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"Science for Sustainable Technology"

2025

8. International Conferences On
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28-30 May / Budapest,HUNGARY

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International Conferences on Science and Technology
Life Science and Technology
May 28-30, 2025 in Budapest - HUNGARY

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Dear Readers;

The 8th of ICONST organizations was held in Budapest-HUNGARY between May 28-30, 2025 with the theme of 'science for sustainable technology' again. In recent years, weather changes due to climate change have reached a perceptible level for everyone and have become a major concern. For this reason, scientific studies that transform technological progress into a sustainable one is seen as the only solution for humanity's salvation. Here we ask ourselves "which branch of science is responsible for sustainability?". Sustainability science is an interdisciplinary field of study that covers all basic sciences with social, economic, ecological dimensions. If we consider technology as the practical application of scientific knowledge, the task of scientists under these conditions is to design products that consume less energy, require less raw materials, and last longer.

ICONST organizations organize congresses on sustainability issues of three main fields of study at the same time in order to present different perspectives to scientists. This year, 215 papers from 20 different countries presented by scientists in ICONST Organizations.

36 papers from 8 countries (Albania, Belgium, Kosovo, Lithuania, Pakistan, Poland, Slovakia and Türkiye) presented in our International Conference on Life Science and Technology organized under ICONST organizations. Turkey is the country with the highest participation with 46%, followed by Albania with 16.6%, Belgium, Kosovo and Poland with %8.5, Slovakia with 5.5, Lithuania, and Pakistan with 3.5%. Outside of Türkiye participant rate is totally 54%.

As ICONST organizations, we will continue to organize organizations with the value you deserve in order to exchange ideas against the greatest threat facing humanity, to inspire each other and to contribute to science. See you at your future events.

ICONST Organizing Committee

Some Geophyte Taxa in Bağbaşı Plateau (Denizli/Türkiye)

ELIF SENA ISITAN*[1], OLCAY DÜŞEN[2]

Abstract: Geophytes are plants that have underground storage organs and reproduce through these organs. This group manages to survive adverse conditions by storing nutrients in structures such as bulbs, rhizomes, corms and tubers. Many showy flowers such as tulips, hyacinths, lilies and orchid species are geophytes. Türkiye has one of the richest geophyte floras in the world. They are especially widespread in the Mediterranean, Aegean and Central Anatolia regions. Geophytes are of great importance in terms of landscaping, ornamental plant cultivation, medicinal plants and ecological balance. The protection of natural areas in particular is a critical issue for the sustainability of endemic species. The aim of this study was to determine some geophyte taxa in Bağbaşı Plateau, located in Denizli Province, Türkiye. Geophyte taxa were collected especially in autumn and spring seasons of 2024. Geophyte species were dried according to standard herbarium techniques and preserved in the herbarium of Pamukkale University (PAMUH). The identification of the specimens was carried out using The Flora of Turkey and other related floras, and the results were confirmed by herbarium specimens. As a result of this research, 9 families were identified in the study area. These families are Amaryllidaceae, Asparagaceae, Colchicaceae, Iridaceae, Liliaceae, Orchidaceae, Papaveraceae Primulaceae and Ranunculaceae. Among the samples collected from the region are endemic taxa.

Keywords: Bağbaşı Plateau, Denizli, Endemic, Geophyte, Türkiye

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Amaranthus cruentus endophytic changes under the cadmium treatment

JANA ŽIAROVSKÁ, DAGMAR MORAVČÍKOVÁ

Abstract: Amaranthus species are characterized as to have a phytoremediative potential as they have different mechanisms to overcome heavy metals stress. To prepare different phytoremediation strategies in the future, we must understand not only different molecular mechanism in plants, but environmental aspect connected to endophytic bacterial communities should be understand, too. Plants benefit from association with endophytic bacteria in different ways, one of them is, that bacteria increasing plant resistance to abiotic environmental stresses, including those induced by heavy metals. Different bacteria play an important role in mitigating of metal toxicity through various mechanisms such as metal chelation, transformation and sequestration. Here, in Slovakia breeded variety of *Amaranthus cruentus* - Pribina was analysed for the composition of its endophytic bacterial communities after Cd treatment. Based on the obtained data, phylums with potential Cd remediation capabilities were identified. Our findings reveal significant changes in the specific endophytic bacterial populations following the exposure to cadmium and following phyla were returned with the most notable increase in the abundance: *Actinobacteriota*, *Chloroflexi*, and *Firmicutes*. Understanding the microbial dynamics under the heavy metal stress will provide in the futute the very specicfic insights to individual phytoremediation strategies.

Keywords: endophytes, rhizosphere, soil, *Amaranthus cruenthus.*

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Probiotics as Biofertilizers and Biocontrol Agents: Revolutionizing Citrus Cultivation for Sustainable Agriculture

SOHAIB AFZAAL*[1]

Abstract: Citrus crops, including oranges, lemons, limes, and grapefruits, are economically significant but face challenges such as soil degradation, nutrient deficiencies, and susceptibility to diseases. Environmental stressors like high temperatures and drought further exacerbate these issues, leading to significant economic losses for producers. Conventional agricultural practices often rely on synthetic fertilizers and pesticides, contributing to environmental pollution. Probiotics, beneficial microorganisms known for their human/animal health benefits, have emerged as sustainable biofertilizers and biocontrol agents in agriculture. This mini-review explores the potential of probiotics to enhance citrus cultivation by improving soil health, promoting plant growth, managing diseases, and increasing stress tolerance. Probiotics such as Bacillus subtilis, Pseudomonas fluorescens, and Lactobacillus plantarum have demonstrated their efficacy in citrus cultivation through various mechanisms. These include nitrogen fixation, phosphate solubilization, production of plant growth hormones, and biocontrol of pathogens. Studies have shown that probiotics can significantly enhance the growth, yield, and quality of citrus fruits while reducing the incidence of diseases like citrus canker and root rot. Probiotics also improve the nutrient composition of citrus by-products, making them valuable for high-value food or feed materials. This review highlights the mechanisms by which probiotics benefit citrus crops, including nutrient mobilization, phytohormone production, and induction of systemic resistance. Additionally, it addresses the challenges and future perspectives of using probiotics in citrus cultivation. Despite the promising potential, issues such as variability in field performance, formulation and application methods, and regulatory considerations need to be addressed.

Keywords: Lactic acid bacteria, Citriculture, Endophytes, Beneficial Bacteria, Biofertilizers, Biopesticides

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Examination of Uncontrolled VOC Emissions of Urban Trees in Düzce/Turkey

Nermin BAŞARAN*[1]

Abstract: Vegetation has long been recognized for its vital role in particularly in mitigating the effects of climate change by improving urban air quality. What has been largely overlooked, however, is vegetation's role in the formation of secondary pollutants. Biogenic volatile organic compounds (BVOCs) emitted by vegetation contribute significantly to the total volatile organic compounds (VOCs) released into the atmosphere. This study examined the impact of various structural characteristics of common plant species used in public open and green spaces in Düzce city on VOC emissions. The study's findings revealed that land use, species type, and the structural characteristics of the species have a direct impact on the emission of isoprene, monoterpenes, and other VOCs. Urban vegetation emits 2381.4 kg/year of VOCs per hectare, significantly higher compared to forests and woodlands, which emit 663.2 kg/year per hectare. Croplands emit 128.2 kg/year per hectare, followed by rivers and lakes at 22.02 kg/year, grasslands at 3.0 kg/year, and wetlands and heathlands/scrub at 1.2 kg/year of VOCs. The VOC emissions from vegetation species are directly influenced by tree characteristics such as age, height, crown diameter, leaf area index, and leaf biomass. In the study area, Quercus petraea Liebl. and Abies nordmanniana (STEV.) SPACH subsp. equi-trojani are the two species with the highest contributions to VOC emissions, releasing an average of 127.4 kg/year of isoprene and 168.6 kg/year of monoterpene per individual, respectively, followed by Quercus cerris L. and Populus nigra L. As result of, The high O3 concentrations observed in urban and suburban areas may be due to uncontrolled VOC emissions from urban trees in Duzce. Therefore, reliable measurements are essential to develop a more accurate VOC emission inventory for the primary tree species in Düzce.

Keywords: BVOC, Düzce, Isoprene, Monoterpene, Urban tree

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Enhancing Environmental Awareness in Hazelnut Farming: The Need for Sustainable Agricultural Extension in Düzce

TUĞBA ÇİFTÇİ*[1], AYFER AYBİKE KARADAĞ[2]

Abstract: The conventional agrarian perspective in Düzce poses a significant threat to the sustainability of agricultural landscapes, particularly in the realm of hazelnut cultivation. Traditional spraying and fertilization practices, often based on anecdotal information rather than a thorough understanding of land structure, soil characteristics, and environmental factors, are adversely impacting ecosystem health. These uninformed practices have the potential to degrade soil quality, pollute water resources, and reduce biodiversity.This study has two primary objectives: first, to assess the level of awareness among farmers regarding agricultural extension activities within the context of sustainable management of agricultural landscapes in Düzce; and second, to determine the impact of this awareness on environmental outcomes. To achieve these objectives, farmers were asked open-ended questions, and their responses were visualized using word clouds. The findings reveal that while farmers are generally familiar with established issues such as air pollution, environmental pollution, and erosion, a substantial 80–90 percent remain unaware of broader environmental challenges, including global climate change, biodiversity loss, and the effects of pesticides on water resources and the atmosphere. These results underscore the urgent need to restructure agricultural extension activities, placing a stronger emphasis on environmental sustainability.

Keywords: Agricultural landscapes, Agricultural extension, Environmental sustainability, Farmer awareness

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In vitro Clonal Propagation of *Allium ramosum* L.

MENEKŞE BETÜL KAYA[1,2], FEVZIYE ÇELEBI-TOPRAK[1,2], ALI RAMAZAN ALAN[1,2]*

Abstract: *Allium ramosum* is a wild relative of *A. tuberosum*. It is an alien species in Europe and was introduced from East Asia as a spice plant in the late 20th century. A detailed experiment to aiming to develop a tissue culture-based technique allowing efficient clonal propagation of *A. ramosum* was carried out. Culturing immature whole flower buds in MS medium containing 2 mg l^{-1} dichlorophenoxyacetic acid (2,4-D) and 2 mg l^{-1} 6-benzylaminopurine (BAP) resulted in regeneration of multiple shoots from the basal parts of cultured flower buds. Regenerated shoots were separated from the flower buds and placed in Magenta boxes containing MS medium without plant growth regulators to induce root development. Almost all shoots developed well-developed roots in MS. Rooted plants were transferred to in vivo for acclimatization. Clonally propagated *A.ramosum* plants produced in this study are currently grown in an unheated greenhouse for morphological characterization and seed production.

Keywords: *Allium ramosum*, tissue culture, biotechnology, flow cytometry

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Androgenesis Induction in Broccoli (*Brassica oleracea* var. *italica*)

HASAN GÜVEN[1,2], ALİREZA LACHİN[1,2], İBRAHİM ÇELİK[1,2], FEVZİYE ÇELEBİ-TOPRAK[1,2], ALİ RAMAZAN ALAN[1,2*]

Abstract: Broccoli (*B. oleracea* var. *italica*) is an important cool season crop, which mainly produced for its floral heads. It was thought to be developed from *B. oleracea* by continuous selection for differentiated inflorescences. Consumption of broccoli is becoming more popular in Türkiye. However, broccoli varieties grown in Türkiye are imported F1 hybrids. Our research team initiated a broccoli breeding project as part of cool season crop development program. We developed an anther culture-based androgenesis technique allowing production of fully homozygous broccoli lines in one generation. In this communication, we present the findings obtained from a group of broccoli lines (F1 hybrids and breeding materials) present in our collection. Isolated anthers were cultured in NLN-13 and B5 media containing 1 mg l^{-1} dichlorophenoxyacetic acid (2,4-D) and 1 mg l^{-1} α-naphthalene acetic acid (NAA). Culturing anther with late uninucleate and early binucleate microspore in androgenesis induction medium provided androgenic embryos from all donor broccoli lines used in the study. However, broccoli lines showed substantial differences in their responses to induction.

Keywords: *Broccoli,* androgenesis, biotechnology, haploid

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Comparison of Total Flavonoid and Total Phenolic Contents, and Antioxidant Activity in Different Populations of Endemic *Helichrysum compactum* Boiss. (Asteraceae)

NİLÜFER TÜRKOĞLU*[1], BATIKAN GÜNAL[1], GÜRKAN SEMİZ[1]

Abstract: : *Helichrysum compactum* Boiss. is a perennial plant belonging to the Asteraceae family. Generally known as "Altınotu" in Anatolia, *Helichrysum* is also used for reducing kidney stones, treating colds, managing diabetes, and addressing stomach disorders. This study determines and compares the total flavonoid, total phenolic contents, and antioxidant activities of different parts of *H. compactum* from two different populations. Aluminum chloride, Folin–Ciocalteu, and DPPH methods were used to determine the total flavonoid content, total phenolic content, and antioxidant activity, respectively. The highest total phenolic content was found in the methanolic flower extracts of the Denizli (154.781 ± 2.91 mgGAE/g) and Antalya (145.731 ± 4.60 mgGAE/g) populations. The highest flavonoid contents were identified in the chloroform extract of the stem from the Denizli population (131.004 ± 4.34 mgRU/g – 78.416 ± 2.46 mgQE/g) and the methanolic flower extract of the Antalya population (130.891 ± 5 mgRU/g – 78.352 ± 2.83 mgQE/g). The highest antioxidant activity was detected as 33.92 µg/ml in methanolic stem extracts and 20.71 µg/ml in methanolic flower extracts of the Antalya population. It is believed that different climatic conditions may account for the variations observed between the Antalya and Denizli populations. Therefore, it was concluded that the endemic *H. compactum* contains high levels of total flavonoids and phenolic substances in the flower and stem parts and demonstrates high antioxidant activity. With further research, it is believed that the discovery of flavonoids and phenolic compounds will enable the industrial use of this plant, which is significant from an ethnobotanical perspective. Additionally, it is thought to be a source of natural bioactive substances that may replace synthetic ones in the food, cosmetic, and pharmaceutical industries.

Keywords: Antioxidant activity, *Helichrysum compactum*, total flavonoid, total phenolic.

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Modelling the Current and Future Potential Distribution of *Thymus kotschyanus* (Wild Thyme)

AYŞEGÜL TEKEŞ DÜDÜKÇÜ[1], SERKAN ÖZDEMİR[2*]

Abstract: This study aimed to determine the current and future potential distribution areas of Thymus kotschyanus Boiss. & Hohen., a medicinal and aromatic plant species with significant ecological and economic value. The study area is limited to the Eastern Anatolia Region of Türkiye. Species occurrence records were obtained from the Global Biodiversity Information Facility (GBIF), while climate data were sourced from the WorldClim database. Future climate projections were evaluated for the year 2100 under four different Shared Socioeconomic Pathways (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5). Species distribution modelling was performed using the MaxEnt algorithm. The performance of the model was assessed using the Area Under the Curve (AUC) metric, yielding values of 0.941 for the training dataset and 0.933 for the test dataset, indicating that the model was performed at an "excellent" level. According to the modelling results, the most influential environmental variables shaping the potential distribution of the species were identified as BIO3 (isothermality), ELEVATION, BIO14 (Precipitation of the Driest Month), ASPECT, and BIO2 (Mean Diurnal Range). The current habitat suitability map shows that the species had a distinct distribution pattern within the region. Projections based on future climate scenarios indicate that while the most optimistic scenario (SSP1 2.6) shows minimal deviation from the current distribution, the most pessimistic scenario (SSP5 8.5) suggests a substantial reduction in suitable habitat areas. This study highlights the vulnerability of T. kotschyanus to climate change and underscores the importance of species distribution modelling to inform long-term conservation strategies, particularly for endemic and medicinal plant species.

Keywords: climate change, MaxEnt, species distribution modelling, SSP scenarios, Thymus kotschyanus

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Multiple Ways of Utilisation of Suberinic Acid Residues in Wood Composites Technology

GRZEGORZ KOWALUK[*1], JULIA DASIEWICZ[2], ANITA WRONKA[1]

Abstract: The sustainable valorisation of biomass residues plays a crucial role in advancing circular economy principles within the wood composites industry. Suberinic acid residues (SAR), derived from birch bark post-extraction processes, have emerged as promising bio-based additives and binders for engineered wood products. Recent studies demonstrate multiple pathways for incorporating SAR into wood composites, enhancing their mechanical, physical, and environmental performance.
The incorporation of SAR powders into structural particleboards shows that the particle fraction size significantly affects mechanical properties, such as internal bond strength and modulus of rupture, supporting material design within a circular economy framework. Investigations into multiphase biopolymers enriched with SAR reveal improvements in mechanical resilience and potential for sustainable material development.

Particleboards manufactured with added Betula bark residues exhibit enhanced selected physical and mechanical properties. Additionally, the development of barrier films based on biopolymers and SAR, combined with nano-zinc oxide, significantly improves barrier properties against water vapour and oxygen.

From an environmental perspective, utilizing SAR in wood composites finishing contributes to carbon capture and storage, offering an innovative approach to reducing the carbon footprint. Furthermore, integrating post-treatment bark biomass into plywood adhesives has been shown to enhance bonding performance and eco-efficiency.

Initial investigations confirmed the fundamental potential of SAR as a partial or complete replacement for synthetic adhesives in wood composites, reducing dependency on petrochemical resources.

Overall, the multifaceted utilisation of suberinic acid residues – from direct incorporation into particleboards and plywood to functional film production – opens promising avenues for the development of sustainable, high-performance wood composites, contributing to a more circular and resource-efficient bioeconomy.

Keywords: suberinic acid residue, wood composites, circular economy, biopolymers, particleboards, plywood, sustainable materials

Acknowledgement: The research presented is a part of Project BarkBuild that is funded under the ERA-NET Cofund Forest Value Program through Vinnova (Sweden), Valsts izglītības attīstības aģentūra (Latvia), Ministry of Education, Science and Sport (JIA) (Slovenia), Academy of Finland, The Research Council of Norway, and the National Science Centre, Poland (Agreement No. 2021/03/Y/NZ9/00038). The Forest Value Program received funding from the Horizon 2020 Research and Innovation Program of the European Union under Grant Agreement No. 773324.

Selected activities of the presented study were completed within the Student Furniture Scientific Group (Koło Naukowe Meblarstwa), Warsaw University of Life Sciences – SGGW, Warsaw, Poland.

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The Progress in Research on Circular Economy in Wood-Based Composites

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Abstract: The wood-based composites sector is increasingly embracing circular economy principles, aiming to minimise waste, promote recycling, and extend the lifecycle of lignocellulosic materials. Recent research efforts have focused on the recycling and upcycling of various wood-based waste streams, revealing promising strategies to enhance sustainability and material performance.

Studies on recycling post-consumer wood products, such as window frames, have demonstrated that high-quality particleboards can be manufactured by incorporating recycled materials, preserving satisfactory mechanical and physical properties. Simultaneously, the upcycling of wood dust generated during particleboard recycling has been explored as a functional filler in layered composite structures, offering an effective solution for material valorisation without compromising product integrity.

The effects of multiple mechanical recycling cycles on particleboards have been systematically investigated, showing that while some deterioration in mechanical properties occurs, optimised processing and blending strategies can sustain acceptable product standards. Additionally, research into alternative raw materials, such as pine branch particles of varying sizes and contents, has confirmed the feasibility of producing high-performance boards from non-conventional sources.

Broadening the scope, the upcycling and recycling potential of diverse lignocellulosic waste biomass types has been assessed, highlighting their adaptability for integration into wood composites manufacturing. These findings collectively support a transition towards more circular and resource-efficient production models in the wood-based materials industry.

Further research scenarios could include the development of hybrid composites combining recycled wood with bio-based polymers, exploration of advanced surface treatments to mitigate property degradation during multiple recycling loops, and life-cycle assessment studies to evaluate the environmental benefits comprehensively. Investigating digital technologies, such as smart sorting and AI-driven material quality prediction, may also open new avenues for optimising recycling processes. Lastly, expanding the range of feedstocks to include agro-waste or urban wood residues could further strengthen the role of wood composites in future sustainable construction systems.

Keywords: circular economy, recycling, upcycling, wood composites, particleboard, lignocellulosic biomass, sustainable materials

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Valorization of Underutilized Hazel (*Corylus avellana* L.) Wood for the Manufacture of Single-Layer Particleboards with Structural Properties

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Abstract: Hazel wood (Corylus avellana L.), despite its availability in European forests, is often considered a low-value species with limited industrial application. This study explores the potential for hazel wood valorization through its incorporation into single-layer particleboards intended for structural use. Laboratory-scale boards were produced using particles obtained from hazel chips, both barked and debarked, and mixed with industrial pine particles at varying mass ratios: 0%, 5%, 10%, 25%, 50%, and 100%. An additional variant composed entirely of particles from debarked hazel chips was also included.

The physical and mechanical properties of the boards were evaluated according to EN standards. The parameters tested included modulus of rupture (MOR), modulus of elasticity in bending (MOE), internal bond strength (IB), screw withdrawal resistance (SWR), density profile (DP), thickness swelling (TS), and water absorption (WA) after water immersion. The bulk density of hazel particles was also determined, revealing significantly higher values than those of the reference pine particles, with barked hazel particles showing the lowest bulk density among the hazel variants.

The results demonstrated that all board variants met the strength requirements for P5 type boards defined by EN 312 in terms of MOR and MOE, although a gradual decrease in these properties was observed with increasing hazel content. Notably, thickness swelling increased markedly in boards containing more than 25% hazel particles, suggesting reduced dimensional stability. Despite these limitations, the study highlights the technical feasibility of incorporating hazel wood particles, especially those from debarked chips, into structural particleboards, offering a promising pathway for enhancing the value chain of this underutilised species.

Keywords: hazel wood, particleboard, structural panels, biomass valorization, mechanical properties, underutilized species

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Evaluation of Socioeconomic Conditions and Land Use of Beekeeping Activities in Artvin-Şavşat Region

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Abstract: To make land use classifications according to the needs of humans living in rural areas, social and economic characteristics of humans need to be considered. In this regard, it is not possible to say that the preferred land use and socioeconomic conditions are fully utilized in the Artvin-Şavşat region, where beekeeping activities are carried out intensively. In this study, it is aimed to reveal the preferred land use and socioeconomic conditions for beekeeping activities in the Artvin-Şavşat region. Based on the information obtained, socioeconomic activities mapping of the study area will be presented. For this purpose, areas where beekeeping activities are located within the study area were recorded as polygon data during field studies carried out between 2019 and 2020. Later, forest management plans for the study area between 1987 and 2017 were obtained. Based on the forest management plans of the study area, land use classification was divided into classes such as forest, bush, agriculture, water and settlement. Land use and beekeeping activities obtained as polygon data were converted to raster format with the "*Polygon to Raster*" extension of the ArcGIS Pro software. Based on these two maps in raster format, the socioeconomic activities map of the study area was created with the help of the Weighted Overlay (Spatial Analyst) add-on of the ArcGIS Pro program. According to this mapping, it has been determined that beekeeping activities in the Artvin-Şavşat region are concentrated in settlements and their surroundings. As a result, while the economy of Artvin-Şavşat district is largely based on animal husbandry and agriculture, beekeeping activities should not be ignored. Because in the socio-economic activities map, even the surroundings of 65 villages in the Artvin-Şavşat district were determined to be the most suitable areas for beekeeping activities. Finally, this study emphasizes the importance of making a comprehensive and systematic land use capability classification of a region by looking at the socioeconomic conditions of a particular area.

Keywords: ArcGIS Pro, Artvin-Şavşat, socioeconomic situation, land class, weighted overlay class.

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Environmental Impacts of Next-Generation Biodegradable Materials

YLLİ KORTOÇİ

Abstract: The development of next-generation biodegradable materials aims to address the environmental challenges posed by conventional plastics. This paper analyzes the lifecycle environmental impacts of novel biodegradable polymers derived from renewable resources such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), and starch-based composites. It compares their biodegradability, mechanical properties, and suitability for various applications. The environmental benefits, including reduced landfill accumulation and lower greenhouse gas emissions, are quantified through lifecycle assessment (LCA) studies. The paper also discusses potential risks related to biodegradation products and interactions with natural ecosystems. Manufacturing processes and feedstock sourcing are evaluated for sustainability. Regulatory frameworks and market trends influencing the adoption of biodegradable materials are examined. Challenges such as higher production costs, limited performance under certain conditions, and end-of-life management are addressed. The paper concludes by emphasizing the importance of holistic assessment and innovation to maximize the environmental advantages of biodegradable materials while minimizing unintended consequences.

Keywords: Biodegradable Materials, Lifecycle Assessment, Renewable Polymers, Environmental Impact, Sustainable Materials, Plastic Pollution.

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Conversion of Food Waste into Bioenergy

YLLI KORTOCI

Abstract: The increasing volume of food waste represents both an environmental challenge and an untapped resource for renewable energy production. This study evaluates current technologies for converting food waste into bioenergy, focusing on anaerobic digestion, fermentation, and thermochemical processes such as pyrolysis and gasification. Anaerobic digestion is highlighted as an effective method for producing biogas rich in methane, which can be utilized for heat and power generation. The research also examines process optimization strategies including co-digestion with other organic wastes and pre-treatment techniques to enhance yield and stability. Fermentation processes for bioethanol production from carbohydrate-rich food residues are analyzed with regard to microbial strain selection and substrate preparation. Thermochemical conversion is discussed as a versatile approach capable of producing syngas, bio-oil, and biochar, which can be further processed into various biofuels and soil amendments. Environmental benefits such as reduced landfill use and greenhouse gas emissions are quantified, alongside economic considerations like cost, scalability, and policy incentives. The paper advocates for integrated waste management systems combining multiple conversion technologies to maximize bioenergy recovery and contribute to circular bioeconomy goals.

Keywords: Food Waste, Bioenergy, Anaerobic Digestion, Fermentation, Pyrolysis, Circular Bioeconomy.

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Diversity of Mycobiota in Ash Wood (Fraxinus excelsior L.) from Trees of Varying Health Status in Two Forest Habitat Types

DIANA FIEDOROWICZ, MARTA BEŁKA

Abstract: This study aimed to examine the diversity of fungal communities in ash wood (Fraxinus excelsior L.) from trees of varying health status, growing in two forest habitat types in western Poland. In May 2024, wood samples were collected from 24 randomly selected trees in Bolewiny Forest District (Babimost Forest Inspectorate), located in ash-alder swamp forest (OlJ) and moist broadleaved forest (Lw). Increment cores were taken at breast height from living trees, and from the base and 1.3 m height in dead trees. Tree health was assessed using modified decay classification scales, and site metadata were recorded with the mBDL app. All trees were photographed and mapped in QGIS. In the laboratory, wood samples were sectioned into annual rings and cultured on 2% malt extract agar to isolate mycobiota. The study forms a basis for understanding fungal colonisation patterns in relation to tree condition and habitat type.

Keywords: Fraxinus excelsior, mycobiota, tree health status, forest habitat types, wood-inhabiting fungi.

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The Influence of Polystyrene Panels on The Efficient Performance of Buildings

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Abstract: Urbanization and the development of construction technology aims to integrate environmental and energy issues in the handling of construction projects. In order to design a sustainable project, a balance must be achieved between environmental, economic, social and technical issues. Masonry is an important element of a building. It can be made with different materials such as brick, wood, sandwich panels, polystyrene panels with galvanized rails, concrete panels, etc. In our country, the construction of buildings with a reinforced concrete frame and external and internal partitions with lightweight brickwork has become massive. This paper presents the attempt to open a new possibility in our country for the replacement of brick masonry in b/a frame buildings with polystyrene panels reinforced with galvanized iron bars by making a technical and economic analysis because it also affects the improvement of the response efficiency of these buildings. At the end of the work, we found some efficient advantages of using these panels, such as standardization of construction, ease of building construction, more efficient costs, energy efficiency, improved thermal insulation characteristics.

Keywords: Downsizing of structural elements, Polystyrene panels reinforced with galvanized iron bars, Classic brick masonry, Technical-economic comparison, Advantages of use.

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INTRODUCTION

Since the masonry occupies a significant part in the weight of the object, which negatively affects the efficient response of the buildings, we think that the replacement of this masonry with alternative materials (polystyrene panels reinforced with galvanized iron bars) is technically and economically beneficial. The reduction of the weight of the walls leads to the reduction of the dimensions of the structural elements (beams, columns, slabs), and therefore the cost of construction and, in particular, the improvement of the energy performance of the buildings. The process of reducing the cost of the object will continue with the reduction of the weight of the superstructure, which also reflects the construction of the foundations, which will be of lighter dimensions, compared to the case when classical masonry would be used.

In the following, the development of the topic will begin with the great opportunities we have with the use of polystyrene panels, its favorable technical and economic characteristics, i.e. we will stop at the realization of polystyrene panels with galvanized iron bars and the necessity of their use in the country. our massively.
For this, it is necessary to compare the technical-economical application of alternative materials (polystyrene panels reinforced with galvanized iron carrier) from classic masonry and the argumentation for the introduction without wasting time in mass use.

1. PRESENTATION OF THE CURRENT SITUATION OF BUILDINGS IN OUR COUNTRY

The technology of building buildings with a reinforced concrete frame, with external and internal partitions with lightweight brick masonry, is the most used technology in our country. This is the construction technology of almost 100% of constructions in our country, in Albania, specifically in Durrës. But the damage caused by the 2019 earthquake also brought to attention the problems that had the very large damages suffered by the infill brick walls in most of the affected buildings.

One of the reasons is the technology of building traditional walls made of ceramic bricks as well as the considerable weight these typologies have in the construction of the building. Figure 1 shows a typical building built with a reinforced concrete frame and filled with bricks.

Fig 1. B/A frame building with infill masonry with lightweight bricks

Fig. 2+3. Internal and external walls with polystyrene panels reinforced with iron brackets (Photo by the authors)

2. TECHNICAL ANALYSIS OF BRICK WALL BUILDINGS

For the purpose of this study, technical and economic analysis for the construction of the internal dividing walls of an object have been conducted. Firstly, in th following are presented technical analysis of classic partition walls with brick vs. walls with polystyrene panels reinforced with iron bars. For comparison, the properties and characteristics of brick walls were analyzed based on parameters, as:

Wall thickness (cm)
Wall weights (kg)
Thermal insulation coefficient (W/m2K)

References are standard SSH 2505:1987, EN 771-1:2011+ A1:2015 for ceramic bricks [3].

Fig. 4. Brick with holes

2.1 PHYSICAL AND MECHANICAL CHARACTERISTICS OF BRICKS

Brick is an element of baked clay widely used in construction. These elements are connected to each other by means of different types of mortars, to give walls or other structures, making them permanent. [1] Bricks are usually produced in standard sizes and in large quantities. They have been called one of the most durable elements in the entire history of construction.

The test for determining the resistance of bricks consists of:

- The sample stays in the water for a period of 24 hours
- Then the sample is placed in the device for measuring the resistance
- The apparatus is loaded until the destruction of the sample

Resistance is calculated with the formula: R=F (N) /Ac (mm^2)

F-Destructive force

- Thermal conductivity

One of the challenges of today's construction is saving energy. This is achieved by using such materials that do not allow or minimize the transmission of heat between environments.

Thermal conductivity (λ) is a coefficient derived from experimental tests and is measured in W/mK. The smaller the value of this coefficient, the better a material resists thermal conductivity.
If we take a sample of finite size, we can calculate its thermal conductivity with the formula:

$\lambda = W \cdot L/A. T1/(T2-T1). (\theta 1-\theta 2)$

Classic masonry has a thermal conductivity in average values of:

$0.6 < \lambda < 1$(W/mK)

However, according to the different type of brick material different values result. This relatively high coefficient shows us that classic masonry does not represent efficiency in heat preservation, and as a result, other thermo-insulating layers must be used on it. to have no heat loss. [4] This leads to increased element weight, additional insulating material, more labor time, all of which are ultimately reflected in the cost.

- Fire resistance

Brick masonry has satisfactory fire resistance. A wall with a cross section of 10 cm thick and a plaster of 1.25 cm will have a resistance of almost 2 hours to exposure to a fire. [2] Brick can withstand significant temperatures of up to 1000 °C, compared to ordinary concrete masonry, which can withstand temperatures of no more than 450 °C, due to water loss. It is a fact that the non-combustibility of brick masonry makes the use of this material more widespread, especially in areas where the incidence of fires is higher.

- Water absorption

Many experimental tests have been done to measure the amount of water absorption in classical masonry. A wall built with very strong bricks that do not absorb much water may be more permeable to rain than a wall built with highly absorbent bricks. water. [6] This is because rain will more easily penetrate a small crack in the mortar between densely placed bricks than when the bricks are saturated. The amount of water that a brick wall can absorb is a very important indicator of its density, and consequently its resistance, but not a sufficient factor to "behave well" on the wall. The term "good behavior" describes the ability of bricks in a particular situation to withstand rain, frost and wind, without losing resistance, without breaking and preserving the texture and color.

- Acoustic insulation

Acoustic insulation of a wall is a characteristic that does not allow sound to pass from one side of it to the other. This should not be confused with sound absorption, which is a property of materials for absorbing sound waves, which allows the reduction of noises, echoes or vibrations [7]. The loudness of sounds is measured in decibels (dB). The decibel is the smallest size that the human ear can hear and is a logarithmic unit. Due to their compact texture, brick walls have a good response to noise pollution. The acoustic insulation of this masonry varies from 45 dB for a 12 cm thick wall to 50 dB for a 25 cm thick wall. The frequency range varies from 300 to 2000 Hz. However, in areas that result in high noise pollution, such as congested urban areas, additional noise-insulating layers are needed on the component masonry of the structure, to avoid this phenomenon.

- Creation of mold/accumulation of salts

This is a phenomenon in which salts dissolved in water are deposited and accumulated gradually on the surface of the masonry, creating an unsightly layer of white crystals. These salts may originate from the raw material that is used before the bricks are made, i.e. from the clay. But in most cases, mold is created by external factors, such as groundwater, atmospheric pollution, mortar components and other materials in contact with brickwork. The concentration of salts depends on their content in the material itself and on the degree of water saturation of the brick. In most cases, the small concentration of salts or mold on the surface of the masonry does not cause damage, and can be easily removed by water. [5] In cases where we have significant quantities, they can lead to cracks or the creation of salt dust on the surface of the masonry. Salts accumulated behind the surface of the brick, in contact with water, expand and lead to crumbling and disintegration of the masonry. This phenomenon is also caused by the absorption of salts from the mortar rich in cement, as shown in figure 5:

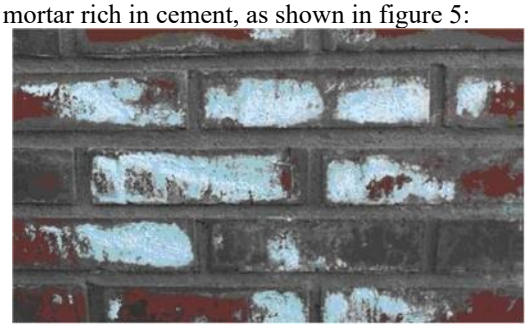


Fig. 5. The phenomenon of the creation of mold and the accumulation of salts in the brick wall (from “Building materials” book, F. Kadiu)

3. PRESENTATION OF MASONRY WITH POLYESTER PANELS REINFORCED GALVANIZED IRON TUBES

Given that the masonry occupies a significant part in the weight of the object, which negatively affects the efficient response of the buildings, we think that the replacement of this masonry with alternative materials (polysterol panels reinforced with galvanized iron bars) is technically and economically beneficial.

In Albania, the construction industry is one of the most important economic sectors. Growing urbanization due to demographic changes, increased investments and the creation of industrial-commercial regions are accompanied by the demand of investors for the development of alternative technologies and materials.

Materials that deviate from traditional schemes in construction technology in terms of improving its key elements will be considered as alternative technologies and materials:

- Lifespan of the facility
- Technical characteristics of materials
- performance
- functionality
- Economic viability

Following the topic, the application of reinforced polystyrene panels with galvanized iron pipes will be addressed. In the framework of the use of increasingly new technologies, in order to increase the speed of construction, reduce costs, increase stability in time, save energy, we think that the reinforced polystyrene panel is a serious competitor compared to the classical masonry used. until today. The research-study work will focus especially on the advantages of this element, its comparison both from the mechanical-technical side, but also the economic ones (which are the main ones in Albania), with any other known technology that can be used in our country, the introduction and the best possible adaptation in the Albanian market.

The demand for construction at the lowest cost is closely related to urbanization, natural population growth, demographic changes, the economic, social and political situation of a country. It includes everyone, from decision makers to beneficiaries and consumers.

Guaranteeing "adequate" housing is one of the main problems of the 21st century. Worldwide, 18% of urban housing units are temporary and 25% do not meet building regulations.

Urbanization and the development of construction technology aims to integrate environmental and energy issues in the handling of construction projects. To design a sustainable project, a balance must be achieved between environmental, economic, social and technical issues.

This study focuses on engineering facilities and the impact of construction materials, components of the walls. The data show that 60% of the cost of civil buildings up to the average level goes to the design and construction materials. Moreover, walls + plastering make up about 50% of the total cost and about 45% of the construction time. [10] The origin of the materials, the applied technology and the requirements for labor power have the main impact on the selection of the type of material used for masonry construction.

The selected topic will be addressed by highlighting the advantages of this material compared to traditional masonry, accompanied by a presentation of its technical, physical-mechanical characteristics. Presentation of alternative materials. Presentation of reinforced polystyrene panels with galvanized iron bars [7].

Reinforced polystyrene with galvanized iron carrier is a construction material consisting of two elements:

- **Expandable Polystyrene (PZ)**, which by its own properties plays the role of spatial determinant, thermal insulator, and insulator.
- **Galvanized iron pipe ø= 3mm**, which by means of longitudinal and transverse connections guarantees the structural integrity, rigidity of the element, as well as by means of connections with the supporting construction (metallic, b/a) guarantees the connection of the panels with the building structure.

Fig. 6. Polystyrene panels reinforced with galvanized iron bars (Photo on site by the authors)

Reinforced polystyrene is used in the form of prefabricated panels. These panels are produced in different thicknesses to suit different architectural projects. The use of reinforced polystyrene panels with an iron carrier in the structure is in several cases:

- in b/a structures, in metal constructions,
- for external partitions,
- for internal partitions,
- for thermal insulation of partitions and soles,
- for external surrounding walls,
- for supporting reinforcement in b/a structural element (beams, columns, etc.), replacing wooden molds.

The following figures show parts of the work for the assembly of these panels Figure 7. a, b as well as some constructive details in Figure 8 a, b, as follows in a civil building:

a. Realization of internal walls and soles b. Realization of internal walls

Fig. 7. a, b The method of making masonry with polystyrene panels with galvanized reinforcement.

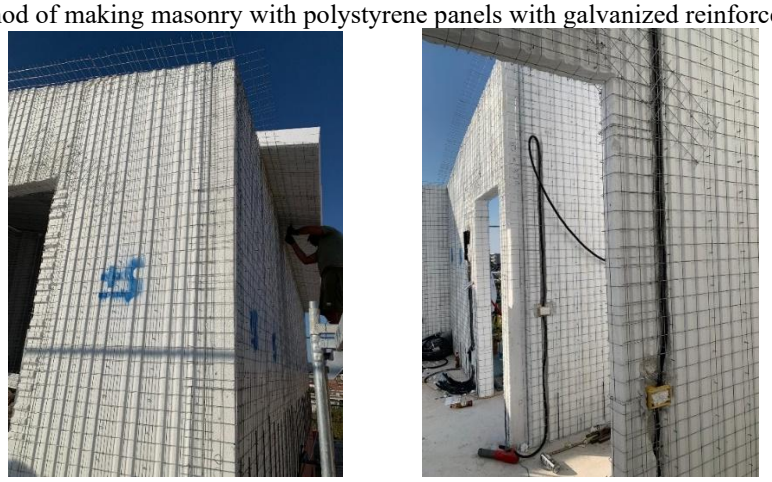


Fig. 8. a, b, Details of constructive joints

3.1 TECHNICAL CHARACTERISTICS OF POLYSTYRENE (some of the characteristics)

Specific weight

The density of PZ is considered as its main characteristic, which also affects other mechanical properties. Also, the production cost of PZ depends on the chosen density of the material. The density of PZ for common uses ranges from 11 to 30 kg/m3. With this specific weight, PZ material can be easily transported with wings after production, during transport and on site.

