potasyum (5750.63±949.37 mg/kg), kalsiyum (5127.50±786.52 mg/kg) ve sodyum (1297.50±226.62 mg/kg) düzeylerinin belirgin biçimde yüksek olduğunu ortaya koymaktadır. Elde edilen sonuçlar, kestane kapsüllerinin mineral maddelerce dengeli ve lif yönünden güçlü bir bitkisel kaynak olduğunu, bu yönüyle hayvansal yem katkılarından biyokompozit üretimine, organik gübreden toprak iyileştirici formülasyonlara kadar geniş bir kullanım yelpazesinde değerlendirilebileceğini göstermektedir. Ayrıca kapsül yapısının yüksek lif ve mineral içeriği, çevre dostu üretim yaklaşımlarında, özellikle biyobozunur ambalaj, dolgu malzemesi ve kompostlaştırılabilir polimer üretimi gibi alanlarda yenilikçi bir biyokütle alternatifi olarak öne çıkmaktadır. Bu araştırma, literatürde sınırlı biçimde ele alınan kestane kapsülünün kimyasal yapısına ışık tutmakta ve kestane üretim zincirinde katma değer yaratabilecek yeni değerlendirme yollarına bilimsel temel oluşturmaktadır.

Anahtar Kelimeler: Atık, mineral madde, kimyasal kompozisyon.

Bu araştırma, TÜBİTAK tarafından desteklenen "TOVAG 123O056" numaralı proje kapsamında elde edilen veriler doğrultusunda hazırlanmıştır.

GİRİŞ

Kestane (*Castanea sativa* Mill.), tarım ve ormancılık ekonomisinde önemli bir ağaç olarak kabul edilir ve yüzyıllardır kırsal alanların en önemli gıda kaynaklarından birini temsil eder (Squillaci vd., 2018). Kestane meyvesi, uzun yıllardır insan beslenmesinde yaygın olarak kullanılan besleyici bir gıda olmakla birlikte, meyve dışındaki kısımları da yapısal özellikleri ve zengin fenolik içeriğiyle dikkat çekmektedir (Silva vd., 2020). Bu kısımlar arasında yer alan ve halk arasında "kapçık" veya "kapsül" olarak bilinen dikenli dış yapı, meyveyi çevresel koşullardan ve mekanik etkilerden koruyan karmaşık ligninimsi bir formdadır (Pinto vd., 2017). Bu kapsüller genellikle toprakta bırakılarak böcek larvalarının büyümesini teşvik eder ve sonuç olarak mahsul hasarına yol açar (Vázquez vd., 2012) veya tarlada yakılarak atmosfer ve toprak üzerinde olumsuz etki yaratır (Costa-Trigo vd., 2019). Kestane üretiminin her yıl artmasıyla birlikte büyük miktarda kapsül atığı ortaya çıkmaktadır. Ancak, bu materyalin potansiyel kullanım alanları ve değerlendirilme olanakları üzerine bilgiler sınırlı kalmaktadır (Pinto vd., 2017). Kapsül yapısının kimyasal bileşimi, biyolojik özellikleri ve endüstriyel açıdan değerlendirilebilirliği, kestane üretim zincirinde sürdürülebilirlik hedefleri doğrultusunda araştırılması gereken önemli bir konudur. Yıllık kestane üretim miktarı göz önüne alındığında, her sezon çok büyük miktarda kapsül atığı oluştuğu halde bu materyalin bilimsel ve endüstriyel açıdan değerlendirilmesi yeterince araştırılmamıştır (Braga vd., 2015).

Bitki yan ürünleri üzerine yürütülen çalışmalar, genellikle kabuk ve yaprak gibi daha ulaşılabilir materyallere odaklanmıştır. Örneğin kestane kabuğu, yüksek tanen içeriği, antioksidan kapasitesi ve mineral zenginliği nedeniyle hem gıda hem de kozmetik uygulamalarında değerlendirilmiştir (Barreira vd., 2008). Ancak kapsül, kabuktan farklı olarak çok daha yüksek lignifikasyon derecesi, yüksek toplam lif oranı ve belirgin mineral birikimi göstermektedir (Kılıç Pekgözlü vd., 2022). Bununla birlikte, kapsülün kimyasal kompozisyonu üzerine bugüne dek ayrıntılı bir çalışma yayınlanmamış olması, bu materyalin potansiyel kullanım alanlarının tam anlamıyla anlaşılmasını engellemektedir (Dönmez vd., 2016). Bitkisel atık malzemeler arasında kestane, fındık ve antep fıstığı kabukları, yüksek selüloz–hemiselüloz içerikleri, belirgin lignin oranları, yapısal dayanıklılıkları ve zengin fenolik bileşikleri sayesinde hem koruyucu kabuk yapısının önemini ortaya koymakta hem de biyokompozit ve endüstriyel kullanım açısından değerli bitkisel atık materyaller olarak öne çıkmaktadır (Dönmez vd., 2016). Kestane kapsülünün de benzer odunsu nitelikler taşıdığı bilinse de kompozisyon düzeyindeki verilerin eksikliği nedeniyle bu materyal çoğu zaman sadece yakacak veya düşük değerli organik atık olarak kullanılmaktadır (Costa-Trigo vd., 2019). Bu çalışmada, Karadeniz Bölgesi'nden temin edilen doğal kestane popülasyonlarına ait kapsüllerin kimyasal kompozisyonu incelenmiştir.

MATERYAL VE METOT

Materyal

Kapsüller, Ordu ili sınırları içinde bulunan (40°59'9.6972'', 37°9'41.9472'') sekiz yetişkin kestane ağacından toplanmıştır. Tüm ağaçlar aynı çeşit ve yaş grubunda seçilerek örneklerde genetik ve çevresel faktörlerden kaynaklı varyasyon en aza indirilmiştir. Kapsüller toplandıktan sonra yabancı materyallerden ayrılmış, 40°C'de kurutulmuş ve öğütülerek analize hazır hale getirilmiştir (Şekil 1).

Şekil 1. Kestane kapsüllerinin öğütülmesi.

Kül Tayini

Kurutulan numuneler, 550°C'de kül fırınında yakılarak organik bileşenlerden arındırılmış ve bu şekilde toplam inorganik madde miktarı tespit edilmiştir (AOAC, 1995).

Ham Protein Tayini

Numunelerdeki toplam azot içeriği belirlenmiş, elde edilen değer 6.25 katsayısı ile çarpılarak ham protein oranı hesaplanmıştır (AOAC, 1995).

Ham Yağ Tayini

Ham yağ içeriğinin belirlenmesi için numuneler Sokselet ekstraksiyon cihazında dietileter çözgeni ile muamele edilmiştir (AOAC, 1995).

Mineral Madde Analizi

Mineral analizi için numuneler önce kül fırınında inorganik hale getirilmiş, ardından uygun asit karışımında çözündürülerek atomik absorbsiyon spektrofotometresi ile Sodyum, Potasyum ve Kalsiyum düzeyleri ölçülmüştür (AOAC, 1990).

Asit Deterjan Lif (ADF) ve Nötr Deterjan Lif (NDF)

ADF analizinde numuneler asidik deterjan çözeltisi ile işlenerek selüloz ve lignin fraksiyonları belirlenmiştir. NDF analizinde ise nötr deterjan çözeltisi kullanılarak hemiselüloz, selüloz ve lignin içeriği hesaplanmıştır (Van Soest vd., 1991).

SONUÇLAR ve TARTIŞMA

Kestane kapsülleri, kestane ağacının meyvesini koruyan dış katmandır. Bu çalışmada, kestane kapsüllerinin genel kimyasal bileşimi belirlenmiş olup sonuçlar Tablo 1'de sunulmuştur.

Tablo 1. Kestane çiçeğinin genel bileşimi (kuru maddede).

	Ortalama	**Minimum**	**Maksimum**	**St hata**	**St sapma**
Ham kül, %	3.54	2.82	4.48	0.118	0.472
Ham protein, %	3.95	3.18	4.87	0.117	0.469
Ham yağ, %	1.94	0.73	3.34	0.280	0.791
NDF, %	57.75	53.21	66.01	0.883	3.531
ADF, %	41.06	36.96	46.91	0.647	2.588
K, mg/kg	5750.63	4585	6935	335.652	949.366
Ca, mg/kg	5127.50	3980	6175	278.077	786.520
Na, mg/kg	1297.50	985	1595	80.123	226.621

Kestane kapsülleri, kestane ağacının meyvesini koruyan yapısal bir unsur olmasının yanı sıra lif, mineral ve besin maddeleri bakımından dikkate değer bir bileşim göstermektedir. Literatürde kestane kapsüllerinin kimyasal bileşimi üzerine yapılan çalışmalar oldukça sınırlıdır. Bu nedenle elde edilen veriler kestane kapsüllerinin yem kaynağı olarak potansiyelinin anlaşılması açısından önem taşımaktadır.