Table 1. From Standard ASTM C 578-95 EPS Densities

Type	XI	I	VIII	II	IX
Density (kg/m3)	12	15	18	22	29

Table 2. Physico-mechanical properties of polystyrene [7]

Characteristics	
The density of PZ	15–640 kg/m3
Jung's modulus (E)	3000–3600mPa.s.
Resistance (s_t)	46–60 MPa
distortions	3–4%
Coefficient of linear deformations (a)	8×10−5 /K
Specific Heat (c)	1.3 kJ/(kg·K)
Absorptionof water (ASTM)	0.03–0.1
decomposition	X years, still decaying

Thermal resistance

PZ consists of 98% air and 2% polystyrene. The air found in PZ is a very good thermal insulator. The "R" value measures the thermal resistance of materials. The R-value for ordinary soils and concrete is generally much less than 0.1 m3 C/W. The value of 0.5-0.8 m3 C/W of the R-factor of PZ is much higher than that of soils and concrete. The value of the R-factor increases with the increase in density. To see the thermal efficiency, we took a cross-section of an external wall, as in the figure below, where the layers are (from left to right: interior paint layer, plaster layer, galvanized iron carrier, polystyrene layer, betony 12cm-15cm with consistency of class S4 or S5, galvanized iron carrier, polystyrene layer, plaster layer, graffiti layer.

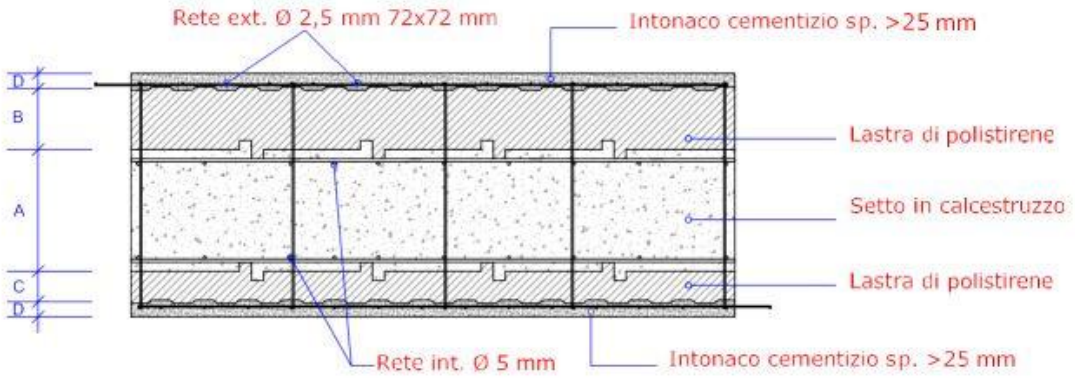


Fig. 15. Graph of the relationship between thermal resistance and density (data obtained from Systempiu, https://systempiu.com/)

*Network ext. carrier- the outer iron
Intocano- External plastering
Lastro di polysterino- Polysterol layer
Setto- Concrete layer

Thermo-acoustic properties

PZ has very good acoustic properties. These properties of acoustic insulation make it a very good substitute for other, heavier or larger materials.

Durability
No deficiencies in terms of durability have been found in the PZ elements. For this material, a lifetime is guaranteed, more than a cycle of 100 years.

4. TECHNO-ECONOMIC ANALYSIS OF THE USE OF POLYESTER PANELS REINFORCED WITH IRON BARS, INSTEAD OF BRICK MASONRY

The development of complex structures, tall and large buildings, has made a better performance of concrete necessary in recent years. The use of reinforced polystyrene panels with iron carrier in the structure is getting more and more developments. Good thermal insulation, durability and reduction of own weight are some of the main advantages.

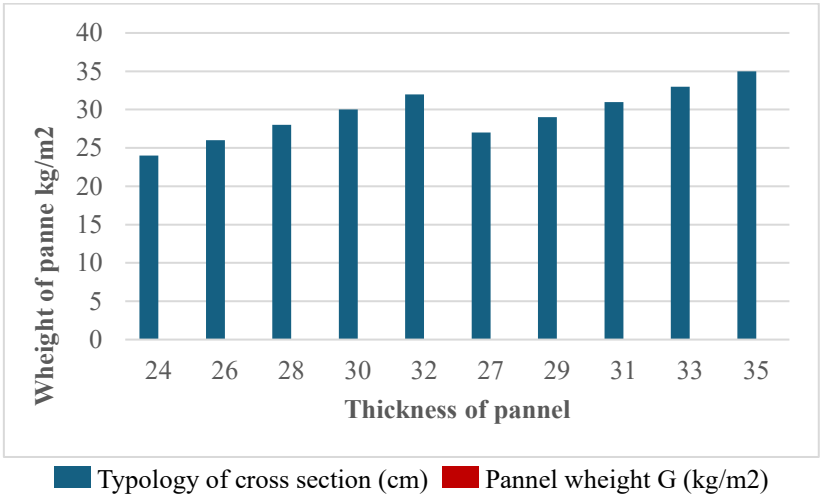
4.1 Use of lightweight concrete panels is essential in technical and cost terms

The points where the economic benefits are more obvious are: material savings, machinery, reduction of working hours and transportation of materials. All these give their effect on the total cost of the structure.

❖ **Savings in material**

The use of reinforced polystyrene panels with iron supports in the structure significantly reduces its total weight. This gives effect in 2 phases in the focus of reducing the overall cost: in the design phase during construction. [11] In the design phase, cost reduction is achieved by reducing the volumes and the amount of materials needed to build the facilities. So less material for the lightweight concrete composition itself, less reinforcing factors.

Reducing the weight of the walls also reduces the size of the structural elements (beams, columns, slabs), and therefore the material needed for their construction. All this reduction in the weight of the superstructure means that the foundations are not the same size as they would be if classical masonry was used. So there is no need to use additional reinforcing armor (10% less), also the reduced dimensions require less material.



Graph 1. Dependence of panel weight on its thickness (from KIBE.AL)

❖ **Savings on shipping**

In the most common case of shipping reinforced polystyrene panels with iron rails, the order is made for significant quantities. The reduced weight of these panels compared to classic masonry means that more elements can be included during a transport interval, thus reducing the cost of transporting materials.

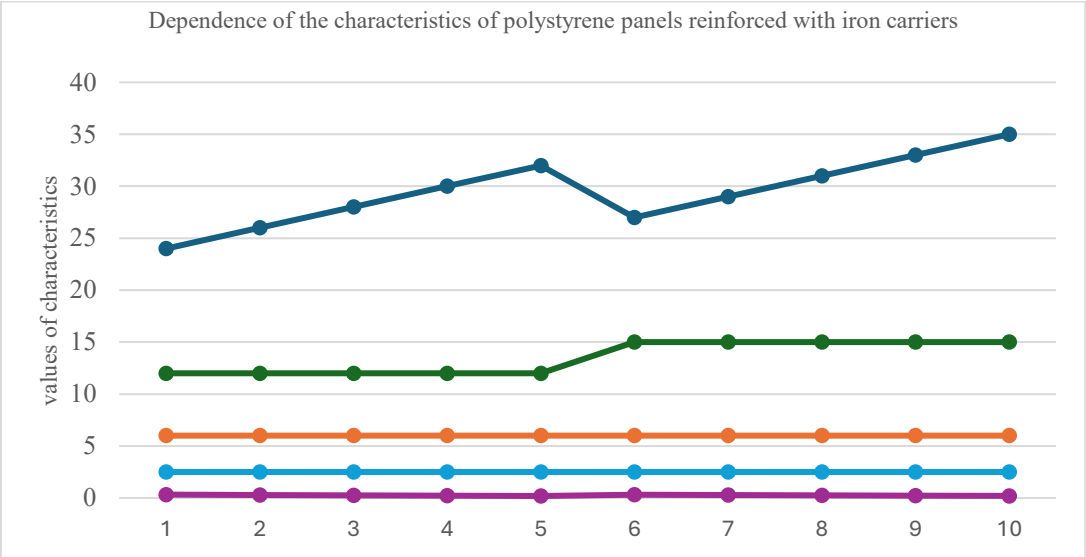
❖ **Labor savings**

It is perhaps the most important factor that gives its undisputed effect in reducing the overall cost of the structure. This is shown in three main aspects: significant reduction of time and quantity of the workshop, easier work for the assembly of panels, smaller demand for the skill level of the workers.

Only a few non-skilled workers are required to assemble the panels. [9] Once they are received ready-made, and the only work of the workers consists in placing them in the object. According to the data, only three workers are needed for the installation and assembly of 50 m² of polystyrene panels reinforced with iron bars, increasing

productivity up to 150-200 %. Eg: For the construction of a 200 m² house with polystyrene panels reinforced with iron bars, only 5 days and 3 non-specialized workers are needed.

While in multi-storey buildings, the use of these panels realizes their assembly of 220 rooms in 30 days.



	1	2	3	4	5	6	7	8	9	10
Typology of coss section	24	26	28	30	32	27	29	31	33	35
Polisteril layer inside (cm)	6	6	6	6	6	6	6	6	6	6
Concrete layer	12	12	12	12	12	15	15	15	15	15
Polisteril layer outside (cm)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Heat transmition U W/m2K	0.324	0.281	0.249	0.223	0.202	0.322	0.28	0.247	0.22	0.201

Graph.2 Dependence of the characteristics of the reinforced panels (from the Systempiu catalog)

4.2 ADVANTAGES OF PANELS REINFORCED WITH IRON CARRIER (PZ):

Advantages of use:

- Perfect thermal insulation, PZ consists of 98% air, which makes it a perfect thermal insulation material.
- Proven insulation, PZ absorbs noises, both those of horizontal elements and those of partition walls that are transmitted through the air.
- Resistant to moisture, PZ resists the corrosive action of water.
- Long life, PZ does not decompose, as a result it can be used forever.
- Adequate mechanical ability, flexible production technology makes PZ material suitable for all uses.
- Economically, PZ offers the best product/price ratio compared to any other insulating material.
- Ease of transport, due to its relatively light weight, PZ material offers ease of transport both from the place of production to the facility and within the construction site.
- Ease of installation, PZ is light, practical and easy to use, which makes it quite easy to install in the facility.
- Self-extinguishing, in case of fire, PZ exhibits self-extinguishing properties, preventing the spread of fire.

Environmental advantages:

- Safe enough, PZ is non-toxic and non-active material. It does not contain chlorofluorocarbons (CFCs) or hydrofluorocarbons (HCFCs). Therefore, it does not affect the ozone layer. Also, PZ does not contain nutrients, excluding the possibility of molds or microorganisms.
- Recyclable material After its use, PZ can be easily recycled, serving as a raw material for the production of similar materials. The selection of the recycling method depends on technical, environmental and economic studies.

- Health conditions, PZ material is health-friendly, not endangering it during installation and during use. PZ does not emit pathogenic dust that can harm the health of people around.
- Meets all European fire protection requirements.

If we put in a table the data obtained from the relevant standards of these materials, we will get the following table:

Table 3. Comparison of some characteristics of the two materials [3] [7]

Characteristics	**Unit**	**symbol**	**brick wall**	**polystyrene panel**
Wall thickness	cm	d	25	25
The weight of the wall	kg/m2	G	222	10.44
Sound insulation coefficient	dB	Rw	43	82
Thermal insulation coefficient	W/m2K	U	1.1	0.324
Application time	h/m2	t	3.35	1.1

For a wall with a thickness of 25 cm and an area of 100 m2, we would have a benefit in weight: 21,156 kg construction time: 225 hours
we also have a benefit in the coefficients of thermal insulation + sound insulation.

4.3 Economic efficiency of panels with reinforced polyesterol

In continuation of this topic, the technical-economic characteristics of reinforced polystyrene panels will be discussed, comparing them with traditional masonry.
It is also important to reflect an economic evaluation of the use of these panels, accompanied by a comparative economic study of two types of masonry, highlighting the advantages in the economic viability of using reinforced polystyrene panels.

4.3.1 Application example, economic effect

In order to present the economic effectiveness, we have monitored the construction of an additional floor, above 2 existing floors. The facility is presented as follows:

Fig. 9 The main facade of the building

We have taken into study an object with 10 floors, with the following data: Floor area: Slope = 500 m²
Circumference = 100 ml

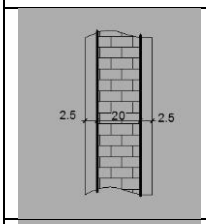
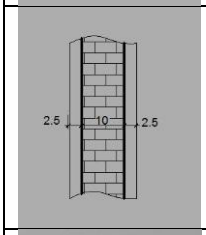
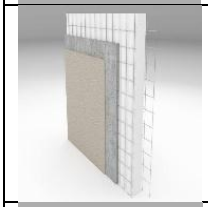
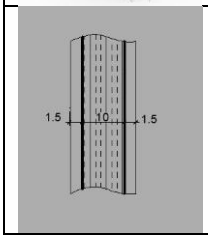
Floor height: Hkatit = 3 m
Length of the inner walls: Inner walls = 200 ml

For this building below we are presenting an economic assessment when this building could be built with classic brick walls with bira vs. walls with polystyrene panels reinforced with metal brackets.

4.3.2 Calculation of wall loads

Below are presented load table of the two wall typologies.

Table 4. Wall loads

Cross section detail	1m3 bricks 20 x 25 x25cm	1m3 bricks 10 x 25 x 25 cm	1m3 wall with polystyrene b=20cm	1m3 wall with polystyrene b=10cm
	Apartments gn=612 kg/ml Commercial gn = 816 kg/ml			
		Apartments gn = 495 kg/ml Commercial gn = 656 kg/ml		
			Apartments gn = 190 kg/ml Commercial gn = 250 kg/ml	
				Apartments gn = 186 kg/ml Commercial gn = 248 kg/ml

4.3.3 CALCULATIONS OF ECONOMIC COSTS

Taking into study an object with 10 floors, with the following data:

Slope = 500 m²
Circumference = 100 ml
Height = 3 m
Internal sludge = 200 ml
Selling price = 700€/m²

A. *The building is made of brick masonry*: (tmes = 25 cm)

External walls = 100 ml x 0.25 mx 10 kt x 3 m = 750 m³

Vmurat.in.=200 ml x 0.12 mx 10 flors x 3 m=720 m³ (tmes = 12 cm)
Average price F+V with perforated brick = 15000 ALL/m³
F+V brick wall: 1,470 m³ x 15,000 ALL/m³ = 22,050,000 ALL

Total. With brick: 22,050,000 ALL

B. *The building is made of polystyrene panels reinforced with iron bars*:
S10cm=L xhx nkat =.100 x 3 x 10= 3000 m²
S_{20cm} =L x h x nkat =.200 x 3 x 10= 6000 m²
Value (S x cmim)t10cm = 6000 m² x 2.000 ALL/m² = 1200000 ALL
Value (S x cmim)t20cm = 3000 m² x 3.000 ALL/m² = 900000 ALL

Amount 1: 21,000,000 ALL

Difference brick walls - Panel = 22,050,000-21,000,000 = **1,050,000** ALL
+ Reduction of project dimensions. of structural elements. with 10%:
(vlera mesatare e elementeve strukturale.-soleta-tra-kolona) = 20,000ALL/m²
Vl.tot.e el.str. = 20,000ALL/m² x 500 m² x 10 kt = 1,000,000,000 ALL
10% of 1000.000.000 Amount 2: 10.000.000 ALL
Also the reduction of time by 80% (for sip. 500Sqm, 1470 m³ of brick, it would take 14 op according to the manual, so 20,580 op or 2,572 dpIf we assume that we have 15 workers, then on average these works last 170 dp, or 5 months).

80% x 5 months = 4 months less

Sale price: 700€/m² x 500 m² x 1 kt = **€350,000**
Based on the data of the central bank, for the interest rate of deposits, if I deposit the amount of €350,000 for the 4 months less that the works last, I will have at the end of them an interest/profit of ~ **€950**.

CONCLUSIONS

The demand for construction at the lowest possible cost is closely related to urbanization, natural population growth, demographic changes, the economic, social and political situation of a country. It involves everyone, from decision makers to beneficiaries and consumers.
The benefits of using polystyrene panels reinforced with iron carrier. Why should they be used instead of classic masonry?
The positive sides of using this technique, Swot Analysis:

Table 5: Swot analysis

No.	Typology of efficient effect	Brick masonry	Polyester panel
1	Lower volumetric weight	no	yes
2	Construction standardization	yes	yes
3	Easier and faster shipping	no	yes
4	Reduces labor needs	no	yes
5	High efficiency in energy saving, save up to 80% of energy	no	yes
6	Small impact on the environment.	yes	yes
7	Very good thermal and noise insulation	yes	yes
8	Flexible material, it can take different forms according to architectural requirements	no	yes
9	Self-extinguishing and fire-resistant material	yes	yes
10	Reduces build time	no	yes
11	Reduces construction cost	no	yes
12	Decreases the object's weight	no	yes
13	In cases of reconstruction, the panels are reusable, avoiding the effects of demolition of classic walls	no	yes
14	The construction technology is more precise, guaranteeing the linearity of the elements	no	yes
15	Very good efficient behavior, minimal earthquake consequences	no	yes

16	Surface with resistance comparable to brickwork	yes	yes

In conclusionwe would recommend the use of these polystyrene panels reinforced with galvanized iron carrier to minimize construction costs and maximize the performance of the facility.

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Detection of antibiotics and aflatoxin residues in milk

MARIOLA KODRA*[1], MERITA STAFASANI[1], DHURATA FETA[1]

Abstract: Because of its high nutritious values in containing proteins, fats, lactose, minerals, vitamins, water, etc. milk is considered to be one of the most consumed food products in the while world ensuring the quality of milk for human consumption is an important challenge. Milk is a product that is normally produced by the mammary glands of cattle animals, and special attention must be paid toward antibiotics residues that might be present in milk because of their usage to treat different health problems of cattle. Small amounts of antibiotic residues taken from milk consumption can contribute to antibiotic resistance in human, especially in infants. Aflatoxin M1 (AFM1) is metabolic products of aflatoxin B1, present in milk and milk products, as a result of animal consuming contaminated feed. According to IARC Aflatoxin Mi is considered as possibly carcinogenic to humans (Group 2B), so affecting the quality and safety of milk and milk products. The aim of our study was to detect the presence of antibiotics residues (tetracycline, β-lactams and chloramphenicol), as well of aflatoxin M1 in fresh milk aimed to be used for human consumption of further processing, in raw milk, pasteurized and Ultra heat treated (UHT) milk. Pasteurized and UHT milk samples were collected from different markets and fresh milk samples were collected from the free markets and livestock cattle in different area of Tirana as well. A total of 36 milk samples were analyzed by using rapid test kit (Ring Bio mark), and the obtained resulted showed that UHT and pasteurized milk samples resulted negative for the three types of antibiotics, but only one sample of fresh milk resulted positive for β-lactams and chloramphenicol residues. From all the analyzed milk samples 47% of them resulted positive for aflatoxin M1 residues, most of them were fresh milk from livestock cattle. Even though rapid test kits are widely used as a good method for detection of antibiotics and aflatoxin residues in milk and milk products, we emphasize the importance of sophisticated analytical instruments that must be further used in order to verify and determine the content levels of these important indicators of milk quality and safety meant for human consumption or further processing.

Keywords: milk, mycotoxin, aflatoxin M1, milk antibiotics, milk quality and safety, rapid test.

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1. INTRODUCTION

Milk is a food product rich in macro and micro nutrients essential for humans' growth as well as for their health well-being (Djekic I, et al. 2020). Among traded food products, milk is considered as the one with high nutritive values and the mostly consumed, that contains water, mineral, vitamins, proteins, carbohydrates like lactose, lipids, etc., (Omairi R, et.al 2022). Because of the balanced content of proteins, carbohydrates and lipids, bovine milk is me most consumed food product globally and plays an important role on global economy (Costa, L.V. et.al 2024.).

In veterinary medicine antibiotics are used in animals for therapeutic purposes to treat diseases by targeting certain microorganisms, as well as to promote animal growth (Alenezi, M.S. et.al 2024; Omairi R, et.al 2022). If antibiotics are not used according to their proper description and according to strict regulations, they can migrate to food products as antibiotic residues (Omairi R, et.al 2022).

Several studies have reported a connection between consumption of food with antibiotic residues and antimicrobial resistance in human (Londoño-Carmona J, et.al 2024; Layada, S., et. al 2016) thus becoming a global concern for human health (E.O. Simbine-Ribisse et al. 2024). Allergies, toxicity, hypersensitivity, aplastic anemia, alterations in gastrointestinal microflora, and the selection of resistant intestinal bacteria are among other human health problems created by consumption of milk containing antibiotic residues above the maximum residue limit (MRL) set by European Commission and Codex Alimentarius Commission (Costa, L.V. et.al 2024; Alenezi, M.S. et.al 2024). Beside this, antibiotic residues in milk have also negative effect to milk processing and transformation by inhibiting starter cultures thus causing negative economic effect for the milk processing industries (E.O. Simbine-Ribisse et al. 2024). From 16 selected article, Costa, L.V. et.al 2024, showed that 13 of them reported presence of antibiotic residues in milk with the lowest incidence was 0.09%, found in Italy and the highest was 82.70% in

Tanzania. Therefore, continuous and rigorous monitoring of antibiotic residues in milk is very important for human health and safety as well as for milk processing industries. Several analytical techniques are prescribed in literature to determine and identify antibiotic residues in milk. The most commonly used are microbiological and immune assays, mainly because are of low costs and because they require short time analysis, but have limited sensitivity and require confirmation by other instrumental techniques (Layada, S., et. al 2016). Among instrumental techniques, chromatography (Liquid chromatography (LC) accompanied by UV-IVS spectrometry or mass spectrometry (MS) are reported as the mostly used, being precise with high specificity and accuracy for many types of antibiotics, but they require proper sample preparation, well trained staff and consequently have high costs (Sachi S, et.al 2019; Omairi R, et.al 2022; Costa, L.V. et.al 2024).

Another indicator of milk quality and safety is the presence of aflatoxin residues, that are secondary metabolites produced by some types of fungus of Aspergillus genus present in animal feed, and because of their carcinogenic and hepatotoxic effects in humans and animals, are considered as important mycotoxins (de Souza, C., Mousavi Khaneghah, A.., & Fernandes Oliveira, C. A. 2021). Regarding used animal feed, its contamination with mycotoxins can occur because of several environmental conditions like temperature changes and high humidity, or even because of inappropriate storage condition that stimulate fungus growth and then mycotoxin production (Shahata, M., & Wafy, Y. 2024). The most toxic aflatoxin is aflatoxin B1, that by International Agency for Research on Cancer is listed in Group 1 of carcinogens, that produces the hydroxylated metabolite Aflatoxin M1 (S.Z. Iqbal, et.al 2015). Aflatoxin M1 is considered to be less toxic compared to aflatoxin B1 and it is produced in liver and then secreted to milk of mammals that have consumed contaminated food (Temamoğulları, Füsun & Kanici, Ayse. 2013). It has been reported that aflatoxin M1 is stable during milk processing in temperature, like during processing in ultra-high temperature, or during sterilization and pasteurization temperatures, as well as in other methods used for milk processing, and these toxins can be present even in dairy products (de Souza, C., Mousavi Khaneghah, A.., & Fernandes Oliveira, C. A. 2021; Panara, A. et.al 2022).

In order to protects the consumer, regulation have been drafted on determining the maximum levels of food contaminants, as it is the European Commission Regulation No 466/2001 that determines that the maximum level of aflatoxin M1 in raw milk, or milk for the manufacture of milk-based products or heat-treated milk, is 0.05 µg/kg (EC, European Commission (2001)) and according to European Commission Regulation No 1881/2006 the maximum level of aflatoxin M1 for infant milk formulae is 0.025 µg/kg (EC, European Commission. 2006).

The aim of our study was to detect presence of antibiotic residues (tetracycline, β-lactams and chloramphenicol) as the mostly used to treat animals' health problems and to detects aflatoxin M1 presence, in UHT, pasteurized and raw milk by using rapid test kits.

2. MATERIAL AND METHOD / MATERYAL VE METOT

Sample collection and preparation
Pasteurized and UHT cow milk samples were collected on different supermarkets randomly selected. The fresh milk samples were collected from cows on livestock regime of six different farms, and two raw milk samples were collected from families as milk intended only for family usage. All milk sample were kept in refrigeration conditions till analyzed. Before each measurement, milk samples were codified, brought to room temperature and homogenized.

Detection of antibiotics and aflatoxin M1 in milk
Antibiotics and aflatoxin M1 test in milk were performed by using rapid test kit (Ring Bio mark) and milk samples were tested for the presence of:

Chloramphenicol – Detection Limit (LOD) of 0.1ppb
β-Lactams - Detection Limit (LOD) of 2 - 8 µg/l
Tetracycline - Detection Limit (LOD) of 80 – 100 µg/l
Aflatoxin M1 - Detection Limit (LOD) of 0.05ppb

For antibiotic and aflatoxin M1 (AMF1) residues assay, instructions described in package were followed and test strips reading was performed in accordance with the templates given by the manufacturer. For each milk sample two parallel measurement were performed.

3. RESULTS

The 36 milk samples were analyzed for presence of tetracycline, chloramphenicol and beta-lactams residues by using rapid test kits Ring Bio and all of the types of analyzed milk samples resulted negative for the tetracycline

residues. Only one case of milk sample collected from livestock cattle resulted positive for the presence of beta lactams and chloramphenicol (Table 1 and Figure 1).

Table 1. Results of antibiotics residues detection in analyzed milk samples

Milk type	tetracycline		beta lactams		chloramphenicol	
	negative	positive	negative	positive	negative	positive
UHT milk	6	0	6	0	6	0
Pasteurized milk	6	0	6	0	6	0
Raw milk	2	0	2	0	2	0
Cattle livestock milk	22	0	21	1	21	1

These results show that in terms of presence of antibiotic residues, analyzed milk samples are of good quality, and in this aspect, they can be used for human consumption or for further processing or production of dairy products.

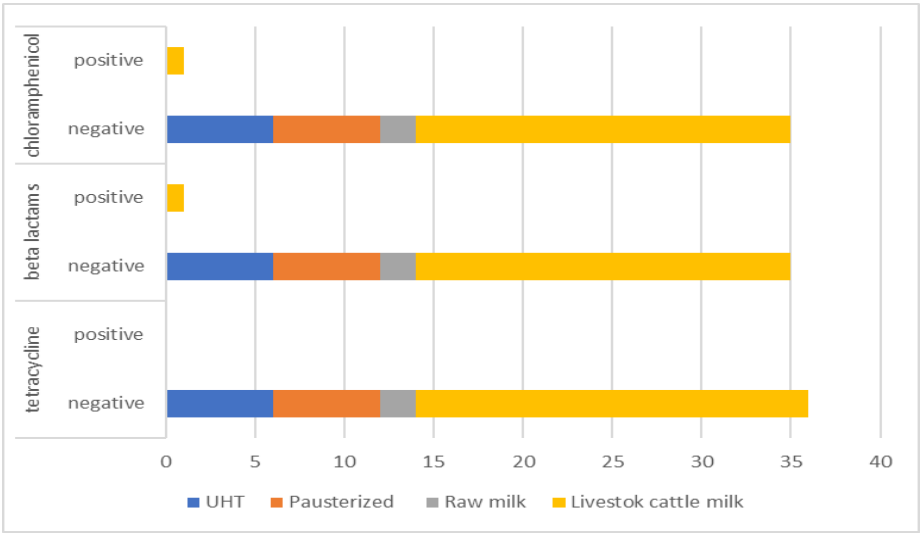

Figure 1. Detection of antibiotic residues in milk samples

Compared to antibiotic residues, results for aflatoxin M1 presence in milk are somewhat different, because all the type of analyzed milk had in cases of positive results. From 12 samples of UHT and pasteurized milk we have got the same results, 50% of them have tested positive for the presence of aflatoxin M1 (Table 2).

Table 2. Results of aflatoxin M1 residues detection in analyzed milk samples

Milk type	aflatoxin M1		
	negative	positive	% positive sample
UHT milk	3	3	50%
Pasteurized milk	3	3	50%
Raw milk	2	0	0%
Livestock cattle milk	11	11	50%
Total	18	17	48.5%

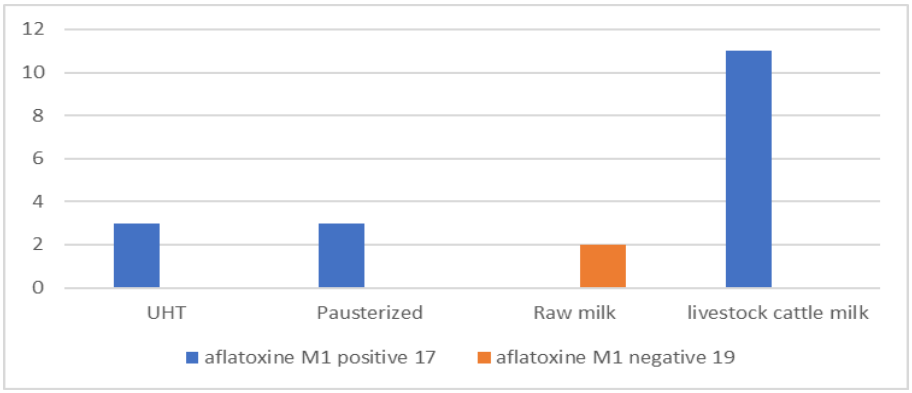

Figure 2. Number of milk samples tested positive for AMF1

Both samples of raw milk resulted negative for presence of AFM1, while from the 22 livestock cattle milk samples 50% resulted positive for AMF1 (Figure 2). In total, 53% of all types of milk analyzed for AFM1 presence, resulted negative and 48.5 % of them resulted positive (Table 1).

Positive results for AMF1 presence were obtained from fresh milk collected from livestock cattle (65% of total samples), followed by pasteurized milk (18% of total samples) and by UHT milk (17% of total samples) (Figure 3).

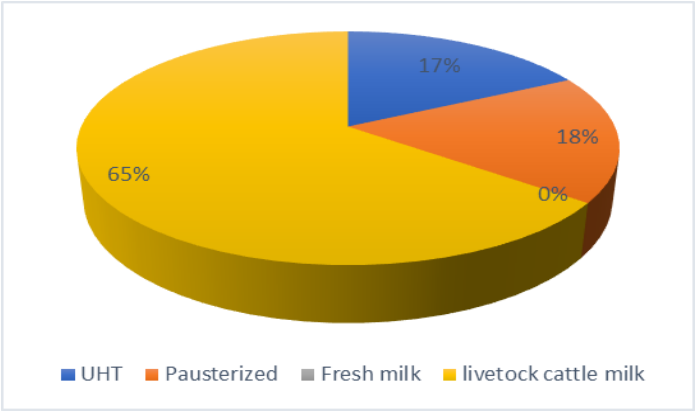

Figure 3. Comparison of milk samples tested positive for AMF1 (%)

It is worth noting that raw milk samples, collected on village families, tested negative for both AFM1 and antibiotic residues This may somehow explained by the fact the farmers can take better care of their livestock when they possess one or two livestock, compared to farmers who raise and take care for a larger number of animals in stables, varying from 15 to 23 animal per farm. Another problem affecting quality of livestock cattle milk, might also be the fact that in most of them the employees are not specialists but family members with few knowledge in raising and caring for livestock.

4. DISCUSSION AND CONCLUSIONS

The method we used and the results we have obtained are in accordance with most of the data from literature as presented in the following. By using an immunoenzymatic commercial kit that meets the FDA and Food Codex standards for quick detection of antibiotic residues (Londoño-Carmona et.al 2024) reported that from 102 milk samples analyzed, 6% tested positive for beta-lactams. In a systematic review of the last decade (Costa, L.V. et.al (2024) reported and 56.25% of the studies employed rapid kits to detect residues, 18.75% chromatography, and 25% both techniques. These authors have also reported that because of their wide range of antibacterial activity, beta lactams have been reported as the most commonly used antibiotics for treating mastitis, and the most frequently reported antibiotic is tetracycline followed by beta-lactams and sulfonamides.

Even though, rapid test kits have a wide usage in detecting antibiotic residues in milk and milk products they do not always produce reliable results and must be followed by other detecting techniques like chromatography that are more accurate and sensitive (Layada, S., Benouareth, D. E., Coucke, W., & Andjelkovic, M. 2016; Alenezi, M.S. et.al 2024; Costa, L.V. et.al 2024).

Food products safety from antibiotic residues is guaranteed by regulation of Food and Drug Administration (FDA) that allows use of some specific drugs in animals provided that they are not carcinogenic, are used in small quantities and that will not be present in animal products after a period of time (Alenezi, M.S. et.al 2024). In order to protect public health from pharmacologically active substances on foodstuff of animal origine the EU Commission Regulation (EU) No 37/2010 has established maximum residues limits (MRL) values (Commission regulation (EU) No 37/2010).

Many studies have reported presence of aflatoxin M1 cattle feed, mainly because of bad management practices for management of nutrients, inappropriate harvest conditions, processing and food storage without forgetting to mention unstable climacteric conditions like temperature and high humidity (Djekic I, et.al 2020; Shahata, M., & Wafy, Y. 2024). Maize, grains and peanut grown in warm climacteric conditions have been reported as agricultural crops where the presence of aflatoxin has been found more frequently (A.F. Alshannaq, et.al 2018). In a study conducted in Saudi Arabia, from 343 analyzed milk samples, only 20 of them (5.50%) resulted positive for the presence of AFM1 and the other part resulted between the limits, suggesting that the regulation of Saudi Food and Drug Authority (SFDA) for aflatoxin M1 had significantly reduced milk and its products from contamination with AFM1 (Y. Almasoud et al. 2024). Another study conducted in Concórdia – SC, Brazil. AFM1 presence was reported in 52 analyzed fresh milk samples ranging from ≤ LDD (0.09 µg L-1) to 3.385 µg L-1, where 40.4 % of samples were above the limit allowed by the Brazilian regulation, which is 0.5 µg L-1 and 59.6% of samples showed levels higher than allowed by the European Union (0.05 µg L-1) (Gonçalves et al. 2017).

El-Kest, Maha et.al (2016) have reported that 22% of raw milk samples and 15% of UHT milk samples resulted positive for presence of AFM1 (ppt), from which respectively 21% e raw milk and 9% of UHT milk samples exceeded the EU limits of 0.05ppb. From a total of 385 raw milk samples analyzed for presence of AFM1, Djekic I, et.al (2020) reported that 46.2% of them exceeded EU limits and 21.3% exceeded Serbian regulation, suggesting that in terms of contamination with AFM1, farms produced milk of low quality in spring and autumn compared with the winter and summer period, but the Estimated Daily Intake of AFM1 was in the range of 62–74 10-3 ng/kg bw/day that was considered to be within prescribed limits, regardless of seasonal variation.

Even though aflatoxin M1 are considered to be less harmful compared to aflatoxin B1 (Reports of the Scientific Committee for Food, 1996) regulations have been drafted in order to determine the maximum level of their content in milk and milk products intended for human consumption, and in Europe this limit is 0.05 µg/kg (Commission regulation (EC) No 466/2001) at a similar value with the detection limit of rapid test kits used in our study, of 0.05 ppb.

CONCLUSIONS

In this study, 36 sample of fresh milk, pasteurized and UHT milk were analyzed for antibiotic (tetracycline, chloramphenicol, beta-lactams) and aflatoxin M1 residues, by using Ring Bio rapid test. Results of analyzed milk samples showed that most of them resulted negative for the three of antibiotics residues content and only one sample of fresh milk resulted positive for beta-lactams and chloramphenicol. This is a good indicator for quality and safety of milk intended for human consumption in order to avoid antibiotic resistance that arise by taking antibiotics from milk and its products, especially in kids. All the 36 milk samples were analyzed also for aflatoxin M1 residues, and results showed that 50% of stable cattle, UHT and pasteurized resulted positive, while all the fresh milk samples resulted negative. In terms of aflatoxin M1, this means that milk is of low quality, and further analyzes are needed to determine aflatoxin M1 levels in milk. Further improvement is also needed in the way animal feed is produced, because it is the main source of aflatoxin in milk. In conclusion of this study, it is worth noting that rapid tests are widely use but they often carry uncertainty of the obtained results, and therefore they must be followed by other sophisticated more reliable and precise techniques.

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Peer-review
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Author Contributions
Conceptualization: M.K.; Investigation: M.K., M.S; Material and Methodology: M.K., M.S; Writing-Original Draft: M.K., M.S.,D.F.; Writing-review & Editing: M.K., M.S.,D.F.; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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Strategic Impact Assessment of Wind Energy Potential: The Case of Cittaslow in Turkey

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Abstract: This study aims to evaluate the wind energy potential of Cittaslow member cities in Türkiye and to analyze their suitability for wind energy development through a Strategic Impact Assessment (SIA) approach. Cittaslow, characterized by its commitment to sustainable living, cultural heritage, and environmental stewardship, presents a unique context for decentralized renewable energy integration. However, implementing wind energy in such sensitive settings requires a multi-dimensional evaluation. The methodology follows a four-step process: (1) acquisition of high-resolution wind data, (2) identification of existing wind power installations, (3) GIS-based site suitability analysis using multi-criteria decision-making (MCDM), and (4) a strategic impact assessment using SWOT analysis. The GIS-based evaluation identified cities like Seferihisar, Foça, and Şarköy as highly suitable due to strong technical indicators and favorable socio-cultural conditions. Conversely, cities such as Akyaka, Finike, and Şavşat were deemed unsuitable due to low wind potential despite having strong tourism and ecological value. The findings suggest that context-sensitive, small-scale wind energy projects could be successfully integrated into suitable Cittaslow without compromising their core values. The SIA-SWOT framework offers a comprehensive planning tool that balances technical feasibility with cultural and ecological sensitivity, supporting both local policy development and broader rural sustainability goals.

Keywords: Wind Energy, Strategic Environmental Assessment, Cittaslow, Renewable Energy.

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1. INTRODUCTION

The increasing severity of global environmental challenges has made it imperative to meet growing energy demands through sustainable means. In this context, the shift of local governments toward environmentally conscious energy policies has become a critical strategy for reducing carbon emissions and addressing climate change. One urban model that aligns closely with the principles of sustainability is the Cittaslow movement, which promotes environmentally harmonious lifestyles and actively encourages the integration of renewable energy sources into local energy production systems (Presenza, 2015). Originating in Italy in 1999, the Cittaslow philosophy has since expanded internationally and includes several cities in Türkiye. Turkish members of the network, such as Seferihisar, Gökçeada, Taraklı, and Vize, have adopted local policies that prioritize the protection of natural resources, enhancement of local quality of life, promotion of sustainable living practices, and preservation of cultural identity (Degirmenci and Sarıbıyık, 2015). However, while these cities promote environmentally friendly approaches, the long-term impacts of energy infrastructure projects are often overlooked in local planning. To fully align with the principles of sustainable development, energy initiatives must be evaluated not only in terms of technical feasibility but also in terms of environmental carrying capacity, visual landscape impact, social acceptability, and their effects on cultural heritage (Wierzbicka, 2020). In this regard, the Strategic Impact Assessment (SIA) emerges as a key planning tool that allows for multi-dimensional evaluation from the earliest stages of energy planning. SIA expands the focus of environmental assessments to include not only ecological impacts, but also economic development, social welfare, and cultural value preservation -thereby offering decision-makers a more holistic and sustainable framework (Presenza et al., 2015). Moreover, SIA facilitates the incorporation of Cittaslow-related principles—such as low carbon emissions, local production, eco-friendly transportation, and conservation of natural resources—into energy planning processes (Batyk et al., 2021). As a result, renewable energy projects such as wind power can be designed and implemented not only to meet energy production goals, but also to preserve the unique identity and values of Cittaslows.

It is well established that renewable energy sources support the Sustainable Development Goals, aligned with the core principles of the Cittaslow movement. While various applications exist for solar, biomass, and geothermal sources, a significant number of Türkiye's Cittaslows are located in coastal regions or topographical zones with advantageous wind regimes, which makes them highly suitable for wind energy production (Özüpekçe, 2021).

Cities such as Gökçeada, Seferihisar, and Akyaka are noted for their consistent wind flows throughout the year, and the preservation of their natural landscapes enhances the feasibility of implementing environmentally friendly energy investments. Harnessing this potential would not only contribute to local energy independence but also support environmental sustainability by reducing carbon emissions (Brodziński and Kurowska, 2021). However, wind energy investments cannot be evaluated based solely on technical suitability. For such projects to be successfully implemented and publicly accepted, a strategic assessment of multi-dimensional factors is necessary, including environmental protection, visual landscape integrity, preservation of cultural heritage, biodiversity impacts, and local socio-cultural sensitivities. Tools such as SIA can systematize such layered evaluations, ensuring that wind energy projects do not conflict with Cittaslow principles (Wierzbicka, 2022). Moreover, detailed analysis of the visual and spatial impacts of wind turbines on urban identity and tourism potential is critical to preserving the foundational values of slow cities (Candan Hergül and Göker, 2022). Therefore, the evaluation of wind energy potential in Türkiye's Cittaslows must go beyond energy production alone and consider spatial planning, community acceptance, environmental ethics, and long-term sustainability principles. Nevertheless, several studies have highlighted significant shortcomings in renewable energy policies across Türkiye's Cittaslow municipalities. For example, research conducted in similar settlements in Poland shows that local governments often fail to integrate renewable energy planning into broader development strategies, leading to inadequate implementation (Batyk et al., 2021). A similar situation may be applicable in Türkiye, where the lack of proper analysis of local potentials leads to inefficiencies in energy generation and hinders the full realization of Cittaslow criteria (Wierzbicka, 2022). Furthermore, the spatial expansion trends observed in Türkiye's Cittaslows indicate increasing pressure on natural environments. A study by Özüpekçe (2021) notes that some slow cities are expanding rapidly, posing risks to the balance between planning and natural resource protection. At this point, environmentally friendly and land-efficient energy solutions such as wind power can play a vital role in achieving sustainability goals. A summary of relevant studies on this topic is presented in Table 1.

Table 1. Previous studies about wind energy potential in Cittaslows

Citation	Study Area	Study Aim	Key Findings (Focused on Wind Energy Relevance)
Degirmenci and Sarıbıyık (2015)	Turkey (Taraklı)	Explore Cittaslow in historic areas within a sustainability context	As seen in the case of Taraklı, the preservation of historical texture and natural resources necessitates sensitive site selection for energy projects.
Batyk et al. (2021)	Poland (35 Cittaslow municipalities)	To assess the support for renewable energy deployment by Cittaslow local governments	Cittaslow municipalities give low priority to renewable energy; a mismatch is observed between energy strategies and sustainability goals.
Farelnik (2021)	Poland (Cittaslows)	Discuss the role of revitalization in Cittaslow development	Revitalization improves resilience and supports regional sustainability.
Özüpekçe (2021)	Turkey (17 Cittaslows)	Temporal urban expansion analysis using Built-up Index	Some cities expanded rapidly; others showed controlled growth.
Wierzbicka (2022)	Poland (Cittaslows)	Evaluate environmental and energy policy activities post-Cittaslow certification.	Improvement from 71% to 75% in meeting energy/environmental criteria.
Hergül and Göker (2022)	Turkey (Osmaneli)	Evaluate urban image suitability for Cittaslow participation	In cities like Osmaneli, where the urban fabric is preserved, wind energy investments can be developed in harmony with the visual landscape and aesthetics.

In this context, the main objective of this study is to assess the wind energy potential of Türkiye's Cittaslow member cities and to analyze this potential through an SIA framework. The study aims to explore how such potential can be integrated into sustainable energy policies. In environmentally sensitive, small-scale urban contexts, the viability of renewable energy systems depends not only on technical factors but also on social acceptance, environmental and visual landscape impacts, and cultural compatibility (Wierzbicka, 2020; Farelnik, 2021). The proposed holistic approach focuses on integrating wind energy in a way that strengthens, rather than disrupts, the unique identity of Cittaslows. SIA enables the anticipation of long-term socio-environmental effects and offers a transparent, science-based guide for decision-makers. This framework also addresses the need for "locally adapted technological transformation," often overlooked in Cittaslow development planning.

2. MATERIAL AND METHOD

2.1. Study area

The material of this study consists of cities in Türkiye that are officially designated as members of the Cittaslow network. As of 2025, there are 26 such cities across the country, distributed among diverse geographical regions including the Aegean, Mediterranean, Marmara, Black Sea, Central Anatolia, Eastern Anatolia, and Southeastern Anatolia (Cittaslow Türkiye, 2025). This study focuses on the spatial and strategic integration of wind energy potential within Türkiye's Cittaslow (slow city) network. As illustrated in Figure 1, these cities are located across various ecological and climatic zones-coastal, inland, and mountainous with distinct natural characteristics that influence renewable energy planning. Cittaslows prioritize sustainable living, local culture, and environmental stewardship, making them ideal candidates for decentralized renewable energy initiatives such as wind farms. Cities such as Seferihisar, Foça, Akyaka, and Finike, located along the Aegean and Mediterranean coasts, are characterized by maritime climates and high wind potential. In contrast, Black Sea cities like Gerze, Perşembe, and Şavşat feature dense forest cover and humid, rainy conditions. Interior cities such as Güdül, Göynük, and Eğirdir lie on high plateaus or within valleys and experience a continental climate. Meanwhile, cities like Kemaliye, Halfeti, and Ahlat in the Eastern and Southeastern regions are found in mountainous areas with arid and harsh climatic conditions. These natural variations play a critical role in determining the feasibility and suitability of wind energy deployment (Unal Cilek et al., 2022). Particularly in coastal areas and natural wind corridors—such as valleys and ridgelines—conditions are favorable for the implementation of small- to medium-scale wind energy systems. Additionally, many Cittaslows are situated in or near ecologically sensitive areas, including protected sites, biodiversity hotspots, and traditional agricultural landscapes. This spatial and ecological context presents a strategic advantage for the adoption of environmentally responsible and community-integrated wind energy projects, which are in line with the fundamental values of the Cittaslow movement.

Figure 1. The geographic locations of Cittaslows in Türkiye

2.2. Methodology

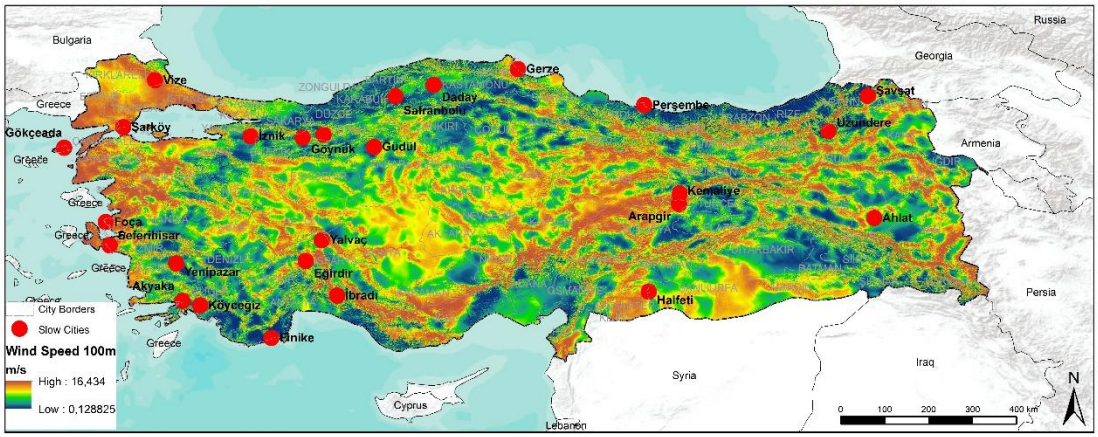
This study adopts a multi-stage methodological approach to assess the wind energy potential in Turkey's Cittaslows, with an emphasis on strategic and spatial sensitivity. The process involves both quantitative data analysis and qualitative evaluation techniques. This study follows a four-step methodological framework:

- Wind data collection and analysis
- Determination of existing wind power installations
- GIS-based site selection for wind energy development
- Strategic impact assessment via SWOT analysis

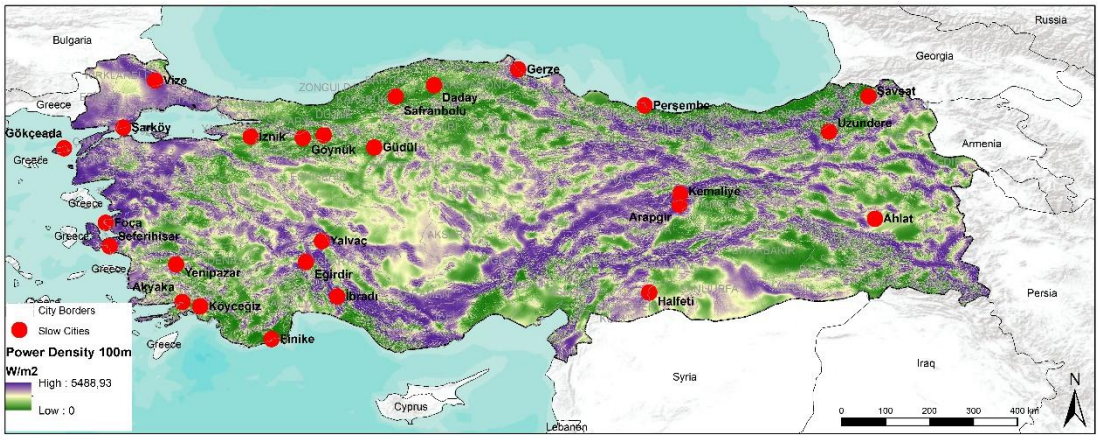
2.2.1. Wind data collection and analysis

The primary dataset was obtained from the Global Wind Atlas (GWA), a high-resolution and globally consistent data source for assessing wind energy potential. The key variable used is the mean wind power density, which represents the average kinetic energy flux per unit area perpendicular to the wind direction, measured in watts per square meter (W/m²). These values are statistically modeled using Weibull distributions, which better capture the

temporal variability of wind speeds. Additionally, data on the mean wind speed for each location were analyzed to characterize the overall wind regime of the study area. The study also incorporates the geospatial distribution of existing wind farms, enabling an assessment of current wind energy infrastructure and its spatial relationship with high-resource areas. Furthermore, data on the capacity factor for IEC Class 1 turbines were used. The capacity factor serves as an indicator of a wind turbine's annual energy performance; higher capacity factors correspond to higher expected annual energy output. It is important to note that capacity factor maps provided by the Global Wind Atlas offer estimates based on modeled wind conditions. These estimates alone do not determine the suitability of a site for wind turbine installation. Other critical factors such as topography, land use, environmental impact, and grid connectivity must also be evaluated during site selection. Together, these datasets form the analytical foundation of this study, enabling a spatially comprehensive assessment of wind energy potential across the target regions (Figure 2).



(a)



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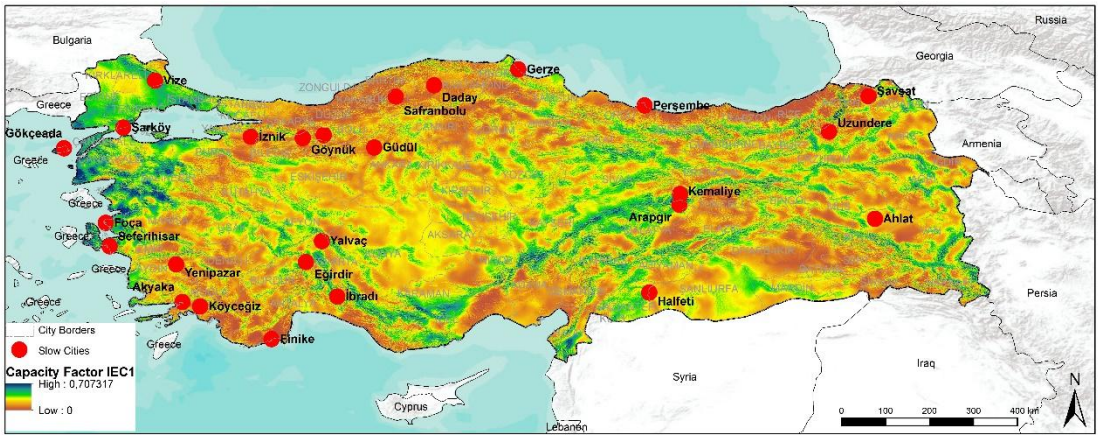

(c)

Figure 2. (a) Wind speed at 100 meters, (b) Power density at 100 meters, (c) Capacity factor (IEC-Class 1)

2.2.2. Determination of existing wind power installations

To assess the current extent and spatial distribution of wind energy infrastructure in and around Türkiye's Cittaslows, existing wind power installations were identified, mapped, and analyzed using geospatial tools (Figure 3). The primary dataset was obtained from the GWA, an open-access, high-resolution global resource developed jointly by the World Bank Group and DTU Wind Energy. This platform provides standardized data on wind speed, power density, and technical feasibility at various hub heights, which is essential for contextualizing wind energy potential at the regional scale (World Bank Group and DTU, 2023). In addition to the GWA, national data sources were used to enhance reliability and local relevance. Specifically, spatial and technical information on operational wind energy projects was obtained from the Turkish Ministry of Energy and Natural Resources (MENR) and the Energy Market Regulatory Authority (EMRA). These official datasets include project-level attributes such as installed capacity (MW), commissioning year, license status, and geographic coordinates, which were essential for cross-verification and refinement of the international data (MENR, 2024; EMRA, 2024). Using Geographic Information Systems (GIS), all identified wind energy facilities were georeferenced and layered with Cittaslow municipal boundaries. Each facility was categorized according to:

- Operational status (commissioned, under construction, decommissioned),
- Scale (small-scale local systems vs. utility-scale wind farms),
- Topographic and ecological context, including proximity to sensitive landscapes or urban centers.

Spatial analyses such as buffer zones and overlay assessments were then conducted to evaluate the interaction between existing wind infrastructure and the natural, cultural, and spatial characteristics of Cittaslow areas. This mapping exercise not only reveals the current wind energy landscape but also helps highlight areas of potential synergy or conflict between renewable energy expansion and the Cittaslow principles of ecological preservation and cultural integrity.

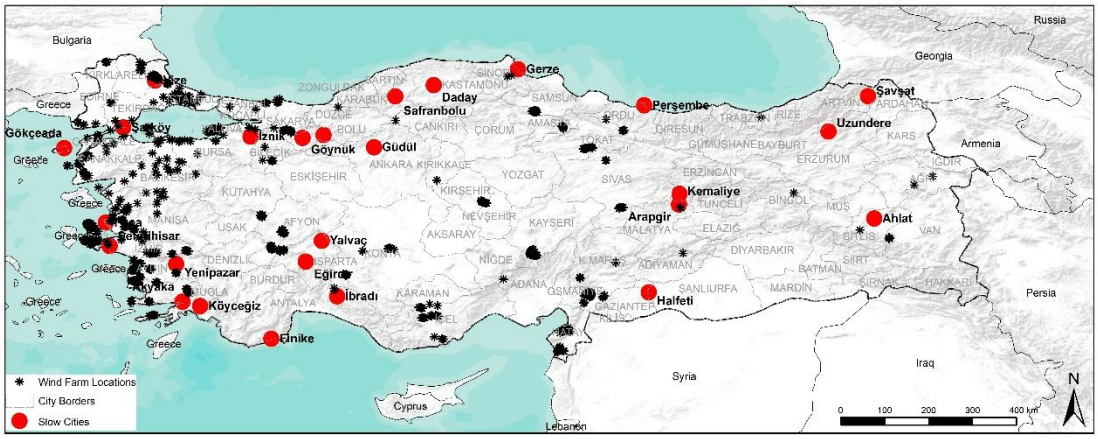

Figure 3. Wind power locations of Cittaslows in Türkiye

2.2.3. GIS-based site selection for wind energy development

This phase of the study employs Geographic Information Systems (GIS) integrated with a Multi-Criteria Decision-Making (MCDM) framework to identify and prioritize suitable areas for wind energy development within Cittaslows in Türkiye. Given the diverse topographic, ecological, and socio-cultural characteristics of these regions, GIS-based spatial analysis provides a robust platform for evaluating multiple environmental and technical constraints simultaneously. The site selection process was based on a weighted overlay analysis, in which key criteria were standardized, weighted according to their importance, and spatially analyzed using raster-based GIS tools. The main criteria included:

- Wind speed (at 100 m hub height): Indicative of long-term energy generation potential.
- Wind power density (W/m²): Reflects the concentration of wind energy per unit area.
- Capacity factor (IEC Class 1): Represents the efficiency of a wind turbine operating under specific wind conditions.

Each raster layer was reclassified and normalized to a common scale (0 to 1) and weighted based on expert judgment and literature standards. The final suitability map was generated by combining these layers, producing a spatially explicit classification of high, moderate, and low suitability and unsuitable zones for potential wind farm development.

2.2.4. Strategic impact assessment via SWOT analysis

In the final phase of the methodology, a SIA was conducted to evaluate the broader implications of integrating wind energy systems into Türkiye's Cittaslows. This was operationalized through a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, a widely used strategic planning tool in energy and sustainability research that helps identify internal and external factors affecting the success of renewable energy initiatives (Presenza et al., 2015). The SWOT framework was developed based on the technical results of the previous GIS-based site selection process, combined with contextual insights from literature and policy documents on Cittaslow principles. The analysis considered the following dimensions:

- **Strengths:** Technological suitability (e.g., wind corridors, favorable terrain), existing policy support for renewables, and alignment with Cittaslow goals such as decentralization and sustainability.
- **Weaknesses:** Potential visual and ecological impacts, limited municipal capacity for project implementation, and lack of local experience with wind energy systems.
- **Opportunities:** Rising national and EU-level support for green energy transitions, potential for ecotourism branding, and community-based energy models.
- **Threats:** Resistance from residents due to perceived disruption of landscape aesthetics, regulatory barriers in protected zones, and potential conflicts with agricultural land use.

This analysis enables a qualitative assessment of how wind energy development could strengthen or challenge the long-term sustainability goals of Cittaslows. It also supports the identification of strategic recommendations, such as siting turbines outside heritage viewsheds, promoting participatory planning, and linking renewable energy initiatives to local economic development strategies (Wierzbicka, 2022). By integrating the SWOT framework with the spatial data outputs from earlier steps, the analysis provides a more holistic understanding of the viability and acceptability of wind energy investments in culturally sensitive and ecologically diverse urban contexts.

3. RESULTS

Based on the spatial multi-criteria evaluation conducted through GIS, the wind energy suitability of Türkiye's Cittaslows was classified into four distinct categories: Highly Suitable, Moderately Suitable, Low Suitability, and Unsuitable. This classification integrates both technical wind parameters and context-sensitive criteria, offering a strategic perspective for sustainable energy planning across culturally significant regions. The spatial analysis presented in Figure 4 reveals notable variations in wind farm suitability across Türkiye's Cittaslows.

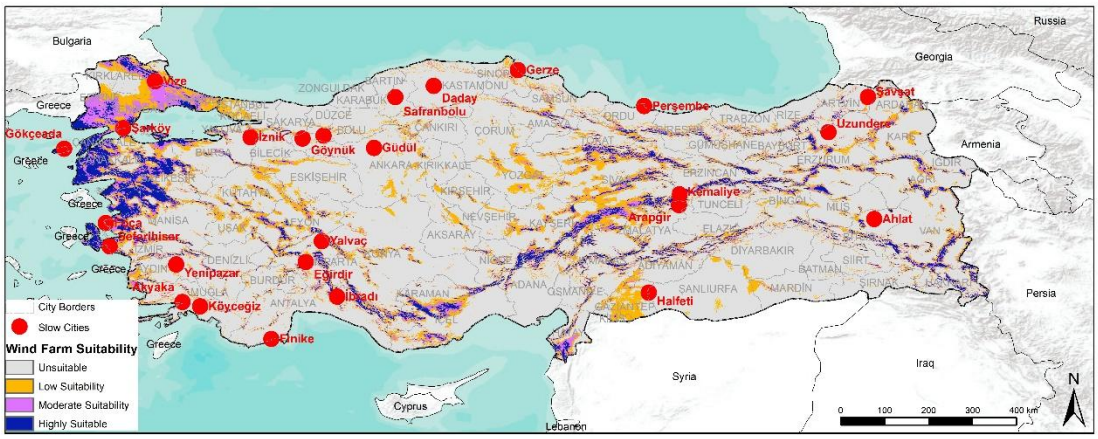

Figure 4. Wind farm suitability map of Cittaslows in Türkiye

Cities classified as "Highly Suitable", including *Foça, Şarköy, and Seferihisar*, exhibit strong technical potential with capacity factors exceeding 0.28 and robust wind power density values. These locations also benefit from cultural and tourism assets that support community-based renewable energy development. In contrast, cities such

as *Gerze, Gökçeada, Kemaliye, and Vize* fall into the “Moderately Suitable” category. Although they present favorable wind conditions, infrastructural limitations and insufficient public visibility reduce their overall viability for wind energy investments. Cities like *Arapgir, Halfeti, and Yenipazar*, identified as “Low Suitability”, offer socio-cultural advantages such as local product branding and ecotourism potential. Yet, their technical parameters remain suboptimal for effective wind power generation. Lastly, *Akyaka, Finike, Şavşat, and Mudurnu* are categorized as “Unsuitable” due to consistently low wind speeds and power density levels. Nevertheless, their strong ecological and cultural tourism capacities suggest alternative sustainable development pathways that may complement rather than compete with renewable energy priorities.

SWOT analysis served as a critical integrative tool linking geospatial wind suitability outputs with socio-economic and cultural characteristics of Türkiye’s Cittaslows (Table 2 and Table 3). Each row in the matrix operationalizes the Strategic Impact Assessment (SIA) by aligning technical metrics - average wind speed, power density, and capacity factor - with qualitative dimensions grounded in Cittaslow values and local development contexts. For instance, high wind potential cities like Seferihisar, Şarköy, and Foça, categorized as "Highly Suitable," exhibit unique opportunities such as ecotourism and sustainable branding, despite threats like urban expansion or marine pollution. Conversely, towns with "Unsuitable" classifications, such as Akyaka or Şavşat, highlight the importance of environmental preservation and nature-based tourism over industrial energy infrastructure. The matrix reflects how site-specific strengths (e.g., organic farming in Gökçeada or viticulture in Şarköy) can be leveraged to support decentralized, culturally sensitive energy models, while acknowledging challenges such as limited infrastructure, seasonal tourism pressure, or socio-demographic risks. This synthesis enables a more holistic understanding of renewable energy integration, providing grounded strategic insights for policy and planning in heritage-rich, ecologically diverse urban territories.

Table 2. Wind farm suitability assessment for Cittaslows in Türkiye

Slow Cities	Wind_Speed	Power Density	Capacity Factor	Suitability Class
Ahlat	3,7	99	0,09	Unsuitable
Akyaka	3,0	43	0,04	Unsuitable
Arapgir	5,8	315	0,24	Low Suitability
Daday	3,2	59	0,06	Unsuitable
Eğirdir	5,5	381	0,23	Low Suitability
Finike	2,3	28	0,03	Unsuitable
Foça	6,5	278	0,28	Highly Suitable
Gerze	5,2	236	0,20	Moderately Suitable
Gökçeada	6,9	354	0,33	Moderately Suitable
Göynük	3,8	83	0,09	Low Suitability
Güdül	3,8	107	0,10	Unsuitable
Halfeti	4,5	101	0,11	Low Suitability
İbradı	3,2	70	0,07	Unsuitable
İznik	3,8	146	0,12	Unsuitable
Kemaliye	6,9	359	0,31	Moderately Suitable
Köyceğiz	2,1	46	0,04	Unsuitable
Mudurnu	3,2	73	0,07	Unsuitable
Perşembe	3,1	48	0,05	Low Suitability
Safranbolu	1,9	23	0,02	Unsuitable
Şarköy	6,8	375	0,33	Highly Suitable

Şavşat	1,3	9	0,01	Unsuitable
Seferihisar	7,1	349	0,35	Highly Suitable
Uzundere	3,5	115	0,10	Unsuitable
Vize	6,4	350	0,29	Moderately Suitable
Yalvaç	3,9	135	0,11	Unsuitable
Yenipazar	4,5	144	0,14	Low Suitability

Table 3. SWOT analysis of wind energy integration in Türkiye's Cittaslows based on local socio-economic and environmental characteristics (developed by Cittaslow Türkiye, 2025)

Cittaslow	Suitability Class	Strengths	Weaknesses	Opportunities	Threats
Ahlat	Unsuitable	Cultural heritage, Van Lake proximity	Limited access roads	Cultural tourism	Migration, lack of investment
Akyaka	Unsuitable	Protected wetlands, low urbanization	High seasonal influx	Ecotourism	Environmental degradation
Arapgir	Low Suitability	Natural landscape, local production	Lack of branding	Organic agriculture	Youth outmigration
Daday	Unsuitable	Equestrian and plateau tourism	Remote access	Agri-tourism	Aging population
Eğirdir	Low Suitability	Lake ecosystem, recreational potential	Lake pollution risk	Protected area tourism	Water scarcity
Finike	Unsuitable	Citrus production	Tourism competition	Gastronomy branding	Climate variability
Foça	Highly Suitable	Coastal and historic urban identity	Seasonal overcrowding	Diving tourism	Marine pollution
Gerze	Moderately Suitable	Black Sea coast, fishing culture	No industrial activity	Rural development	Outmigration
Gökçeada	Moderately Suitable	Organic farming, insular isolation	Transport isolation	Slow tourism branding	Water stress
Göynük	Low Suitability	Traditional Ottoman townscape	Underdeveloped services	Heritage tourism	Structural decay
Güdül	Unsuitable	Close to Ankara, natural caves	Lack of recognition	Trekking and caving	Pollution risks
Halfeti	Low Suitability	Riverfront history and scenic views	Submerged heritage areas	Boat tours and ecotourism	Tourism overload
İbradı	Unsuitable	Dense forest ecosystem	Poor road infrastructure	Forest-based ecotourism	Deforestation risk
İznik	Unsuitable	Religious and historical identity	Low international visibility	Faith-based tourism	Water contamination
Kemaliye	Moderately Suitable	Canyon tourism, stone architecture	Hard to access	Adventure tourism	Underinvestment
Köyceğiz	Unsuitable	Lake and hot spring ecology	Tourism pressure on shorelines	Health & wellness tourism	Pollution pressure
Mudurnu	Unsuitable	Preserved traditional architecture	Neglected structures	Boutique accommodation	Architectural degradation
Perşembe	Low Suitability	Coastal village atmosphere	Infrastructure deficit	Rural entrepreneurship	Coastal erosion
Safranbolu	Unsuitable	UNESCO heritage status	Over-tourism risk	Conservation-focused tourism	Decay of heritage assets
Şarköy	Highly Suitable	Viticulture, coastal accessibility	Weak tourism planning	Wine route tourism	Uncontrolled development
Şavşat	Unsuitable	Alpine meadows and biodiversity	Inaccessibility	Nature-based tourism	Severe winters
Seferihisar	Highly Suitable	Pioneer in Cittaslow and sustainability	Urban sprawl threat	Sustainable model promotion	Urban expansion
Uzundere	Unsuitable	Waterfall and biodiversity	Insufficient promotion	Ecotourism	Climate change
Vize	Moderately Suitable	Antique heritage and green setting	Limited promotion	Cultural tourism	Loss of cultural identity
Yalvaç	Unsuitable	Ancient city remains	Low visitor numbers	History tourism	Tourism stagnation

Cittaslow	Suitability Class	Strengths	Weaknesses	Opportunities	Threats
Yenipazar	Low Suitability	Local gastronomy and farming	Rural depopulation	Slow food tourism	Loss of rural workforce

4. DISCUSSION AND CONCLUSIONS

This study aimed to assess the spatial suitability of wind energy development in Türkiye's Cittaslows using a GIS-based multi-criteria evaluation, followed by a strategic impact assessment through SWOT analysis. The findings highlight significant spatial differentiation among the 26 Cittaslow in terms of technical feasibility, environmental sensitivity, and alignment with the values of the Cittaslow movement. The suitability analysis revealed that Foça, Şarköy, and Seferihisar are the most promising candidates for wind energy investment due to their high wind speeds, power density values, and capacity factors exceeding 0.28. These cities also exhibit strong socio-cultural infrastructure, including ecotourism and public awareness—factors that enhance the community acceptability of renewable energy systems (Wierzbicka, 2022). In contrast, cities like Akyaka, Finike, Şavşat, and Mudurnu, which scored low on wind potential, should instead prioritize alternative sustainability strategies such as ecotourism, cultural heritage protection, and nature conservation—core tenets of the Cittaslow philosophy (Presenza et al., 2015). The SWOT analysis further deepened this interpretation by framing the feasibility of wind projects not only in technical terms, but also through social, environmental, and strategic lenses. Among the strengths, high wind corridors and community-level energy independence were prominent. However, weaknesses included limited municipal experience and possible visual conflicts with protected landscapes—risks previously discussed in the literature on slow cities and renewable integration (Batyk et al., 2021). Opportunities such as EU-backed funding mechanisms, green branding, and local energy cooperatives offer practical pathways to overcome these barriers. Moreover, aligning wind energy planning with Cittaslow principles of decentralization, cultural preservation, and environmental stewardship ensures that renewable energy infrastructure can enhance rather than disrupt the identity and ecological value of these unique cities. As Wierzbicka (2022) notes, integrating environmental and energy goals in Cittaslow municipalities requires place-sensitive approaches that move beyond standardized renewable energy planning. In conclusion, this study contributes to the growing body of literature advocating for context-aware renewable energy development by demonstrating how technical data, spatial analysis, and strategic frameworks like SWOT can be combined effectively. For policy-makers and local governments, the results underscore the importance of balancing energy ambitions with the cultural and ecological uniqueness of slow cities. Future work may focus on participatory planning models and dynamic energy simulations to further support community-driven sustainability in Cittaslow contexts.

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Physicochemical Composition of Olive Pomace for a Sustainable Valorization

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Abstract: Olive pomace (OP), the solid by-product from olive oil production, represents a significant source of bioactive compounds, including polyphenols with high antioxidant properties. The growing interest in the sustainable valorisation of the olive oil production chain has driven efforts to recover high-value compounds from this low-cost byproduct. This study aims to characterise the physicochemical properties of OP obtained from different olive oil extraction systems (two-phase and three-phase), collected during the harvest seasons from 2022 to 2025. Comprehensive physicochemical analyses, including the determination of moisture, ash, dry matter, total extractives, protein content, minerals, total carbohydrates, cellulose, neutral and acid detergent fibres, and total soluble sugars, were conducted to assess the composition of OP samples. The total phenolic content and the total antioxidant activity of hydroalcoholic olive pomace extracts were quantified using the Folin–Ciocalteu method and the DPPH radical scavenging assay, respectively. Results revealed that OP samples contained high levels of crude fibres (33.6-38.5%), total carbohydrates (30% -40%), and oil (8.06 to 14.82 g/100 dry OP). OP samples from the three-phase extraction process exhibited higher protein content (5.6-7.34%), as determined by the Kjeldahl method using the N-Analyzer FOSS system. The pH, ash, minerals, and lignin contents were found to be 4.7-5.15, 1.25-3.35%, 3.8-6.02%, and 30.8-38.5%, respectively. Hydroalcoholic extracts demonstrated high phenolic content (9.56-32.59 mg GAE/g DW) and strong antioxidant activity (13.46-35.23 µmol TE/g DW). The results prove that the olive pomace studied is rich in nutrients and could be considered a valuable source for obtaining high-added-value products.

Keywords: olive pomace, valorization, sustainable, value added products.

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1. INTRODUCTION

The olive oil industry plays a vital economic, environmental, and social role in Mediterranean countries, which are responsible for approximately 98% of global olive oil production (Gullón et al., 2020). The growing demand for olive oil is largely attributed to its distinctive organoleptic characteristics and well-established health benefits (Di Giovacchino et al., 2017). This sector is a fundamental component of the agro-industrial economy in the Mediterranean basin, where olive mills are predominantly situated and substantial land areas are dedicated to olive cultivation (Manzanares et al., 2020). Furthermore, 75% of global olive oil production originates from Mediterranean Member States of the European Union (Lozano-Sànchez et al., 2014).

Olive oil production involves several mechanical extraction processes. In brief, olives after milling and malaxation are submitted to pressing systems, such as i) press olive oil extraction, ii) three-phase centrifugal olive oil extraction, and iii) two-phase centrifugal olive oil extraction where the press and three-phase centrifugal systems generate large volumes of liquid effluent compared to the two-phase centrifugation process, which is considered more ecological (Ochando-Pulido et al., 2020).

The virgin olive oil production chain generates significant quantities of by-products (such as olive pomace and olive mill wastewater) and wastes (including olive leaves and wood), depending on the extraction techniques used for olive oil manufacture (Abbattista et al., 2021). Currently, the generation of these by-products is high and tends to increase, posing a major environmental concern in Mediterranean regions due to the large volumes produced in short periods and their high content of organic matter and phenolic compounds (Difonzo et al., 2021; Banias et al., 2017). These by-products have diverse environmental impacts, including resource depletion, land degradation, air emissions, and waste generation (Pampuri et al., 2021).

Olive mill wastewater (OMWW) is one of the main by-products of the olive oil industry, with generation rates ranging from 1.2 to 1.8 m³ per ton of processed olives (Haddad et al., 2017). This effluent is characterized by a high organic load, elevated levels of suspended solids and fats, acidic pH, high electrical conductivity due to its salt content, and dark coloration caused primarily by phenolic substances (García-Pastor et al., 2023; Hadidi et al., 2021). The disposal of OMWW presents a significant environmental challenge due to its high content of phenolic compounds, which are largely responsible for its pronounced phytotoxicity and pollution potential. Additionally, the discharge of OMWW into the environment contributes to toxicity and ecological degradation, making it a pressing environmental issue with complex technological, economic, and social dimensions (Markhali, 2021). Consequently, OMWW is widely regarded as one of the most polluting effluents generated by the agro-food industry, owing to its substantial environmental load (Pikuli and Devolli, 2024a). Controlled application to agricultural soils has been shown to enhance physical, chemical, and biological soil properties (Kavdir and Killi, 2008). Despite these concerns, several studies have highlighted the potential of OMWW for beneficial reuse. These improvements are primarily attributed to the presence of valuable organic compounds in OMWW, including organic acids, alcohols, lipids, nitrogenous substances, sugars, and potassium (Roig et al., 2006). Furthermore, OMWW has been investigated as a promising substrate for biogas production, offering a sustainable and energy-efficient pathway for its valorization (Demirer et al., 2000). Additionally, when properly managed, OMWW represents an inexpensive and accessible source of natural antioxidants, primarily due to its high polyphenolic content. These bioactive compounds can be extracted and utilized as natural antioxidants in the food and pharmaceutical industries (Niaounakis and Halvadakis, 2006).

Among the various waste streams and by-products generated by the olive oil industry, olive pomace (OP) is regarded as the most significant, both in terms of volume and compositional complexity. According to Foti et al. (2022) and Cooksey (2017), one tonne of processed olives generates approximately 500 - 600 kg of OP. This by-product is a heterogeneous lignocellulosic matrix composed of olive husk, pulp, crushed stones, and residual olive mill wastewater. It typically exhibits a high moisture content of approximately 65%, although this value varies depending on the extraction technology employed (Regni et al., 2017). Specifically, pomace obtained through pressing or the traditional three-phase decanter system generally contains between 20% and 50% moisture, whereas pomace produced by the modern two-phase extraction method may exhibit moisture levels of up to 70%. The two-phase system is considered more environmentally sustainable than the conventional and three-phase extraction process of olive oil production, primarily due to its elimination of added process water, thereby significantly reducing wastewater generation (Dermeche et al., 2013).

Olive pomace, a lignocellulosic residue generated during olive oil production, is recognized as a potential source of cellulose, hemicellulose, and lignin. The efficient extraction of high-purity cellulose from OP is essential for its valorization into high-value bioproducts, including biofuels, bioplastics, and nanomaterials. Compositional analyses have shown that OP contains approximately 16.2% cellulose, 18.96% hemicellulose, and 31.7% lignin on a dry weight basis (Miranda et al., 2019). To facilitate cellulose recovery, several pretreatment strategies—such as hydrothermal treatment and enzymatic hydrolysis—have been employed. These methods have enabled the production of cellulose nanofibers from OP, which are suitable for use as reinforcing agents in biodegradable composite materials (Sagdic-Oztan et al., 2023). These developments highlight the potential of OP as a renewable raw material and underscore the importance of optimizing extraction processes to enhance its economic and environmental value.

Nowadays, olive pomace is currently utilized in various sectors, including agriculture, where it functions as a soil conditioner and organic fertilizer, bioenergy generation, and as a raw material for the extraction of bioactive compounds. These compounds include hydroxytyrosol, tyrosol, oleuropein, caffeic acid, and squalene, which are widely applied in the pharmaceutical, food, and cosmetic industries (Nunes et al., 2018; Dermeche et al., 2013). The compositional profile of OP is characterized by a rich array of bioactive substances, such as phenolic compounds, uronic acids, oily residues, and a residual oil content ranging from 3% to 4.5% on a wet basis. This biochemical complexity renders OP a promising and economically viable source of high-value compounds, including polyphenols and fatty acids, both known for their potent antioxidant properties (Nunes et al., 2021; Gullón et al., 2020). Owing to its abundance and bioactive richness, OP has attracted growing interest for its potential in sustainable, high-value applications, particularly in the formulation of functional food ingredients and nutraceuticals (Nunes et al., 2016).

The present study aims to comprehensively evaluate the physicochemical composition of olive pomace obtained from various extraction systems. Several physico-chemical analyses were conducted to determine key parameters such as moisture content, ash, dry matter, total extractives, protein content, minerals, total carbohydrates, cellulose, neutral detergent fiber (NDF), acid detergent fiber (ADF), and total soluble sugars. Additionally, the total phenolic

content and antioxidant activity of hydroalcoholic extracts of olive pomace were determined to evaluate their potential as valuable sources of bioactive compounds.

2. MATERIALS AND METHODS

2.1. Sample collection and preparation

A total of 35 samples of olive pomace were obtained from the extraction of olives using two- and three-phase centrifugal systems during the harvest seasons from 2022 to 2025. Samples labeled OP1, OP2, and OP3 were collected from three olive oil processing facilities in southern and central Albania. Specifically, OP1 originated from processing the Kalinjoti olive cultivar to produce extra virgin olive oil using the three–phase extraction system. According to genetic studies, Kalinjoti is recognized as the most predominant autochthonous cultivar in southern Albania. Samples OP2 and OP3 were derived from processing various olive cultivars using two- and three-phase extraction methods, respectively. To prevent biodegradation, all collected samples were immediately stored at 4 °C. Olive pomace samples were then dried in a tray dryer at a controlled temperature of 45–50 °C for 48 hours, followed by milling with a flour mill for 10 seconds to obtain a uniform particle size of approximately 1 mm.

2.2 Analytical method for the characterisation of physico-chemical composition of OP

Protein content
The nitrogen content was determined using the Kjeldahl method with a Foss protein analyzer, based on the procedure described by Zhao et al. (2020). For the analysis, 0.3 g of dried olive pomace (OP) was subjected to acid digestion. The protein content was subsequently calculated from the nitrogen content of the dry biomass using a nitrogen-to-protein conversion factor of 6.25.

Moisture and ash content determination
Moisture content of the olive pomace samples was determined gravimetrically. Approximately 10 g of each sample was dried in a forced-air oven (LBX OVF series) at 105 ± 1 °C for 48 hours, or until a constant weight was reached, following the procedure described by Moya et al. (2010). The final weight was recorded and used to calculate the total water content, based on the difference between the initial and final weights. Moisture content was expressed as a percentage of the initial weight of the olive pomace samples or their respective extracts.