Tablo 1'den görüldüğü gibi, kestane kapsüllerinin ham kül içeriği ortalama %3.54, ham yağ içeriği %1.94, ham protein içeriği ise %3.95 olarak belirlenmiştir. Protein düzeyinin nispeten düşük olması kapsüllerin doğrudan protein kaynağı olarak sınırlı katkı sağlayacağını düşündürmektedir. Ancak lif içeriği açısından değerlendirildiğinde, NDF (%57.75) ve ADF (%41.06) oranlarının yüksek olması, kestane kapsüllerinin yapısal karbonhidratlar yönünden zengin ve sindirilebilirliği düşük bir materyal olduğunu göstermektedir. Mineral içerikleri değerlendirildiğinde; potasyumun (5750.63 mg/kg) diğer minerallere kıyasla oldukça yüksek olduğu görülmektedir. Bu durum kapsüllerin mineral dengesine katkı sağlayabileceğini, ancak yüksek K düzeyinin ruminant rasyonlarında diğer minerallerle birlikte dikkatle değerlendirilmesi gerektiğini göstermektedir. Kalsiyum (5127.50 mg/kg) ve sodyum (1297.50 mg/kg) içerikleri ise kapsüllerin mineral yönünden destekleyici bir materyal olabileceğini ortaya koymaktadır. Bazı bileşenlerde gözlenen yüksek standart sapma ve hata değerleri, özellikle mineral içeriklerinde aynı bölgeden sağlanan materyaller olsa da çevresel koşullar (toprak yapısı, iklim, ağacın gelişim dönemleri) kaynaklı varyasyonların etkili olduğunu düşündürmektedir. Genel olarak, kestane kapsülleri yüksek lif ve belirgin mineral içeriğiyle doğrudan yüksek besleyici bir yem kaynağı olmamakla birlikte rasyonlarda lif ve mineral dengesi açısından değerlendirilebilecek tamamlayıcı bir materyal niteliği taşımaktadır.

SONUÇ ve ÖNERİLER

Bu çalışma, kestane üretimi sırasında büyük miktarlarda ortaya çıkan ve çoğunlukla atık olarak bırakılan kestane kapsülünün kimyasal yapısını ortaya koyarak literatürdeki eksikliği gidermektedir. Elde edilen bulgular, kapsüllerin düşük düzeyde protein ve yağ içermesine karşın, yüksek NDF ve ADF değerleri ile belirgin bir lif yoğunluğuna sahip olduğunu göstermiştir. Bu durum, kapsülü besleyici niteliği sınırlı olmakla birlikte yapısal özellikleri güçlü, dayanıklı ve değerlendirilebilir bir bitkisel biyokütle haline getirmektedir. Mineral madde analizleri, özellikle potasyum ve kalsiyum düzeylerinin yüksek olduğunu ortaya koymuştur. Bu bulgu kapsüllerin organik gübre, toprak düzenleyici ve kompost hammaddesi olarak kullanılabileceğini göstermiştir. Aynı zamanda kapsülün lif ve mineral kompozisyonu, kestane kabuğu ve diğer odunsu bitki yan ürünleriyle benzer nitelikler taşıdığını ortaya koymaktadır. Bu benzerlik kapsüllerin biyokompozit malzeme, biyobozunur ambalaj, dolgu maddesi ve çevre dostu polimer üretimi gibi endüstriyel uygulamalarda değerlendirilebilir bir kaynak olduğunu desteklemektedir.

Son olarak, kestane kapsülü yalnızca bir tarımsal artık değil; çevresel sürdürülebilirliği, atık azaltmayı ve döngüsel ekonomi yaklaşımını destekleyebilecek potansiyele sahip bir biyokütle kaynağıdır**.** Bu çalışma, kapsülün bilimsel açıdan tanımlanmasına ve gelecekte katma değerli ürünlere dönüştürülmesine yönelik bir adım niteliği taşımaktadır.

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The Role of New Technologies and Artificial Intelligence in Food Waste Disposal

Gıda Atıklarının Bertarafında Yeni Teknolojilerin ve Yapay Zekanın Rolü

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ABSTRACT

Food waste has become a major environmental and economic problem alongside the rapidly growing population. According to FAO data, approximately 13% of total food production worldwide, or 931 million tons of food per year, is lost during the post-harvest period. A significant portion of this waste comes from household consumption and retail sources. Traditional disposal methods increase greenhouse gas emissions such as methane and lead to inefficient use of natural resources. Therefore, effective management of food waste and AI-supported solutions are critical for sustainability. New technologies convert waste into energy and added value. Anaerobic digestion breaks down organic waste in an oxygen-free environment using microorganisms to produce biogas and nutrient-rich “digestate”; this reduces waste volume while generating renewable energy. Composting is a method that breaks down organic waste under controlled conditions and returns it to the soil. Innovative techniques such as closed-system composting accelerate the process and reduce odor issues by optimizing temperature, humidity, and aeration. Artificial intelligence applications are revolutionary in waste detection and separation. Deep learning models, especially convolutional neural networks (CNN), can classify organic and other waste types with high accuracy. This reduces the error rate in manual separation and lowers labor requirements. Artificial intelligence supports process optimization in waste-to-energy recovery processes. In biogas plants, AI models monitor parameters such as temperature, pH, and humidity to optimize fermentation conditions. Deep learning techniques analyze the chemical composition of waste to precisely adjust process parameters, thereby increasing plant efficiency and enabling more effective implementation of circular economy principles. AI-powered sensors and robotic automation increase recycling rates and accelerate processes. As a result, new technologies and AI integration make food waste disposal more environmentally friendly and sustainable. Biological methods such as anaerobic digestion and composting recover energy, while artificial intelligence and biotechnology predict waste and convert it into valuable products. These applications increase resource efficiency while creating added value for the ecosystem. However, obstacles such as high investment costs, infrastructure deficiencies, and data gaps limit the widespread adoption of these technologies. In the future, the integration of artificial intelligence with IoT and big data technologies will make food waste management processes smarter, more traceable, and more sustainable. Thus, the holistic use of these technologies promises a greener future by transforming food waste disposal.

Keywords: Food waste, sustainable waste management, artificial intelligence, anaerobic digestion, composting, logistics optimization.

ÖZET

Gıda atıkları hızla artan nüfusla birlikte çevresel ve ekonomik açıdan büyük bir sorun haline gelmiştir. FAO verilerine göre dünya genelinde hasat sonrası dönemde toplam gıda üretiminin yaklaşık %13'ü, yani yılda 931 milyon ton gıda kaybolmaktadır. Bu atıkların önemli bir bölümü evsel tüketim ve perakende kaynaklıdır. Geleneksel bertaraf yöntemleri metan gibi sera gazı emisyonlarını artırmakta ve doğal kaynakların verimsiz kullanımına yol açmaktadır. Bu nedenle gıda atıklarının etkin yönetimi ve yapay zekâ destekli çözümler sürdürülebilirlik açısından kritik öneme sahiptir. Yeni teknolojiler atıkları enerjiye ve katma değere dönüştürür. Anaerobik sindirim, organik atıkları oksijensiz ortamda mikroorganizmalarla ayrıştırarak biyogaz ve besin açısından zengin "digestat" üretir; bu sayede atık hacmi azalırken yenilenebilir enerji elde edilir. Kompostlama ise organik atıkları kontrollü koşullarda ayrıştırıp toprağa kazandıran bir yöntemdir. Kapalı sistem kompostlama gibi yenilikçi teknikler, sıcaklık, nem ve havalanmayı optimize ederek işlemi hızlandırmakta ve koku sorununu azaltmaktadır. Yapay zekâ uygulamaları atık tespiti ve ayrıştırmasında devrim niteliğindedir. Derin öğrenme modelleri, özellikle konvolüsyonel sinir ağları (CNN), organik ve diğer atık türlerini yüksek doğrulukla sınıflandırabilmektedir. Böylece elle yapılan ayrıştırmadaki hata oranı azalmakta ve iş gücü ihtiyacı düşmektedir. Atıkların enerji geri kazanım süreçlerinde yapay zekâ, proses optimizasyonunu desteklemektedir. Biyogaz tesislerinde yapay zekâ modelleri sıcaklık, pH, nem gibi parametreleri izleyip fermentasyon koşullarını en uygun hale getirir. Derin öğrenme teknikleri atıkların kimyasal bileşimini analiz ederek süreç kriterlerini hassas şekilde ayarlar; bu sayede tesis verimliliği artar ve döngüsel ekonomi ilkeleri daha etkin uygulanır. Yapay zekâ destekli sensörler ve robotik otomasyon, geri dönüşüm oranlarını yükseltip süreçleri hızlandırır. Sonuç olarak, yeni teknolojiler ve yapay zekâ entegrasyonu gıda atıklarının bertarafını daha çevreci ve sürdürülebilir hale getirmektedir. Anaerobik sindirim ve kompostlama gibi biyolojik yöntemler enerjiyi geri kazanırken, yapay zekâ ve biyoteknoloji atıkları önceden tahmin edip değerli ürünlere dönüştürmektedir. Bu uygulamalar kaynak verimliliğini artırırken ekosisteme katma değer yaratmaktadır. Ancak yüksek yatırım maliyetleri, altyapı yetersizlikleri ve veri eksikliği gibi engeller bu teknolojilerin yaygınlaşmasını sınırlamaktadır. Gelecekte yapay zekânın IoT ve büyük veri teknolojileriyle entegrasyonu sayesinde gıda atık yönetimi süreçleri daha akıllı, izlenebilir ve sürdürülebilir olacaktır. Böylece bu teknolojilerin bütüncül kullanımı, gıda atıklarının bertarafını dönüştürerek daha yeşil bir gelecek vaat etmektedir.

Anahtar Kelimeler: Gıda atıkları, sürdürülebilir atık yönetimi, yapay zekâ, anaerobik sindirim, kompostlama, lojistik optimizasyon.

GİRİŞ

Gıda atıkları, küresel ölçekte önemli bir çevresel, ekonomik ve sosyal sorun teşkil etmektedir. Dünya nüfusunun hızlı artışı ile birlikte gıda üretimindeki artış, tarımsal atık miktarlarını da benzer oranda yükseltmekte ve doğal kaynakların tüketilmesine yol açmaktadır (Ozkan vd., 2022). Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO) verilerine göre, yılda yaklaşık 931 milyon ton gıda israf edilmekte olup, bu atıkların büyük kısmı evsel tüketimden kaynaklanmaktadır (FAO, 2022). Geleneksel bertaraf yöntemleri, örneğin çöp depolama alanları, metan emisyonları ve kaynak israfı gibi olumsuz etkilere neden olmakta bu da sürdürülebilirlik hedeflerini tehdit etmektedir.

Gıda atıklarının yönetimi ve bertarafı, küresel ölçekte çevresel sürdürülebilirlik açısından kritik bir öneme sahiptir. Bu süreçlerin etkinliğini artırmak amacıyla geliştirilen yapay zeka uygulamaları, son yıllarda atık yönetimi sistemlerinde önemli bir dönüşüm yaratmıştır. Yapay zeka, veriye dayalı analiz ve öngörü yetenekleri sayesinde gıda atıklarının azaltılması, sınıflandırılması, taşınması ve enerjiye dönüştürülmesi gibi süreçlerde önemli katkılar sağlamaktadır. Örneğin, oteller ve restoranlar gibi konaklama sektöründe yapay zeka tabanlı stratejiler, tüketim kalıplarını tahmin ederek israfı en aza indirmekte ve kaynak tahsisini iyileştirmektedir. Bu stratejiler, evsel ortamlara uyarlanarak daha geniş bir etki yaratma potansiyeline sahiptir. YAPAY ZEKA sistemleri, atık miktarını ve türünü izleyerek mutfak personeline porsiyon boyutlarını ayarlamak, envanteri optimize etmek için içgörüler sağlar (Clark vd., 2025). Bu entegrasyon, sadece ticari sektörlerde değil, bireysel hanelerde de gıda israfını azaltarak küresel sürdürülebilirlik hedeflerine katkı sunar.

Ayrıca, yapay zekanın gıda tedarik zincirindeki rolü, üretimden tüketime kadar uzanmakta ve kaynak verimliliğini artırmaktadır. Bu teknolojiler, iklim değişikliği ve kaynak kıtlığı gibi küresel zorluklara karşı etkili çözümler üretmekte, aynı zamanda ekonomik faydalar sağlamaktadır.

Gıda Atıklarının Bertarafı ve Sürdürülebilirlik

Sürdürülebilir gıda üretimi, doğal kaynakların korunması ve atık yönetimini bütüncül bir yaklaşımla ele almayı gerektirmektedir. Gıda tedarik zincirinde meydana gelen kayıplar, ekonomik maliyetlerin yanı sıra çevre kirliliğine de yol açmaktadır. Atık yönetimi, öncelikle atık oluşumunun önlenmesi, azaltılması ve geri kazanımı üzerine odaklanmalıdır. Yeni teknolojiler, bu süreçte kritik rol oynamakta; örneğin, organik atıkların enerji veya gübreye dönüştürülmesi, sera gazı emisyonlarını azaltarak Birleşmiş Milletler Sürdürülebilir Kalkınma Hedefleri'ne (SKH) katkı sağlamaktadır (FAO, 2018).

Gelişmekte olan ülkelerde, yetersiz beslenme ve atık yönetimi sorunları daha belirgindir (Pawlak ve Kołodziejczak, 2020). Bu bağlamda, teknolojiler atık bertarafını optimize ederek kaynak verimliliğini artırmakta, örneğin biyogaz üretimi yoluyla enerji geri kazanımı mümkün kılmaktadır. Ancak, teknolojilerin uygulanması, altyapı ve maliyet gibi zorluklarla karşı karşıyadır (Sharma vd., 2021). Bu zorluklar, özellikle düşük gelirli bölgelerde erişilebilirlik sorunlarını beraberinde getirmekte, bu nedenle politika yapıcıların teşvik mekanizmaları geliştirmesi gerekmektedir.

Atıkların doğru sınıflandırılması, geri dönüşüm süreçlerinin verimliliğini artırmak için kritik bir adımdır. Geleneksel elle sınıflandırma yöntemleri hem maliyetli hem de hata oranı yüksek olduğundan, yapay zeka tabanlı görüntü işleme teknikleri sıklıkla tercih edilmektedir. yapay zekanın gıda sektöründeki rolü, üretimden atık yönetimine kadar uzanmakta ve sürdürülebilirliği artırmaktadır. Örneğin, yapay zeka, tarımsal uygulamalarda ürün hastalıklarını teşhis ederek verimi artırırken, atık yönetiminde konaklama sektöründe tüketim tahminleri yaparak israfı azaltmaktadır.

Ayrıca, yapay zeka tabanlı buzdolabı sistemleri gıda maddelerini tanıyarak durumlarını analiz eder ve kullanım veya bertaraf önerileri sunar, böylece evsel atık azaltımına katkı sağlar. Yapay zeka, büyük dil modelleri kullanarak gıda mağaza verilerini analiz ederek tüketici davranışlarını ve pazar trendlerini anlamada da rol oynar (Belwal vd., 2025).

Gıda endüstrisinde yapay zeka, atık azaltımında kritik bir rol oynar; örneğin, makine öğrenimi algoritmaları tedarik zinciri lojistiğini optimize ederek nakliye sırasında atık riskini azaltır. Yapay zeka destekli envanter yönetim sistemleri talep tahmin ederek aşırı üretimi önler ve tedarik zincirlerini optimize eder. Öngörüsel analitikler, tüketici tercihlerini analiz ederek stok fazlalığını azaltır ve gıda son kullanma tarihlerini doğru tahmin ederek envanter rotasyonunu iyileştirir. Yapay zeka sensörleri depolama koşullarını izleyerek bozulmayı önler, restoranlarda fiyatlandırma ve menü planlamasını optimize eder. Bu teknolojiler, ABD'de yıllık 119 milyar pound gıda atığını azaltarak maliyet tasarrufu sağlar ve sürdürülebilir uygulamaları teşvik eder. Bu örnekler, teknolojilerin küresel ölçekte nasıl entegre edilebileceğini göstermekte, ancak kültürel ve ekonomik farklılıkların dikkate alınması gerekmektedir.

Yeni Teknolojiler

Anaerobik sindirim

Anaerobik sindirim, gıda atıklarının oksijensiz ortamda mikroorganizmalar tarafından parçalanarak biyogaz ve besin zenginleştirici biyogaz atığı (digestat) üretilmesini sağlayan bir teknolojidir. Bu yöntem, atık hacmini azaltırken yenilenebilir enerji kaynağı olarak biyogaz üretmekte ve gübre olarak kullanılabilecek yan ürünler sağlamaktadır. Örneğin, Quasar Energy Group gibi şirketler, büyük ölçekli uygulamalarda bu teknolojiyi kullanarak atıkları enerjiye dönüştürmektedir.

Tarımsal atık yönetiminde, anaerobik sindirim, organik atıkların değer kazanımında önemli bir rol oynamaktadır. Araştırmalar, bu teknolojinin metan emisyonlarını %90 oranında azalttığını göstermektedir. Ancak, başlangıç yatırımı yüksek olup, gelişmekte olan ülkelerde adaptasyon sınırlıdır (Singh, 2017). Anaerobik sindirim, gıda atıklarının biyogaz üretimine dönüştürülmesinde etkili olup, yapay zeka ile entegre edildiğinde süreç parametrelerini optimize ederek verimliliği artırır. Bu entegrasyon, gerçek zamanlı izleme ve öngörüsel analitikler yoluyla yakıt tüketimini ve emisyonları azaltır (Fang vd., 2023). Ayrıca, bu yöntem, döngüsel ekonomi prensiplerini destekleyerek atıkların ekonomik değere dönüşümünü hızlandırır ve uzun vadede enerji bağımsızlığına katkı sağlar.

Kompostlama yöntemleri

Kompostlama, organik atıkların kontrollü ortamda ayrıştırılarak toprağı zenginleştiren kompost haline getirilmesidir. In-vessel kompostlama (kapalı sistem kompostlama veya reaktör tipi kompostlama) gibi yenilikçi yöntemler, kapalı sistemlerde sıcaklık, nem ve hava akışını optimize ederek süreci hızlandırmakta ve kokuları minimize etmektedir. OREGON Green Fertilizer gibi uygulamalar, gıda atıklarını yüksek kaliteli komposta dönüştürmektedir.