Ash content of the olive pomace was determined using a gravimetric method. Approximately 5 g of dried OP sample was placed in a pre-weighed crucible and incinerated in a muffle furnace at 650 ± 5 °C for 8 hours, or until a constant weight was reached. The residue was then cooled in a desiccator and weighed. Ash content was calculated as a percentage of the initial dry weight of the sample (Nunes et al., 2021).

Detergent Fibre
The contents of neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to the method described by Mertens (2002). NDF measures all insoluble cell wall material, including hemicelluloses, cellulose, and lignin, while ADF measures only cellulose and lignin. These fibre fractions are widely used to evaluate the structural carbohydrate content and nutritional quality of plant-based feedstuffs.

Oil Content Determination
The oil content of the olive pomace was determined using Soxhlet extraction with hexane as the solvent. A 5 g portion of dried OP was subjected to continuous extraction using a Universal Extractor, following standard procedures for lipid quantification (Azadmard-Damirchi & Dutta, 2008). Each sample was extracted through 30 complete cycles, and analyses were conducted in triplicate.

Total Carbohydrate Estimation by Difference
The total carbohydrate content was estimated by the difference method, which is commonly employed in proximate analysis, especially for plant-based materials such as olive pomace. This method involves calculating carbohydrate content indirectly by subtracting the measured percentages of moisture, crude protein, crude fat, and ash from the total composition (100%) of the sample. The formula is as follows:

$$\text{Total Carbohydrates (\%)} = 100\% - (\text{Moisture} + \text{Crude Protein} + \text{Crude Fat} + \text{Ash})$$

This approach is recommended by the Food and Agriculture Organization (FAO, 2003) and is widely used when direct carbohydrate quantification is not performed.

Determination of Total Extractives

The total extractives content in olive pomace was determined using a standard Soxhlet extraction method based on procedures described by the AOAC (920.39) and ISO 14453:2001.

Approximately 3.0 g of the dried OP sample was accurately weighed and placed in a cellulose extraction thimble. Soxhlet extraction using n-hexane as the solvent was performed for 6 hours with continuous reflux. Following extraction, the solvent was evaporated using a rotary evaporator under reduced pressure. The residue was then dried in an oven at 40 °C until a constant weight was achieved. The total extractives were calculated gravimetrically and expressed as a percentage of the dry weight OP (DW) using the following formula:

Total Extractives (%) = (Mass of extract residue / Mass of dry OP) × 100

Determination of Lignin Content

The lignin content in olive pomace was determined using the Klason method (TAPPI T222 om-15) with some modifications. Olive pomace samples were oven-dried at 60°C, ground to less than 1 mm, and extracted with a 2:1 ethanol–benzene solution in a Soxhlet apparatus for 6 hours. Extractive-free samples (0.5 g) were hydrolyzed with 72% H_2SO_4 at 30 °C for 1 to 2 hours, followed by dilution to 4% acid and autoclaving at 121 °C for 1 hour. The acid-insoluble residue was filtered, dried at 105 °C, and weighed. Lignin content was calculated gravimetrically and expressed as a percentage of dry weight OP using the following equation:

Lignin (%) = (Mass of acid-insoluble residue / Dry mass of OP) x 100

Determination of Cellulose Content

Cellulose was isolated from olive pomace following the method described by Brendel et al. (2000), with slight modifications. Approximately 250 g of dried olive pomace was treated with a mixture of 80% (w/w) aqueous acetic acid and 70% (w/w) nitric acid under continuous stirring. The extraction was carried out at room temperature to remove lignin and hemicellulose. The resulting residue was thoroughly washed with distilled water, followed by 95% ethanol, to eliminate residual nitric acid and solubilized degradation products. The residue was then dried in a hot air oven at 60 °C for 24 hours to obtain the purified cellulose fraction.

Total suluble sugar content

Total soluble sugars in olive pomace were determined using the phenol–sulfuric acid method, as described by Nielsen (2010), with slight modifications. An aliquot of 0.5 mL of the hydroalcoholic extract was mixed with 0.5 mL of 5% (w/v) phenol solution, and 2.5 mL of concentrated sulfuric acid (98% H_2SO_4) was added rapidly. The reaction mixture was incubated in a water bath at 80 °C for 15 minutes, then cooled to room temperature. The absorbance was measured at 490 nm using a UV–Vis spectrophotometer. Quantification was performed using a standard calibration curve prepared with D-(+)-glucose in the concentration range of 0.2–1.0 mg/L ($R^2 = 0.997$). Results were expressed as the percentage of total soluble sugars relative to the dry weight of olive pomace.

Determination of total phenolic content and total antioxidant activity of olive pomace extracts

The total phenolic content (TPC) of the olive pomace (OP) hydroalcoholic extracts was determined using the Folin–Ciocalteu colorimetric method, as described by Pikuli and Devolli (2024b). A calibration curve was prepared using gallic acid standards ranging from 0 to 1 mg/mL ($R^2 = 0.9996$). Absorbance was measured at 760 nm, and TPC values were expressed as milligrams of gallic acid equivalents per gram of dry wieght OP (mg GAE/g DW). Total antioxidant activity (TAA) was measured using the DPPH assay, as modified by Pikuli and Devolli (2024b). The reduction in absorbance was measured at 515 nm, using methanol as the blank. A calibration curve was prepared using Trolox as the standard, and the results were expressed in μmol Trolox equivalents per gram of dry weight olive pomace (μmol TE/g DW).

2.3 Statistical Analysis

All analyses were conducted in triplicate, and results were presented as mean ± standard deviation. Statistical analysis was performed using one-way ANOVA (Tukey's test) with a significance level of $p < 0.05$, using SPSS version 27.

3. RESULTS AND DISCUSSIONS

Table 1 presents the physicochemical composition of olive pomace (OP) samples obtained from olive oil extraction using two-phase and three-phase centrifugal systems during the 2022–2025 harvest seasons. The results are expressed as mean ± standard deviation ($n = 3$).

Moisture content was determined gravimetrically in both crude and dried olive pomace samples. Crude OP samples were dried in a forced-air oven at 40–50 °C for 48 hours to prevent the degradation of bioactive compounds. The

moisture content of crude olive pomace ranged from 56.3% to 60.7% in samples obtained from the three-phase centrifugal extraction system, while it was approximately 70% in OP samples derived from the two-phase system. A statistically significant difference ($p < 0.05$) was observed between the two extraction systems.

The results presented in Table 1 show that the ash, protein, and mineral contents of olive pomace ranged from 1.87% to 3.00%, 5.51% to 7.19%, and 4.20% to 5.89%, respectively. The lowest values for these parameters were observed in OP3 samples obtained from the three-phase centrifugal extraction system.

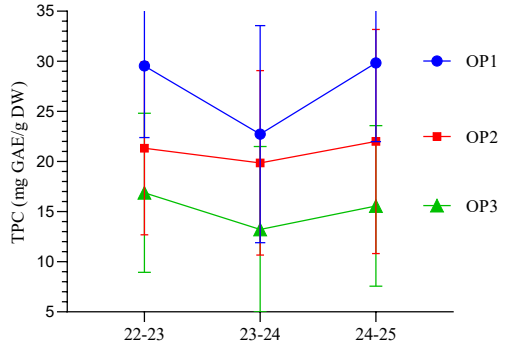
According to the data presented in Table 1, olive pomace samples contained 8.65% to 14.19% residual oil. This parameter is crucial for optimizing the efficiency of olive oil production. The residual oil is recovered through solvent-based extraction methods to produce "olive pomace oil." Before this extraction process, the pomace must be dried, making both residual oil and moisture content critical factors in determining its commercial value (Baysan et al., 2017; Miranda et al., 2019).

Table 1. Physico-chemical compositions of olive pomace samples

Parameters	OP1		OP2		OP3	
	mean	Std	mean	Std	mean	Std
Moisture of crude olive pomace (%)	60.67	2.62	56.33	6.94	70.00	1.63
Moisture of dried OP (% DW)	5.27	0.09	4.64	0.43	5.13	0.34
Ash (% DW)	3.00	0.27	2.69	0.20	1.87	0.44
pH	4.92	0.10	4.90	0.16	5.16	0.11
Minerals (% DW)	5.89	0.09	5.15	0.12	4.20	0.29
Oil residue (% DW)	14.19	0.76	11.23	0.24	8.65	0.43
Protein (% DW)	7.19	0.16	6.19	0.42	5.51	0.21
Total crude fibre (% for DM)	37.00	0.82	35.70	2.69	36.13	2.05
NDF (% DW)	48.43	1.52	39.95	1.92	35.97	1.96
ADF (% DW)	34.85	0.48	32.20	0.85	28.03	3.08
Total carbohydrate (% DW)	38.33	1.25	35.00	1.63	32.33	2.05
Cellulose (% DW)	26.50	0.99	18.30	4.28	20.90	2.01
Lignin (% DW)	37.33	1.03	34.33	1.25	32.10	1.10
Total extractives (% DW)	26.83	1.31	24.00	1.63	20.67	2.05
Total soluble sugars (% DW)	6.32	0.09	6.17	0.05	5.83	0.18

*Std-standard deviation

The results showed that crude fiber content ranged from 35.70% to 37.00%, total carbohydrates from 32.33% to 38.33%, cellulose from 18.30% to 26.50%, and total soluble sugars from 5.83% to 6.32%, all expressed on a dry weight basis of the olive pomace (DW) samples. The data revealed that total lignin content in the olive pomace samples ranged from 32.10% to 37.33%, while total extractives (in water and ethanol) ranged from 20.67% to 26.83%.



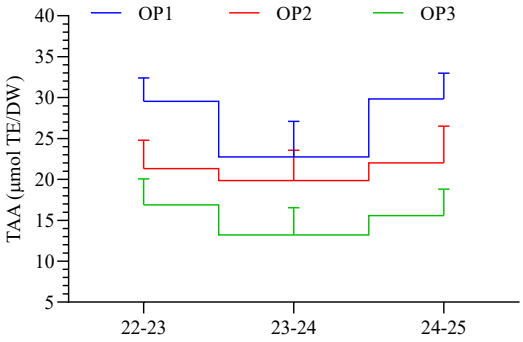


Figure 1. Total phenolic content (TPC) and total antioxidant activity (TAA) of olive pomace ethanolic extracts

The total phenolic content and total antioxidant activity of olive pomace hydroalcoholic extracts (ethanol 80%) are presented in Figure 1. The total phenolic content (TPC) and total antioxidant activity (TAA) in dry weight of olive pomace ranged from 12.09 to 31.03 mg GAE/g DW and 18.25 to 32.70 μmol TE/g DW, respectively. Among the samples analyzed, the highest levels of total phenolic content (TPC) and total antioxidant activity (TAA) were observed in the extracts of OP1 and OP2, derived from three-phase and two-phase extraction systems, respectively. Notably, the OP1 extract, obtained from the Kalinjoti cultivar, exhibited significantly higher TPC and TAA values compared to those of extracts derived from other olive cultivars (Fig. 1).

The total phenolic content and total antioxidant activity of the hydroalcoholic extracts of olive pomace obtained in the present study are in agreement with the findings of Pikuli and Devolli (2024b), who reported similar ranges in their analysis. These results align with previous studies that have consistently highlighted the significant antioxidant potential of olive pomace (Zhao et al., 2022, Nunes et al., 2018). Furthermore, the findings reinforce the nutrient-rich profile of olive pomace, reported by Cravotto et al. (2022) and Di Giovacchino et al. (2017). Additionally, the sustainable valorization of OP aligns with the principles of circular bioeconomy and sustainable food systems, offering an effective strategy for waste reduction and resource recovery within the olive oil industry.

4. CONCLUSIONS

The present study demonstrates the potential of olive pomace as a valuable source of essential nutrients and bioactive compounds. Through several physico-chemical analyses, we characterized the key components of olive pomace, including moisture content, ash, dry matter, total extractives, protein content, minerals, total carbohydrates, cellulose, neutral detergent fiber (NDF), acid detergent fiber (ADF), total soluble sugars, total phenolic content, and total antioxidant activity.

The findings revealed that olive pomace not only possesses substantial nutritional value but also exhibits significant antioxidant activity, highlighting its potential for diverse applications in the food, nutraceutical, and pharmaceutical industries. The management of olive pomace residues is crucial for environmental preservation and the sustainable utilization of agro-industrial by-products. Their valorization aligns with the growing demand for innovation and sustainability in the food system. Further research should be carried out regarding the sustainable utilization and valorization of olive pomace, contributing to the development of functional foods and bioactive-rich products.

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Conflict of Interest
The authors have no conflicts of interest to declare.

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Analysis of Phenolic and Aromatic Compound in Dandelion (*Taraxacum officinale* L.) Flowers using UPLC-MS/MS and HS-SPME/GC-MS

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Abstract: The study aimed to clarify the floral scent components of fresh dandelion flowers, the specific phenolic chemical compounds of the extracts obtained from these flowers, and their antioxidant ability using the CUPRAC test. Analyses of the floral scent component of dandelion were conducted using a Trace 1300 GC equipped with an ISQ7000 Single Quadrupole Mass Spectrometer (qMS). The polyphenolic components of methanolic extracts from dandelion flowers were characterized using UPLC MS/MS. Monoterpene hydrocarbons represented the main class of aromatic components in fresh dandelion flowers, comprising 57% of the total. The main constituents identified in dandelion flowers comprised monoterpene hydrocarbons (57%), oxygenated monoterpenes (3.88%), sesquiterpene hydrocarbons (0.7%) and non-terpenes (34.88%). HS-SPME analysis indicated that the predominant scent component of fresh flowers was D-limonene (47.28%). UPLC MS/MS analysis revealed that the fresh flowers exhibited high concentrations of quercetin (7271.7 µg/g), quercetin 3 glucuronide (4231.1 µg/g), quercetin 3 sulfate (3207.5 µg/g) and chlorogenic acid (1164.1 µg/g), respectively. Significant concentrations of caffeic acid (237.4 µg/g), ferulic acid (194.5 µg/g), rutin (169.9 µg/g) and β-carotene (53.3 µg/g) were detected. The CUPRAC of dandelion flowers was established as 0.04 ± 0.0014 mmol TR per gram of fresh flower. The results of this study indicate that dandelion flowers may serve as a formidable alternative to synthetic antioxidants.

Keywords: Dandelion, scent compounds, CUPRAC, HS-SPME, antioxidant, UPLC MS/MS

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1. INTRODUCTION

The dandelion (*Taraxacum officinale* L.) is a species of the Taraxacum genus of the Asteraceae family (Wirngo et al., 2016). Species belonging to the Taraxacum genus have traditionally functioned as medicinal herbs. The name clearly reflects its origins in the Greek words “taraxis,” signifying inflammation and “akeomai,” denoting healing. In English-speaking countries, the common name for dandelion, originating from the French term “dent-de-lion,” refers to the plant's serrated leaves. The term "pissenlit" translating to "bedwetter" in French, is often used to reference its diuretic characteristics (Schütz et al., 2006). Tradition uses dandelion as an aperitif, mild laxative, tonic, stimulant and primarily as a diuretic through infusions and decoctions (Schütz et al., 2006). Dandelion is cultivated or gathered from wild habitats for therapeutic and culinary purposes. It is mostly cultivated and produced in Bulgaria, Romania, Hungary and Poland (Brock, 2004). Dandelion is located in tropical regions, cool highland areas (1200-1500 m elevation) and warm sub-temperate and temperate zones of the northern hemisphere. It can withstand drought and frost (Honek et al., 2009).

Dandelion contains phytochemicals including triterpenes, terpenoids, and phenolics such as apigenin, luteolin, caffeic acid, chlorogenic acid, and isoquercitrin. The bioactive compounds make dandelion a significant source of natural antioxidants (Beğiç, 2022). Dandelion flowers may serve as potential antioxidant sources due to their rich content of phenolic compounds, such as flavonoids, coumaric acid and ascorbic acid. Their flower extracts function as effective hydrogen donors, hydrogen peroxide scavengers, and reducing agents. Numerous studies have demonstrated the antioxidative effects of dandelion. Hagymasi et al. (2000) suggested that dandelion extracts have hydrogen-donating, reactive oxygen species formation-inhibiting and radical-scavenging activities. Hagymasi et al. (2000) indicated that the ethyl acetate fraction of dandelion flower reduced reactive oxygen species (ROS) by mitigating ROS-induced DNA damage, and this decrease was due to the presence of bioactive compounds such as luteolin and luteolin-7-O-glucoside.

Considering the potential applications of dandelion, it is essential to elucidate its chemical composition in greater detail. This study aims to analyze the composition of scent compounds in dandelion flowers, characterize phenolic compounds and assess the total antioxidant capacity of extracts derived from these flowers.

2. MATERIAL AND METHOD

2.1. Plant Material

The plant material utilized in this study was collected from the research farm at Isparta University of Applied Sciences, Faculty of Agriculture, in May 2025 (Figure 1). The freshly collected dandelion flowers were maintained at -20 °C until their use in the analyses.

Figure 1. Overview of the dandelion flowers used in the research

2.2. Phenolic Extraction of Dandelion Flowers

Fresh dandelion flowers (2 g) were extracted using an ultrasonic bath system (LAB.ULT.4045, internal dimensions: 300 mm × 150 mm × 100 mm) with 40 mL of methanol-water (80:20, v/v) solvent (Önder et al. 2023). The extraction parameters included a temperature of 45 °C, a duration of 30 min, a solid/solvent ratio of 2:40 (w/v), a maximum nominal output power of 150 W, and an ultrasonic frequency of 40 kHz. The resulting extracts were filtered through 0.45 µm PTFE filters (Isolab, Germany) to remove impurities. Filtered aliquots were stored at -20 °C until further analysis.

2.3. SPME Sampling

Solid-phase microextraction (SPME) samples were conducted utilizing a 75µm SPME fiber assembly of Carboxen/Polydimethylsiloxane (CAR/PDMS) with 15 mL headspace vials (Supelco Ltd., Bellefonte, PA, USD) containing about 2.00 g of fresh dandelion flowers. The sample was placed on a heating block at 60 °C and maintained for 20 min to attain temperature equilibration. A CAR/PDMS fiber was placed in the vial and held at 60 °C for 45 min to adsorb volatile compounds from the flowers. The fiber was then placed in the gas chromatograph's injection port for 5 min at 250 °C to facilitate the desorption of aroma compounds.

2.4. Analysis of GC-qMS Method

Analyses of the scent components of dandelion were conducted using a Trace 1300 Gas Chromatograph equipped with an ISQ7000 Single Quadrupole Mass Spectrometer (qMS) from Thermo Scientific. The inlet temperature was 250 °C. The Trace GOLD TG-624SilMS GC column (60 m × 0.25mm I.D. × 1.4 µm film thickness, Thermo Fisher Scientific Inc., Waltham, Massachusetts, USA) was used as the analytical column for chromatographic separation. GC-MS analysis was performed under the specified conditions. Helium was used as a carrier gas with a flow rate of 1.5 mL/min. The split ratio was 1:5. The GC oven started at 35 °C with a 3 min hold, subsequently increasing at a rate of 2 °C/min to 100 °C, started at 100 °C with a 1 min hold and increased by 5 °C/min to 120 °C, started at 120 °C with a 1 min hold and increased by 5 °C/min to 200 °C, started at 200 °C with a 1 min hold and increased by 5 °C/min to 220 °C, and held at this temperature for 1 min. The detector temperature is 280 °C. The total run time was 64 min.

Chromatographic analyses were performed using Xcalibur software. The qMS functioned in electron ionization mode, with a scan range of 33 to 400 m/z. Compounds were identified through comparison with the Saturn spectra reported in Willey 1n.l and the NIST 0.5 (National Institute of Standards and Technology) database. Parent, molecular, and qualifying ions were selected for each identified compound. Peak areas for each compound were calculated by integrating the peaks with library verification in the spectrum obtained from the instrument. The

peak area for each compound was divided by the total area of all peaks from the spectrum to calculate the % content ratio of that compound. The content profile of the components belonging to the sample was obtained by using this calculation method for each of the detected volatile components.

2.5. UHPLC-MS/MS Analyses

The chemical contents of the samples were isolated using a Dionex Ultimate 3000 high-performance liquid chromatograph (Thermo Fisher Scientific, USA). Phytochemicals in the dandelion flowers were detected using a Thermo Scientific Q-Exactive Series ultra-high-resolution mass spectrometer. The UPLC chromatograph instrument consisted of a vacuum exhaust system, pump system, sample tray with a temperature control system, automatic sampler, chromatographic column, column temperature control system and DAD detector. The equipment was used alongside a Thermo Scientific Hypersil GOLD aQ (2.1 mm × 100 mm, 1.9 µm) column (C18, 4.6 mm × 150 mm, 5 µm).

Filtrated dandelion flower extracts at 0.45 µm were subsequently analyzed using UHPLC-MS with a UHPLC-MS/MS column (Thermo Scientific Ultimate 3000 UPLC, Thermo Scientific-TSQ Fortis, Thermo Fisher Scientific Inc., Waltham, Massachusetts, USA) equipped with a Hypersil GOLD RP C18 (1.9 µm, 50 mm × 2.1 mm). A Thermo Scientific TSQ Fortis triple quadrupole mass spectrometer (Thermo Fisher Scientific Inc., Waltham, Massachusetts, USA) was utilized for the analysis. The evaporation temperature in the electrospray ionization module was 40 °C, the auxiliary gas pressure was 20 Arb, the sheath gas pressure was 50 Arb, and the spray voltage was ±3500 V. The mobile phases employed for analysis were as follows. A gradient flow program utilized mobile phase A (water:methanol 95:5, 0.1% formic acid, 4 mM ammonium formate) and mobile phase B (methanol:water 95:5, 0.1% formic acid, 4 mM ammonium formate) (Ateş & Unal, 2023). The flow rate was maintained at 0.3 mL/min, the column temperature was set at 40 °C and the injection volume was 10 µL. Chromatographic analyses were performed using Xcalibur software. Analytical purity standards of phenolic compounds with known concentrations were analyzed and the data obtained with the device were compared with the analytical results of the samples. Quantitative results were obtained by comparing the data obtained with the device. A 7 min linear gradient was programmed as follows (Table 1).

Table 1. Mobile Phase Gradient Flow Diagram

Time	Flow (mL/min)	Mobil Phase A	Mobil Phase B
0	0.300	100 %	0 %
2.0	0.300	100 %	0 %
4.0	0.300	50 %	50 %
4.5	0.300	0 %	100 %
6.0	0.300	0 %	100 %
6.5	0.300	100 %	0 %
7	0.300	100 %	0 %

2.6. Total Antioxidant Capacity

The total antioxidant capacity (TAC) of the infusions was assessed using the CUPRAC test, as described by Apak et al. (2006). In summary, the following substances were injected in sequence into a glass tube: 1 mL of copper(II) solution (Cu(II)), 1 mL of neocuproin solution (Nc), 1 mL of ammonium acetate buffer (NH_4Ac), 0.3 mL of a sample solution (diluted 10-fold) and 0.8 mL of distilled water. Samples were incubated at 25 °C in the dark for 30 min. Absorbance measurements were obtained at 450 nm against the reagent blank solution.

Reagent blank solution: 1 mL Cu(II) + 1 mL Nc + 1 mL NH_4Ac + 1.1 mL H_2O
Sample solution:1 mL Cu(II) + 1 mL Nc + 1 mL NH_4Ac + 0.5 mL sample + 0.6 mL H_2O

The total antioxidant capacity of the samples was calculated to be mmol trolox/g- fresh weight (FW).

$$TAC\ (mmol\ TR/g - FW) = \frac{A}{\varepsilon_{TR}} x\ \frac{V_m}{V_s}\ x\ S_f\ x\ \frac{V_E}{m}$$

3. RESULTS / DISCUSSION

3.1. Scent aromatic components of dandelion flowers

Headspace solid phase microextraction (HS-SPME) is a technology noted for its exceptional efficiency and accuracy, cost-effectiveness and portability. It employs a specialized fiber composed of fused silica, which is covered with a substance to capture scent compounds. The scent compounds found in the dandelion flowers were listed in Table 2. Monoterpene hydrocarbons were the predominant class of scent compounds in fresh dandelion flowers, accounting for 57% of the total. In contrast, the flowers contained low concentrations of oxygenated monoterpene (3.88%) and sesquiterpene hydrocarbons (0.7%). The main scent chemical categories identified in dandelion flowers included monoterpene hydrocarbons (57%), aldehyde (28.19%) and oxygenated monoterpenes (3.88%). The fresh flowers predominated in d-limonene (47.28%) and 2-hexenal (16.19%) compounds. It also contained significant concentrations of hexanal (5.59%), p-cymene (4.41%), 1,8-cineole (3.54%), nonanal (3.23%) and α-myrcene (2.73%). HS-SPME analyses identified six non-terpene compounds in dandelion flowers: 2-hexenal, hexanal, 2,4-heptadienal, 2-methylbutanal, nonanal and decanal, all of which are classified as aldehydes. Other non-terpene components included alkanes (dodecane, n-eicosane, and n-docosane), ketones (1-penten-3-one and sulcatone), aliphatic alcohol (cis-3-hexen-1-ol), furanoid (trans-linalool oxide) and aromatic hydrocarbon (hemellitol) (Table 2).

Table 2. The floral scent compounds of dandelion flowers

No	Compound	Chemical structure	Molecular class	Area %
1	α-Thujene	$C_{10}H_{16}$	MH	1.46
2	α-Pinene	$C_{10}H_{16}$	MH	0.12
3	β-Pinene	$C_{10}H_{16}$	MH	0.31
4	cis-3-Hexen-1-ol	$C_6H_{12}O$	AA	2.09
5	α-Myrcene	$C_{10}H_{16}$	MH	2.73
6	α-Phellandrene	$C_{10}H_{16}$	MH	0.07
7	p-Cymene	$C_{10}H14$	MH	4.41
8	d-Limonene	$C_{10}H_{16}$	MH	47.28
9	1,8-Cineole (Eucalyptol)	$C_{10}H_{18}O$	OM	3.54
10	Nonanal	$C_9H_{18}O$	Ald	3.23
11	Decanal	$C_{10}H_{20}O$	Ald	0.38
12	α-Ocimene	$C_{10}H_{16}$	MH	0.12
13	α-cis ocimene	$C_{10}H_{16}$	MH	0.29
14	γ-Terpinene	$C_{10}H_{16}$	MH	0.21
15	Dodecane	$C_{12}H_{26}$	Alk	0.16
16	trans-Linalool oxide	$C_{10}H_{18}O_2$	F	0.15
17	α-Linalool	$C_{10}H_{18}O$	OM	0,14
18	Hexanal	$C_6H_{12}O$	Ald	5.59
19	2-Hexenal	$C_6H_{10}O$	Ald	16.19
20	2,4-Heptadienal	$C_7H_{10}O$	Ald	2.18
21	Terpinen-4-ol	$C_{10}H_{18}O$	OM	0.11
22	α-Terpineol	$C_{10}H_{18}O$	OM	0.09
23	2-Methylbutanal	$C_5H_{10}O$	Ald	0.62
24	1-Penten-3-one	C_5H_8O	K	0.64
25	Bicycloelemene	$C_{15}H_{24}$	SH	0.09
26	α-Cubebene	$C_{15}H_{24}$	SH	0.13
27	Sulcatone (6-methyl-5-hepten-2-one)	$C_8H_{14}O$	K	1.26
28	Hemellitol (1,2,3-Trimethylbenzen)	$C_6H_3(CH_3)_3$	AH	0.33
29	α-Copaene	$C_{15}H_{24}$	SH	0.22
30	α-Bourbonene	$C_{15}H_{24}$	SH	0.12
31	β-Caryophyllene	$C_{15}H_{24}$	SH	0.05
32	Germacrene D	$C_{15}H_{24}$	SH	0.02
33	Cadinene	$C_{15}H_{24}$	SH	0.07
34	n-Eicosane	$C_{20}H_{42}$	Alk	1.22
35	n-Docosane	$C_{22}H_{46}$	Alk	0.84
Molecular class compositions				

Monoterpene hydrocarbon (MH)	57
Oxygenated monoterpenes (OM)	3.88
Sesquiterpene hydrocarbon (SH)	0.7
Aliphatic alcohol (AA)	2.09
Alkane (Alk)	2.22
Aldehyde (Ald)	28.19
Ketone (K)	1.9
Furanoid (F)	0.15
Aromatic Hydrocarbon (AH)	0.33
Total	**96.46**

3.2. Profile of Phenolic and Flavonoid Components in Fresh Dandelion Flowers

The methanolic extract was analyzed using UHPLC–MS/MS to identify the bioactive compounds present in dandelion flowers. The compounds identified using UHPLC-MS/MS are shown in Table 3. Chromatographic analysis of the 25 phenolic compounds (apigenin, apigenin 7 glucoside, β-carotene, caffeic acid, caftaric acid, catechin, chlorogenic acid, cyanidin, delphinidin, epicatechin, epicatechin gallate, epigallocatechin, epigallocatechin gallate, ferulic acid, gallic acid, gallocatechin, kaempferol, kaempferol 3 glucuronide, lutein, p-coumaric acid, quercetin, quercetin 3 glucuronide, quercetin 3 sulfate, rosmarinic acid, rutin, syringic acid and vanilic acid) was performed using UPLC MS/MS. It was determined that 13 of the 25 compounds examined by UPLC MS/MS were not synthesized. UPLC MS/MS analysis indicated that the fresh flowers were characterized by high concentrations of quercetin (7271.7 µg/g), quercetin 3 glucuronide (4231.1 µg/g), quercetin 3 sulfate (3207.5 µg/g) and chlorogenic acid (1164.1 µg/g). Significant concentrations of caffeic acid (237.4 µg/g), ferulic acid (194.5 µg/g), rutin (169.9 µg/g) and β-carotene (53.3 µg/g) were observed. Aqueous methanol extracts of fresh dandelion flowers were determined to contain low concentrations of vanillic acid (15.1 µg/g), apigenin (11.7 µg/g), p-coumaric acid (3.6 µg/g), apigenin 7 glucoside (3.5 µg/g), and kaempferol 3 glucuronide (1.1 µg/g). A total of eight flavonoid compounds were synthesized at 14914 µg/g in dandelion flowers, followed by five phenolic compounds at 1614.7 µg/g and one carotenoid compound at 53.3 µg/g.

Table 3. UPLC MS/MS results of individual phenolic and flavonoid components of Dandelion fresh flowers

Phenolic compound	Class	µg/g
Apigenin	Flavonoid	11.7 ± 1.14
Apigenin 7 glucoside	Flavonoid	3.5 ± 0.37
β-Carotene	Carotenoid	53.3 ± 2.74
Caffeic acid	Phenolic acid	237.4 ± 8.99
Caftaric acid	Phenolic acid	nd
Catechin	Flavonoid	nd
Chlorogenic acid	Phenolic acid	1164.1 ± 14.97
Cyanidin	Flavonoid	nd
Delphinidin	Flavonoid	nd
Epicatechin	Flavonoid	nd
Epicatechin gallate	Flavonoid	nd
Epigallocatechin	Flavonoid	nd
Epigallocatechin gallate	Flavonoid	nd
Ferulic acid	Phenolic acid	194.5 ± 18.47
Gallic acid	Phenolic acid	nd
Gallocatechin	Flavonoid	nd
Kaempferol	Flavonoid	16.5 ± 1.73
Kaempferol 3 glucuronide	Flavonoid	1.1 ± 0.03
Lutein	Carotenoid	nd
p-Coumaric acid	Phenolic acid	3.6 ± 0.31
Quercetin	Flavonoid	7271.7 ± 48.42

Quercetin 3 glucuronide	Flavonoid	4232.1 ± 185.36
Quercetin 3 sulfate	Flavonoid	3207.5 ± 101.96
Rosmarinic acid	Phenolic acid	nd
Rutin	Flavonoid	169.9 ± 4.89
Syringic acid	Phenolic acid	nd
Vanilic acid	Phenolic acid	15.1 ± 0.23
Class compositions		
Phenolic acid		1614.7
Flavonoid		14914
Carotenoid		53.3
Total		**16582**

nd, not determined.

3.3. Total antioxidant capacity

The antioxidant capacity of methanolic extracts from fresh dandelion flowers was assessed using the CUPRAC test. The CUPRAC method demonstrates that antioxidants reduce the cupric neocuproine [Cu^{2+} -Nc] complex, which shows maximum light absorption at 450 nm (Gülçin et al., 2020). The CUPRAC value of dandelion flowers was determined as 0.04 ± 0.0014 mmol TR per gram of fresh flower. The antioxidant capacity of dandelion can be attributed to the phenolic and flavonoid compounds found in its flowers. Many studies have reported that phenolic and flavonoid compounds possess antioxidant effects. The dandelion flowers analyzed in this study exhibit significant antioxidant ability, particularly due to chlorogenic acid, quercetin, caffeic acid and ferulic acid (Bender and Atalay, 2021; Apak et al., 2008; Gülçin, 2006; Bener et al., 2013).

4. CONCLUSIONS

In conclusion, assessing the bioactivity and conducting phytochemical screening of dandelion flowers is crucial for potential applications in food, pharmaceuticals and cosmetics. The phytochemical composition of dandelion flowers was described using UPLC MS/MS and GC-qMS/MS techniques. Scent aromatic analyses indicated that monoterpene hydrocarbon compounds 57% of the total profile in dandelion flowers. Approximately 83% of the monoterpene hydrocarbon compounds were composed of d-limonene. Conversely, the concentration of other terpene components, including oxygenated monoterpenes and sesquiterpene hydrocarbons, was minimal. The predominance of aldehyde group components was seen among the non-terpene components. Methanol extracts of fresh flowers were determined to be abundant in phenolic and flavonoid components. The predominant components among flavonoid compounds were identified as quercetin, quercetin 3 glucuronide and quercetin 3 sulfate. The CUPRAC assay demonstrated that extracts from dandelion flowers possess strong antioxidant activity. In conclusion, dandelion flowers may serve as an alternative source of natural antioxidants.

Ethics Committee Approval
N/A

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Ecological Rehabilitation of Saline Soils and Tourism Potential of Saline Plants: An Evaluation on Nature-Based Applications

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Abstract: Saline soils are an essential indicator of problems such as land degradation, desertification, and decreased productivity in Turkey and worldwide. However, rehabilitation of these complex ecosystems with suitable species carries the potential to produce alternative economic values in addition to ecological recovery. This study examines the environmental rehabilitation of saline soils with halophyte (salinophilic) plant species and the possible ecotourism and health tourism opportunities. Although Çankırı Salt Cave is an increasingly popular destination in the context of health tourism, the nature-based transformation potential of the surrounding saline soil areas has not yet been investigated. Some halophyte plant genera that can be naturally found in such areas or are known to be tolerant to salinity (*Salicornia, Atriplex, Tamarix*, etc.) stand out as taxonomic groups that have ecologically adapted to these environments. However, scientific data on the natural distribution of these species in Çankırı, their potential for rehabilitation purposes and their integration with tourism are limited. This situation reveals the need for research and planning in terms of both ecological restoration and botanical-based nature tourism. In this context, transforming salty areas into nature-compatible landscape designs and thematic walking trails can contribute to integrating nature-based solutions and sustainable tourism strategies at the local level.

Keywords: Saline soil, halophyte plants, ecological restoration, health tourism, Çankırı Salt Cave, sustainable land use

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1. INTRODUCTION

Saline soils represent a growing global environmental challenge, with significant repercussions for agricultural productivity, ecological sustainability, and socioeconomic stability. It is estimated that over 20% of the world's irrigated land is affected by salinity, resulting in significant reductions in arable land and posing a serious threat to global food security (Dong et al., 2022). This problem is particularly severe in arid and semi-arid regions, such as parts of Turkey, where soil salinization is intensifying due to climate change, inefficient irrigation practices, and high evaporation rates.

The economic implications of soil salinization are substantial. According to the United Nations, global economic losses resulting from salinity-induced land degradation are estimated at approximately $27.3 billion annually (Qadir et al., 2014; Turcios et al., 2021). These losses reflect both direct impacts, such as reduced crop yields, and indirect consequences, including decreased water quality, infrastructure deterioration, and limitations on industrial and domestic water supplies.
In addition to reducing the amount of cultivable land, salinity has profound effects on agricultural systems. It restricts crop choices, diminishes both the quantity and quality of agricultural output, and disrupts local biodiversity. Salinity stress also harms soil health and microbial activity, further degrading productivity. For many staple crops, yields in salt-affected soils are significantly lower, often achieving only 20–50% of their potential under optimal conditions (Shrivastava & Kumar, 2015).

Moreover, soil salinization jeopardizes the livelihood security of millions of people who depend on agriculture, especially in vulnerable regions. Its cascading effects on food systems, water availability, and land usability make it a critical barrier to sustainable development and climate resilience. The ongoing expansion of salinized areas worldwide underscores the urgent need for effective mitigation strategies and adaptive land management practices (Qadir et al., 2014). In addition to affecting agriculture, saline soils alter ecological processes by changing the chemical and physical properties of the land. These changes reduce soil fertility, limit water availability, and disrupt native plant communities, threatening biodiversity and ecosystem stability (El-Ramady et al., 2024). In response to these challenges, halophyte plants, species that thrive in high-salinity environments, have become a vital component of ecological rehabilitation strategies. Halophytes possess physiological and morphological

adaptations that enable them to tolerate saline conditions, regulate soil salt levels, and help restore degraded ecosystems (Ventura et al., 2024). Their potential in sustainable agriculture is increasingly recognized, providing new opportunities for crop production in areas prone to salinity (Tang et al., 2023).

The degradation of land due to salinity has widespread effects not only on ecological health but also on social and economic systems. Salinization negatively impacts soil microbial communities and nutrient cycling, making it challenging to maintain plant productivity (Ismayilov et al., 2021). Economically, the diminished viability of agricultural land forces local communities to either adopt costly reclamation strategies or abandon cultivation altogether, undermining rural livelihoods and long-term food security (Turcios et al., 2021). This situation calls for innovative, interdisciplinary solutions, particularly those that leverage the functional properties of halophyte species to rehabilitate land and enhance resilience against climate and land-use pressures (Wang et al., 2024).

In this context, halophytes serve not only as agents of bioremediation but also contribute to broader ecosystem functions. They enhance soil structure, support carbon sequestration, stabilize landscapes, and provide habitat for various species (Ismayilov et al., 2021). Their multifunctional values place them at the intersection of ecology, economy, and culture, especially within the framework of nature-based solutions (Ventura et al., 2024). These strategies aim to address environmental degradation while generating socio-economic benefits, including eco-tourism and health tourism.

The Çankırı Salt Cave in Central Anatolia, Turkey, is already a recognized destination for health tourism, particularly for respiratory therapies. However, the surrounding saline landscapes remain underutilized and unexplored in terms of their ecological and touristic potential. Native halophyte species naturally found in these areas (e.g., *Salicornia, Atriplex, Tamarix*) present a unique opportunity to integrate land rehabilitation with sustainable tourism practices. Nature tourism based on these ecosystems not only promotes biodiversity conservation but also provides economic incentives for local communities, aligning environmental protection with rural development (Luković et al., 2020; Vuković and Antić, 2019).

This study aims to review existing scientific literature on the ecological restoration of saline soils through halophyte-based approaches and to evaluate the potential for integrating these practices with nature-based tourism models, particularly in the context of the Çankırı Salt Cave region. By synthesizing interdisciplinary knowledge, this review seeks to contribute to the sustainable use of saline landscapes through ecological, economic, and culturally relevant pathway

2. MATERIAL AND METHOD

This study is structured as a literature review that aims to evaluate the potential for ecological rehabilitation of saline soils using halophyte plant species. It also explores how these landscapes can be integrated into nature-based and healthy tourism strategies. The review employs a qualitative synthesis of relevant academic publications, scientific reports, and grey literature. Literature was identified through systematic searches conducted in databases such as Google Scholar, ScienceDirect, Web of Science, and Scopus. The search process included combinations of keywords such as “saline soils,” “halophyte plants,” “ecological restoration,” “nature-based solutions,” “salt cave tourism,” “Çankırı Salt Cave,” and “sustainable tourism in saline areas.” Inclusion criteria focused on sources that were academic and directly related to soil salinity, halophyte ecology, restoration approaches, or tourism applications, published in either English or Turkish. Non-academic materials or sources lacking clear references were excluded from consideration. After selecting the relevant literature, the findings were thematically categorized into three core areas: (1) ecological features of saline environments and halophyte species, (2) the role of halophytes in rehabilitation efforts, and (3) opportunities for integrating saline ecosystems into sustainable tourism and landscape design. This methodology enables an interdisciplinary evaluation of how saline areas, especially those surrounding the Çankırı Salt Cave, can be transformed into ecologically and economically valuable landscapes through nature-based approaches.