Türkiye'de tarımsal atıklardan kompost üretimi Marmara ve Akdeniz bölgelerinde yaygındır, ancak diğer bölgelerde sınırlıdır. Bu teknoloji, çöp depolama alanlarına giden atık miktarını azaltarak sürdürülebilir tarıma katkı sağlar. Dezavantajı, büyük ölçekli operasyonlarda enerji tüketimidir (Ozkan vd., 2022). Kompostlama, yapay zeka ile birleştirildiğinde dinamik programlama yoluyla atık üretim desenlerine uyum sağlar ve kaynak tahsisini iyileştirir. Gelecekte, yapay zekanın IoT ile entegrasyonu kompostlama süreçlerini daha verimli hale getirecektir (Fang vd., 2023). Bu entegrasyon, yerel topluluklarda kompostlama tesislerinin yönetimini kolaylaştırarak, toprağın verimliliğini artırır ve çevre dostu tarım uygulamalarını teşvik eder.

Biyoteknolojik yaklaşımlar

Biyoteknoloji, gıda atıklarının dönüştürülmesinde umut vadeden bir alandır. Kara asker sineği (Black Soldier Fly-BSF) biyodönüşümü, larvaların atıkları tüketerek protein zengin hayvan yemi ve organik gübre üretmesini sağlar. Ynsect ve AgriProtein gibi şirketler, bu yöntemi kullanarak atık hacmini hızlıca azaltmaktadır.

Mikrobiyal yöntemler, atıkların katma değerli ürünlere dönüştürülmesinde benzer prensiplere dayanır. Örneğin, atıklardan pektin eldesinde mikrodalga ve ultrases gibi teknolojiler enerji tasarrufu sağlar (Gavahian vd., 2021). Biyoteknoloji, metan emisyonlarını azaltarak çevresel bütünlüğü korur (Kusmayadi vd., 2021). Biyoteknolojik yöntemler, yapay zeka sensörleri ile birleştirildiğinde raf ömrünü uzatarak bozulmayı azaltır; örneğin, Strella'nın muz olgunlaşmasını izleyen sensörleri tutarlılık sağlar. Bu yaklaşımlar, gıda endüstrisinde yenilikçi ürün geliştirme fırsatları yaratmakta ve atıkların biyoyakıt veya farmasötik maddelere dönüşümünü mümkün kılmaktadır.

Diğer Yenilikçi Yöntemler

Atık bertarafında mikrodalga, ohmik ısıtma, darbeli elektrik alan, yüksek basınç ve ultrases gibi işleme teknolojileri, polisakkaritlerin ekstraksiyonunda enerji tasarrufu sağlar (Gavahian vd., 2021; Ozkan vd., 2022). Atık-enerji dönüşümü, atıkları biyoyakıtlara çevirerek fosil yakıt bağımlılığını azaltır.

Blockchain, gıda izlenebilirliğini artırarak israfı önler. Robotik sistemler, atık ayrıştırmasını hızlandırır. Bu yöntemler, endüstriyel ölçekte standardizasyon gerektirir (Sharma vd., 2021). Yenilikçi yaklaşımlar, yapay zeka ile bozulma tahminlerini geliştirerek tedarik zincirini optimize eder. Örneğin, robotik kollar ve sensörler entegre edilerek atık işleme hatları otomatikleştirilmekte, bu da iş gücü maliyetlerini düşürürken verimliliği artırır.

Yapay Zeka Uygulamaları

Atık tespiti ve ayrıştırma

Derin öğrenme modelleri, özellikle CNN (Convolutional Neural Network), organik ve diğer atık türlerini yüksek doğrulukla ayırabilmektedir (Fotovvatikhah vd., 2025). Benzer şekilde, yapay sinir ağları ve özellik birleştirme teknikleri kullanılarak atıkların otomatik sınıflandırılması mümkün olup, yaklaşık %91,7 doğruluk oranı elde edilmektedir (Mohammed vd., 2022). Transfer öğrenme tabanlı yaklaşımlar ise şehirsel atıklarda sınıflandırma başarısını artırmaktadır (Lin vd., 2023). Bu teknikler sayesinde gıda atıkları doğru bertaraf süreçlerine yönlendirilmekte, endüstriyel uygulamalarda iş gücü ihtiyacı azalmakta ve maliyet ile zaman açısından önemli kazanımlar sağlanmaktadır.

Yapay zeka tabanlı akıllı çöp kutuları, gerçek zamanlı izleme ile toplama verimliliğini artırır ve atık ayrıştırmasını otomatikleştirir (Alourani vd., 2025). Yapay zeka, atık yönetiminde paradigma kayması yaratır; akıllı kutular, rota optimizasyonu ve dinamik programlama ile sürdürülebilirliği artırır. Gelecekte, yapay zekanın IoT ile entegrasyonu veri kalitesini iyileştirerek etik kaygılara odaklanacaktır (Olawade vd., 2024). Bu sistemler, belediye hizmetlerinde yaygınlaşarak toplu atık yönetimini daha etkili hale getirir.

Enerji geri kazanımı ve işlem optimizasyonu

Gıda atıklarının geri dönüştürülerek biyogaz, kompost veya enerji üretimine yönlendirilmesi, çevresel sürdürülebilirlik açısından önemli avantajlar sağlamaktadır. Yapay zeka, bu dönüşüm süreçlerinde işlem parametrelerini analiz ederek verimliliği artırmakta, enerji kayıplarını minimize etmekte ve maliyetleri düşürmektedir (Fang vd., 2023). Özellikle biyogaz üretiminde, yapay zeka tabanlı modeller sıcaklık, nem, pH ve mikrobiyal aktivite gibi faktörleri değerlendirerek optimum fermentasyon koşullarını belirlemekte ve sürecin yan ürünlerinin kalitesini denetlemektedir. Ayrıca, derin öğrenme teknikleri kullanılarak atıkların kimyasal bileşen analizleri yapılabilir; bu sayede proses kriterleri hassas biçimde ayarlanabilmekte ve karmaşık atık kategorileri yüksek doğrulukla sınıflandırılabilmektedir (Sayem vd., 2025). Bu yaklaşımlar, döngüsel ekonomi ve kaynak verimliliği ilkelerinin uygulanmasında kritik bir rol oynamaktadır.

Yapay zeka, enerji geri kazanımında akıllı sensörler ve robotik ile entegre olup geri dönüşüm oranlarını artırır. Şehirlerde yapay zeka, atık yönetim maliyetlerini düşürür ve çevresel etkiyi minimize eder. Yapay zeka, atık izleme ve analitiklerde kamerelerle atık sıcak noktalarını belirleyerek azaltma stratejileri geliştirir; Winnow ve Leanpath gibi sistemler gıda atığını yarıya indirir. Leanpath, üretken yapay zeka ile mutfak verilerini analiz ederek önleyici eylemler önerir. Bu optimizasyonlar, enerji üretim tesislerinde verimliliği %20-30 oranında artırabilir.

Lojistik ve rota optimizasyonu

Atık toplama ve taşımada rota planlaması, maliyet, enerji verimliliği ve çevresel sürdürülebilirlik açısından kritik bir süreçtir. Yapay zeka tabanlı algoritmalar, atık toplama araçlarının güzergâhlarını optimize ederek gereksiz yakıt tüketimini azaltmakta ve karbon salımını düşürmektedir (Fang vd., 2023). Bu sistemler, gerçek zamanlı trafik verileri ve sensörlerden gelen doluluk bilgilerini değerlendirerek en uygun toplama planını oluşturur. Ayrıca, makine öğrenmesi modelleri geçmiş verilerden yararlanarak atık birikim eğilimlerini tahmin edebilir ve toplama sıklığını buna göre dinamik biçimde ayarlayabilir. Son yıllarda geliştirilen akıllı sistemler, konteyner doluluk oranlarını sensörlerle izleyerek anlık veri temelli rota planlaması yapabilmekte, böylece hem operasyonel maliyetleri azaltmakta hem de çevresel etkinliği artırmaktadır (Alourani vd., 2025).

Lojistikte yapay zeka, talep planlamasını iyileştirerek perakendecilerin siparişlerini optimize eder; Shelf Engine ve Afresh gibi şirketler %14.8 atık azaltımı sağlar. Bütün market sektöründe uygulanması 907.372 ton atık önleyebilir ve 13.3 milyon metrik ton CO_2 emisyonunu azaltabilir. Bu optimizasyonlar, lojistik zincirlerde sürdürülebilir taşımacılığı teşvik eder.

Karar destek sistemleri ve politika uygulamaları

Yapay zeka tabanlı karar destek sistemleri (Decision Support Systems, DSS), atık yönetiminde stratejik planlamayı destekleyen önemli araçlardır. Bu sistemler, geniş veri setlerini ve IoT sensörlerinden elde edilen bilgileri analiz ederek farklı bölgelerdeki atık türlerini ve yoğunluklarını belirler; böylece kaynak dağılımı, geri dönüşüm oranı ve sürdürülebilirlik politikaları açısından yöneticilere veri temelli öneriler sunar (Fotovvatikhah vd., 2025). Ayrıca, yapay zeka modelleri yalnızca teknik sınıflandırma işleviyle sınırlı kalmayıp, sistem düzeyinde politika geliştirme süreçlerine de katkı sağlamaktadır. Uygulama örneklerinde, şehir yönetimleri yapay zekâ destekli atık sınıflandırma hizmetlerini devreye alarak karbon ayak izini azaltmakta ve enerji verimliliğini artırmaktadır. Belediyeler için akıllı atık sınıflandırma hizmet tasarımlarının bu hedeflere ulaşmada etkili bir model sunduğunu göstermektedir (Zhang vd., 2023)

Karar destekte yapay zeka, gıda ortamını anlamada büyük dil modellerini kullanır ve cinsiyet kapsayıcı yeniliklerle marjinal toplulukları güçlendirir (Belwal vd., 2025). Yapay zeka, beslenme analizinde Swin Transformer modelleri ile gıda görüntülerini değerlendirerek sağlıklı beslenmeyi teşvik eder (Belwal vd., 2025). Bu sistemler, politika yapımında veri odaklı kararları kolaylaştırır.

Yapay Zeka ve Nesnelerin İnterneti

Yapay zeka ve IoT, atık yönetimini optimize etmekte kritik rol oynar. Yapay zeka, stok seviyelerini izleyerek israfı öngörür ve akıllı çöp kutuları atık ayrıştırmasını otomatikleştirir. Winnow gibi sistemler, mutfak atıklarını kamerayla kaydederek nedenlerini analiz eder.

IoT sensörleri, atık doluluk seviyelerini gerçek zamanlı izleyerek toplama verimliliğini artırır. Dijital dönüşüm, tedarik zinciri izlenebilirliğini artırarak atık azaltımına katkı sağlar (De Bernardi ve Azucar, 2020). Bu teknolojiler, evsel atıklarda %20 azalma sağlayabilir (Dahlén ve Lagerkvist, 2010). Yapay zeka ve IoT entegrasyonu, atık yönetiminde gerçek zamanlı izleme ve öngörüsel analitikler sağlar (Olawade vd., 2024).

Restoranlarda yapay zeka sensörleri, kameralar ve ölçekler entegre edilerek gerçek zamanlı atık izleme yapılır; Leanpath, Winnow ve Kitro gibi şirketler %30-53 atık azaltımı sağlar. Bu sistemler, bulut tabanlı platformlarla talep tahmini ve envanter optimizasyonu yapar. Faydaları arasında ekonomik tasarruf (%6-8 gıda maliyeti azalması) ve çevresel etki azalması yer alır. Zorluklar, personel direnci ve başlangıç maliyetleridir, ancak otomasyonla aşılır. Evsel adaptasyon için politika desteği ve eğitim gereklidir (Clark vd., 2025). Bu entegrasyon, teknolojilerin günlük hayatta nasıl uygulanabileceğini gösterir.

SONUÇ

Yeni teknolojiler, gıda atıklarının bertarafını sürdürülebilir hale getirerek çevresel etkileri minimize etmektedir. Anaerobik sindirim ve kompostlama gibi yöntemler enerji geri kazanımı sağlarken, yapay zeka ve biyoteknoloji israfı öngörür ve dönüştürür. Bu teknolojiler katma değer yaratır ancak altyapı ve maliyet zorlukları aşılmalıdır. Gelecek çalışmalar, gelişmekte olan ülkelerde erişilebilirliği artırmaya odaklanmalıdır.

Yapay zeka teknolojileri, gıda atıklarının bertarafında yalnızca teknik bir araç değil, aynı zamanda stratejik bir sürdürülebilirlik bileşenidir. Atıkların doğru sınıflandırılması, enerji dönüşüm süreçlerinin optimize edilmesi, lojistik planlamanın iyileştirilmesi ve karar destek mekanizmalarının geliştirilmesi yoluyla yapay zeka, çevresel etkinin azaltılmasına doğrudan katkı sağlamaktadır. Bununla birlikte, veri eksikliği, yüksek yatırım maliyetleri ve altyapı yetersizlikleri gibi zorluklar, bu teknolojilerin yaygınlaşmasını sınırlamaktadır. Gelecekte, yapay zekanın nesnelerin interneti (IoT) ve büyük veri teknolojileriyle entegrasyonu sayesinde gıda atık yönetimi süreçlerinin daha akıllı, izlenebilir ve sürdürülebilir hale geleceği öngörülmektedir.

Yapay zekanın gıda sektöründeki entegrasyonu, tarımdan tüketime kadar tedarik zincirini dönüştürür ve küresel sorunları çözer (Belwal vd., 2025). Yenilikler, akıllı ev sistemleri ve politika çerçeveleriyle desteklenmelidir (Clark vd., 2025). Sonuç olarak, bu teknolojilerin bütüncül kullanımı, gıda atıklarının bertarafını dönüştürerek daha yeşil bir gelecek vaat etmektedir.

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Utilisation of Grape Residues Processed in the Food Industry

Gıda Sanayinde İşlenen Üzümlerin Artıklarının Değerlendirilmesi

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ABSTRACT

Reducing and reusing waste generated in the food industry is of strategic importance in terms of environmental sustainability and the circular economy. A significant portion of Turkey's annual grape production is directed towards wine, fruit juice and dried grape processing, a process that generates large quantities of by-products, primarily pomace, but also including skins, seeds, stems and leaves. These residues offer broad biotechnological and economic potential due to their rich content of phenolic compounds, unsaturated fatty acids, vitamins, and fibres. However, if not adequately utilised, they pose a risk of environmental pollution. Concrete examples of this potential include the use of pulp as a soil conditioner through composting, its use as a low-cost feed source in the feed industry, its utilisation in fermentation processes for the production of citric acid, ethanol, methanol and biogas, and its use as a food additive in dried and ground form. Grape seeds, due to their high antioxidant content and unsaturated fatty acids, can be transformed into a functional raw material in the food, cosmetics, and biofuel industries; the leaves, rich in phenolic compounds, can be utilised not only for pickling consumption but also in the production of natural dyes and food preservatives. Similarly, grape stems, notable for their lignocellulosic structure, can be used as a filler material in polymer composites and provide a valuable source of biomass rich in tannins. The effective utilisation of grape processing residues not only reduces negative environmental impacts but also enables the creation of added value in various fields such as functional foods, energy, biotechnology, and cosmetics. In this context, integrating grape residues into sustainable production systems is emerging as a strategic necessity in terms of increasing efficiency in the agricultural industry and protecting natural resources.

Keywords: Grape, residue, sustainability.

ÖZET

Gıda endüstrisinde ortaya çıkan artıkların azaltılması ve yeniden değerlendirilmesi, çevresel sürdürülebilirlik ve döngüsel ekonomi açısından stratejik bir öneme sahiptir. Türkiye'de yıllık üzüm üretiminin kayda değer bir kısmı şarap, meyve suyu ve kuru üzüm işlenmesine yönlendirilmekte, bu süreçte cibre başta olmak üzere kabuk, çekirdek, sap ve yapraklardan oluşan yüksek miktarda yan ürün açığa çıkmaktadır. Söz konusu artıklar, içerik bakımından zengin fenolik bileşikler, doymamış yağ asitleri, vitaminler ve lifler sayesinde biyoteknolojik ve ekonomik açıdan geniş bir potansiyel sunmaktadır. Ancak yeterince değerlendirilemediğinde çevresel kirlilik riski taşımaktadırlar. Cibrenin kompostlama yoluyla toprak düzenleyici olarak kullanımı, yem sanayinde düşük maliyetli bir besin kaynağı olması, fermentasyon süreçleriyle sitrik asit, etanol, metanol ve biyogaz üretiminde değerlendirilmesi, ayrıca kurutulmuş ve öğütülmüş formuyla gıda katkı maddesi olarak işlev görmesi bu potansiyelin somut örnekleridir. Üzüm çekirdeği, yüksek antioksidan içeriği ve doymamış yağ asitleri nedeniyle gıda, kozmetik ve biyoyakıt endüstrisinde işlevsel bir hammaddeye dönüşebilirken; yapraklar fenolik bileşikler açısından zengin olup salamuralık tüketimin yanı sıra doğal boya ve gıda koruyucu üretiminde değerlendirilebilmektedir. Benzer şekilde, lignoselülozik yapısıyla dikkat çeken üzüm sapı polimer kompozitlerde dolgu malzemesi olarak kullanılabilmekte ve tanen açısından değerli bir biyokütle kaynağı sunmaktadır. Üzüm işleme artıklarının etkin şekilde değerlendirilmesi, yalnızca çevreye olan olumsuz etkilerin azaltılmasını değil, aynı zamanda fonksiyonel gıda, enerji, biyoteknoloji ve kozmetik gibi farklı alanlarda katma değer yaratılmasını da mümkün kılmaktadır. Bu bağlamda, üzüm artıklarının sürdürülebilir üretim sistemleri içine entegre edilmesi, tarımsal sanayide verimliliğin artırılması ve doğal kaynakların korunması açısından stratejik bir gereklilik olarak ortaya çıkmaktadır.

Anahtar Kelimeler: Üzüm, artık, sürdürülebilirlik.