3. CONCEPTUAL FRAMEWORK

3.1 Saline Soils and Halophyte Plants

Soil salinization refers to the buildup of soluble salts in the soil, which has negative impact on plant growth and overall soil health. This issue is primarily caused by both natural processes and human activities, such as improper irrigation practices, inadequate drainage, and poor land management (Ghassemi et al., 1995). Approximately 20% of the world’s arable land is affected by soil salinization, making it a significant challenge that undermines agricultural productivity and poses a threat to food security. Soil salinity presents a significant environmental

challenge globally with serious implications for agriculture, biodiversity, and ecological stability. The causes of salinization can be broadly categorized into natural and human-induced factors (Debez et al., 2010). Natural causes often include climatic factors such as aridity, high evaporation rates, and geological features that lead to the accumulation of soluble salts in the soil. In arid and semi-arid regions, high evaporation can result in saline water rising to the surface, leaving salts behind as it evaporates (Rahman et al., 2021). Meanwhile, anthropogenic activities, particularly irrigation with low-quality water, land mismanagement, and industrial processes, exacerbate soil salinity, leading to land degradation and reduced soil fertility (Mann et al., 2023).

In Turkey, salinization is notably prevalent in Central and Southeastern Anatolia, where semi-arid conditions and irrigation mismanagement contribute to land degradation and declining crop productivity (Akca et al., 2020). Globally, saline soils are found in over 100 countries, particularly across coastal zones, arid regions, and inland basins, affecting approximately 20% of irrigated lands (Vargas et al., 2018). Salinity directly inhibits plant growth by altering water availability and creating toxic environments for crops (Munns and Tester, 2008). The global economic implications of salinization are vast. An estimated annual loss of productive land due to salinization is projected to reach billions of dollars, disproportionately affecting countries with economies heavily reliant on agriculture (Vargas et al., 2018). In many instances, the agricultural interventions, including crop selection and management practices, exacerbate the situation, resulting in a feedback loop that exacerbates the salinity problem (Majeed and Muhammad, 2019). Monitoring of soil salinity in regions like the Keriya River basin demonstrates a complex interaction between soil type and salinity levels (Luo et al., 2021). Understanding the distribution and extent of these saline soils is vital for management and remediation efforts, especially given Turkey's agricultural reliance on these lands.

These saline habitats support a unique group of salt-tolerant plant species known as halophytes, which can survive and reproduce in high-salinity environments (Vaziriyeganeh et al., 2022). Halophytes, defined as plant species that thrive in saline conditions, play a crucial role in stabilizing saline soils and restoring soil fertility (Dölarslan and Gül, 2012). These plants possess unique physiological, anatomical, and biochemical adaptations that enable them to survive and proliferate in environments with high salt concentrations, such as coastal areas, salt marshes, and saline soils (Kumari et al. 2015; Hsouna et al., 2022).

The classification of halophytes can be divided into different categories based on their salt tolerance (Tong et al., 2023).
The modern classification of halophytes has evolved to incorporate not only salinity tolerance but also soil characteristics, groundwater depth, and specific phenological and reproductive traits (Hassan et al., 2020). Based on these criteria, halophytes are commonly divided into seven functional groups. Hyperhalophytes are species capable of thriving in extremely saline environments, typically with salinity levels exceeding 100 $dS \cdot m^{-1}$. Hydrohalophytes include species adapted to saline aquatic or wetland habitats, often tolerating salinity levels greater than 1000 ppm. Euhalophytes are typically found in saline deserts and marshes and are characterized by their capacity either to accumulate salt within their tissues or to excrete salt through specialized structures. The fourth group, haloxerophytes, comprises species that are well adapted to arid environments and can survive in habitats where groundwater is deeper than 4 meters. Halogemimesophytes, the fifth group, are plants suited to desert and semi-desert ecosystems, particularly along the margins of water bodies, exhibiting both xerophytic and mesophytic traits. The sixth group, halogemipetrophytes, consists of species capable of extending their root systems to depths of approximately 8 meters, allowing access to deep water sources in arid conditions. Finally, metahalophytes are distinguished by their high capacity to accumulate and tolerate heavy metals and ions, making them particularly valuable for phytoremediation and ecological restoration of contaminated saline soils (Jeschke and Wolf 1993; Toderich and Tsukatani 2007). This classification underscores the ecological diversity and adaptive complexity of halophytic species in response to varied environmental stressors. Key genera of halophytes such as *Salicornia, Atriplex*, and *Tamarix* exhibit a variety of adaptive traits that enable them to survive extreme salinity through mechanisms like ion compartmentalization and osmotic adjustment (Flowers and Colmer, 2008). For example, Salicornia species can accumulate high levels of sodium ions, which assist in their osmotic adjustment and facilitate overall survival in saline habitats (Shuyskaya et al., 2020).

Among the most studied halophyte genera are *Salicornia, Atriplex*, and *Tamarix*. *Salicornia*, commonly known as glasswort, is a succulent annual plant that relies on salt accumulation in vacuoles and tissue succulence to maintain osmotic balance (Flowers and Colmer, 2008; Piirainen et al., 2017). *Atriplex* species excrete salt through specialized glands and produce compatible solutes like proline and glycine betaine to regulate osmotic pressure (Cheeseman, 2014; Nikalje et al., 2017). *Tamarix* species, often found in the riparian and coastal zones, exhibit a high capacity for ion regulation and tolerance to drought and salinity, making them valuable for erosion control and land rehabilitation (Dang et al., 2013; Ksouri et al., 2011). These halophytes not only play a crucial role in maintaining ecosystem stability in saline habitats but also have practical applications in sustainable agriculture,

ecosystem restoration, and phytoremediation. Their physiological traits, such as selective ion transport, salt sequestration, antioxidant activity, and stress signaling, highlight their potential as model species for research on salinity tolerance and their role in mitigating the adverse impacts of soil salinization on food security and environmental health (Faustino et al., 2019; Liu and Esfandani-Bozchaloyi, 2022).

Physiological adaptations of halophytes reflect their evolutionary responses to saline environments. These adaptations encompass mechanisms such as the synthesis of osmoprotectants (e.g., proline), enhanced ion transport regulation, and specialized salt glands that extrude excess salts from the plant (Adhikari et al., 2019). Effective management of ions like potassium and sodium within halophytes is essential for their survival and optimal growth under high salinity (Nahar et al., 2016). As research advances, halophytes are increasingly recognized not only for their ecological importance but also for their potential in agricultural applications—acting as models for developing salt-tolerant crops and rehabilitating degraded lands (Hameed et al., 2024).

3.2 Use of halophytes in ecological rehabilitation

Halophytes are increasingly recognized for their vital role in ecological rehabilitation, particularly in improving saline soils and restoring degraded ecosystems. These salt-tolerant plants contribute to soil health, enhance biodiversity, and support various ecosystem services, making them indispensable to sustainable land restoration strategies. By boosting microbial activity and enhancing soil structure, halophytes influence critical nutrient cycling processes that are essential for the functioning of soil ecosystems. For instance, the cultivation of species such as *Atriplex* and *Suaeda* has been linked to increased bacterial richness and enhanced nutrient availability, thereby contributing to overall soil fertility and quality (Li and Liu, 2020; Gao et al., 2022). Their ability to stabilize soils also helps prevent erosion and encourages the establishment of vegetation cover, which are key components of successful land rehabilitation (Wortley et al., 2013).

Global restoration efforts have demonstrated the effectiveness of halophytes in diverse contexts. In Australia, for example, *Tecticornia* and *Sclerolaena* have been used to rehabilitate brine-affected soils, resulting in significant improvements in vegetation cover and soil conditions (Shaygan et al., 2018). Similarly, in southern China, projects that integrated native halophytes into restoration frameworks while addressing local livelihood needs achieved both ecological and socioeconomic benefits (Cao et al., 2017). Beyond their restoration functions, halophytes make significant contributions to ecosystem services, including carbon sequestration, erosion control, and biodiversity conservation. Their ability to grow in saline environments makes them ideal candidates for reclaiming unproductive lands and expanding the potential for both agricultural and conservation purposes (Nikalje et al., 2017). Additionally, many halophytes provide economically valuable products, including fodder, food, and bioactive compounds, aligning restoration efforts with rural development goals (Luković et al., 2020). Integrating halophytes into Nature-Based Solutions (NbS) frameworks further amplifies their value, as NbS promotes the use of biodiversity and natural processes to address societal challenges, such as food insecurity and climate resilience. For instance, incorporating halophytes into agroforestry systems enhances biodiversity, supports carbon storage, and improves soil health (Gupta et al., 2024). Strategically designed restoration initiatives that leverage the ecological capacities of halophytes offer a holistic approach to combating land degradation, fostering ecosystem resilience, and supporting sustainable livelihoods (Cao et al., 2017; Nikalje et al., 2017; Hameed et al., 2024). In this context, the multifunctional nature of halophytes underscores their growing relevance in addressing the global challenges of salinity, environmental degradation, and climate change.

3.3 Health and nature tourism potential in saline environments

Saline environments have been utilized for various health-related therapies, notably speleotherapy and salt therapy. Speleotherapy involves therapeutic treatments conducted in salt mines or caves and has been shown to alleviate respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD) through the inhalation of aerosolized salt particles (Crișan-Dabija et al., 2021). Research indicates that exposure to saline aerosols significantly improves respiratory function and enhances the overall quality of life for patients with chronic respiratory conditions (Oleksa et al., 2022). Similarly, salt therapy, which takes place in specially designed environments where patients inhale salt-infused air, has gained recognition for its effectiveness in treating various respiratory disorders and skin diseases such as eczema and psoriasis (Crișan-Dabija et al., 2021; Oleksa et al., 2022). These therapeutic practices are increasingly being integrated into holistic health regimens that capitalize on the natural benefits of saline environments.

Halophyte landscapes are not only ecologically significant but also possess aesthetic and recreational value. The unique beauty of these environments, characterized by vibrant plant species like *Salicornia* and *Atriplex*, can create visually striking biological communities that attract nature tourism. The diverse flora and fauna supported by saline

ecosystems enhance biodiversity and provide opportunities for recreational activities such as birdwatching, photography, and educational tours (Zhou et al., 2023). Such experiences promote mental well-being, given the restorative effects often associated with nature-based tourism (Raman et al., 2021).

The potential for nature tourism in saline environments is vast, particularly through thematic trails, botanical tours, and eco-landscaping initiatives. Creating thematic walking trails that showcase halophyte species, their ecological roles, and the unique characteristics of saline soils can offer educational experiences for tourists while fostering a greater appreciation for these often-overlooked environments (Zhou et al., 2023). Botanical tours focused on the health benefits of specific halophytes and their adaptations to saline conditions combine leisure with learning and enhance tourist engagement. Furthermore, eco-educational routes within saline environments can inform visitors about the importance of conservation and the role of halophytes in combating land degradation. This approach aligns well with sustainable tourism models that emphasize capacity building for local communities while preserving natural ecosystems.

Sustainable tourism initiatives in saline environments can yield multiple benefits, including environmental conservation, community empowerment, and enhanced visitor experiences. By adopting a framework that prioritizes ecological integrity, such as integrating halophytes into landscape management and tourism programs, the negative impacts of traditional tourism on fragile saline habitats can be minimized (Vanissa et al., 2020). Additionally, involving local communities in tourism initiatives can create economic opportunities while promoting environmental stewardship, ensuring that the benefits of tourism are equitably shared (Vanissa et al., 2020; Zhou et al., 2023).

From a sustainable tourism perspective, the integration of health and nature tourism in saline environments aligns well with the principles of conservation and sustainability. Evaluating tourism practices through the lenses of ecological impact, economic benefit, and community involvement is crucial for ensuring the long-term viability of these initiatives (Vanissa et al., 2020; Zhou et al., 2023). By prioritizing conservation and education alongside recreational experiences, nature tourism can positively contribute to both human health and environmental restoration.

In conclusion, the potential for health and nature tourism in saline environments is vast and multifaceted. The therapeutic properties of these unique ecosystems, combined with their recreational and aesthetic values, provide a promising foundation for developing sustainable tourism initiatives. Through well-structured programs focused on education, community engagement, and ecological preservation, saline environments can become valuable assets in the broader context of health tourism and environmental conservation.

3.4 Assessment of the potential of Çankırı salt cave and surrounding areas

Geotourism is an emerging concept within the tourism industry that promotes sustainable travel by highlighting geological and geomorphological features in natural landscapes (Ólafsdóttir, 2019). This approach not only emphasizes scenic beauty but also the touristic value of landforms, rock formations, minerals, and caves. In this context, the Çankırı Salt Cave in Turkey stands out as a key geotourism destination due to its unique salt composition and specific microclimatic conditions. These distinctive features also enhance their appeal in the health and wellness tourism sector, particularly because of the therapeutic environments that salt caves provide. Given the increasing global interest in alternative and nature-based tourism experiences, it is both timely and essential to assess the full tourism potential of the Çankırı Salt Cave.

The physical characteristics of salt caves, including stable air temperature (18–24ºC), moderate to high humidity (40–60%) which are conducive to respiratory health (Nugraha et al., 2024), and the presence of mineral aerosols, are known to contribute to their therapeutic effects (Endre, 2015). These environmental conditions create an ideal setting for treating respiratory conditions, such as asthma and chronic obstructive pulmonary disease (COPD) (Metel et al., 2023; Nugraha et al., 2024). Research has demonstrated that inhaling aerosols in salt caves can alleviate symptoms in individuals with respiratory illnesses, making speleotherapy (therapy using cave environments) a promising complementary health intervention (Smith et al., 2014; Kendrová et al., 2016). In regions like Eastern Europe, the tradition of utilizing salt caves for health purposes is well established and linked to positive health outcomes. These findings reinforce the therapeutic potential of the Çankırı Salt Cave and align with existing literature that supports the efficacy of salt therapies in managing chronic conditions (Horowitz, 2010; Smith et al., 2014).

Beyond its health benefits, the economic and environmental sustainability of the Çankırı Salt Cave can be enhanced through guided geotourism. Promoting eco-friendly tourism practices is essential for preserving the geological

heritage of such natural sites while supporting local economies. Research into effective tourism development models emphasizes the importance of striking a balance between ecological conservation and community engagement. These models advocate for responsible visitor management to prevent overuse and degradation (Kantor et al., 2016; Vuković and Antić, 2019). Furthermore, community-based tourism initiatives can foster local participation, reinforce cultural identity, and contribute to heritage conservation (Kantor et al., 2016).

In addition to respiratory health, there is growing recognition of the broader wellness benefits associated with salt cave therapy. Studies suggest that exposure to the calming environment of salt caves can help reduce stress and improve mental well-being, offering a holistic approach that integrates both physical and psychological health benefits (Horowitz, 2010; Kendrová et al., 2016). The tranquil atmosphere and sensory qualities of salt caves contribute to relaxation, enhancing their therapeutic value. In summary, the Çankırı Salt Cave represents a valuable natural resource with significant potential in both the health and tourism sectors. Strategic development should consider not only its medical and therapeutic benefits but also its role in supporting sustainable local development. As a case study, it exemplifies how health, ecology, and tourism can be successfully integrated to foster community resilience and environmental stewardship.

4. DISCUSSION AND CONCLUSIONS / TARTIŞMA VE SONUÇLAR

The ecological rehabilitation of saline soils and the integration of halophyte-based landscapes into sustainable tourism frameworks represent an interdisciplinary approach that aligns closely with global priorities for climate resilience, biodiversity conservation, and rural development. A review of the literature shows that halophyte species offer significant ecological value, especially in degraded, salt-affected environments where conventional plants struggle to survive. These plants not only help restore soil function and promote biodiversity, but they also provide important ecosystem services such as erosion control, carbon sequestration, and stabilization of microhabitats (Ismayilov et al., 2021; Gao et al., 2022; Ventura et al., 2024). Furthermore, their adaptability to harsh environments and multifunctional uses, ranging from fodder and bioactive compounds to landscape aesthetics and educational tourism, make them excellent candidates for inclusion in Nature-Based Solutions (Luković et al., 2020; Gupta et al., 2024).

Despite extensive international research on halophyte ecology and the rehabilitation of saline land, significant gaps remain in Turkey, particularly regarding the regional mapping of native halophyte species, their ecological roles, and their socio-economic applications. While the Çankırı Salt Cave is increasingly recognized for its therapeutic and geotourism potential, the surrounding saline environments have not been adequately explored.

Examining the broader implications of cave tourism on the environment reveals that such activities can lead to harmful changes in cave ecosystems, including pollution and habitat disruption (Aydın & Yüceer, 2020). Therefore, any tourism initiatives in Çankırı must take these environmental impacts into account and employ strategies that minimize disturbances to the local ecology, especially considering the unique microbial communities found in cave environments (Leuko et al., 2017; Pellegrini and Ferreira, 2016). Furthermore, integrating educational programs focused on the cave's natural features can enhance the visitor experience while promoting greater environmental awareness and conservation efforts. Interaction between tourism and local communities can further enrich this educational aspect. For instance, involving local populations in conservation discussions has the potential to improve both community well-being and ecological stewardship (Okonkwo et al., 2017). By leveraging local knowledge and culture, Çankırı Salt Cave can evolve from being just a passive tourist attraction into a vibrant part of the local heritage. Cave tourism also holds the potential for significant economic benefits. For example, the development of tourism at Agu-Owuru Cave in Nigeria has greatly contributed to local economies (Okonkwo et al., 2017). Çankırı can similarly capitalize on this potential by promoting its salt cave not only as a tourist destination but also by situating it within a broader geotourism framework that emphasizes preservation and ecological education. This approach mirrors strategies employed in successful cave tourism destinations worldwide, where the balance between visitor experience and environmental protection is carefully maintained (Zieliński et al., 2022).

Globally, several successful case studies illustrate how halophyte landscapes have been effectively restored and transformed into ecologically functional and economically valuable areas. For example, projects in Australia that implement *Tecticornia* and *Sclerolaena* (Shaygan et al., 2018) and community-based initiatives in southern China that integrate local livelihoods with native halophyte restoration (Cao et al., 2017) demonstrate scalable models for holistic landscape rehabilitation. In comparison, Turkey's saline regions, especially in Central and Southeastern Anatolia, hold untapped potential for similar applications, given their ecological degradation, tourism potential, and proximity to culturally significant sites like the Çankırı Salt Cave (Dang et al., 2013; Akca et al., 2020). However, implementing these strategies in Turkey faces challenges, including a lack of institutional coordination,

limited public awareness, and inadequate investment in nature-based and interdisciplinary approaches (Vanissa et al., 2020). Overcoming these barriers requires collaboration among environmental scientists, tourism developers, local authorities, and policymakers to co-design sustainable and inclusive strategies (Zhou et al., 2023).

Integrating halophyte-based restoration with tourism presents both strengths and limitations. On the one hand, this integration supports the diversification of rural economies, enhances ecosystem resilience, and promotes public education and environmental stewardship (Wortley et al., 2013; Nikalje et al., 2017). On the other hand, risks such as over-tourism, habitat disruption, and inconsistent policy support must be carefully managed through adaptive planning and evidence-based regulation (Kantor et al., 2016). Designing interpretive trails, botanical gardens, and educational signage within saline landscapes, especially near popular tourist destinations like the Çankırı Salt Cave, can serve as low-impact yet high-value interventions that promote both conservation and tourism (Zhou et al., 2023).

From a strategic standpoint, several key recommendations emerge for stakeholders. Policymakers should prioritize the inclusion of saline habitats and halophyte-based systems in national and regional land-use plans, supporting them with funding, technical guidelines, and cross-sectoral partnerships. Local authorities should invest in capacity-building and community-led tourism initiatives that align ecological restoration with cultural identity and economic development. Researchers should focus on field-based studies in areas like Çankırı to assess native halophyte diversity, monitor ecological impacts, and develop replicable restoration-tourism models. Collaborative frameworks involving universities, local governments, and civil society organizations can significantly enhance knowledge transfer and innovation in this field (Tang et al., 2023; Wang et al., 2024).

In conclusion, the ecological rehabilitation of saline soils and the strategic use of halophyte plants offer a sustainable and multifaceted approach to addressing land degradation, enhancing ecosystem services, and diversifying economic opportunities in regions like Çankırı. Integrating these approaches within a broader framework of nature-based planning and sustainable tourism can transform saline landscapes into ecological, educational, and recreational assets. As the impacts of climate change and land degradation continue to intensify, leveraging the ecological potential of halophytes, while ensuring local community benefits and environmental sustainability, represents a vital step toward resilient and inclusive regional development. Future research and policy must, therefore, focus on scaling nature-based, halophyte-driven interventions across Turkey's saline-prone regions, ensuring their alignment with global sustainability goals and local socio-ecological realities.

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Annual Changes in European Bee-eater (*Merops apiaster*) Migration Timing: The Case of Türkiye

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Abstract: The European Bee-eater (*Merops apiaster*) is widely distributed across Europe, North Africa, and Western Asia, and constitutes an important component of the Palearctic–Afrotropical migration system. Türkiye occupies a strategically important position for this species, functioning both as a breeding ground and as a key stopover site along its migratory pathway. This makes the region an ideal model system for studies on migration phenology. The present study aims to quantitatively assess long-term shifts in the spring (April–May) and autumn (September–October) migration timing of the European Bee-eater in Türkiye.

The dataset comprises 13,881 verified observation records of the species in Türkiye, collected between 1876 and 2025 and obtained from GBIF (accessed 21 May 2025). Following data cleaning, duplicate entries were removed and observation dates were converted to the Day of Year (DOY) format for analysis. For spring migration, the first observation day (First DOY) and mean arrival day (Mean DOY) were calculated; for autumn migration, the last observation day (Last DOY) and mean departure day (Mean Departure DOY) were determined. Time-series trends were analysed using linear regression, and migration period length was defined as the interval between the earliest and latest annual observation dates.

Results indicate that First DOY advanced by an average of –0.38 days/year, while Mean DOY advanced by –0.08 days/year. In autumn, Last DOY was delayed by +0.52 days/year, whereas Mean Departure DOY advanced slightly by –0.10 days/year. Overall, the migration period lengthened by +1.91 days/year. These findings suggest that earlier arrivals by pioneering individuals and delayed departures by a small number of individuals contribute to the overall extension of the migration period.

These phenological changes are likely driven by climate change, food availability, and variations in ecological conditions. The species' high ecological tolerance appears to be associated with its flexible use of both natural and agricultural habitats. Expanding long-term phenological monitoring and establishing bird research centres across Türkiye will be essential for the effective conservation of migratory species.

Keywords: Climate change, migration period, phenological shifts

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INTRODUCTION

The European Bee-eater (*Merops apiaster*) is a migratory bird species widely distributed across Europe, North Africa, and Western Asia, distinguished by its striking plumage and unique behavioral patterns (Stiels et al., 2021). As a long-distance seasonal migrant moving between the Palearctic and Afrotropical regions, it provides important ecosystem services and is sensitive to climate change and anthropogenic pressures. Consequently, it is regarded as a valuable biological indicator species (Hahn et al., 2019; Stiels et al., 2021).

With an insectivorous diet, the European Bee-eater has potential as a natural biocontrol agent of agricultural pests (Bastian & Bastian, 2023). Its burrowing behavior further qualifies it as an ecosystem engineer (Casas-Crivillé & Valera, 2005), as the tunnels it excavates for nesting enhance soil aeration and create microhabitats. However, the species has specific ecological requirements for breeding, roosting, and using stopover sites during migration, making it vulnerable to habitat alteration (Dell'Ariccia et al., 2020).

European Bee-eaters breed in Europe and western Asia, migrating to tropical central Africa for the winter. To complete their 4,000–6,000 km journey, they rely on strategically located stopover sites to replenish energy reserves. Türkiye, positioned at a biogeographical crossroads, serves as both a breeding range and a major migration corridor during spring and autumn. In particular, the southern coast and Central Anatolian Plain provide essential roosting habitats and food resources (Hahn et al., 2019).

In recent decades, climate anomalies, shifts in temperature regimes, and habitat fragmentation have driven significant changes in migration phenology (Dellwisch et al., 2022; Sapir et al., 2011). In some European populations, spring migration has advanced, while autumn migration has shifted towards later dates (Dellwisch et al., 2022). These temporal shifts have cascading ecological effects, influencing energy balance, breeding success, food availability, and predator–prey interactions (Sapir et al., 2011). Moreover, failed breeders have been observed departing as early as mid-July, whereas successful breeders often leave in late August to early September (Yosef et al., 2006).

In Türkiye, the Central Anatolia, Aegean, and Southeastern Anatolia regions are particularly important both as stopover sites during migration and as colonial breeding areas. Because migration timing can vary substantially from year to year, monitoring these changes is critical not only for understanding local population dynamics but also for gaining insights into the broader Palearctic–Afrotropical migratory system. Beyond its ecological value, the bee-eater's vivid coloration and distinctive behavior make it an attractive subject for birdwatching tourism, environmental education, and public awareness initiatives. However, its interactions with the beekeeping sector have led to its classification as a species of special concern and, in some areas, as an invasive species (Goras et al., 2023; Moreno-Opo et al., 2018), underscoring the need to balance conservation goals with human economic activities.

The objective of this study is to statistically assess long-term changes in the timing of European Bee-eater migration, with a particular focus on first arrival dates in Türkiye. While numerous long-term studies on the species' migration phenology have been conducted across Europe, few systematic multi-year analyses exist for Türkiye. Situated at the intersection of Afro–Palearctic migration flyways, Türkiye supports large numbers of both migratory and breeding bee-eaters, making it strategically important for monitoring seasonal movements. This study examines long-term phenological data from diverse ecological regions across the country and identifies annual trends in spring arrival and autumn departure dates.

MATERIALS AND METHODS

Data Collection

Data on European Bee-eater were obtained from the Global Biodiversity Information Facility (GBIF; accessed 21 May 2025). All records within the geographic boundaries of Türkiye were extracted, and only verified observations confirming the species' presence in the region were retained for further analysis, resulting in a total of 13,881 records.

Each record included latitude and longitude coordinates. Duplicate entries were removed using the dataCleaning() function. For the purposes of this study, the data from March to December were used.

Migration Analysis Methods

During spring migration, we determined both the mean arrival day (Mean DOY) and the first recorded arrival date (First DOY) for each year (Dinsbergs et al., 2023; Askeyev et al., 2023). For autumn migration, the departure date was defined as the end of the autumn/early winter migration period. Accordingly, we calculated the last day of the year with a record (Last DOY) and the mean departure day (Mean Departure DOY) following the approach of Mayror et al.

All analyses were conducted in Python 3 (van Rossum & Drake, 2009). The pandas library (McKinney, 2010) and numpy (Harris et al., 2020) were used for data processing and analysis, while matplotlib (Hunter, 2007) and seaborn (Waskom, 2021) were employed for data visualization. Observation dates were converted to Day of Year (DOY) format to allow cross-year comparisons. Separate spring and autumn subsets were created, and each was analyzed for temporal trends using linear regression on the time-series data. The direction of annual change (earlier/later) was determined from the sign of the regression slope, and coefficients of determination (R^2) were calculated. The least squares method was applied to estimate trend lines, and all figures were generated within the same Python environment.

RESULTS

Total Data and General Distribution

This study consists of 13,881 legitimate observation records of European bee-eater that drawn from GBIF. opiniojuris.org (May 21, 2025) These records span the breeding months and migration seasons of Türkiye which indicates their historical distribution as well as present one.

Consideration of seasonal distribution showed the highest number of entries in spring with 6,035 records. Next come summer with 4,179 records, and autumn with 3,654 records (winter features in just one observation). So, this pattern suggests that both migration and breeding phenology of the species is strong in spring followed by more gradual autumn migration period within Turkish borders. Because March, November and December were represented very little in the number of datasets available they were excluded from the analysis (Figure 1).

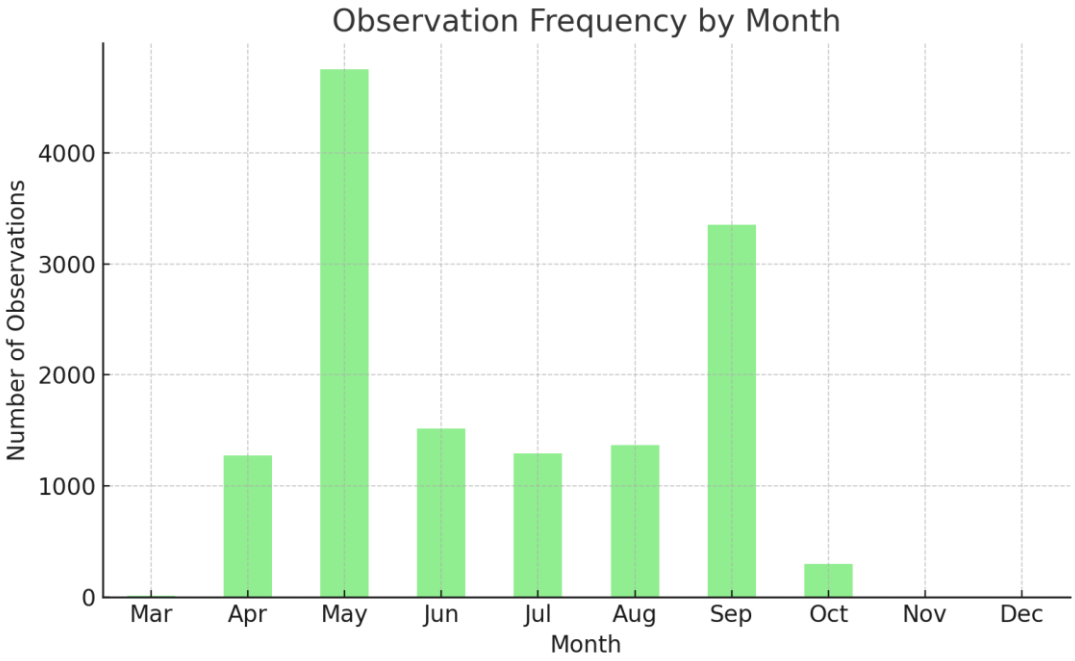

Figure 1. Number of European bee-eater observations by month

Marmara and Aegean regions were distributed in wide range, respectively (Figure 2) for the regional distribution analysis, however the Eastern Anatolia region, Mediterranean region, Southeastern Anatolia Region and Central Anatolia Region have shown dense observation numbers limitedly towards particular cities mostly then the Black Sea region with the lowest observation density.

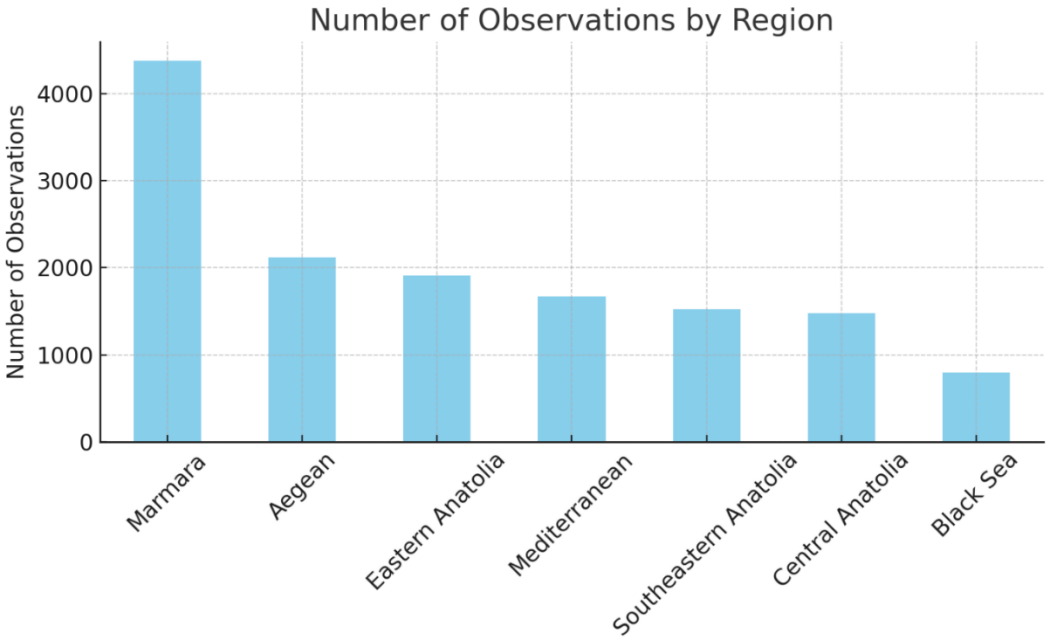

Figure 2. Number of European bee-eater observations by region

These assessments give a general view of the temporal as well as spatial timing of the European bee-eater breeding and migration periods in Türkiye which may be useful as an important reference for information on their ecological requirements.

Spring Migration Timing (April–May)

Based on the records between April and May from 1876 to 2025, the timing of spring migration was examined based on the observations of European bee-eater recorded within Türkiye as part of this study. The first sighting day and the average arrival day were computed on a yearly basis, and trends over time were analyzed using linear regression analysis.

Results demonstrate that first observation day values have advanced 0.38 days/year on average per year and this best-fit line accounts for approximately 48 % of the variation in seeding dates over the years. This is very obvious a trend that over time the first observations become increasingly early. Transmission mean day of arrival has also been advancing (average change of −0.08 days/year) but the explanatory power is modest (R^2 = 0.15). This indicates that the overall mean arrival day might move a little bit earlier but with much less influence on temporal variability (Figure 3).

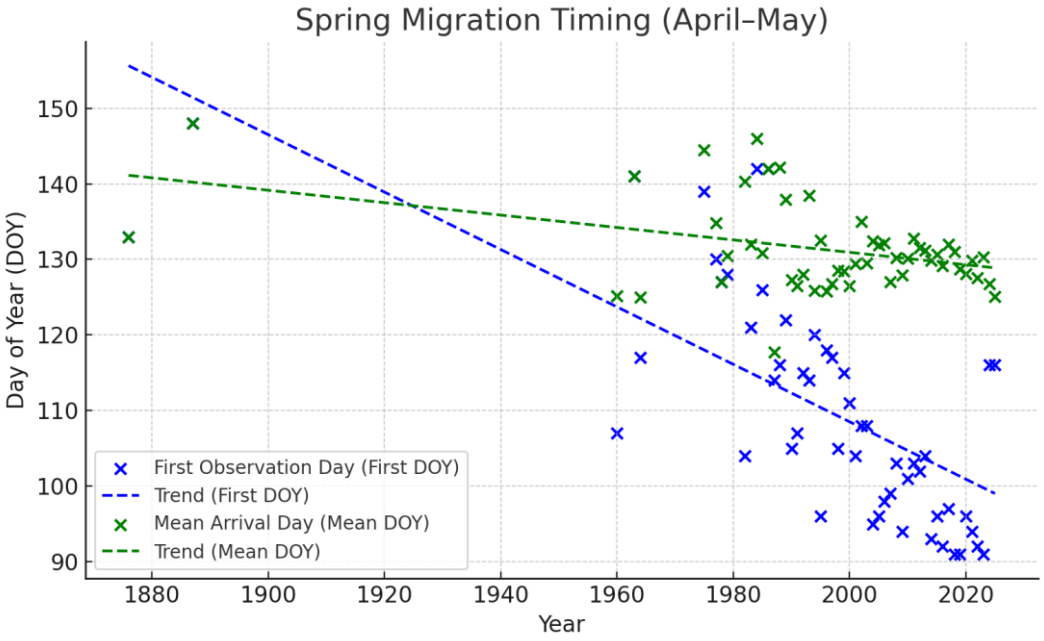

Figure 3. Timing of European bee-eater spring migration

Results The results show a consistent advancing trend of the onset date in spring migration through time, while the overall mean arrival date is weaker. This discrepancy could be due to the fact that the vanguard of migrant individuals tail more closely on climatic or ecological cues.

Autumn Migration Timing (September–October)

Using European bee-eater records from September and October between 1876 and 2025 within Türkiye's borders, the timing of autumn migration was analyzed. For each year, the last observation day (Last DOY) and mean departure day (Mean Departure DOY) were calculated, and these values were evaluated over time using linear regression analysis.

The results indicate that last observation day values have shown a delay over the years, at an average rate of +0.52 days/year ($R^2 = 0.31$). This finding suggests that the end of the autumn migration period tends to shift to later dates over time. In contrast, mean departure day values show a slight trend toward earlier dates, at an average rate of –0.10 days/year, but with very low explanatory power ($R^2 = 0.04$) (Figure 4).

These results indicate a partial delay in the end of the migration period, but no substantial change in the population's average departure time. Differences in early or late departure patterns may be linked to environmental factors such as climate variability, availability of food resources, and regional ecological conditions.

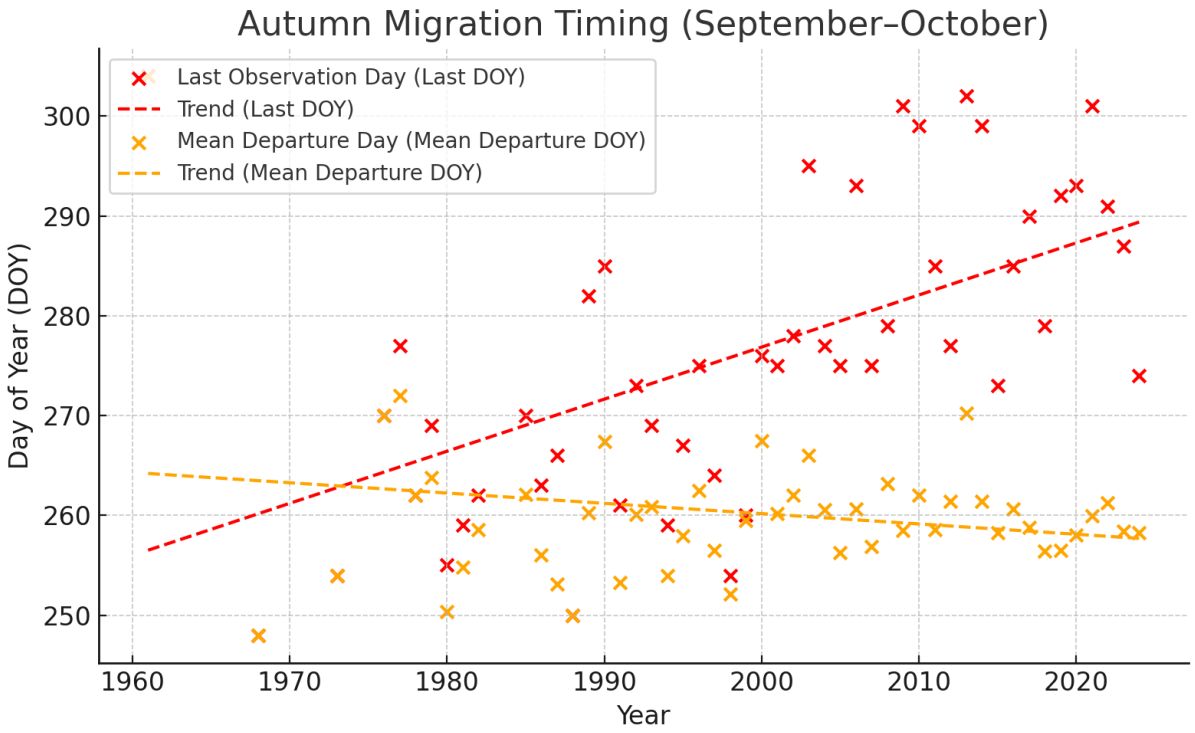

Figure 4. Autumn migration timing of the European bee-eater

Migration Period Length

Using data covering the April–October period for the European bee-eater, the annual migration period length was calculated. The difference between the earliest and latest observation dates in each year was defined as the migration period length.