GİRİŞ

Gıda kayıpları ve israfı gezegenimizin sürdürülebilirliğini tehlikeye atan ciddi bir sorunu temsil etmekte, her yıl küresel gıda üretiminin üçte birinden fazlası gıda tedarik zincirinde kaybolmakta veya israf edilmekte bu da çeşitli ekonomik, çevresel ve sosyal etkilere neden olmaktadır. Gıda kayıpları tüm gıda tedarik zincirinde meydana gelmekle birlikte, ekonomi ile çevre üzerinde olumsuz etkileri mevcuttur ve etik açıdan uygun değildir (Atlı, 2024). Gıda endüstrisinde üretim esnasında yaşanan aksaklıklar nedeni ile son ürünün sağlaması gereken kalite parametrelerine uymadığı için atık olarak değerlendirilen çıktılar (ıskartalar) ve girdilerden kaynaklanan ve son üründe kullanılmadığı için girdiden ayrıştırılan artıklar (örn. üzüm suyu üretiminde üzüm posası, peynir üretiminde peynir altı suyu vb.) önem arz etmektedir (Altınok, 2022). Atık Yönetimi Yönetmeliği'ne göre atık; "üreticisi veya fiilen elinde bulunduran gerçek veya tüzel kişi tarafından çevreye atılan veya bırakılan ya da atılması zorunlu olan herhangi bir madde veya malzeme" olarak ifade edilmektedir. Gıda atıkları tarladan sofraya, gıda tedarik zincirinin her aşamasında, üretici, işlemci, perakendeci ve tüketicilerden kaynaklı, kaybolan gıda olarak tanımlanabilmektedir. Gıda ve Tarım Örgütü'ne göre ise gıda atıkları, perakende ve tüketim aşamalarında meydana gelen gıda kayıpları olarak belirtilmektedir. Üretim ıskartaları gibi kalite kontrol kriterlerine uygun olmayan ürünlerden oluşan gıda atıkları, proses koşullarında yapılan iyileştirmeler ile bir noktaya kadar azaltılabilmektedir (Özkan vd., 2022).

Gıdaların işlenmesi sırasında, son ürünlerin niteliği gereği açığa çıkan artıkların ise ayrıca değerlendirilmesi gerekmektedir. Yağ üretiminde kullanılan ay çekirdeklerinin küspesi, meyve suyu sanayinde çıkan meyve posası, meyvelerin çekirdekleri ve kabukları gibi artıklar insanlar için direkt besin niteliği taşımayacak şekillerde değerlendirilmeye çalışılmaktadır. Gıda sanayi artıklarının hayvan yemi olarak kullanımı, kompost üretimi vb. uygulamalar, besin değeri yüksek olan gıdaların israfı olarak değerlendirilebilecek geri kazanım çalışılmalarından bazılarıdır (Altınok, 2022).

Doğal kaynakların korunması ve sürdürülebilirliğin sağlanabilmesi için, üretimden tüketime kadar işleme, depolama, taşıma ve dağıtım gibi tedarik zincirinin tüm aşamalarında gıda kayıplarının ve artıklarının en aza indirilmesi temel bir gerekliliktir. Bununla birlikte, tarımsal kalıntılar, gıda işleme artıkları veya bitkisel ve hayvansal kökenli yenmeyen kısımlar gibi bazı gıda fraksiyonlarının israfı kaçınılmaz olmaktadır. Bu tür organik artıkların geri dönüştürülmesi; biyokütle ve hayvansal yan ürünlerden çeşitli kimyasallar, biyoyakıtlar ve enerji elde edilmesi yoluyla hem yenilenemeyen kaynakların tüketiminin azaltılmasına hem de çevresel sürdürülebilirliğin desteklenmesine önemli katkılar sağlamaktadır. Gıda üretim sistemi ve tedarik zinciri, çiftçilerden perakendecilere, tüketicilerden sanayiye kadar birçok paydaşın ortak çabasını gerektirirken; toprak, su, enerji, fosil yakıtlar ve insan emeği gibi pek çok kaynağın birbiriyle etkileşim içinde olduğu karmaşık bir yapıyı barındırmaktadır. Bu çerçevede, gıda artıklarının azaltılmasında en önemli adım, aşırı üretim ve aşırı tedarikin önlenmesidir. Ayrıca ortaya çıkan gıda artıklarının diyet lifi, hayvan yemi, biyogaz, biyopolimer, biyoplastik, biyoyakıt, enzim, nutrasötik, aroma ve biyosorbent gibi çeşitli katma değerli ürünlere dönüştürülmesi, çevresel etkilerin azaltılmasına yönelik sürdürülebilir ve çevre dostu bir yaklaşım sunmaktadır (Okumuş, 2023; Özkan vd., 2022).

Son yıllarda çevresel kirliliğin azaltılması ve artık yönetiminin etkinleştirilmesi amacıyla, bitkisel üretim süreçlerinde ortaya çıkan hasat artıklarının ve hammaddesi tarımsal ürünlere dayanan çeşitli endüstriyel yan ürünlerin farklı alanlarda yeniden değerlendirilmesi yaygınlaşmıştır. Bu kapsamda, artıkların geri kazanımı ve katma değerli ürünlere dönüştürülmesi açısından öne çıkan tarımsal sanayi ürünlerinden biri de üzümdür (Bekar, 2016). Üretimi esas olarak sofralık meyve, meyve suyu ve kuru üzüm olarak taze tüketime yöneliktir. Diğer önemli kullanım alanları şarap endüstrisidir. Endüstrileşmesinde yaklaşık % 20'si yan ürün haline gelir. Genellikle bu yan ürünler yüksek karlı artık olarak değerlendirilmemekte, çoğunlukla açık alanlara atılmakta ve potansiyel olarak çevresel sorunlara yol açmaktadır. Bu nedenle, çevre dostu endüstriyel üretime olan talebin artması ve üzüm endüstrisinde operasyonel verimliliği artırma ve yan ürün işleme maliyetini en aza indirmenin zorluğu, bu sektörü, önleyici entegre artık yaklaşımlarını benimsemeye doğru yönlendirmeye başlamıştır. Üzüm işleme sırasında ortaya çıkan katı maddelerin, gerekli düzeyde değerlendirilmediği takdirde çevreye zararlı olabileceğini belirtmişlerdir. Bu nedenle, artık maddeler toprağa verildiğinde, zengin besin maddeleri içeren akarsu ve kaynaklarına zarar vererek sudaki canlıları yok etmektedir. Ancak, uygun şekilde değerlendirildiğinde, bu artıklar başka amaçlar için faydalı bir hammadde olarak kullanılabilir. Posa ve çekirdekler endüstriyel artık olarak değerlendirilmekle birlikte, vitaminler, polifenoller, doymamış yağ asitleri ve besin bileşenleri açısından zengin olması nedeniyle insan sağlığı üzerinde olumlu bir etkiye sahiptir (Ferrari vd., 2019).

Üzüm işleme artıklarının insan beslenmesi açısından değerlendirilmesine ilişkin çeşitli yaklaşımlar söz konusudur. Bunlardan bazılarına üzüm çekirdeği ya da üzüm kabuğunun direkt gıda olarak tüketilebileceği ürünlere işlenmesi (örneğin üzüm çekirdeğinin tamamıyla çekirdek yağı ve çekirdek ununa işlenmesi), sahip olduğu biyoaktif bileşenlerin ekstraksiyonu ile bunların takviye edici gıda üretiminde kullanılması ya da gıdalara eklenmesiyle çeşitli özellikleri açısından geliştirilmiş ve zenginleştirilmiş fonksiyonel ürünlerin elde edilmesi, biyoteknolojik proseslerde substrat olarak kullanılarak organik asitler, enzimler vb. maddelerin sentezlenmesi örnek olarak verilebilir (Uz ve Coşkun, 2025).

Alternatif kullanımları arasında, bileşimi itibariyle üzüm posası, özellikle üzüm çekirdeği yağı ve polifenollerin (çoğunlukla antosiyaninler, flavonoller, flavanoller, fenolik asitler ve resveratrol) ekstraksiyonu, fermentasyon yoluyla sitrik asit, metanol, etanol ve ksantan üretimi ve metanizasyon yoluyla enerji üretimi gibi farklı işlemler yer alır. Bu nedenlerden ötürü, üzüm artıklarının doğru bir şekilde değerlendirilmesi ekonomik, sosyal ve çevresel faktörler açısından önemli bir gelişmedir (Mammadova vd., 2020).

Üzüm İşleme Sürecinden Kaynaklanan Artıklar

Türkiye'de yıllık yaş üzüm üretimi ortalama 4 milyon ton düzeyindedir. Bu miktarın yaklaşık % 3'ü şarap üretiminde kullanılmaktadır. Şıralık olarak işlenen üzümlerden % 15-25 oranında posa elde edildiği göz önünde bulundurulduğunda, ortaya çıkan üzüm posası miktarının oldukça yüksek olduğu anlaşılmaktadır. Üzüm işleme sürecinde açığa çıkan ve "cibre" olarak adlandırılan bu posanın bileşimi; yaklaşık % 50 kabuk, % 25 çekirdek ve % 25 saptan oluşmaktadır (Bekar, 2016). Ancak, üretim bölgelerinde açığa çıkan bu artıklar uygun şekilde bertaraf edilmezse ciddi miktarlarda birikime yol açmakla birlikte, su kirliliği, toprak bozulması, bitki örtüsüne zarar, enerji tüketimi ve hoş olmayan gaz ve kokuların salınımı da dahil olmak üzere olumsuz çevresel ve ekonomik etkilere neden olur (Bekar, 2016; Uz ve Coşkun, 2025).

Bununla birlikte, cibre; enerji kaynağı, aktif karbon, çeşitli kimyasal maddeler ve düşük maliyetli hammadde üretimi gibi farklı amaçlarla etkin bir biçimde kullanılma potansiyeline sahiptir. Dolayısıyla, bu artığın değerlendirilmesi hem temiz enerji üretimi hem de çevre kirliliğinin azaltılması açısından önemlidir (Bekar, 2016).

Üzüm Artıklarının Bileşimi ve Değerlendirme Yöntemleri

Cibrenin özellikleri ve değerlendirilme şekilleri

Kompostlama sürecine tabi tutulan cibre (Organik maddelerin mantar, bakteri ve protozoa gibi çeşitli mikroorganizmaların etkisiyle aerobik bozunma yoluyla daha kararlı ürünlere dönüşmesi) yaklaşık olarak % 30 nem, % 1.5 azot, % 2 potasyum ve % 0.5 fosfor içeriğine sahiptir. Yapılan bir araştırmada, cibrenin suda çözünebilir mikro besin elementleri ppm cinsinden; Fe 1.82, Mn 0.13, Cu 2.41 ve Zn 0.43 olarak belirlenmiştir. Asmanın farklı kısımlarında katalaz, askorbik asit, oksidaz, peroksidaz, polifenoloksidaz, pektin metil esteraz ve pektin esteraz gibi enzimlerin bulunduğu bilinmektedir. Kompostlanmış cibre, bağcılıkta, bahçecilikte ve diğer bitkisel üretim alanlarında değerlendirilerek bitki besleme açısından önemli bir katkı sağlamaktadır (Bekar, 2016; Songür ve Çakıroğlu, 2016).

Şarap yapım sürecinde tamamen ekstrakte edilmedikleri için yüksek miktarda fenol bileşiği içerir. Bu fenol bileşikleri aktif antioksidan, antimikrobiyel, antivirüs ve soğuk algınlığı önleyici özellikleri nedeniyle insan sağlığı üzerinde faydalı etkilere sahip olabilirler. Bu nedenle, üzüm posalarından fenol bileşiklerinin yeterli ekstraksiyonu için etkili yöntemler kullanmak önemlidir (Mammadova vd., 2020).

Cibrenin yeniden değerlendirilerek ekonomiye kazandırılabileceği en önemli alanlardan biri yem sanayisidir. Yaş cibre, silaj katkı maddesi olarak değerlendirilebilmekte; kurutulmuş formu ise küspe üretiminde kullanılabilmektedir. Her ne kadar cibre ilavesi yapılan silajlarda yüksek ham selüloz içeriği nedeniyle organik madde sindirilebilirliği azalmış olsa da, özellikle yoğun cibre üretiminin gerçekleştiği gıda işletmelerine yakın bölgelerde düşük maliyetli ve kolay ulaşılabilir bir yem kaynağı olarak kullanılma potansiyeli taşımaktadır. Literatürde, kurutulmuş cibre veya üzüm çekirdeği ilavesi yapılan yemlerin tavukçulukta değerlendirilebileceğine dair bulgular yer almaktadır. Bunun yanı sıra, süt koyunculuğu, süt sığırcılığı, balık yetiştiriciliği ve hatta yün-et tavşanı yetiştiriciliğinde kullanımına yönelik yürütülen çalışmalarda da çeşitli olumlu sonuçlar rapor edilmiştir (Odabaşıoğlu vd., 2022).

Üzüm cibresi yalnızca yem kaynağı olarak değil, aynı zamanda doğal boya üretiminde de değerlendirilmektedir. Fermentasyon süreci sonunda açığa çıkan cibreden yıllık yaklaşık 10.000 ton doğal renklendirici bileşik (antosiyaninler) elde edilebilmektedir. Bu suda çözünebilen boyar maddeler, örneğin kiraz reçeli gibi bazı gıda ürünlerinde renklendirici olarak kullanılmaktadır. Bunun yanı sıra, üzüm posasının belirli koşullar altında kurutulup öğütülerek un formunda gıda endüstrisinde kullanılması da mümkündür. Yapılan çalışmalar, bisküvi üretiminde una % 10 oranına kadar üzüm posası ilavesinin ürün özelliklerini olumsuz yönde etkilemediğini ve tüketici beğenisini kazandığını ortaya koymuştur. Ayrıca yoğurt, salata sosu ve benzeri ürünlere eklenerek fenolik bileşikler açısından zenginleştirilmesi, cibrenin gıda katkı maddesi olarak önemini artırmaktadır (Bekar, 2016).

Üzüm cibresinin geleneksel işlenmesi, damıtma, kompostlama veya katı artık sahasına boşaltma, yakma, gaz haline getirme ve piroliz yöntemleri ile gerçekleştirilir. Üzüm cibresi geleneksel olarak grappa gibi üzüm cibresi içkileri üretmek için damıtılır. Kompostlama, şarap imalathanesi artıklarını toprak düzenleyici olarak kullanılmaya uygun bir ürün haline getirmek için ucuz ve kolay bir yöntemini sunar. Üzüm artıklarının kompostlanması yaygın olarak incelenmiş olup, bu yöntemin hem üzüm posasını yönetmek hem de değerli bir gübre üretmek için uygulanabilirliği konusunda fikir birliği vardır. Yanma, gaz haline getirme ve piroliz, damıtma işleminin aksine, bu alternatifler daha fazla artık ürün üretmez veya tesis dışına nakliye gerektirmez. Üzüm cibresi gibi yüksek su içerikli hammaddelerin kullanıldığı yanma prosesleri tutuşma sorunlarına yol açar ve bu nedenle hammaddenin uygun şekilde ön işlemden geçirilmesi gerekir. Genellikle kurutma uygulanır, ancak bu genellikle prosesin genel verimliliğini düşürür. Buna rağmen, yanmanın üzüm cibresinden enerji ve elektrik üretimi için etkili bir yöntem olduğu gösterilmiştir. Piroliz ve gazlaştırma ise, yanmaya alternatif olarak değerlendirilmesi gereken iki yöntemdir. Gazlaştırma, oksijen eksikliği olan bir ortamda karbonlu bir yakıttan gaz üretimini içerir. Piroliz, özellikle şarap endüstrisinde hem gazlaştırmaya hem de yanmaya bir alternatif sunar. Piroliz, oksijenin olmadığı bir ortamda biyokütlenin termal ayrışmasını sağlayarak biyokömür, biyoyağ ve biyogaz üretilmesini sağlar (Zhang vd., 2017).

Üzüm çekirdeğinin özellikleri ve değerlendirilme şekilleri

Üzüm çekirdeği, toz formunda işlenerek çeşitli gıda ürünlerinde kullanılabilmektedir. İçerik bakımından değerlendirildiğinde, yaklaşık % 14–17 oranında yağ ile birlikte 0.8-1.2 g/kg düzeyinde E vitamini, ayrıca C vitamini ve beta-karoten içermektedir. Üzüm çekirdeği yağının özellikle doymamış yağ asitleri, özellikle de linoleik asit bakımından zengin olduğu bilinmektedir. Doymamış yağ asidi oranının yüksek oluşu, bu yağı beslenme açısından değerli kılmaktadır. Günümüzde üzüm çekirdeği hem toz formunda ticari olarak satılmakta hem de ekmek, pasta gibi fırıncılık ürünlerinde katkı maddesi olarak kullanılmaktadır. Ayrıca laktaz enzimi üretiminde de hammadde olarak değerlendirilmekte, bunun yanı sıra üzüm çekirdeğinden yağ elde edilerek biyodizel üretiminde kullanılabilmektedir. Üzüm çekirdeğinin hem antioksidan kapasitesinin yüksek olması hem de içerdiği protein ve yağ oranı sayesinde yem olarak değerlendirilebilir (Bekar, 2016; Odabaşıoğlu vd., 2022).

Üzüm çekirdeği ekstresi, kozmetik endüstrisinde antioksidan içeriği nedeniyle önemli bir yere sahiptir. Ancak diğer katkı maddelerine kıyasla daha yüksek maliyetli olması, kullanım düzeyini sınırlamaktadır. Üzüm çekirdeği yağı ise aromaterapi alanında hem taşıyıcı yağ olarak hem de terapötik amaçlarla değerlendirilmektedir (Bekar, 2016).