The analysis results show that migration period length has increased over the years at an average rate of +1.91 days/year ($R^2 = 0.55$). This trend suggests that the migration period has been gradually lengthening over time (Figure 5).

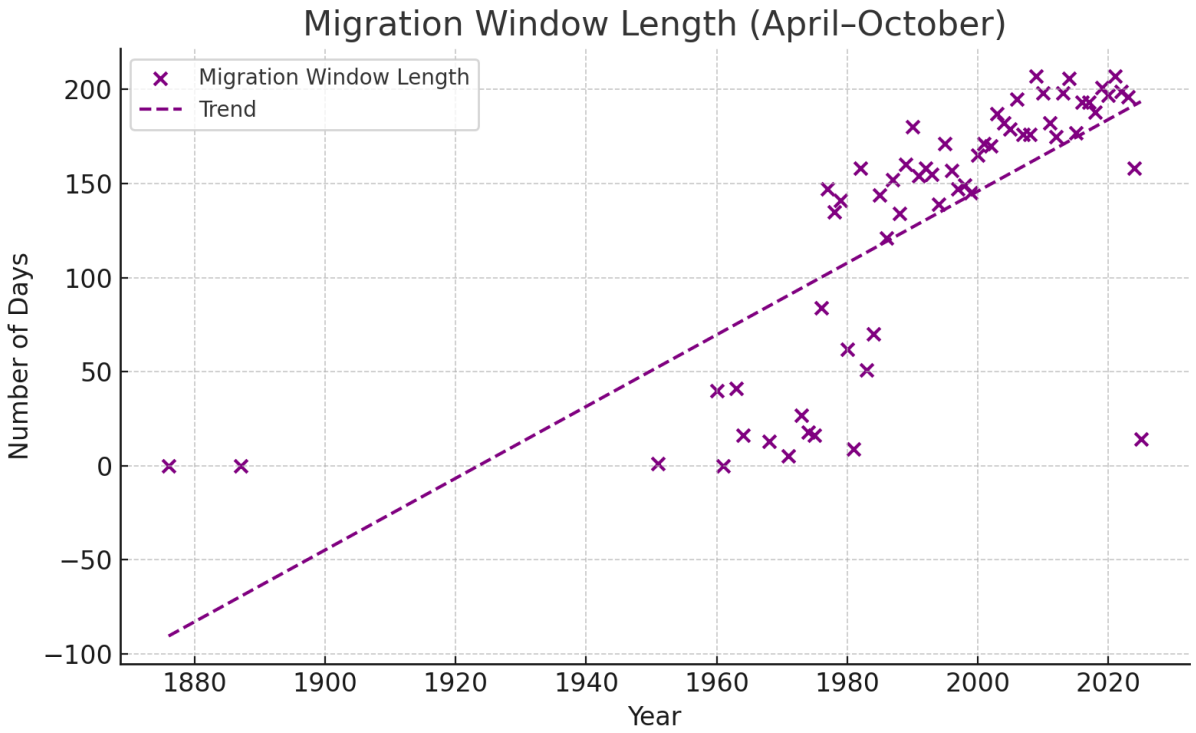

Figure 5. Migration period length of the European bee-eater

DISCUSSION AND CONCLUSION

The results of this study demonstrate that the migration phenology of the European Bee-eater in Türkiye has undergone significant long-term changes. The observed advancement of spring passage by –0.38 days/year suggests a contemporary trend towards earlier trans-Saharan migration, consistent with an expanding body of research linking shifts in migration timing to global climatic drivers (La Sorte et al., 2020; Nemes et al., 2023). Earlier studies have shown that pioneering individuals are often the first to respond to climatic cues, accelerating migration to capitalize on favorable breeding conditions (Hüppop & Hüppop, 2019; Gordo, 2007). The presence of this phenomenon in the Turkish dataset provides compelling evidence for early migratory movements along the Mediterranean corridor.

The relatively modest change in mean arrival date (–0.08 days/year) suggests that these shifts are primarily driven by a subset of individuals migrating much earlier, rather than by a uniform shift across the entire population. Nemes et al. (2023) reported that species expanding their range northwards tend to arrive earlier to align with earlier vegetation green-up, yet the overall population-level changes tend to be more conservative.

In autumn, Western European colonies of bee-eaters have been shown to delay their last observation dates by approximately +0.52 days/year (Chamberlain et al., 2000; Dellwisch et al., 2022), a pattern mirrored in our findings. Dellwisch et al. (2022) also noted that in some regions the autumn migration period has become delayed or lengthened. In our study, this contrasts with a slight advancement in mean departure date (–0.10 days/year), suggesting that the extended migration period is driven largely by a few late-departing individuals rather than by a population-wide delay. This pattern may be explained by extended parental care (Jenni & Kéry, 2003), high regional food availability, and relatively mild climatic conditions that enable some individuals to remain longer in a given area. The opposing directions in last observation date and mean departure date therefore point to variation in migratory strategies among individuals.

The observed annual increase in migration period length (+1.91 days/year) is largely attributable to earlier arrivals, with late departures also contributing to delayed last observations. However, the mean departure date indicates that this prolonged migration window is not the result of a uniform delay across the population, but rather of early arrivals combined with a small number of late departures. This deviates from the “both early arrival and late departure” model described in previous studies (Moussus et al., 2011; Thorup et al., 2017).

While these results are not definitive, they provide evidence that European Bee-eaters may be exhibiting increased plasticity in migratory timing as part of an evolutionary response to climate change. Végvári et al. (2010) and Stiels et al. (2021) noted the species' broad ecological tolerance, possibly linked to its eurytopic, hemibiotic nature, which allows it to inhabit both intensively managed agricultural landscapes and natural habitats. Nevertheless, the flexibility of migratory timing is likely constrained by factors such as climate change, habitat alteration, and shifts in seasonal food availability, and may emerge only under specific environmental conditions.

Long-term monitoring in Türkiye is essential to determine whether these phenological responses remain consistent over time or are themselves changing. Such efforts will enhance our ability to model future migration and breeding distributions under various climate change scenarios.

The empirical evidence presented here supports the conclusion that European Bee-eater migration in Türkiye has changed in both spring and autumn, albeit in opposite directions, ultimately leading to a prolonged migration season over the past 150 years. The observed earlier spring arrivals, partial delays in autumn departure, and overall extension of the migration period indicate that flexible timing strategies have evolved in response to climatic and environmental variability. However, these strategies are not uniform across the population, highlighting the need for region-specific ecological studies.

For the European Bee-eater, as well as for other migratory and resident bird species in Türkiye, collaboration with expert ornithologists and the establishment of adequately equipped bird research centers are essential. Migration studies require continuous, high-quality data collected by specialists over multiple decades to ensure accurate long-term monitoring and effective conservation planning.

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Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions
Conceptualization: H.S.; Investigation: H.S.; Material and Methodology: H.S.; Supervision: H.S.; Visualization: H.S.; Writing-Original Draft: H.S.; Writing-review and Editing: H.S.

Conflict of Interest
There is no conflict of interest to declare.

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United Nations Sustainable Development Goals in terms of Invasive Alien Species in Türkiye

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Abstract: The main purpose of this study is to examine the intersection between Invasive Alien Species (IAS) and the United Nations Sustainable Development Goals (SDG), focusing on the Turkish context. The relevance of IAS to the SDG targets has been identified particularly in the areas of ecosystem degradation, economic loss, negative impact on human health, international mechanisms and biodiversity loss. In terms of these five areas, the relevance level of IAS was found to be 41%. The impact of the IAS on 7 SDG in terms of five areas was found to be "high". Drawing on international literature and national policy frameworks, this study investigates the impacts of IAS on terrestrial and aquatic ecosystems, agricultural production, human health, and climate action. The research evaluates the legal and institutional framework in Türkiye, identifies existing gaps, and proposes strategic recommendations for enhancing IAS management through an integrated SDG approach.

Keywords: Biodiversity Loss, Invasive Alien Species, Ecosystem Degradation, Sustainable Development Goals.

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1. INTRODUCTION

The Millennium Development Goals (MDGs) announced in 2000 marked an important start in reducing global poverty and improving health and education services. However, the limited scope of these goals and their partial failure have highlighted the need for a more inclusive and holistic approach to development (De Jong and Vijge, 2021). Accordingly, the Sustainable Development Goals (SDG), adopted in 2015 under the leadership of the United Nations (UN), were shaped as 17 global goals that bring together environmental, social and economic dimensions. The SDG include concrete targets to end poverty, protect the planet and increase global prosperity by 2030 (SDG, 2025).

In recent years, Türkiye has strengthened its digital infrastructures, reorganized its institutional structures and prepared strategy documents on sustainable development in order to produce policies in line with these goals. The digitalization process, which has accelerated especially since the 2000s, has led to a significant transformation in public administration and service delivery (Bilbay, 2024; Çeliksoy and Akça, 2024). However, despite this transformation process, many areas in Türkiye where environmental threats should be systematically assessed within the SDG framework are still not sufficiently on the agenda of policymakers. One of these is invasive alien species (IAS) (Early et al. 2016).

IAS are a serious problem on a global scale, threatening native species communities, degrading ecosystem services, causing economic losses and negatively affecting human health (Essl et al. 2020; Gentili et al. 2021). However, the impacts of these species, especially on local biodiversity, are still largely uncertain and long-term observations are insufficient (Downey and Richardson, 2016). Moreover, the lack of information on IAS in marine environments is even more pronounced (Gentili et al. 2021). International literature emphasizes that invasive species have different levels of spread in different biogeographic regions of the world and that this spread poses a constant and increasing threat.

As Türkiye is located at the crossroads of the Euro-Siberian, Mediterranean and Irano-Turanian biogeographic regions, it is highly vulnerable to IAS pressure. This indicates that in Türkiye, IAS are a strategic threat not only to the environment, but also to economic and social development (CBD, 2023). The spread of IAS is particularly pronounced in sensitive ecosystems such as wetlands, forests and agricultural areas, shrinking the habitats of native species. In this context, SDG 14 (Life Below Water) and SDG 15 (Life on Land), which are among the SDG declared by the UN in 2015, directly focus on the problem of IAS and call on countries to take measures to prevent the introduction and mitigate the impacts of invasive species under target 15.8 (SDG, 2025).

However, despite the environmental conventions to which Türkiye is a party and the strategy documents it has developed, there has been no systematic assessment of the extent to which IAS management is compatible with

the SDG (IUCN, 2025). This points to a serious gap in policy development and implementation. Most of the existing studies in the literature treat IAS only as an ecological problem, ignoring the multidimensional relationship of these species with SDG.

This study examines the relationship between IAS and SDG targets in the case of Türkiye through thematic analysis and evaluates the level of these relationships through a scoring method. The aim of the study is to present the IAS-SDG interaction in a holistic and systematic manner, and to propose a structural framework that can provide data for policy making at the national level. In addition, the capacity of environmental policies, strategy documents and legal regulations in Türkiye regarding IAS management is critically analyzed. The findings obtained in this context are intended to enable comparative analyses not only for Türkiye but also for countries with similar ecological characteristics.

2. MATERIAL AND METHOD

This study employs a mixed-methods approach that integrates thematic analysis and qualitative content analysis, supplemented by a basic quantitative scoring technique, to examine the relationship between IAS and the SDG. The methodology is designed to first explore conceptual linkages qualitatively and then assess their intensity through an operationalized scoring model to enhance the analytical depth of the findings.

Thematic analysis, as defined by Braun and Clarke (2006), is a method for identifying, analyzing, and reporting patterns (themes) within data. It organizes and describes datasets in rich detail while also interpreting various aspects of the research topic. In this study, thematic analysis was employed to classify and interpret the IAS–SDG relationship through recurring ecological, socio-economic, and governance-related themes. The analysis was guided by international and national policy documents, scientific literature, legal frameworks, and biodiversity strategy reports. This approach allowed the extraction of thematic trends related to IAS impacts across different SDG dimensions, offering both descriptive depth and conceptual insight (Sandelowski, 2000; Toker, 2022).

In parallel, qualitative content analysis was utilized to systematically examine textual materials, such as legislation, international agreements, and policy strategies, by categorizing the presence, frequency, and contextual meaning of IAS-related terms. As described by Aziz (2015) and Alanka (2024), content analysis enables the quantification of textual meaning through the identification of latent patterns and deeper interpretative constructs embedded in language. This method is especially relevant for analyzing how different institutions conceptualize and respond to IAS threats within the broader sustainability agenda.
The data sources include:

- **Primary policy documents**, including the Ulusal Biyoçeşitlilik Stratejisi ve Eylem Planı and official reports from the Republic of Türkiye's Ministry of Agriculture and Forestry, the Ministry of Environment, Urbanization and Climate Change, and the General Directorate of Forestry;
- **Scientific literature** from peer-reviewed journals indexed in Scopus, Web of Science, and Google Scholar;
- **International databases**, such as those of the Food and Agriculture Organization (FAO), The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the International Union for Conservation of Nature (IUCN), and Convention on Biological Diversity (CBD); and
- **Legal reviews** covering Türkiye's national legislation as well as relevant European Union (EU) and UN conventions.

To further strengthen the analysis and facilitate comparability across SDG targets, a simple scoring system was developed. Each of the 17 SDG was evaluated based on five IAS impact dimensions[1]:

1. Ecosystem degradation,
2. Economic loss,
3. Adverse human health effects,
4. International mechanisms, and
5. Biodiversity loss.

[1] The 17 Goals of United Nations. https://sdgs.un.org/goals?utm_(accessed 19 Feb 2025).

For each SDG, relevant IAS examples were paired and scored according to how many of these five dimensions they addressed. SDG that aligned with at least three dimensions were retained for in-depth analysis and categorized by relevance intensity: Medium (3 points), High (4 points), and Very High (5 points). A final score was calculated by dividing the total points by the number of assessments conducted.

Altogether, this methodology enables a holistic evaluation of IAS–SDG interactions by combining interpretive richness with a structured assessment framework. The findings are discussed through an analytical content analysis lens, offering policy-relevant insights into how IAS pressures are embedded across sustainability governance dimensions. This mixed methodological structure aligns with the argument that qualitative approaches may inform future quantitative research and hypothesis generation (Hınız and Yavuz, 2023).

3. HISTORICAL BACKGROUND AND DEFINITION OF IAS

The concept of alien species can be traced back to early naturalists such as Augustin Pyramus De Candolle and Charles Darwin, who noted the presence and potential threat of non-native species outside their natural biogeographical ranges (De Candolle, 1855; Darwin, 1859; Pyšek et al. 2004). However, it was not until the mid-20th century that scientists began to understand the ecological risks posed by biological invasions (Elton, 1958; Macdonald ve Jarman 1984; Davis 2009). IAS are defined as species introduced by human activities outside their native range, which spread and cause harmful impacts on environment, economy, or human health (Pyšek et al. 2020). Historical observations of non-native species date back to De Candolle (1855) and Darwin (1859), but IAS-related ecological concerns rose after Elton's (1958) foundational work in invasion biology.

Charles Elton, often considered the father of invasion biology, described invasions as "ecological explosions" sharp increases in certain species populations within newly colonized habitats. Factors such as colonial expansion, global trade, and economic liberalization significantly accelerated the human-mediated spread of flora and fauna beyond their native ranges (Turbelin et al. 2017). After the 1960s, international conventions on IAS and scientific research conducted in this direction are also very important with the increasing concern for environmental protection. For example, conventions such as CITES, Ramsar, Bern, Paris, Bonn, CBD have an important place in shaping international legislation (Elvan and Birben, 2021; Elvan, 2022; Uyar and Elvan, 2024). The frequency of IAS introductions has surged over the past two centuries, with over one-third of initial entries occurring between 1970 and 2014 (Seebens et al. 2017). Recent studies have documented their impacts across all ecological levels from genetics to landscape dynamics revealing significant threats to native biodiversity (Kumschick et al. 2015; Lazzaro et al. 2020). According to the IPBES (2019), IAS are among the top causes of species extinctions globally. In addition to biodiversity loss, the most recent literature on IAS points out that these species have negative impacts on agriculture, ecosystem services and human well-being (including human health), ultimately causing serious economic problems (Pejchar ve Mooney, 2009; McGeoch et al. 2010; Paini et al. 2016).

When we examine the definition of IAS, we encounter many inclusive and incomplete definitions. In general terms, IAS are defined by major international organizations such as the CBD, IUCN, and the World Trade Organization (WTO) as species introduced beyond their natural distributions through human activity, which establish, proliferate, and cause ecological, economic, or health-related damage in their new environments (Pyšek et al. 2020; Essl et al. 2020). In addition, in another definition of IAS, it was pointed out that agricultural production would also be affected (CBD, 2025; IUCN, 2025). In addition, in Turkish legislation, alien and invasive species are defined in Articles 3 and 53 of the Regulation No. 25976 issued in 2005, and their negative effects on agricultural lands and domestic animals are also defined. These definitions emphasize that IAS are characterized not only by the fact that they move to a new area, but also by the harmful effects they have in those areas. These impacts can vary from degradation of ecosystems, extinction of native species, economic losses and threats to human health.

4. DEVELOPMENT PROCESS OF SDG PRINCIPLES

The definition of sustainability can first be explained in relation to the concept of development. The concept of sustainable development was first defined in 1987 in the “Our Common Future” report of the World Commission on Environment and Development (Brundtland Commission). In this report, sustainable development was defined as “development that meets the needs of the present generation without jeopardizing the ability of future generations to meet their own needs”. Based on this definition, it is understood that sustainable development requires a balance of continuity while meeting needs (Brundtland, 1987).

This concept was further reinforced at the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 and an action plan called “Agenda 21” was adopted. This plan presented a comprehensive roadmap covering issues such as environmental sustainability, economic development and social equity. Since the

Stockholm Conference, the Brundland Report and the UNCED held in 1992, significant progress has been made at the international, national and regional levels in defining, developing standards, promoting and implementing sustainable forest management (Şener, 2016).

In the definitions of sustainability, the starting point is to meet the needs of the present without compromising the consumption of future generations and to diversify the ways of meeting these needs (SDG, 2025). Within the framework of ecosystem management, sustainability means sustaining the combination of soil, water, air and biological assets and ecological processes, in other words, sustaining all elements and all relations of this multidimensional system (Geray, 1998).

In the context of setting more inclusive and universal goals, the idea of establishing SDG was put forward at the Rio+20 Conference in 2012 and the "2030 Agenda for Sustainable Development" was adopted by the UN General Assembly in 2015. This agenda includes SDG consisting of 17 main goals and 169 sub-goals. The SDG address the social, economic and environmental dimensions of sustainable development in a holistic manner by setting a wide range of targets such as eradicating poverty, combating hunger, quality education, gender equality, clean water and sanitation, and combating climate change. These goals emphasize the shared responsibility of all countries, with the principle of "leaving no one behind." (SDG, 2025) In order to keep the impacts of IAS under control, it is important to take action, particularly by identifying their direct relevance to SDG targets.

5. THE CONCEPTUAL DISTINCTIONS OF INVASIVE ALIEN SPECIES, INVASIVE SPECIES AND, ALIEN SPECIES

The field of invasion science discusses the actual impacts of IAS on native biodiversity, definitions of terms used, cost estimates of IAS impacts, and ethical and moral dilemmas regarding IAS control methods (Cassini 2020, Sagoff 2020, Shackleton et al. 2022). Furthermore, the positive contributions of non-native species to humans and nature are rarely considered and may need to be included in future conservation management plans to better guide policy (Gaiarsa and Bascompte 2022, Sax et al. 2022). Dueñas et al. (2018) and Barton and Fortunel (2023) noted that further research is needed to assess the impacts and extent of IAS interactions with Threatened and Endangered Species to reduce the high degree of uncertainty regarding the extent of IAS threats. Andersen et al. (2004) and, Green and Groshotz (2021) recommended quantifying interactions between IAS and native communities, including identifying the most problematic invasive taxa (Haines et al. 2024).

The terms alien species, invasive species, and invasive alien species are often used interchangeably, yet they differ significantly in meaning depending on scientific context and geographic or ecological application. These conceptual distinctions are crucial for effective biodiversity management and policy development. According to CBD (2014), an alien species refers to “a species, subspecies or lower taxon, introduced outside its natural past or present distribution; this includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce”. In contrast, an invasive alien species is defined as an alien species whose introduction and/or spread threatens biological diversity. It is important to note that species which were once native to a region but have since gone extinct are not typically considered alien if reintroduced, even after a long absence. This aspect underscores the temporal and historical dimensions embedded in these definitions. Given the potential for confusion, it is advisable that authors and policymakers explicitly clarify how such terms are used within a given context. This can be achieved either by providing explanatory phrases in the text (e.g., stating that “invasive” refers specifically to threats to biodiversity) or by including a brief note at the outset of relevant sections. Such clarification may often be more useful than a formal glossary definition, particularly in interdisciplinary or policy-oriented settings (CBD, 2014; 2025).

In terms of marine, inland and terrestrial invasive species, it is internationally recognized that very few marine species are yet known. The number of alien species in Türkiye's seas was 263 in 2005, 354 in 2011 and 539 in 2020, 105 of which are invasive. While the majority (72%) of the IAS in the Mediterranean Sea arrive via the Suez Canal, a significant proportion (78%) of the IAS in the Black Sea are transported by ships (through ballast water and by attaching to the bodies of ships). In Türkiye’s terrestrial environments and inland waters, 780 alien species were identified in 2021, 156 of which were invasive (Çınar et al. 2021; TOB, 2022; IPBES, 2023). Türkiye's domestic legislation also provides fragmented definitions. For instance, the 2005 regulation on the "Protection and Control of Wildlife and Their Habitats" distinguishes between "alien species" and "invasive species" but lacks an integrated definition of IAS. This distinction leads to inconsistencies in identification and intervention strategies across legal instruments.

The expansion of IAS, which is synonymous with invasive species, and their subsequent impacts are occurring more rapidly today than at any point in documented human history (Seebens et al. 2015, Early et al. 2016, Russell

et al. 2017, Leu et al. 2019, Costante et al. 2022). IAS are believed to be a serious threat to global biodiversity (Doherty et al. 2016, Bellard et al. 2017), with 25% of plant and 33% of animal extinctions attributed to IAS based on data compiled from the IUCN Red list database (Blackburn et al. 2019). In addition, islands have experienced more dramatic increases in IAS in comparison to Mainland environments and have become global hotspots of invasion (Bellard et al. 2016, 2017; Seebens et al. 2017; Moser et al. 2018). Terrestrial and aquatic systems host over 780 alien species, 156 of which are considered invasive (Uysal and Boz, 2018, TOB, 2022) (Table 1). Türkiye's geographical location at the intersection of three continents makes it highly vulnerable to invasive species (Çınar et al. 2021). Like alien species, species that are not only introduced to a region but also cause negative changes in terms of species, ecosystems and biodiversity in those regions are considered invasive (IPBES, 2023).

Table 1. Alien species found in terrestrial habitats and inland waters in Türkiye

	Alien Species	Invasive Alien species
Fish	23	11
Herpetofauna	1	1
Bird	9	9
Plant	450	107
Mammal	4	4
Invertebrate	293	24
TOTAL (number)	780	156

According to Table 1, it is noteworthy that especially bird, mammal and herpetofauna species have the same number of species on the dates referred to as alien species (AS) and IAS. As Türkiye is geographically surrounded by seas on three sides, it has different climates and ecosystems, which affects the distribution of IAS. In Turkish seas, the number of Mediterranean-origin IAS coming through the Suez Canal was 263 in 2005, while it was close to 500 in 2016. As of 2016, 25 AS were identified in the inland waters. The spread of these species threatens the populations of native species and disrupts ecosystem services (TOB, 2022). Marine IAS entries in Türkiye increased to 539 in 2020, 105 of which are classified as invasive, mainly via the Suez Canal and ballast water (Çınar et al. 2021).

6. RESULTS

Species like *Ailanthus altissima* (tree of heaven), *Myocastor coypus* (nutria), *Pomacea canaliculata* (apple snail), *Rhus typhina* (staghorn sumac) pose increasing risks to native flora, wetlands, and agricultural productivity. Türkiye's biodiversity and ecosystem services are under pressure, and existing response mechanisms lack coordination, data integration, and early warning systems These species not only threaten biodiversity, but also jeopardize Türkiye's liabilities under international conventions to which Türkiye is a party, for example; CBD, Bern Convention (IPBES, 2023).

The results are discussed under the following headings: general assessment of the 7 SDG that are directly linked to IAS, measurement of IAS SDG Relevance Level, assessment of the legal situation in Türkiye, current policies in Türkiye and an overview of the current status of combat strategies.

6.1. SDG - IAS Relationship and General Assessment

The 7 SDG identified as relevant to IAS are analyzed below (Hulme, 2009; Kumsar and Kaya, 2021; CBD, 2023). These goals (SDG 2, 3, 6, 13, 14, 15 and 17) were evaluated in the context of IAS using a scoring method.

SDG 2 (Zero Hunger): IAS threaten food security by negatively affecting agricultural production. For example, weeds entering agricultural areas reduce crop productivity, while pests can damage crops. This leads to economic losses (e.g. expenditures on weed control) and food insecurity, especially for subsistence farming communities. Identified as a target with a high risk factor (McGeoch et al. 2010; Paini et al. 2016; IPBES, 2023; CBD, 2025; IUCN, 2025).

SDG 3 (Good Health and Well-Being): Some of the IAS can cause the transmission or spread of diseases that directly threaten human health (vectors, zoonoses, etc.). For example, vector species such as mosquitoes play a role in the spread of diseases such as malaria and dengue fever. There are also plant and animal species that cause

allergic reactions or poisoning (Pejchar and Mooney, 2009; Pyšek and Richardson, 2010; Medlock and Leach, 2015; Pyšek et al. 2020; Essl et al. 2020; Gentili et al. 2021).

SDG 6 (Clean Water and Sanitation): IAS are capable of contaminating water sources and disrupting aquatic ecosystems. They can also threaten drinking water supplies. For example, plants such as water hyacinth (Eichhornia crassipes) cover the water surface, reducing oxygen levels and negatively affecting water quality. This can disrupt water supply and sanitation services. In particular, in freshwater sources, invasive fish species threaten native fish populations (Çınar et al. 2021; TOB, 2022; IPBES, 2023; CABI, 2023; SDG, 2025).

SDG 13 (Climate Action): While climate change can increase the spread and impacts of IAS, IAS can also affect the carbon storage capacity and resilience of ecosystems. Changing climatic conditions allow some IAS to spread to new regions, and IAS can also negatively impact efforts to combat climate change by damaging ecosystems with carbon storage capacity. IAS can displace native species by taking advantage of climate change-induced habitat shifts. For example, in forest ecosystems, invasive plants inhibit carbon uptake by suppressing native vegetation (Hellmann et al. 2008; Bellard et al. 2016; IPBES, 2023; Haines et al. 2024).

SDG 14 (Life Below Water): Marine invasive species threaten ecosystems and fisheries. Threats to marine and freshwater ecosystems are multifaceted. IAS entering marine and freshwater ecosystems reduce biodiversity by competing with native species. For example, the sea walnut (Mnemiopsis leidyi) in the Black Sea has negatively affected fish populations by consuming zooplankton (Gherardi, 2007; Çınar et al. 2021; TOB, 2022).

SDG 15 (Life on Land): IAS' impacts on forests, wetlands and other natural areas can take 3-4 times longer than the average human lifespan to reverse. The degradation of forest ecosystems can disrupt terrestrial life cycles, with consequences such as biodiversity loss and habitat destruction. IAS in terrestrial ecosystems threaten native species in forests, grasslands and other habitats. For example, while a species causes terrestrial habitat destruction in a country where it is invasive, interestingly, the same species may be endangered in its native range. This raises new concerns about both sustainability and the fight against terrestrial/aquatic invasives (IPBES, 2023; Haines et al. 2024).

SKA 17 (Partnership for the Goals): Delay in combating IAS severely reduces the chances of success. Local knowledge and public awareness can be effective in detection. Cooperation with other countries should be made if necessary. Especially cross-border cooperation and information sharing with neighboring countries is critical (IUCN, 2025). To ensure the effectiveness of national and international mechanisms, cross-border information sharing and scientific solidarity against IAS are necessary. It is critical for Türkiye to work with neighbors in the Black Sea and Mediterranean biogeography (Early et al. 2016; IPBES, 2023).

The 7 determined SDG (Figure 1) were assessed in terms of 5 criteria (ecosystem degradation, economic loss, negative impact on human health, international mechanisms, and biodiversity loss) and scored for relevance as shown in Table 2. As can be understood so far, the IAS characteristics that pose obstacles to achieving success in the SDG have been evaluated objectively in terms of the general framework, with reference to literature and legal sources. It is expected that this assessment will be confirmed by statistical measurements in future research and become a separate scientific output.

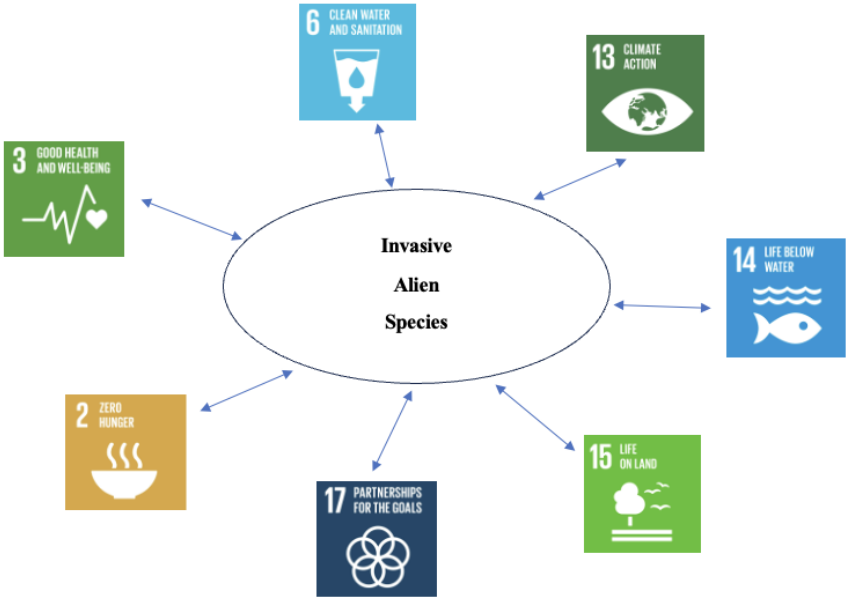

Figure 1. SDG for which IAS were found to have above medium level of relevance in the context of 5 identified topics

When the SDG were evaluated in terms of 5 criteria related to IAS, a level of interest was found as 3 medium, 2 high, 2 very high. The table showing the IAS scoring and their potential impact on SDG achievement is as follows:

Table 2. SDG relevance in terms of 5 criteria

SDG Goal	Impact	IAS Relevance Level	Example IAS and Impact
SDG 2	Economic (Agriculture)	Medium	*Ambrosia artemisiifolia* reducing crop yields (Pyšek and Richardson, 2010).
SDG 3	Human Health	High	*Aedes albopictus* vectoring zoonotic diseases like West Nile virus (Medlock and Leach, 2015).
SDG 6	Ecosystem (Water Quality)	Medium	*Pomacea canaliculata* degrading freshwater habitats (CABI, 2023).
SDG 13	Climate & Habitat Resilience	High	IAS benefiting from shifting climate zones, reducing ecosystem carbon storage (Hellmann et al. 2008).
SDG 14	Marine Biodiversity	Very High	*Mnemiopsis leidyi* altering food chains in the Black Sea (Gherardi, 2007).
SDG 15	Terrestrial Biodiversity	Very High	*Ailanthus altissima* affecting forest regeneration in Mediterranean ecoregions (CBD, 2014).
SDG 17	Institutional Cooperation	Medium	Need for transboundary IAS management with regional stakeholders (Early et al. 2016).

When the level of relationship between IAS and SDG is measured, it is seen that IAS are an ecosystem concern worth thinking about, and improving. According to the data in the table:

- 3 **Medium** → 3 × 3 = 9
- 2 **High** → 2 × 4 = 8
- 2 **Very High** → 2 × 5 = 10

Total = 9 + 8 + 10 = 27

Total SDG count = 3 + 2 + 2 = 7

Mean = 27 ÷ 7 ≈ 3,86

Result: **Above average** → This is approximately the **"High"** level.

SDG and IAS were found to be more than medium relevant. The weighted average of these values (based on a 3–5 point scale) indicates a high relevance score of 3.86. This highlights IAS as a substantial obstacle to achieving SDG targets, especially in biodiversity and climate-related goals.

First of all, 7 out of 17 SDG were found to be directly relevant to IAS. This represents 41% target alignment. The relevance of these directly related SDG was assessed by a simple measurement and found to be high. In other words, it is predicted that when measures are taken on IAS, especially in terms of these 7 SDG, which correspond to approximately half of all SDG, it will be more successful in terms of biodiversity and ecosystem protection

7. LEGAL STATUS OF IAS IN TURKIYE

The naturally or man-made introduction of wild animals and plants into Türkiye can be inadvertent or deliberate. Wild animals and plants can move out of their past or present natural habitat, either directly or indirectly through human activities. Species introductions can occur through transportation, tourism, aquaculture, etc. through negligence, while intentional introductions can also occur through illegal methods. A species, subspecies or sub-taxon (variety, race, etc.) and a part, gamete, seed, egg, etc. of it.; survives, breeds and reproduces outside its past or present natural distribution area due to human impact. In this way, these species harm biodiversity (TOB, 2022; IPBES, 2023).

With the increasing pace of climate change, IAS are disrupting the health of the ecosystem, negatively affecting biodiversity and ecosystem services as well as human health and quality of life. Rapid detection/assessment/intervention is crucial in the fight against IAS. IAS have been identified as the second most common threat associated with the complete extinction of species since 1500 (Bellard et al. 2016). The eradication, control, preventing the spread; and stopping the reproduction of IAS is of great importance not only for biodiversity and ecosystem services, but also for human health, economic and social aspects (Uyar, 2022).

In Turkish legislation, Invasive Species is defined in Article 3 of the "Regulation on the Protection of Hunting and Wild Animals and Their Habitats and the Procedures and Principles of Controlling Pests" numbered 25976 published in the Official Gazette of the Republic of Türkiye in 2005: Invasive species; "Refers to species that harm nature, other species, human health and economy" however the concept of IAS is not used together. Again, in Article 3 of the Regulation, alien species is defined as "Species that do not occur naturally in the nature of Türkiye but come from outside and species that have been taken out of their natural distribution area within the borders of Türkiye". In other words, invasive and alien species are defined separately. In Article 31 of the Regulation, the institutions responsible for the management and administration of the identified alien species and the actions to be taken are stated, and it is determined that this is a definition that will cause these species to be seen only in the class of exotic species, although they are not invasive. Article 36 of the Regulation includes the preparation of a justification report for the invasiveness of native or alien species to be introduced into nature. Article 53 of the Regulation covers the combat against invasive species and research on invasive species (Mevzuat, 2025). In a scientific analysis of invasive plant species in Brazil, it was noted that the lack of clarity in the definition limits the effectiveness of research: "The ambiguity in the definition of IAS limits knowledge and research in this area" (Fachinello et al. 2022).

7.1. Current Policies and Combating Strategies in Türkiye

Türkiye's IAS governance is fragmented across multiple legal instruments. When the domestic law of Türkiye is analyzed . The framework and secondary legislation on IAS is determined as: Forest Law No. 6831, Fisheries Law No. 1380, Environmental Law No. 2872, National Parks Law No. 2873, Customs Law No. 4458, Anti-Smuggling Law No. 5607, Land Hunting Law No. 4915, Biosafety Law No. 27533, Protection of Cultural and Natural Assets

Law No. 18113, Implementation of the Convention on International Trade in Endangered Species of Wild Fauna and Flora Regulation No. 24623, Protection of Hunting and Wild Animals and Their Living Areas, Procedures and Principles for the Fight Against Their Pests Regulation No. 275976, Leasing in Water Products Production Regulation No. 31290, Atatürk University Biodiversity Application and Research Center Regulation No. 30418, Wildlife Protection and Wildlife Development Areas Regulation No. 25976, Wildlife Protection and Wildlife Development Areas Regulation No. 25637, Entry Into and/or Circulation within the Country of Plants, Herbal Products and Other Substances and Harmful Organisms for the Purpose of Scientific Research, Experimentation and Variety Improvement Communiqué No. 2014/59, Biological Monitoring Communiqué No. 30808, Arrangement of Fisheries for Commercial Purposes Communiqué No. 2024/20, 6/1. When the mentioned legislation is examined, it is seen that there is no specific regulation on IAS.

As one of the successful legal practices, there are EU legal practices that Türkiye could take as an example. According to the research on the recent regulation update; in the EU 88 IAS are strictly regulated, 47 animal species of Union concern, 41 plant species of Union concern (EU Regulation, 2014). Over the past five decades, the global human population has more than doubled, consumption has tripled, and international trade, despite regional disparities, has increased nearly tenfold. This acceleration in the world economy has intensified both the pace and magnitude of numerous direct and indirect drivers, particularly those related to trade, travel, and changes in land and sea use. As a consequence, the risk and frequency of biological invasions have significantly increased (IPBES, 2023).

Legal reviews reveal that Türkiye's approach to IAS is fragmented. While IAS-related provisions exist in environmental, forestry, customs, and fisheries laws, there is no unified framework explicitly defining and governing IAS. International commitments such as CITES, CBD, Bern, and Ramsar are legally binding but underutilized in practice (Elvan and Birben, 2021; Elvan, 2022; Uyar and Elvan, 2024).

In addition, when the issue is examined from the perspective of international conventions, there are deficiencies in Turkish legislation. For example, it is considered that Türkiye becoming a party to the Bonn Convention would be a good step for the protection of biodiversity (Uyar and Elvan, 2023). It is seen in the conventions to which Türkiye is a party that IAS are not effectively implemented in domestic law. It is also seen that Article 8 (h) of the Convention on Biological Diversity, to which Türkiye is a party, imposes responsibilities on signatory states regarding IAS. Although there is no explicit regulation on IAS in Turkish legislation, it is possible to state that the CITES Convention is the most important legal regulation that provides control over the movement of IAS between countries.

CITES is not just a trade convention; it works to protect the endangered species that are subject to trade. It is important to look at the issue with an awareness of the protection of natural assets. It is crucial to conduct international research to reduce global concerns and to help countries implement the Convention with better performance. For this reason, it is obvious that increasing the success of CITES implementation and always making improvements will be a more effective legal practice than issuing a new law or regulation (Uyar, 2022).

In Turkish legislation, IAS are not directly regulated by a provision in the Constitution, but are related to indirect articles such as Articles 56 and 169 on environmental protection. There are basic laws that are the basis for issues related to the habitats of invasive species. However, there is no clear and concise definition of IAS in the laws, and IAS is defined in the regulations in an incomprehensive manner. In other words, it has been observed that it is not dealt with in a way that expresses the importance of sanctions. Apart from this basis, since international conventions have the force of law for Türkiye, effective international projects have been carried out by relevant institutions and organizations (TERIAS, MARIAS). Nevertheless, there is an insufficient level of IAS agenda, and it is seen that efforts should be increased to improve both administrative structuring and legal infrastructure.

8. DISCUSSION AND CONCLUSIONS

IAS present not only an ecological threat but also a complex, cross-sectoral challenge that affects public health, food systems, ecosystem services, trade, and climate stability (IPBES, 2023). In the context of Türkiye, effective governance of IAS is instrumental in achieving SDG, particularly SDG 14 (Life Below Water) and SDG 15 (Life on Land), and in making meaningful progress on health (SDG 3), food security (SDG 2), climate action (SDG 13), and international partnerships (SDG 17).

This study revealed that SDG 14 and 15 exhibit a “very high” relevance to IAS; SDG 3 and 13 show “high” relevance; and SDG 2, 6, and 17 fall within the “medium” relevance category. The average alignment score between IAS and relevant SDG was calculated as 3.86 on a five-point scale, indicating a high degree of

interdependency. This classification offers a foundational framework for prioritizing policy action, enhancing national SDG performance metrics, and guiding future monitoring efforts.