Şarap işleme yan ürünlerinden elde edilen üzüm çekirdeği ununun sosislere katılmasının etkileri araştırılmıştır. Yapılan çalışmaya göre; unun farklı konsantrasyonlarında fiziksel, besinsel ve duyusal parametrelerde farklılıklar gözlenmiştir. Sosislerin renk değerleri (L*, a* ve b*) genel olarak üzüm çekirdeği unu miktarının artmasıyla azalmıştır. Bu unun kullanımı ile antioksidan içeriğinden dolayı ürünlerin oksidasyon seviyesinde bir azalma meydana gelmiştir. Sosislerdeki üzüm çekirdeği unu oranındaki artış, protein içeriğini, toplam diyet lifi içeriğini ve su tutma kapasitesini güçlendirmiştir. Üzüm çekirdeği unu seviyesinin % 0.5'in üzerinde olması genel kabul edilebilirliği azaltsa da, % 2'ye kadar olan seviyelere sahip sosisler ortalamanın üzerinde değerlendirilmiştir (Cirqueira et al., 2017).

Özgan (2008), yumurta verimi üzerine yapmış olduğu çalışmada, üzüm çekirdeği yağı ilavesinin, yem tüketimini, yumurta ağırlığını, yumurta verimini, yemden yararlanma oranını ve canlı ağırlığı önemli düzeyde etkilemediğini tespit etmiştir.

Asma yaprağının özellikleri ve değerlendirilmesi

Yapraklar, üzüm mahsullerinin en az incelenen ve değer verilen kısmını oluşturur (Ferrari vd., 2019). Yaprak örneklerinde fenolik bileşiklerden gallik asit, protokateşik asit, kateşin, kafeik asit, klorogenik asit, vanillin, p-kumarik asit, ferulik asit, o-kumarik asit, rutin, hesperidin, quarsetin, luteolin ve kamferolün varlığı belirlenmiştir. Fenolik asitlerden o-kumarik asit, flavonoidlerden de rutin, kateşin ve quarsetinin yaprak örneklerinde en fazla bulunan fenolik bileşikler oldukları bildirilmiştir (Bekar, 2016).

Organik bileşenler açısından zengindir ve bu nedenle yüksek biyoaktivite koşullarına sahip olması beklenmektedir. Bu biyoaktivite, odun külü, bazalt kaya tozu, pirinç kabukları ve bunların yanma veya kömürleşmeden elde edilen türevleri gibi daha az biyoaktif yüke sahip ancak daha fazla besin çeşitliliğine sahip diğer yan ürünlerin kullanımı için faydalı olabilir (Ferrari vd., 2019).

Asmanın farklı kısımları, çeşitli alanlarda değerlendirilebilme potansiyeline sahiptir. Meyvesi; sofralık üzüm, kuru üzüm, koruk turşusu ve saruç gibi ürünlerde; şırası ise alkollü içecekler (şarap, rakı, likör vb.) ile alkolsüz içecekler (meyve suyu, şurup vb.) yanı sıra sirke, koruk ekşisi, pekmez, sucuk (cevizli köme), pestil ve üzüm tarhanası üretiminde kullanılmaktadır. Yaprakları, başta salamuralık olarak (dolma, sarma vb.) değerlendirilmekle birlikte, doğal boyamacılıkta sarı ve sarı-yeşil tonların elde edilmesinde, içerdiği fenolik bileşikler sayesinde gıda koruyucu olarak ve beslenmeyi destekleyici tablet üretiminde kullanılabilmektedir. Ayrıca sonbaharda dökülen yapraklar organik gübre üretimi için hammadde oluştururken, odunu ise bağ fidanı üretiminde anaç veya aşı materyali olarak değerlendirilmektedir (Bekar, 2016).

Üzüm sapının özellikleri ve değerlendirilmesi

Üzüm sapı, lignin, selüloz ve hemiselüloz gibi biyomoleküllerin yüksek içeriğine sahip olduğu göz önüne alındığında endüstriyel süreçler için önemli bir hammadde olabilir. Diğer lignoselülozik hammaddelerle karşılaştırıldığında, üzüm sapı ayrıca flavan-3-ol monomerik ünitelerinden oluşan daha yüksek miktarda yoğunlaştırılmış tanen (proantosiyanidinler) içerir. Ping vd. (2011) yaptıkları bir çalışmada, üzüm sapından ve daha genel olarak düşük fiyatlı tanen açısından zengin hammaddelerden yararlanılarak geliştirilmiş, enzimatik sindirilebilirliğe sahip hamurların üretimi için umut verici bir süreç olabileceğini göstermiştir. Taşdemir ve Şen (2022) ise yaptıkları bir çalışmada, üzüm sapı, çeltik ve cam elyafın artık malzeme olması ve bunların polimerlerde dolgu veya takviye malzemesi olarak yeniden kullanımının sağlaması konusuna dikkat çekmişlerdir.

SONUÇ

Üzüm endüstrisinde ortaya çıkan yan ürünlerin yalnızca bertaraf edilmesi yerine sistematik biçimde işlevsel kaynaklara dönüştürülmesi, hem sektörel gelişim hem de çevre politikaları açısından stratejik bir zorunluluktur. Çekirdek, posa, sap ve yaprak gibi bileşenlerin içerdiği biyolojik değerler, disiplinler arası araştırmalarla desteklendiğinde, biyoteknolojik uygulamalardan yenilenebilir enerji üretimine kadar geniş bir kullanım alanı yaratabilmektedir. Sürdürülebilir tarım ve gıda sistemlerinin inşasında, üzüm artıklarının ekonomik girdiye dönüştürülmesi yalnızca kaynak verimliliği sağlamayacak, aynı zamanda yerel kalkınma ve küresel rekabet gücünü de destekleyecektir.

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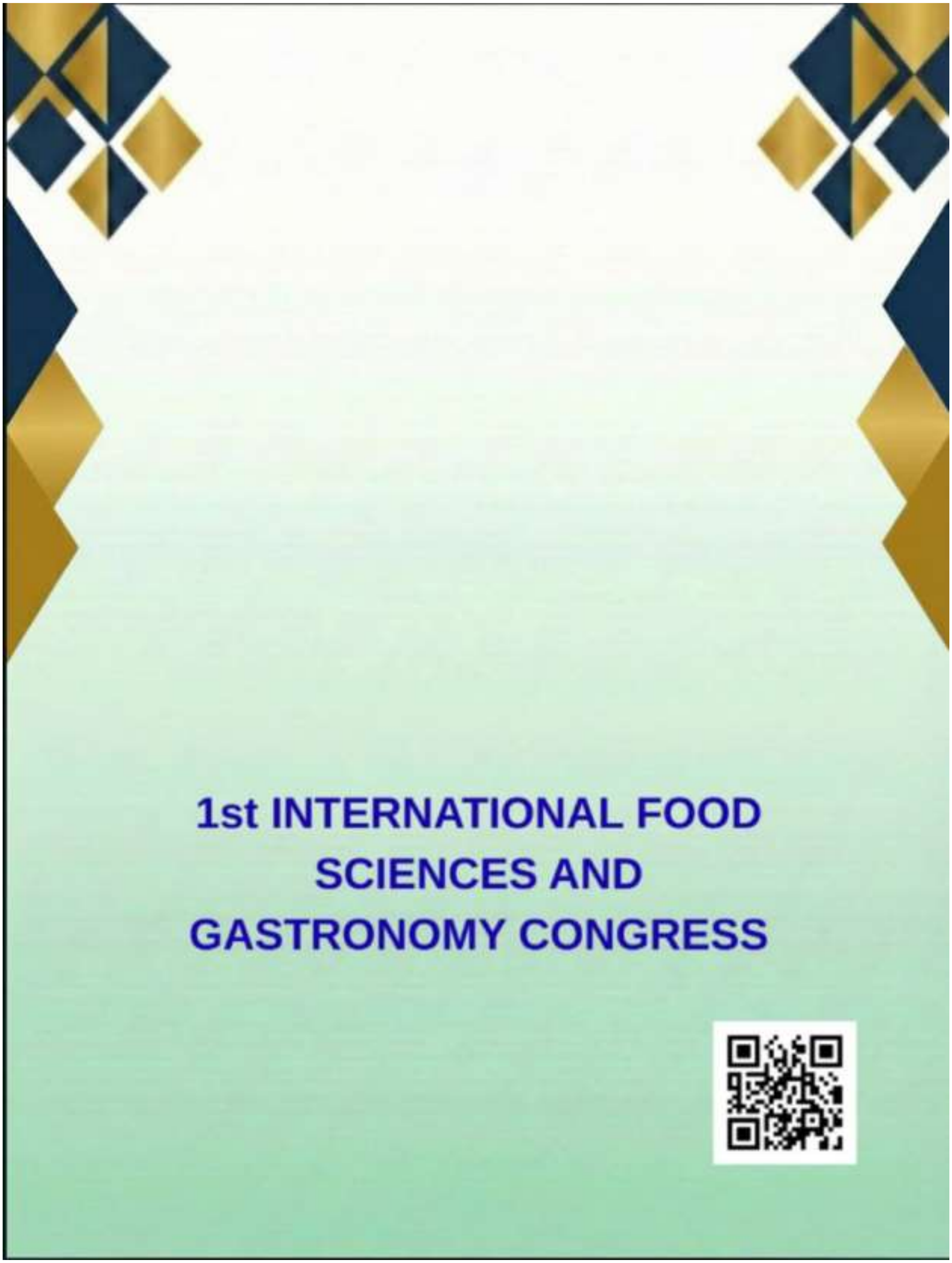
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