As the role of SDG in preventing and managing IAS becomes clearer, national governments are more likely to respond with integrated policies. Under SDG 17, the engagement of diverse sectors, including environment, agriculture, forestry, border control, tourism, health, trade, and community development, is essential for achieving sustainable and coordinated outcomes (Rahel et al. 2008, Seebens et al. 2015, Jewell and Fuller 2021; IPBES, 2023). In Türkiye, policy instruments such as the 11th Development Plan, the National Biodiversity Strategy and Action Plan (UBSEP), and action plans from the General Directorate of Forestry provide a guiding framework. However, gaps in institutional capacity, financing, and inter-agency coordination persist.

IAS-related impacts are especially pronounced in Türkiye due to its unique biogeographical position at the intersection of three continents. This location facilitates the spread of IAS through trade, tourism, and agricultural corridors, with disproportionate effects on sensitive ecosystems such as wetlands, forests, and farmlands. Rodents (*Rattus spp.*), wild boars (*Sus scrofa*), feral goats (*Capra hircus*), invasive fish (e.g., *Lepomis* and *Micropterus*), and plant genera such as *Schinus, Rubus*, and *Psidium* are identified in the literature as globally problematic taxa (Haines et al. 2024). These species also pose risks to Türkiye's native flora and fauna. Therefore, IAS management in Türkiye should be addressed not only from environmental but also economic (Marbuah et al. 2014), institutional and legal aspects (Seebens et al. 2015, Jewell ve Fuller 2021, Hofstadter et al. 2022, Lieurance et al. 2023).

To address these risks, this study endorses the application of the IUCN "Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species" which advocate for prevention as the most cost-effective measure, followed by eradication, containment, and long-term ecosystem recovery. Priority should be given to ecologically sensitive zones, ports of entry, and island ecosystems. Management plans must be transparent, publicly accessible, and regularly updated, with clear identification of target species, methods, and timelines. Where eradication is not feasible, containment strategies should be emphasized. Furthermore, the effectiveness of interventions must be evaluated not merely by population reductions of IAS, but by measurable ecological improvements in native species, habitats, or ecosystem services (IUCN, 2025).

From a legal perspective, a significant deficiency lies in the absence of a scientifically grounded and operational definition of IAS in Turkish legislation. The ambiguity in terminology, such as the interchangeable use of "foreign" and "invasive", contributes to delayed interventions. A dedicated regulation that clearly defines IAS, designates responsible authorities, and outlines preventive and reactive actions is urgently needed. This should be supported by ethical eradication protocols, public awareness campaigns, and inter-ministerial coordination frameworks (Biswas et al. 2018; Haines et al. 2024; IUCN, 2025).
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Technological and statistical tools can further support IAS monitoring and policy implementation. Correlation and regression models, time-series analyses, and spatial performance scores can be generated using statistical software such as R and Python, along with packages like Pandas, Matplotlib, and Tableau. These tools can quantify the progress of biodiversity-focused SDG and reveal spatial distribution patterns, outliers, and institutional performance differentials (Baker and Bode 2021, Eppinga et al. 2021, Engelstad et al. 2022). Box plots and distribution maps, for example, may effectively highlight national variation in SDG 14 and 15 indicators.

To advance policy coherence and institutional responsiveness, Türkiye should integrate IAS priorities into its national legal frameworks and SDG strategies. Lessons can be drawn from global best practices, such as the New Zealand biosecurity model or the European Code of Conduct for Botanic Gardens on Invasive Species (Heywood and Sharrock, 2013; New Zealand, 2025). International agreements like the Convention on Biological Diversity (CBD) should be implemented through national action plans that emphasize early warning systems, real-time border monitoring, and transboundary cooperation.

Importantly, the negative impacts of some IAS may only become apparent decades after initial introduction. Therefore, current observations likely underestimate future damage. However, these impacts are not inevitable; they can be prevented or mitigated through evidence-based governance, early intervention, and coordinated international support (IPBES, 2023). A better alignment between the SDG agenda and IAS prevention efforts will help to unlock financial, technical, and diplomatic instruments available through the UN system. Enhanced cooperation will ultimately contribute to the preservation of global biodiversity and the success of ecosystem-based sustainable development.

As a final note, universities, which generate the bulk of scientific data, should be encouraged to improve SDG-aligned performance metrics through standardized reporting tools and shared datasets. Incentives for SDG-aligned

academic output would foster stronger engagement from the scientific community. IAS remain under-addressed in international forums. Clearer references in UN declarations and policy documents could act as a catalyst for national institutions, particularly in biodiversity-rich countries like Türkiye, to adopt more proactive and strategic responses.

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The importance of relationship between traditional and digital on education

ORTENCA KOTHERJA[1]

Abstract: The relationship between traditional and digital approaches in education plays a crucial role in shaping the well-being of students. Both methodologies, when integrated effectively, can support students' mental, emotional, and academic well-being in different ways. Here's an explanation of their importance: Digitalisation, or the integration of digital technologies into workplace operations, has significantly changed how employees work and interact with each other and their environment. The concept of traditional education has changed radically within the last couple of years. Teaching is an interactive process, which mainly includes the classroom conversation that takes place between the teacher and the student. Teachers of every educational level have begun to use technological tools that effect on broad information that have to explain their pupils, students. This paper aims to explain the important of integration between traditional and digitalized education and their impact over education. This study will briefly explain the major developments occurred in digitized education and its impacts on wellbeing in education. The result of the study show that the connection between traditional and digital teaching is very important on nowdays because this help pupils, students to be more focused on obtaining information, improved communication, provide easier access to information and multimedia resources, and allow for personalized and differentiated learning experiences ect.

Keywords: education, digital education, wellbeing education

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1. INTRODUCTION

The school as an educational institution occupies a special place in the formation of the civic values of students, their preparation to face challenges, the ability to exercise their rights and responsibilities, to live in a multicultural society, to be active and responsible in life and in society. Teachers play an important role in the learning process of students who in most cases try to be copies of their teachers. They are the main basis in the development of a country as they create a strong foundation of knowledge in the younger generations that enable continuous achievement and success. They are perhaps the most important group of professionals for the future of our country, so it is worrying when you think that many of teachers are dissatisfied with their work. Due to the great changes that our country has undergone in time, both in terms of politics and economy, or even since Pandemic, the school has had its own changes to these developments. Along with its physical changes, the concept of teaching has also changed. An important and very fruitful element that affects their professional development and growth is the teaching method. Traditional learning methods mean the physical presence of students, teachers or lecturers. Digital education replaced traditional education by giving the opportunity to receive information even if you are not physically in the classroom or auditorium. Traditional teaching methods over the years and even today have shown effectiveness and productivity in the educational development of individuals of all age groups, promoting active engagement.

Digital technologies have made a fundamental change in the entire education system. It ensures that information is received in a direct way through the visual way as well as receiving information and not being physically in the classroom. Instead of using pen and paper, students today use various software and tools to create presentations and projects. Yusuf.M.O (20005) state that learning through digitization has become an evolutionary way of the educational institution with choice and demand that has a lot of potential to improve and increase the knowledge of students, and to motivate them to take productive information Yusuf, M.O.(2005).

1.1. Traditional and online learning

Traditional methods are based on schools, print media and physical presence of both teachers and students. Digital education is coming and replacing traditional education. People want to know what is happening around them, how and why it is happening. The modern world has moved from the information society to the knowledge society. Educated students became the vulnerable assets of their state. Teaching methods in higher education have changed a lot in recent years. Much more information on any topic is available on internet sources like Google, Wikipedia and YouTube. Online education has created a great variety of information, courses, online training which creates

a very large level of comfort for a large number of individuals who work and are educated in different sectors and institutions. New teaching methods have been developed and the place of traditional education is taken by information obtained through digitization. This great variety of information and new technology increased the availability of education for the rest of the world. Various studies from various researches of researchers claim that university levels all over the world are focusing on their online education. System (Huila M and Ramsauer C) . Traditional classroom instruction does not provide an immediate learning environment, faster assessments, and more engagement. On the contrary, education through digitization manages to complete the problems or information in a shorter time. Some of the efficiencies that such technologies provide are simply unmatched by traditional learning methodologies. Schools and educational institutions to have a more productive teaching should use both traditional and technological methods efficiently, putting the theoretical aspect and the practical aspect using technology in the classroom. Indeed, the adaptability and non-intrusive nature of today's technology make learning more attractive to the next generation. Student learning can be made more dynamic and engaging by presenting classroom tasks through both verbal and visual communication.

1.2 Interaction between traditional and online learning

Digital advances help educators to reduce desk work by replacing textbooks or tablets with all the academic data they need. Students also increasing their clear benefits. The globalization of education has already necessitated the application of digital technologies. With digital technology in education, it creates a productive and developmental environment both in terms of the curriculum and in the delivery of information by bringing developmental educational models. Digital learning is a teaching strategy that uses technology to fulfill the entire curriculum and allows students to learn in an active and understandable way. So education is essentially a type of communication that has expanded the possibilities for transmission and access to educational information. The use of the challenges faced by the technological aspect in terms of teaching and the importance of adaptation should not be underestimated, but it should be observed in such a way that the information given is clear for students, since the technological aspect has a very wide development and use.Tallvid (2015) say that teachers must realize the practical aspect of digitization within the standards of their work practices. Digital education is different from traditional education. This education emphasizes the development of science and innovation, which includes the visionary aspect and the development with information of the cognitive aspect. According Testov.V.A (2017) digital education is only a development of traditional education that presented to researchers a couple of years ago . So is very imoportant to do a connection between tradicional learning with dixhital learning.

1.3 Traditional and digital learning on wellbeing in education.

With the use of digital education, education has become more fun for all levels of age groups studying. at university levels Sushchenko L, Gladysh M, Zubtsova Y, Sushchenko R and Kniazian M (2020). It should be emphasized that digital education is a development of traditional education. Digital learning is making students, students more motivated as the demand to get as much new information as possible has made them more interested in receiving instructions in the classroom. Various studies have shown that digital learning manages to improve motivation and responsibility in students Soares A P, Wunsch L P and Junges K D (2018) . Both types of education have their importance and the way students receive information is based on the techniques and strategies that teachers use as well as the students themselves.. Both types of education they are important and require a very close connection between them. Traditional learning is often related to our way of life Uglov V V, Varlamova I Y, Chistyakov A V, Vasilenko P G, Semaeva O V, Shumakova S Y and Khmeleva A O (2020) and on the other hand advanced education serves to keep in touch with the world and to perceive what is happening. The main aim is to use teaching methods to help the educational change and to understand the best strategies and conditions of the educational aspect of the students. as they acquire new thoughts and knowledge in learning Gillen J and Kucirkova N (2018). Education to be as integrated as possible should focus on the procedure of educational plans of digital media and the educational aspect adapted to traditional education.

Conclusion and Recommendation

Learning is a very important process in the life of each of us. The way that information is transmitted is very important. Learning is a context with information about different and specific issues which is taken in different forms both directly and digitally. traditional teaching methods with hands-on activities and face-to-face interactions promote the development of soft skills, including interpersonal skills, that can only be developed through in-person classroom experiences and in the other hand digital education offer interactivity, engagement, and individualized, adaptive learning. Finding a balance is crucial for both traditional and digital approaches to teaching and learning that suggest that the optimal strategy is the incorporation of digital technologies and

traditional strategies to explain the lesson. The quality of teaching is achieved based on a balance based on educational goals and situations.

Recommendation

- Educational changes must be specific in the way teachers are aware of their relationships with students in order to improve their learning approaches.
- Teachers should continue to help students become active members as well as creators of their own imaginations and encourage physical contact in the classroom, which directly affects social cooperation.
- should be done more studies to lectors to see their knowledge of development on technology. This should help to focus the training in the real difficulties.
- Identification of techniques and strategies for a better combination of techniques and strategies that focus on traditional and digital education.

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Development of Diameter Distribution Models for Brutian pine Stands. A Case Study from Antalya Region

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Abstract: This study aims to model the diameter distribution of natural Brutian pine (*Pinus brutia* Ten.) stands located within the boundaries of the Antalya Regional Directorate of Forestry. Due to its flexibility in representing stand structures and its suitability for biological variables, Johnson's S_B distribution was employed. Both 3-parameter and 4-parameter recovery methods were applied to construct the diameter distribution models. Data were obtained from 61 sample plots distributed across various ecological conditions in Antalya region. The performance of the models was evaluated using the Kolmogorov–Smirnov (K–S) test and the Error Index (EI). The findings indicate that although the 3-parameter method provided lower error values in some cases, the 4-parameter recovery approach generally produced more accurate estimates. The mean EI values were calculated as 15.61 for the 3-parameter method and 14.47 for the 4-parameter method. These results demonstrate that Johnson's S_B distribution can be effectively utilized to model the diameter distribution of Brutian pine stands in Antalya and to support forest management and silvicultural planning processes.

Keywords: Johnson's S_B, diameter distribution model, Brutian pine, Antalya.

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1. INTRODUCTION

Forests constitute the most extensive component of ecosystems and play a vital role in ecological balance, carbon sequestration, and biodiversity conservation. From the perspective of forest science and management, Türkiye has demonstrated significant progress in sustainable forest planning and silvicultural practices. According to the Intergovernmental Panel on Climate Change (IPCC), Türkiye is among the few countries that have achieved a net increase in forest cover in recent decades through effective afforestation, reforestation, and forest rehabilitation strategies (Allen et al., 2018).

The adoption of the Ecosystem-Based Functional Planning (EBFP) approach in 2008 marked a pivotal shift in Türkiye forest management policy. This planning paradigm emphasizes the sustainable utilization of forest resources by necessitating comprehensive and reliable data on all components of forest ecosystems. Among these components, individual trees and forest stands are of paramount importance. For effective implementation of EBFP, the development of dynamic growth and yield models specific to tree species within the planning area is crucial. These models support long-term projections and inform decision-making processes aimed at sustainable forest operations (Huang et al., 2000).

One of the most critical foundations of growth and yield modeling is the diameter distribution of forest stands (Cao, 1997; Cao, 2004). Forest managers often require estimations of the number of trees within specific diameter classes, as tree diameter strongly influences the potential end-use of harvested wood products and the expected economic returns from different timber assortments (Gorgoso et al., 2007; Gorgoso et al., 2014). Furthermore, diameter distribution provides essential insights into stand structure, age composition, and regeneration status—factors that are vital for planning silvicultural interventions.

Tree diameter is also a key determinant in operational forestry, particularly in selecting appropriate harvesting equipment and optimizing wood transportation logistics. Therefore, accurately estimating the diameter distribution enhances the reliability of stand-level growth and yield predictions, ultimately contributing to more consistent and applicable forest management plans. Forest management decisions are inherently tied to the current and projected future status of forest resources (Zhang et al., 2003). Given that tree volume and other key attributes are directly related to diameter, diameter distribution serves as a fundamental descriptor of stand characteristics (Bailey & Dell, 1973). Over the years, various probability density functions (PDFs) have been employed to model diameter distributions in forest stands, including the log-normal, exponential, gamma, beta, Johnson's S_B, and Weibull

distributions (Liu et al., 2014; Diamantopoulou et al. 2015). Each of these functions offers distinct advantages in representing the structural complexity and variability observed in natural and managed forest ecosystems.

Numerous studies have demonstrated the effectiveness of various probability density functions (PDFs) in modeling diameter distributions across diverse forest types and regions (Pogoda et al., 2019; Vega et al., 2022; Rijal & Sharma, 2023). Schmidt et al. (2019) modeled the diameter distributions of *Eucalyptus* stands in Minas Gerais, Brazil, using the Weibull distribution (Miranda et al., 2018). Their study examined the behavior of this distribution in relation to stand age, site quality (bonitet class), and stand density. Similarly, Ciceu et al. (2021) developed diameter distribution models for uneven-aged mixed stands in the southwestern Carpathian region of Romania. Their findings indicated that the Weibull distribution provided the most accurate representation of the stand structures. In Türkiye, recent studies in Türkiye have demonstrated the effectiveness of advanced statistical distributions in modeling tree diameter variability across diverse forest types. Özçelik et al. (2022) developed diameter distribution models for mixed oak stands in the Bilecik region, incorporating *Quercus cerris*, *Q. petraea*, and *Q. frainetto*, and found that the cumulative distribution function (CDF) regression using the Weibull distribution—particularly with the D90 percentile—provided the most accurate results. Expanding on this, Özçelik et al. (2023) assessed Johnson's S_B distribution in natural *Cedrus libani* forests of the Mediterranean region, revealing that over 77% of the stands diameter distributions conformed well to the S_B model when parameter recovery methods were applied. Similarly, Özçelik et al. (2022) employed Johnson's S_B distribution in the Taurus cedar forests of Antalya and demonstrated its capacity to capture highly skewed and irregular diameter structures characteristic of uneven-aged stands. Complementing these findings, Sönmez et al. (2021) successfully modeled the diameter distribution of pure *Picea orientalis* stands in eastern Türkiye, confirming the S_B model's robustness even in relatively homogeneous conifer formations. The importance of diameter distribution in terms of forestry has been demonstrated by many national and international scientific studies (Stankova & Zlatanov, 2010; Calzado & Torres, 2013; Bolat, 2015; Alkan, 2019; Pogoda et al., 2019; Rijal & Sharma, 2023;). Different methods have been developed today. Johnson's S_B method is a distribution model that has individuals in different diameter classes and produces successful results for natural stands. Therefore, it was aimed to develop diameter distribution models with 3 and 4 parameter, parameter recovery method of Johnson's S_B for natural and pure Brutian pine stands in Antalya region.

2. MATERIAL AND METHOD

2.1. MATERIAL

Brutian pine commonly known as Turkish red pine, is the most widely distributed coniferous tree species in Türkiye, covering approximately 5,854,673 hectares, which corresponds to around 27% of the country's total forested area (GDF, 2020). Of this total area, 3,207,914 hectares (55%) are classified as productive high forest, while the remaining 2,646,759 hectares (45%) are categorized as degraded forest lands. The global distribution of Brutian pine is shown in Figure 2.1 (Euforgen, 2024). According to the 2020 forest inventory conducted by the General Directorate of Forestry (GDF, 2020), the standing volume of Brutian pine within these forested areas was reported as 161,654,231 m^3, with an annual increment of 5,011,582 m^3. Although Brutian pine forests represent the dominant conifer resource in Türkiye, they currently contribute only a minor portion to the country's total resin production. However, a significant portion of existing Brutian pine stands are biophysically suitable for resin tapping, suggesting an underutilized economic potential in this regard (Boydak, 2004; Şentürk, 2008; Atalay et al., 2014).

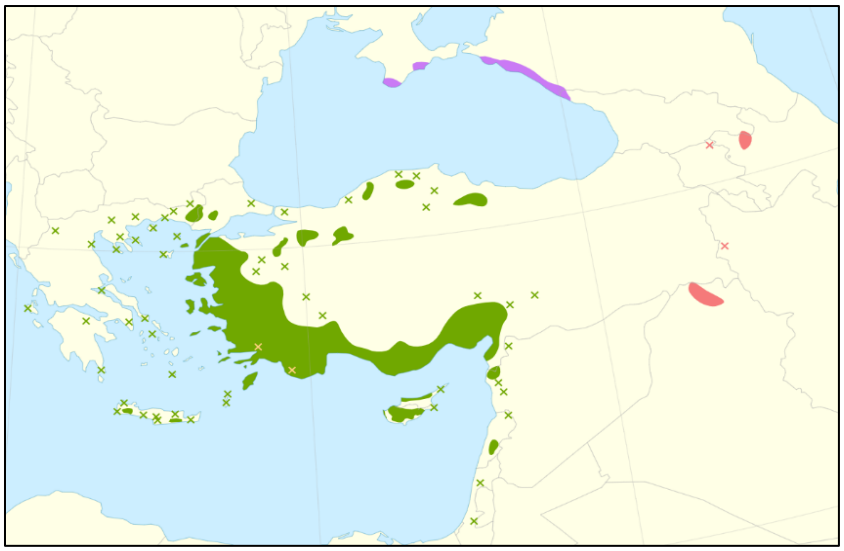

Figure 2.1. Distribution of Brutian pine in the world

In addition to its widespread distribution across Western Anatolia and the Mediterranean region, Brutian pine is also found in small, isolated patches within microclimatic zones where Mediterranean climatic conditions are distinctly observed. These include areas such as the confluence of the Kelkit and Yeşilırmak rivers near Erbaa, as well as Ayancık, Sinop, Boyabat, Amasya, and Zonguldak (Şentürk, 2008; Atalay 20). The species exhibits its most extensive distribution along the Mediterranean coastal belt, its immediate hinterlands, and parts of Southeastern Anatolia. Brutian pine is capable of thriving at elevations up to 1200 meters and stands as the most widely distributed pine species in Türkiye (GDF, 2020).

In the sample plots, the dbh (diameter at breast height) of all trees were measured from two perpendicular directions. The dbh of the subject tree was found by taking the average of these pairs of diameters measured from 1.30 m. In addition, the averages of some stand and distribution variables were calculated for each sample plot. These variables were; mean breast diameter ($\bar{d}$), squared mean breast diameter (d_g), number of trees per hectare (N), breast area per hectare (G), minimum diameter (d_{min}), maximum diameter (d_{max}), median diameter ($d_{0.50}$) and dominant diameter D_0 were calculated. The descriptive statistics such as mean, minimum, maximum and standard deviation for all these variables are given Antalya region in Table 2.1.

Table 2.1. Descriptive statistics for sample plots

Variables	Mean	Min	Max	S. D
$\bar{d}(cm)$	21.32	11.5	43.06	6.37
d_g	22.87	11.4	53.46	8.36
$d_{0.50}$	25.38	10.88	54.00	10.88
$D_0(cm)$	34.34	17.00	62.60	8.69
$d_{min}(cm)$	11.07	8.00	32.00	5.03
$d_{mak}(cm)$	45.55	18.00	60.00	11.82
N	697	125	1200	278.48
$G(m^2/Örnek\ alan)$	25.55	9.84	54.36	9.21
Plot size	600.00	400.00	800.00	163.29

This diameter distribution model effectively captures the relationships among different diameter metrics and clearly reflects the underlying structural characteristics of the stand. While minimum diameter values are concentrated within a narrow range, mean and median diameters exhibit a broader spread, indicating greater variability in central tendencies. Maximum diameter, on the other hand, shows a positive correlation with other variables, reaching relatively higher values. Notably, the mean diameter (d_{ort} (mean of diameter) and d_{med} (median of diameter)) emerges as the most consistent indicators of homogeneity within the diameter distribution (Figure 2.2).

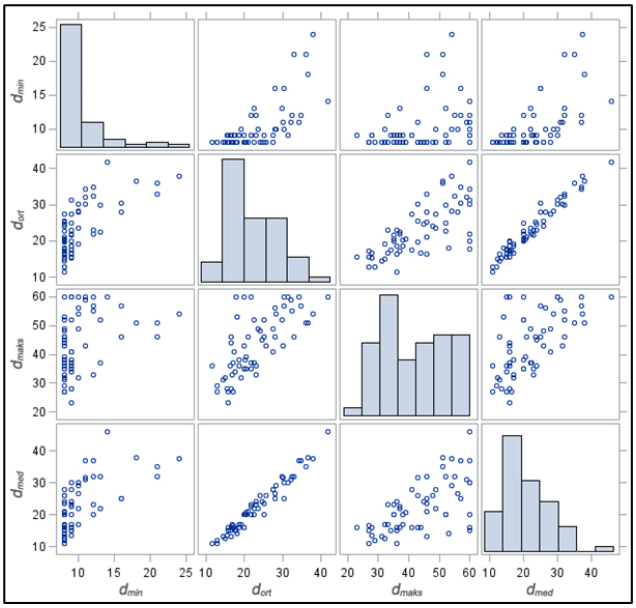

Figure 2.2 Correlation matrix between diameter variables in Antalya region

2.2 METHOD

The Johnson's SB probability density function (PDF) is a component of the distribution system developed by Johnson (1949). The Johnson distribution family comprises three subtypes: SU, SL, and SB, designed respectively for unbounded variables, variables bounded on one side, and variables bounded on both sides. For a random variable X, the Johnson's SB PDF is defined as follows:

$$f(x) = \frac{\delta\lambda}{\sqrt{2\pi}(x-\xi)(\xi+\lambda-x)} exp\left(-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\xi}{\xi+\lambda-x}\right)\right]^2\right), x \in (\xi, \xi+\lambda) \qquad \textbf{(Eq. 1)}$$

Here : $\lambda, \delta > 0,\ -\infty < \xi < \infty,\ -\infty < \gamma < \infty.$

The parameter λ represents the scale, ξ represents the lower bound, and δ and γ are shape parameters. The value γ =0 indicates symmetry.

The SB distribution possesses two important characteristics that make it particularly suitable for representing biological variables. First, due to its bounded nature (ξ as the lower and $\xi + \lambda$ as the upper limit), it ensures that estimates remain within the physical and natural range of the data. Second, the two shape parameters provide considerable flexibility to model a wide variety of distribution shapes (Furtado, 2006; Fonseca et al., 2009). Parameter estimation for Johnson's S_B distribution can be performed using several techniques, including the percentile method, maximum likelihood estimation (MLE), linear and nonlinear regression, and the method of moments. Many of these methods require at least one distribution bound to be predetermined. Although Johnson's S_B distribution has not been as widely applied in forestry as other models, it has been tested for diameter distribution modeling, particularly in stand growth and yield models. However, some parameter estimation methods suffer from drawbacks, such as a lack of coherence between stand-level estimates and derived distribution parameters, and a weak correlation between stand characteristics and parameter variability—especially for shape parameters like γ, which tend to show a poor relationship with stand age. Nonetheless, parameter recovery approaches have demonstrated more successful results (Scolforo et al., 2003).

A general strategy for solving the SB PDF involves reducing the full four-parameter model to a two- or three-parameter version. This is often done by directly estimating one or both of the location (ξ) and scale (λ) parameters from the observed data, while the remaining shape parameters are estimated using methods such as percentiles or moments. Scolforo et al. (2003) proposed a moment-based method to estimate the shape parameters. Parresol (2003) introduced a percentile-moment hybrid method to jointly estimate the scale and shape parameters. Alternatively, parameter recovery models can be employed, wherein stand-level attributes are estimated directly through regression and then used to reconstruct the full diameter distribution. This approach aligns stand characteristics derived from regression with those generated from the S_B distribution. To implement this method, the system of equations must include key stand variables and must be solvable for the S_B parameters. In the three-parameter estimation framework proposed by Parresol (2003), the median and the first two non-central moments

of the distribution are used to estimate the scale and shape parameters, while the location parameter is estimated separately using regression techniques. The location parameter ξ is often modeled as a function of dbh. Once ξ is estimated, the remaining parameters δ and γ can be derived using transformations given by Johnson and Kotz (1970).

Despite there being no closed-form expression for the SB probability density function (PDF), the random variable x (such as breast height diameter) can be described as follows: $X \sim SB\ (\boldsymbol{\lambda, \delta, \xi, \gamma})$**.** The equation is then written as: $\boldsymbol{z = \gamma + \delta\ \ln[(x-\xi)/(\xi+\lambda-x)] \sim N\ (0,1)}$ (Eq. 2) a new variable is given $\boldsymbol{y = (x-\xi)/\lambda}$ (Eq. 3) with its structure following the form $\boldsymbol{z = \gamma + \delta\ \ln[y/(1-y)] \sim N\ (0,1)}$ (Eq. 4). The new random variable y , will follow a distribution with the same shape parameters as X. Using the random variable y, the SB PDF form will be as shown in here : $\boldsymbol{f\ (y) = \frac{\delta}{\gamma(1-y)\sqrt{2\pi}} exp\left(-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{y}{1-y}\right)\right]^2\right),\ 0 < y < 1}$ (Eq. 5). By rearranging the z value in Eq. 4, the equation will be set to zero, and when rearranged in terms of the γ parameter, the shape parameter "γ" can be expressed as a function of the other three parameters as follows. $\boldsymbol{\gamma = \delta \ln\left(\frac{1}{y_{0.50}} - 1\right)}$ (Eq.6), Here, $\boldsymbol{y_{0.50}}$ is the median of $\boldsymbol{\gamma}$ and can be defined as $\boldsymbol{y_{0.50} = (d_{median} - \xi)}$). Using the statistical expectation of $\boldsymbol{\gamma}$ in terms of the X^P variable it can be written as follows $\boldsymbol{\bar{d} = \xi + \lambda\ \mu_1'(Y)}$(Eq. 7)**,** This equation expresses the tree diameter ($\bar{d}$) as a function of the first non-central moment of $\boldsymbol{Y(\mu_1', i = 1)}$ However, Eq. 5 expresses the stand basal area as a function of the first two non-central moments of $\boldsymbol{Y}$. N represents the number of trees per unit area, and k represents the conversion factor for basal area per square meter ($k = \frac{\pi}{40000}$). $\boldsymbol{G = kN[\xi^2 + 2\xi\lambda\ \mu_1'(Y) + \lambda^2 \mu_2'(Y)]}$(Eq. 8). The relationship in Eq. 6 is formulated in Eq. 9, and the elimination of γ in Eq. 7 and Eq. 8 is carried out accordingly. $\boldsymbol{\mu_r'(Y) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} [1 + e^{-\frac{z-y}{\delta}}]^{-r}\ e^{\frac{z^2}{2}} dz}$ (Eq.9). The system of the two equations and the two unknown parameters is nonlinear and must be solved using a numerical method. Given estimates for $\boldsymbol{G, N}$, and the mean diameter ($\boldsymbol{\bar{d}}$), the median diameter ($\boldsymbol{d_{0.50}}$)and the location parameter, Eq. 7 and Eq.8 are solved iteratively for δ and λ. The parameter γ is then determined from Eq. 6. The Eq. 8 can also be written as follows $\boldsymbol{dg^2 = \xi^2 + 2\xi\ \lambda\ \mu_1'(Y) + \lambda^2\ \mu_2'(Y)}$ Eq. 9 can be expressed as a function of the first two non-central moments of $\boldsymbol{Y}$, representing the square of the quadratic mean diameter $\boldsymbol{(d_g)^2}$ as the product of the mean of the basal area distribution $\boldsymbol{\bar{d}_G}$ of tree diameters. As a result, as previously explained, $\boldsymbol{\xi}$ is predetermined, $\boldsymbol{\lambda}$ and $\boldsymbol{\delta}$ are solved iteratively using Eq. (7) and (8), and then the scale parameter γ is determined using Eq. (6). More details about the three-parameter solution approach can be found in Parresol (2003) and Fonseca et al. (2009).

2.3. STATISTICAL EVALUATION

The suitability of the model developed for modeling the diameter distribution of the stands was evaluated using the Kolmogorov-Smirnov (K-S) test and the Error index (EI) developed by Reynolds et al. (1988). For this purpose, 5 cm diameter classes were created, as recommended by Fonseca et al. (2009), Özçelik et al. (2016), and Baş and Özçelik (2022). According to Fonseca et al. (2009), a low error index indicates a small difference between the estimated and measured basal area values in each diameter class. The K-S statistic is widely used to assess the fit between experimental and theoretical distributions. A small K-S value indicates that the sample distribution closely matches the population distribution (Cao et al., 2010).

The EI was calculated for each diameter class using basal area as the weight function. The primary reason for using basal area as the weight function is that it can be precisely calculated. Volume or biomass values, on the other hand, may vary depending on the functions used to calculate them. Additionally, using basal area as the weight function ensures that different weight values are assigned to large and small trees, considering the economic differences based on tree size (Fonseca et al., 2009; Özçelik et al., 2016). The formula for the EI is given below. Here, M represents the number of diameter classes, $\boldsymbol{G_j - \widehat{G_j}}$ are the estimated and observed basal area of diameter class j.

$$\boldsymbol{EI = \sum_{j=1}^{M} \left| G_j - \widehat{G_j} \right|}\ \text{(Eq. 10)}$$

The density function of the Johnson SB distribution was estimated using the parameter solution approach based on the percentile-moment method. This process was carried out with a custom program developed in SAS version 9.1. The program utilized the nonlinear Levenberg-Marquardt (NLPLM) algorithm within the CAPABILITY sub-tab of the interactive matrix language (SAS Institute, 2014).

3. RESULTS

Figure 3.1 shows the diameter distributions, and the corresponding predictions based on three- and four-parameter Johnson's S_B models for sample plots 58, 41, 50, 32, 36, 21, 1, and 3. Among these, plot 58, located in Antalya–

Kumluca, exhibits a right-skewed distribution. Despite minor discrepancies between observed and estimated distributions, both modeling approaches provided satisfactory fits, with error index of 5.8 for the three-parameter model and 4.8 for the four-parameter model. These results confirm the effectiveness of Johnson's S_B distribution in capturing skewed diameter patterns in Mediterranean pine stands.

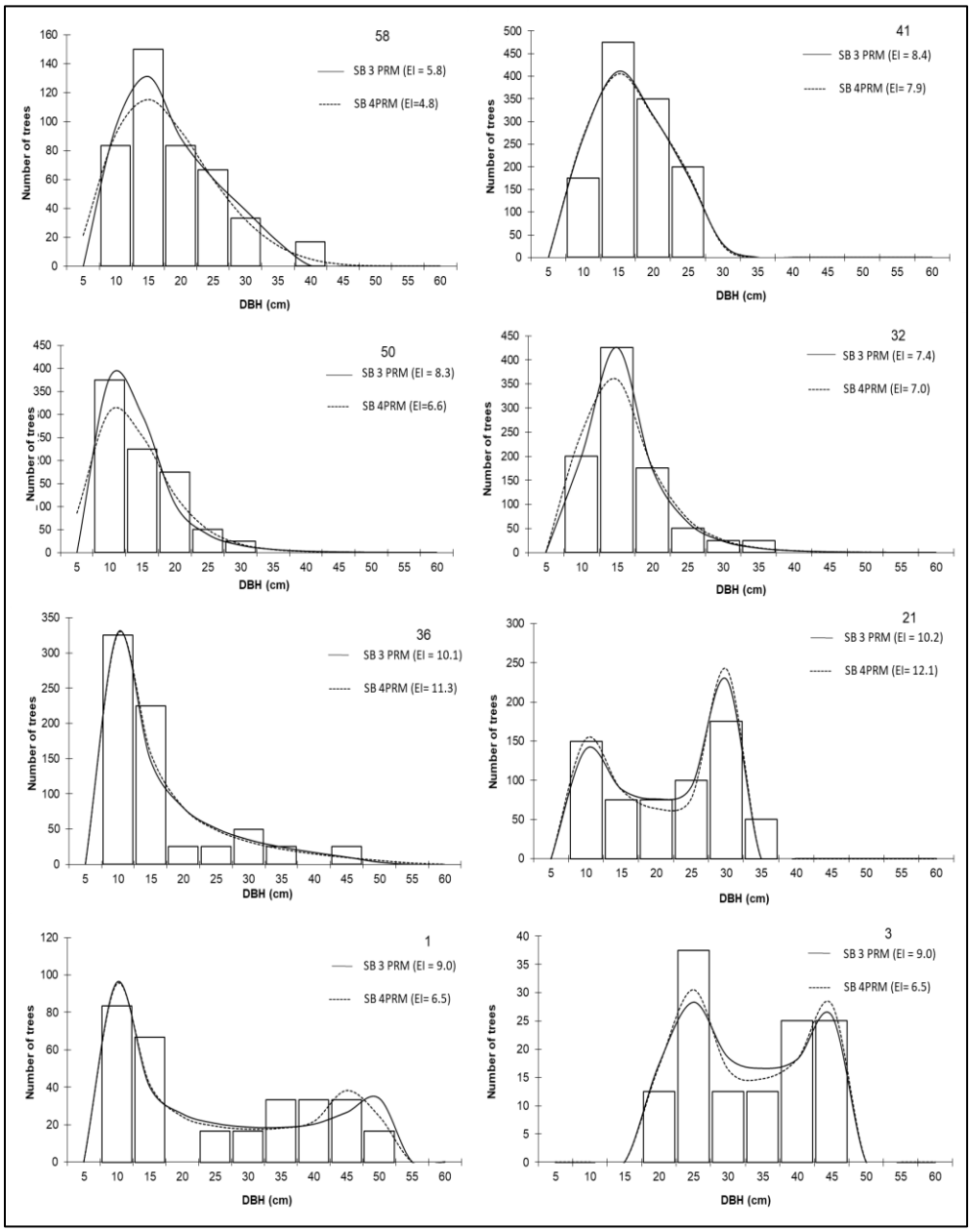

Figure 3.1. Distributions of diameter some sample plots in Antalya region

Similarly, sample plots 36 and 50 also revealed right-skewed distributions. Both three- and four-parameter models performed comparably well, producing closely aligned estimates across diameter classes. Error index for plots 36 and 50 were 10.1 and 11.3 (three-parameter) and 8.3 and 6.6 (four-parameter), respectively. Notably, plot 50, located in Antalya-Korkuteli displayed a wide range of diameters, where the four-parameter model outperformed with lower error. Although the four-parameter model yielded a slightly higher error for plot 36, it still succeeded in reflecting the overall distribution trend effectively.

In contrast, plots 41 and 32 exhibited relatively uniform and unimodal distributions within narrower diameter intervals. In both cases, the predictions from the three- and four-parameter models were nearly identical, with low error index indicating strong model performance (e.g., 7.4 and 7.0 for plot 32). Plot 3, however, showed a bimodal distribution, where observed modes occurred at 15 cm and 20 cm, compared to estimated modes at 10 cm and 30 cm. Despite these deviations, Johnson's SB distribution provided a reasonable approximation. For plots 1, 3, and

21, minor differences between observed and predicted values were observed, with both models generating closely matching estimates—particularly in plot 1, where diameters ranged from 10 to 54 cm and the four-parameter model demonstrated superior performance (EI: 6.5 vs. 9.0). As noted by Parresol et al. (2010), such bimodal patterns are often inadequately modeled by conventional distributions like Weibull or Log-normal, highlighting the value of Johnson's S_B approach in complex forest structures.

Figure 3.2 presents the EI values derived from the three-parameter (3 PRM) and four-parameter (4 PRM) Johnson's S_B distribution models for individual sample plots within the Antalya region (Figure 3.2). The EI values for the 3 PRM model range between 2.43 and 40.96, with a standard deviation of 9.55 and a mean value of 15.61. The distribution of these values across sample plots indicates a generally high level of accuracy in modeling diameter distributions using Johnson's S_B approach.

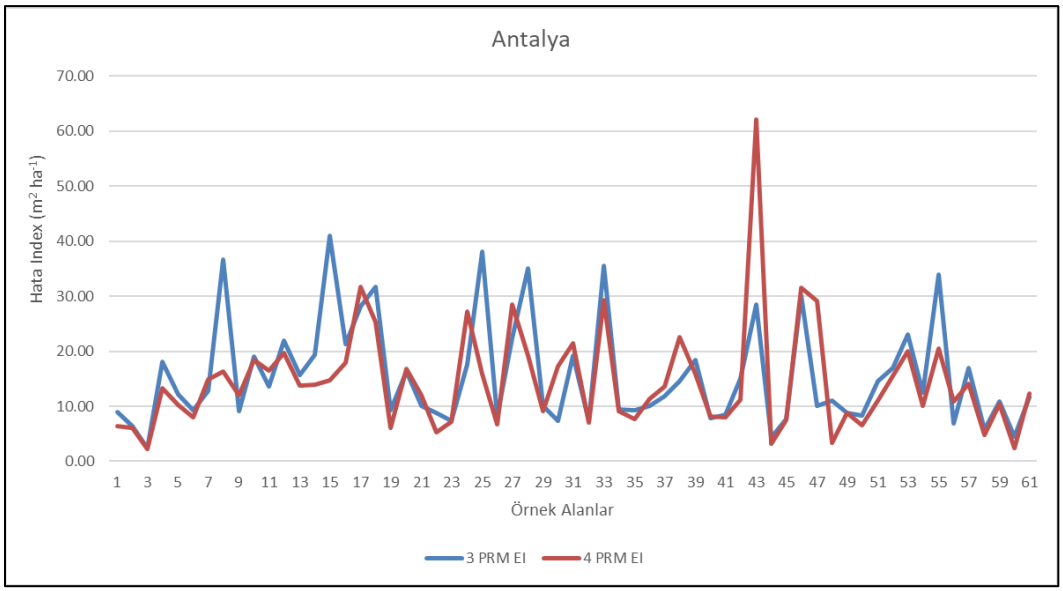

Figure 3.2 Antalya sample plots EI for 3PRM-4PRM

In the case of the 4 PRM model, the EI values range from 2.31 to 62.14, with a slightly higher standard deviation of 9.70 and a marginally lower mean EI of 14.47. While both models produced comparably accurate results, the 4 PRM method displayed a notable outlier at plot 43, which contributed significantly to the upper range of the error spectrum. Overall, the proximity of the mean EI and standard deviations for both parameterizations suggests that each model is capable of effectively capturing the diameter distribution structure of Brutian pine stands in the Antalya region. Furthermore, the 3 PRM approach outperformed the 4 PRM in several sample plots, underscoring its efficiency and stability under certain stand conditions.

The regions whose diameter distributions were tested for Antalya region and named as S_B, S_L and S_U with 4-parameter approach are shown in Figure 3.3. β_1 represents the square of the Skewness value. β_2 represents the kurtosis value and forms the S_B, S_L and S_U intervals. In these intervals, S_U represents the impossible region, while S_L represents the boundaries of the impossible and Johnson's S_B region. The S_B region is known as the interval-region where Johnson's S_B approach makes sound estimates in the 4-parameter solution. Here, only one sample plot (Sample plot 19) is on the S_L border line, while one sample plot (Sample plot 61) is in the impossible region.

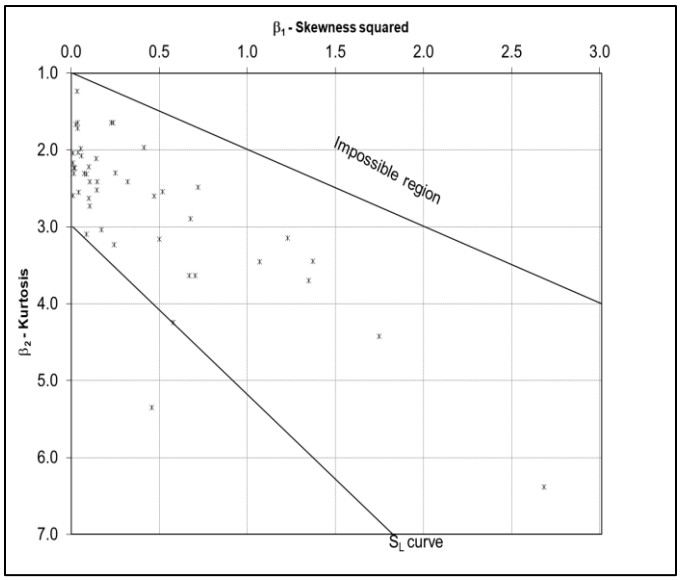

Figure 3.3. S_B-S_L-S_U regions of Antalya region sample plots

Table 3.1 presents a detailed comparison of the three- and four-parameter Johnson's S_B distribution models based on the K–S goodness-of-fit test and EI values across selected sample plots. The results reveal that the four-parameter model generally provides a superior statistical fit, as evidenced by lower K–S values and a shift from significant (*) to non-significant (NS) outcomes in several plots (e.g., plots 4 and 5), indicating a closer alignment between observed and predicted diameter distributions. In terms of accuracy, the EI values for the four-parameter model were consistently lower in many plots, particularly those with broader diameter variation (e.g., plot 8: EI reduced from 36.61 to 16.33), suggesting an enhanced ability to capture complex stand structures. Nevertheless, the three-parameter model outperformed its counterpart in a few instances (e.g., plot 7), implying that simpler models may still be effective under more homogeneous or unimodal conditions. Overall, the findings underscore the adaptive capacity of the four-parameter approach while highlighting that model selection may benefit from consideration of stand-specific characteristics.

Table 3.1. K-S Test and EI values of some sample plots of Antalya region

Sample plots	3 parameter				4 parameter		
	Number of Trees	K-S	Significance level	Error Index	K-S	Significance level	Error Index
1	18	0.337	*	9.01	0.326	*	6.48
2	14	0.053	NS	6.45	0.048	NS	6.04
3	10	0.235	*	2.43	0.224	*	2.31
4	16	0.188	*	18.09	0.128	NS	13.34
5	14	0.164	*	12.19	0.141	NS	10.30
6	13	0.103	NS	9.23	0.098	NS	8.04
7	12	0.440	*	12.73	0.452	*	14.94
8	20	0.283	*	36.61	0.188	*	16.33
9	21	0.041	NS	9.14	0.080	NS	11.93
10	16	0.174	*	19.05	0.130	NS	18.45

Table 3.2 summarizes the EI statistics across all sample plots for both three- and four-parameter models, offering a broader perspective on overall model performance. The four-parameter model yielded a lower mean EI value (14.90) compared to the three-parameter model (15.65), indicating improved predictive accuracy in general. However, the four-parameter model also exhibited a higher maximum EI (62.14) and greater standard deviation (11.15), suggesting greater variability and the presence of outlier cases. This variability may be attributed to specific stand conditions where the additional parameter introduces sensitivity to irregular or highly skewed distributions. Despite these fluctuations, the overall trend favors the four-parameter approach as a more flexible and robust tool for modeling diameter distributions, particularly in structurally diverse forest ecosystems.

Table 3.2 Comparison of EI values of all sample plots for Antalya region

	Min	Max	Mean	SD
3 parameter	2.43	40.96	15.65	9.87
4 parameter	2.31	62.14	14.90	11.15

4. DISCUSSION AND CONCLUSIONS

This study demonstrates that the parameter recovery approach based on Johnson's S_B distribution function is highly effective in characterizing the structurally diverse and heterogeneous stand formations of natural Brutian pine in the Mediterranean Region. The results support its applicability in developing stand-based planning and forest management alternatives. Moreover, the findings contribute meaningfully to the broader body of literature on diameter distribution modeling in forestry. For parameter estimation, both three- and four-parameter recovery methods grounded in percentile-based formulations of Johnson's SB distribution were employed. As highlighted by Fonseca et al. (2009), Mateus and Tomé (2011), and Özçelik et al. (2016, 2023), the Johnson's S_B distribution is particularly suited for modeling biological variables due to its two flexible shape parameters, allowing it to represent a wide range of distribution forms. Numerous previous studies have reported the model's high accuracy in capturing diameter distributions (Parresol, 2003; Fonseca, 2004; Lei, 2008; Kahriman & Yavuz, 2011; Sakıcı et al., 2016; Özçelik et al., 2023).

The analysis of data from 61 sample plots within the Antalya Forest Regional Directorate provided comprehensive insights into the accuracy and practical utility of diameter distribution models. Tree diameters in each plot were categorized into 5 cm diameter classes, a widely adopted methodology in forest biometric research (Parresol, 2003; Ercanlı & Yavuz, 2010; Özçelik et al., 2022). Johnson's SB distribution was favored for its structural flexibility and its aptitude in modeling biological variation. In this study, the performance of both three-parameter and four-parameter solution techniques was evaluated using statistical metrics. While the three-parameter method offered simplicity and ease of application due to its reduced computational demand, the four-parameter approach yielded superior results in capturing broader diameter variation (Sönmez et al., 2010; Dal, 2019; Ciceu et al., 2021). Specifically for the Antalya region, the four-parameter solution exhibited an average EI approximately 18% lower than that of the three-parameter method. Results from the K-S test further confirmed that the four-parameter approach achieved a significantly better fit between observed and theoretical diameter distributions ($P > 0.05$). The four-parameter model also demonstrated enhanced predictive performance in estimating trees within wider diameter classes, reinforcing its practical advantage in structurally diverse forest ecosystems.

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Author Contributions
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Conflict of Interest
The authors have no conflicts of interest to declare.

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Mixed Effects Modelling Approach for DBH-H Relationships of Black pine Stands in Beyşehir Region

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Abstract: Accurate modeling of the diameter at breast height (DBH) and total tree height (H) relationship is fundamental for forest inventory, growth prediction, and sustainable management. This study aimed to develop and compare fixed-effects (FE) and mixed-effects (ME) Chapman-Richards models to predict tree height from DBH in natural black pine stands in the Beyşehir region of Türkiye. A total of 1,846 trees from 60 sample plots were measured, with 40 plots used for model calibration and 20 for validation. The performance of the models was evaluated using statistical metrics including Mean Difference (MD), Mean Absolute Difference (MAD), Root Mean Square Error (RMSE), and Fit Index (FI). The ME model, which incorporated random effects for both the asymptotic (β_1) and shape (β_3) parameters, significantly outperformed the FE model. The best ME model achieved the lowest AIC (4083) and BIC (4094) values, indicating superior model fit. Moreover, with increasing local calibration (1 to 5 trees per plot), prediction errors notably decreased. Using five calibration trees, the ME model attained minimal bias estimates (MD = 0.0061), the lowest RMSE (1.3064), and the highest FI (0.8148). In contrast, the FE model without calibration exhibited considerable systematic bias (MD = 0.6790; RMSE = 2.1382). These findings demonstrate that mixed-effects modeling offers a more flexible and accurate framework for DBH-height predictions, especially in heterogeneous forest conditions. The developed ME model provides a practical and statistically robust tool for improving growth and yield estimations, thereby enhancing decision-making processes in forest management.

Keywords: Pinus nigra, height-diameter, mixed-effects model, Beyşehir.

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1. INTRODUCTION

Sustainable management of forest resources through ecosystem-based functional planning requires dynamic growth and yield models for tree species, among which height-diameter (d-h) relationships are a critical component (Huang et al., 2000). Black pine (*Pinus nigra* JF Arnold.) is one of the most economically and ecologically important tree species in Turkey (GDF, 2023). Diameter at breast height (DBH) and tree height (h) serve as fundamental variables in forest inventories and are key predictors in forest management applications. Temesgen et al. (2008) emphasize that these variables are essential for characterizing stand attributes during management planning. While DBH can be measured easily and cost-effectively, obtaining accurate tree height data is often labor-intensive and expensive. Consequently, height is frequently estimated as a function of DBH in forest inventory studies (Temesgen et al., 2008; Bronisz & Mehtätalo, 2020).

DBH-height relationships underpin forest structure assessment, growth modeling, and carbon stock estimation. These models are widely employed in site index determination, stand stability evaluation, and yield prediction, forming the basis of growth and yield projections (Calama & Montero, 2004; Özçelik et al., 2010; Vospernik et al., 2010; Ercanli et al., 2015; Diamantopoulou et al., 2023). Furthermore, DBH and height variables are integral to single-tree and stand-level volume estimation (Soares & Tome, 2002; Crecente-Campo et al., 2009), structural stand analysis (Gadow et al., 2001), site quality and carbon budget modeling (Gómez-García et al., 2015), and development of growth and yield models (Calama & Montero, 2004; Huang et al., 2009). Recent increases in biomass estimation and carbon budget studies have further amplified their importance (Yuancai & Parresol, 2001). Since many growth and yield models rely on these variables (Temesgen et al., 2008; Huang et al., 2009; Özçelik et al., 2018; Bronisz & Mehtätalo, 2020; Ciceu et al., 2020), accurately quantifying species-specific DBH-height relationships across different growing conditions is crucial for informed decision-making in forest inventory and management (Avery & Burkhart, 2002).

Numerous DBH-height models have been developed for various tree species and regions (Curtis, 1967; Parresol, 1992; Fang & Bailey, 1998; Diéguez-Aranda et al., 2005; Mehtätalo, 2005; Adame et al., 2008; Mehtätalo et al., 2008; Çatal & Carus, 2018; Bronisz & Mehtätalo, 2020; Ercanlı, 2020). In recent years, nonlinear mixed-effects modeling (NLME) and quantile regression (QR) techniques have emerged as alternatives to traditional regression methods, addressing limitations in hierarchical data structures common in forest inventories. Because tree

measurements from the same sampling unit exhibit spatial and temporal autocorrelation, ordinary least squares (OLS) regression—which assumes error independence—may yield biased estimates (West et al., 1984; Lhotka, 2008). To overcome this, researchers increasingly adopt NLME and QR techniques (Calama & Montero, 2004; Trincado et al., 2007; Huang et al., 2009; Özçelik et al., 2018; Bronisz & Mehtätalo, 2020; Zhang et al., 2020). Notably, Xie et al. (2022) found NLME outperformed QR in DBH-height modeling accuracy.

Given the critical role of DBH-height relationships in growth and yield modeling, robust and modern estimation techniques are needed. While QR applications in forestry biometrics remain relatively novel, adoption in Türkiye has been limited (Özçelik et al., 2018; 2019). Further research should explore advanced modeling approaches to enhance height prediction accuracy using DBH and auxiliary variables. This study employs both OLS and QR techniques to develop DBH-height models for natural black pine (Pinus nigra) stands in the Beyşehir region, with two primary objectives: (i) comparing performance of modeling techniques (OLS vs. QR), and (ii) assessing how sample size influences model calibration.

2. MATERIAL AND METHOD

2.1. MATERIAL

In the development of height-diameter models, data were obtained from 60 sample plots comprising a total of 1,846 individual black pine trees. These plots were selected from even-aged pure stands to represent a wide range of site conditions and site quality classes. In order to capture the variability associated with topographic aspect, elevation, and developmental stages, particular attention was given to selecting sample plots from diverse growing environments. The size of each sample plot was determined such that approximately 30 trees would be included, taking into consideration the developmental stage of the stand, resulting in plot sizes ranging from 200 m² to 5,700 m². Trees that were standing dead, severely diseased, wind-thrown, or had significant stem deformities were excluded from measurements and replaced by representative trees selected from adjacent stands. The distribution of the sample sites in natural and pure black pine stands is shown in Figure 1.

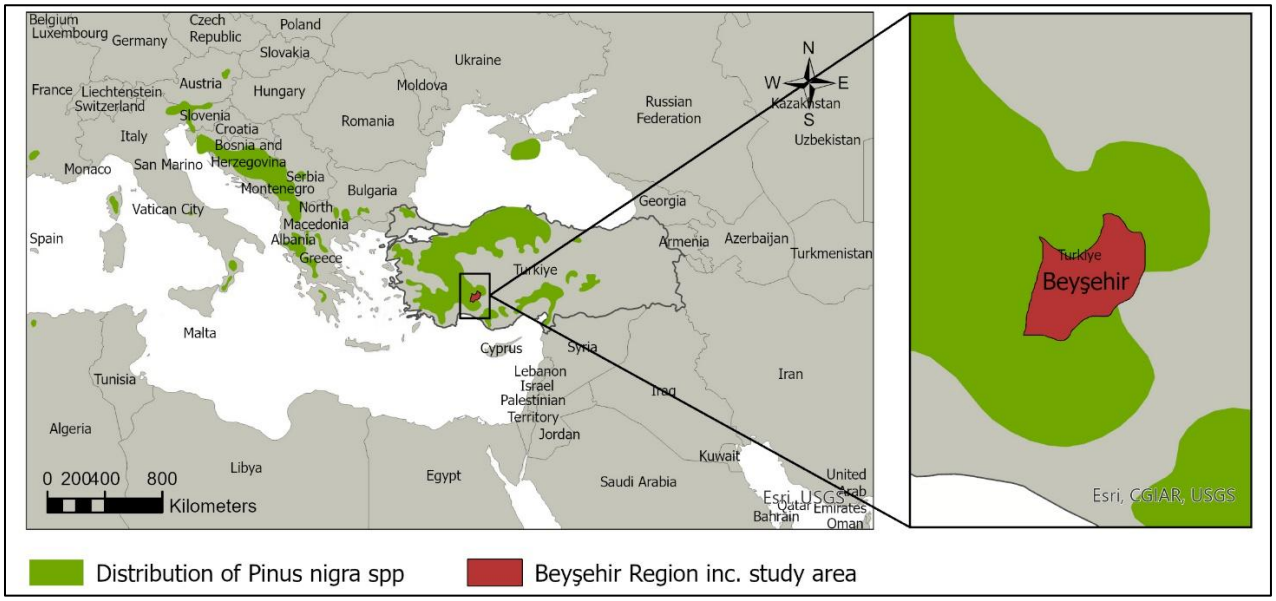

Figure 1. The distribution of the natural and pure black pine stands in northwest Mediterranean region of Türkiye

For each tree, diameter at breast height (d, cm) was measured by averaging two perpendicular readings taken outside the bark at 1.3 meters above ground level. Tree height (h, m) was measured to the nearest 0.05 m using a Laser-Tech TruPulse device. Of the 60 sample plots, 40 were randomly selected for model fitting, while the remaining 20 plots were reserved for model validation. Descriptive statistics for both the fitting and validation datasets are provided in Table 1, and the height-diameter relationship observed in both datasets is shown in Figure 2.

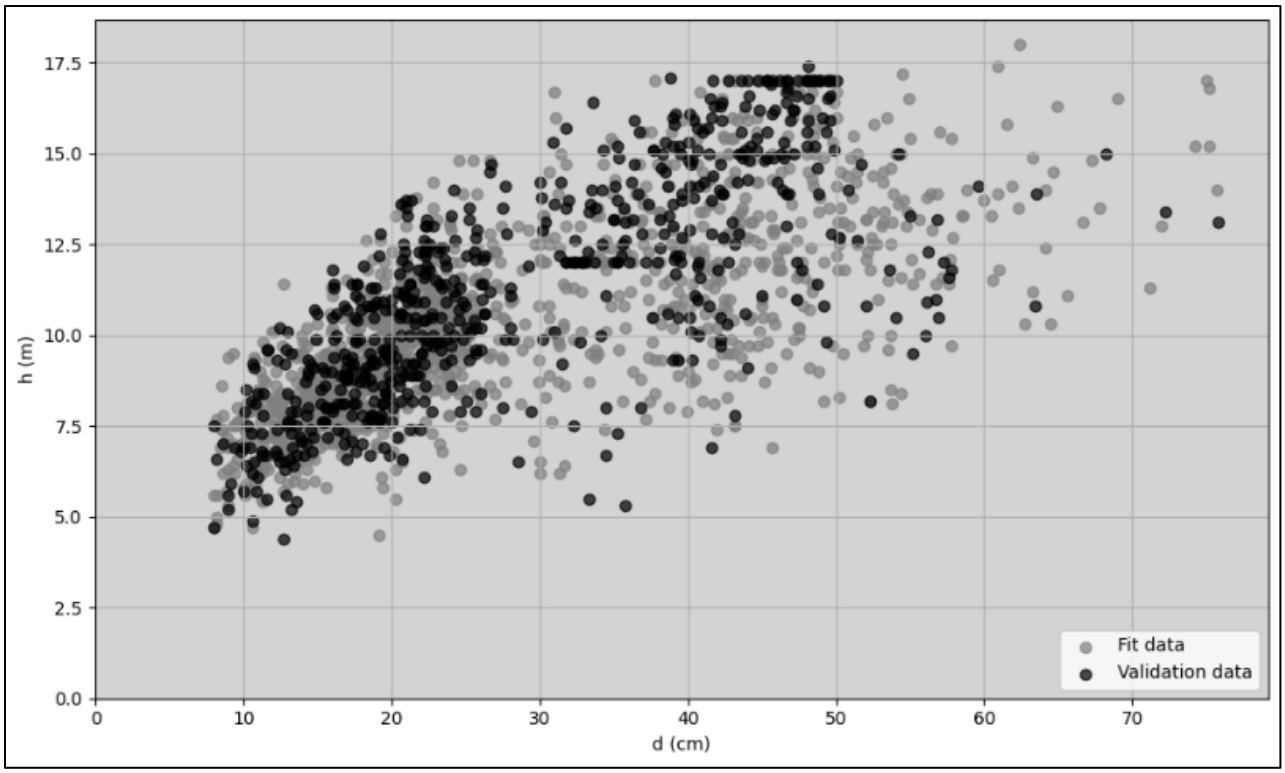

Figure 2. Plots of tree height (h) against the diameter (d) for fitting and test datasets.

Out of the 60 plots, 40 plots were randomly allocated for model development, while the remaining 20 plots were utilized for testing the fitted models. The descriptive statistics of the fitting and test datasets are presented in Table 2.1.

Table 2.1. Descriptive statistics of the fitting and test datasets.

Variable*	Fitting data				Validation data			
	Mean	Min.	Max.	S.D.	Mean	Min.	Max.	S.D.
	Black pine (1224 trees in 40 plots)				*Black pine (622 trees in 20 plots)*			
d (cm)	27.98	8.00	75.70	22.60	28.91	8.00	75.80	13.11
h (m)	10.32	4.50	18.00	2.59	11.21	4.40	17.40	3.04
D0 (m)	36.97	19.62	64.42	15.86	36.75	20.58	62.86	14.18
H0 (m)	11.39	7.98	16.82	2.31	12.42	8.56	16.98	2.72
N (trees ha^{-1})	803	49	1851	566.2	752	119	1741	496.79
Size	864.5	200.96	5698.35	895.75	744.8	200.96	2391.93	632.64

2.2. METHOD

In order to develop d-h models for natural and pure black pine stands, some basic nonlinear height-diameter models widely used in the literature (Zhang, 1997; Huang et al., 1992; Zhang et al., 2005; Bronisz and Mehtätalo, 2020) were selected. For these models, four different criterion values (MD, MAD, RMSE and FI) were calculated using the predicted height and measured tree height values in order to evaluate the prediction performances of the models with the entire data set and the nonlinear least squares (ONLS) method. All base and generalized models given Table 2.

Table 2.2. Candidate base and generalized models tested in this study.

Model	Equation	Equation Number
Monserud	$h = 1.3 + exp(\beta_1 + \beta_2 d^{\beta_3})$	(Eq. 1)
Chapman-Richards	$h = 1.3 + \beta_1(1 - exp(-\beta_2 d))^{\beta_3}$	(Eq. 2)
Weibull	$h = 1.3 + \beta_1\left(1 - exp(-\beta_2 d^{\beta_3})\right)$	(Eq. 3)
Gompertz	$h = 1.3 + \beta_1\left(exp(-\beta_2\ exp(-\beta_3 d))\right)$	(Eq. 4)
Logistic	$h = 1.3 + \beta_1/(1 + \beta_2\ exp(-\beta_3 d))$	(Eq. 5)
Exponential	$h = 1.3 + exp(\beta_1 + \beta_2/(\beta_3 + d))$	(Eq. 6)
Naslund	$h = 1.3 + (d/(\beta_1 + \beta_2 d))^{\beta_3}$	(Eq. 7)
Korf	$h = 1.3 + \beta_1\left(exp(-\beta_2 d^{-\beta_3})\right)$	(Eq. 8)
Bates and Watts	$h = 1.3 + \beta_1 d/(\beta_2 d)$	(Eq. 9)
Modified Chapman-Richards	$h = 1.3 + \beta_1 H_0^{\beta_2}\ \exp\left(-\beta_3 H_0^{\beta_4}\ \exp(-\beta_4 D_0^{\beta}\right.$	(Eq. 10)

$\boldsymbol{h}$ is the total tree height (m), $\boldsymbol{d}$ is the diameter at 1.3 m above ground (cm), $\boldsymbol{H_0}$ id dominant height, $\boldsymbol{D_0}$ is dominant diameter, $\boldsymbol{\beta_i}$ is the estimated *i* parameters.

2.2.1 Fixed-effects model (*FE*)

Nine basic and one generalized basic height-diameter models (Table 2) were tested in the preliminary analysis, separately. While Chapman-Richards (CR) models the best models, respectively among generalized models analyzed and the Chapman-Richards function the best fitted the data used in this study among nine basic model. The Chapman-Richards model was therefore chosen for further analyses using ME and QR approaches. This function can be expressed as follows:

$$h_{ij} = 1.3 + \beta_1(1 - exp(-\beta_2 dij))^{\beta_3} + \varepsilon_{ij} \qquad \text{(Eq. 11)}$$

where d_{ij} and h_{ij} are, diameter at breast height (cm) and total tree height (m) of the *j*th tree in the *i*th plot, respectively, β_i is estimated parameters of the model, and ε_{ij} is the random error.

2.2.2 Mixed-effects model (*ME*)

ME modeling facilitates the analysis of characteristics that are shared among all trees while simultaneously accounting for the variability within and between specific plots. This approach allows all parameters in Equation (11) to be expressed either as fixed effects or as a combination of random and fixed effects. In matrix form, the parameterization of Equation (11) using mixed effects can be represented as follows:

$$y_i = f(b, u_i, d_i) + \varepsilon_i \qquad \text{(Eq. 12)}$$

where $y_i = \left[h_{i1},\ h_{i2}, \ldots,\ h_{in_i}\right]^T$, $d_i = \left[d_{i1},\ d_{i2},\ d_{i3}, \ldots,\ d_{in_i}\right]^T$, $\varepsilon_i = \left[\varepsilon_{i1},\ \varepsilon_{i2}, \ldots\ldots,\ \varepsilon_{in_i}\right]^T$, n_i is number of measured heights for plot i, and u_i and b are column vectors of random- and fixed effects parameters, respectively.

Assumptions made are: $\varepsilon_i \sim N(0, R)$, and $u_i \sim N(0, D)$, where R and D are diagonal matrices, if the ε_i and u_i are independent.

The estimation of the fixed-effects and random-effects parameters in Equation (12) was carried out using the NLMIXED procedure in SAS Software (SAS Institute Inc. 2014). This approach facilitates the fitting of nonlinear *ME* models, yielding robust parameter estimates by incorporating both random and fixed effects into the analysis. When a subsample of trees in plot i are observed, the random parameters u_i for that plot can be estimated by utilizing the first-order Tailor series expansion (Meng & Huang 2009):

$$\hat{\mathbf{u}}_i^{k+1} = \hat{\mathbf{D}}\mathbf{Z}_i^T\left(\mathbf{Z}_i\hat{\mathbf{D}}\mathbf{Z}_i^T + \hat{\mathbf{R}}\right)^{-1}\left[\mathbf{y}_i - \mathbf{f}\left(\hat{\mathbf{b}}, \hat{\mathbf{u}}_i^k, \mathbf{d}_i\right) + \mathbf{Z}_i\hat{\mathbf{u}}_i^k\right] \qquad \text{(Eq. 13)}$$

where $\hat{u}_i^k$ is estimation of random parameters for tree i at the kth iteration, $\hat{D}$ and $\hat{R}$ are estimated the variance-covariance matrix for u_i, $Z_i = \frac{\partial f(b,u_i,d_i)}{\partial u_i}\Big|_{\hat{b},\hat{u}_i}$ and error term, respectively, y_i is the $m \times 1$ vector of measured heights, m is number of measured tree heights used in localizing the height growth model. To estimate u_i, an iterative approach was required. Beginning with an initial value of zero ($\hat{u}_i^0 = 0$), Equation (13) was repeatedly adjusted until the absolute difference between successive iterations fell below a predetermined tolerance threshold. This iterative process resulted in the empirical best linear unbiased predictor (EBLUP) for the random effects.

2.3 EVALUATION CRITERIA

To assess the predictive performance and reliability of the developed models, four statistical evaluation criteria were employed: Mean Difference (MD), Mean Absolute Difference (MAD), Root Mean Square Error (RMSE), and Fit Index (FI). The MD measures the average signed deviation between observed and predicted values, indicating potential systematic bias, with values near zero suggesting unbiased predictions. MAD quantifies the average magnitude of prediction errors regardless of direction, offering a robust measure of overall error magnitude. RMSE, which squares the residuals before averaging, gives greater weight to larger errors and provides an estimate of the standard deviation of the prediction errors, thus serving as a sensitive indicator of model accuracy. Finally, FI evaluates the proportion of variation in observed values explained by the model, comparing the sum of squared prediction errors to the total variance in the observed data; values approaching one indicate a high degree of model fit. Collectively, these metrics offer a comprehensive evaluation of model effectiveness in capturing observed patterns and minimizing prediction errors.

$$MD = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n_i}\left(h_{ij} - \hat{h}_{ij}\right)}{\sum_{i=1}^{n} n_i} \qquad \text{(Eq. 14)}$$

$$MAD = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n_i}\left|h_{ij} - \hat{h}_{ij}\right|}{\sum_{i=1}^{n} n_i} \qquad \text{(Eq. 15)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{n_i}\left(h_{ij} - \hat{h}_{ij}\right)^2}{n}} \qquad \text{(Eq. 16)}$$

$$FI = 1 - \frac{\sum_{i=1}^{n}\sum_{j=1}^{n_i}\left(h_{ij} - \hat{h}_{ij}\right)^2}{\sum_{i=1}^{n}\sum_{j=1}^{n_i}\left(h_{ij} - \bar{h}_i\right)^2} \qquad \text{(Eq. 17)}$$

3. RESULTS

The fit statistics presented in Table 3.1 indicate that introducing random effects into the Chapman-Richards model substantially improves its performance compared to the fixed-effects version. Among the tested combinations, the model including both β_1 and β_3 as random parameters achieved the lowest AIC (4083) and BIC (4094) values, indicating the best overall fit. This suggests that allowing variability in both the asymptote and shape parameters provides a more flexible and accurate representation of the data. In contrast, models with no random effects or with only one random parameter yielded higher AIC and BIC values, reflecting poorer fits. Overall, the results highlight that the model's predictive capacity is significantly enhanced by accounting for random variation, particularly in the parameters β_1 and β_3.

Table 3.1. Fit statistics for various random parameter combinations for the Chapman-Richards Model

Random Parameters	*AIC*	*BIC*
None	4837	4858
β_1	4100	4109

β_2	4271	4279
β_3	4104	4112
β_1 and β_2	4089	4100
β_1 and β_3	**4083**	**4094**
B_2 and β_3	4173	4184
β_1, β_2 and β_3	Not Converge	

[a/] An underlined and bold number represents the combination that leads to the best statistic for Black pine.

Table 3.2 presents the estimated parameter values for both fixed-effects (FE) and mixed-effects (ME) Chapman-Richards models. The FE model yielded parameter estimates of $\beta_1 = 13.7501$, $\beta_2 = 0.03074$, and $\beta_3 = 0.6643$, reflecting an average height trajectory across all plots without accounting for within-plot heterogeneity. In contrast, the ME model showed wider variability, with fixed and random components for β_1, β_2, and β_3, indicating its capacity to capture local deviations from the general trend. For instance, the ME model's β_1 estimate increased to 23.8318, with corresponding modifications in β_2 and β_3, reflecting improved flexibility in model calibration. This distinction emphasizes how mixed-effects modeling can accommodate structural differences among sample plots and more accurately reflect stand-specific growth patterns.

Table 3.2. Estimated parameters for each method.

Type	β_1	β_2	β_3	σ^2	$\sigma^2_{u_1}$	$\sigma^2_{u_2}$	$\sigma^2_{u_1 u_2}$
FE model	13.7501	0.03074	0.6643	3.0275			
ME model	23.8318	0.00417	0.4297	1.4184	45.4406	0.01198	0.6492

Table 3.3 presents a comparative evaluation of the performance of fixed-effects (FE) and mixed-effects (ME) models in modeling height-diameter relationships in natural black pine stands under varying calibration scenarios, involving the measurement of 0 to 5 trees per sample plot. The FE model, when applied without any calibration, produced a substantial systematic bias (MD = 0.6790) and high prediction error (RMSE = 2.1382), with a low fit index (FI = 0.5040), indicating poor model performance. In contrast, the ME model, even with the calibration of just one or two trees per plot, achieved significantly lower error values (e.g., RMSE = 1.4775 and MAD = 1.1658 with two trees) and considerably higher fit indices (FI = 0.7632) compared to the FE model. Notably, the ME model reached optimal performance when five calibration trees were used, yielding nearly unbiased predictions (MD = 0.0061), the lowest error metrics (RMSE = 1.3064, MAD = 1.0294), and the highest fit index (FI = 0.8148). These findings highlight the clear superiority of mixed-effects models over fixed-effects models, especially in structurally heterogeneous forest conditions, and emphasize their practical utility as a reliable predictive tool in forest inventory applications, even with minimal tree height measurements.

Table 3.3. Evaluation statistics [a/] for the two modeling approach (FE and *ME*) for Black pine using calibration scenarios.

Number of trees for calibration	**Modeling approaches**	
	FE	*ME*
Mean Difference (MD)		
0	0.6790	
1		0.2682
2		-0.1579
3		-0.0635
4		-0.0091
5		**0.0061**
Mean Absolute Difference (MAD)		
0	1.7226	
1		1.2780
2		1.1658

3		1.1066
4		1.0563
5		**1.0294**
	Fit Index (FI)	
0	0.5040	
1		0.7085
2		0.7632
3		0.7903
4		0.8073
5		**0.8148**
	RMSE	
0	2.1382	
1		1.6391
2		1.4775
3		1.3902
4		1.3328
5		**1.3064**

Bold number represents the best method for sampling efforts and an underline number represents the best for the evaluation criteria for Black pine.

4. DISCUSSION AND CONCLUSIONS

In this study, we compared fixed-effects (FE) and mixed-effects (ME) Chapman-Richards models for predicting tree height from DBH in natural black pine stands in the Beyşehir region. The ME model, particularly when both the asymptotic (β_1) and shape (β_3) parameters were treated as random effects, significantly outperformed the FE model across all evaluation metrics. These results align with findings from earlier research emphasizing the advantages of nonlinear mixed-effects modeling in accounting for stand-level variability and hierarchical data structures (Calama & Montero, 2004; Trincado et al., 2007; Mehtätalo et al., 2008; Özçelik et al., 2018; Ciceu et al., 2020). The ME model demonstrated robust performance even with minimal calibration (e.g., using just five trees per plot), yielding nearly unbiased predictions (MD = 0.0061) and a high fit index (FI = 0.8148), which is particularly valuable in operational forestry where measurement effort and costs are often constrained. The empirical best linear unbiased predictor (EBLUP) approach used in parameter estimation further enhanced the model's flexibility and practical applicability (Meng & Huang, 2009). These findings confirm that mixed-effects modeling provides a more accurate and adaptable framework for height-diameter estimation, especially in structurally diverse forest conditions. Compared to conventional FE models, the ME approach enables localized calibration and captures plot-level heterogeneity more effectively, making it suitable for integration into growth and yield models, site index determination, and biomass or carbon stock assessments (Gómez-García et al., 2015; Bronisz & Mehtätalo, 2020; Xie et al., 2022). Ultimately, the mixed-effects Chapman-Richards model developed in this study presents a statistically sound and operationally efficient tool for supporting sustainable forest management and decision-making processes in uneven and ecologically varied forest landscapes.

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N/A

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The authors have no conflicts of interest to declare.

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Sustainability and Performance of Agriculture in the Slovak Republic: Quantitative Analysis of Production and Economic Factors

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Abstract: Agriculture is the most important sector of the Slovak national economy, contributing to food security, employment, and also rural development. Over the past decade, Slovakia's agricultural sector has faced a significant transformation due to globalization, technological advancements, and climate change. This study evaluates the position of agriculture within the Slovak economy by analyzing key indicators such as GDP contribution, employment trends, land use, and trade performance in the period 2013 to 2022. Using data from the Slovak Statistical Office, the research identifies a decline in agricultural employment, stable but evolving land use, and shifts in production patterns influenced by EU policies. While agriculture's share of GDP has decreased, Slovakia is an important exporter of cereals and dairy products. The study highlights the need for policies supporting technological innovation, sustainable farming practices, and adaptation to climate change. Future agricultural strategies should focus on enhancing productivity, improving rural livelihoods, and aligning with European sustainability goals.

Keywords: Agriculture, Sustainability, Trade development, Crop yields, Economic indicators, Employment

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1. INTRODUCTION

Agriculture operates within complex systems and has its own multifunctional character. The implementation of agricultural knowledge with a multifunctional approach should enhance its impact on food security and poverty alleviation while also positively influencing human nutrition and livelihoods in terms of equity, environmental sustainability, social justice, and economic viability (Bielik, P. et al., 2020). The character and structure of agriculture as a sector are highly specific. It is heavily dependent on climatic conditions and weather influences. Additionally, it is traditionally linked to rural areas, which are undergoing significant changes. Migration from cities has a substantial impact on farm businesses. Changes in urban populations affect the availability of labor for farms, while also pushing farms to replace human labor with technology (Tóth, M. et al., 2018). Agriculture, considered one of the subsystems of society's economic system, has contributed to the current unfavorable state of the environment. This impact has grown alongside the increasing food demands of modern societies. The risks associated with so-called "conventional agriculture" can no longer be ignored. Therefore, the importance of seeking alternative food production methods that are environmentally friendly and do not threaten biodiversity or consumer health is being emphasized. In this context, "organic farming" is highlighted as a key concept of our time (Látečková et al., 2019). The rise in agricultural prices in recent years has reminded people that agriculture plays a crucial role in food security and poverty alleviation in both high- and low-income countries. Farmers are highly sensitive to weather conditions and other factors that affect not only their individual production but also the prices they face. On the other hand, the lives of ordinary people also depend on the availability and affordability of food (Alston, Pardey, 2014). In the face of current challenges, a swift and radical shift in business approaches toward people and the environment is necessary. In this context, it is worth analyzing one of the concepts that aim to connect business activities with addressing sustainable development challenges—sustainable business models. As some argue, this concept has the potential to expand the current understanding of the role of business in tackling significant socio-ecological issues (Dentchev et al., 2018). Crini G. and Lichtfouse E. (2019) define sustainable agriculture based on three main aspects:

- **Ecological aspects** – These focus on maintaining the quality and vitality of the entire agroecosystem. This includes preserving the health of soil, crops, animals, and humans through biological self-regulating processes. The goal is to minimize losses of nutrients, biomass, and energy.

- **Economic aspects** – This aspect assumes that the farmer produces enough products for their own needs while generating a profit that allows them to cover the costs associated with agricultural activities.

- **Social aspects** – From a social perspective, the concept of social justice is crucial. This means that the distribution of resources within agricultural activities should meet the basic needs of all members of society, ensuring that everyone has equal rights to the use of land and other agricultural resources.

The sustainability and performance of agriculture in the Slovak Republic are significant topics when analyzing its economic framework and environmental policy. Agriculture plays a pivotal role in the economic development of the Slovak Republic, particularly after its accession to the European Union (EU), which has transformed agricultural conditions through initiatives such as the Common Agricultural Policy (CAP) (Širá & Pukała, 2020; Vozárová et al., 2023). This relationship underscores the necessity for innovative management of agricultural practices to enhance sustainability. Širá and Pukała highlighted the importance of integrating environmentally friendly policies into agricultural management, emphasizing that sustainable economic growth relies on transforming consumption and production to align human activities with ecological integrity (Širá & Pukała, 2020). the competitive landscape of Slovak agriculture is influenced by market volatility and pricing mechanisms. The dairy sector, which is integral to Slovakia's agricultural economy, has experienced fluctuations in prices due to liberalized market conditions. This trend has led producers to become increasingly dependent on global market prices (Váryová et al., 2019). Vozárová et al. noted that ongoing changes in the market environment necessitate a focus on sustainability and competitiveness to secure agricultural viability in the long term (Vozárová et al., 2023). Recent research demonstrates that land management, regulatory frameworks, and environmental considerations must work together to enhance agricultural sustainability. Both the legal landscape regarding land acquisition and the enforcement of land ownership rights require refinement for improved implementation of sustainable practices (Palšová et al., 2021). The dynamic shift in land use, following the abolition of the moratorium on foreign land acquisitions, necessitates immediate attention to ensure sustainability and protect local agricultural interests (Szilágyi & Csütörtöki, 2022)

2. MATERIAL AND METHOD

This study analyzes the sustainability and performance of agriculture in the Slovak Republic by applying a quantitative evaluation of production and economic factors over the period 2013–2022. The methodology involves a descriptive statistical analysis and comparative trend evaluation based on official data sources.

Data sources:

The primary data used in this research were obtained from the Statistical Office of the Slovak Republic and Eurostat databases. Supplementary data were sourced from secondary research publications related to Slovak agriculture and rural development.

Indicators analyzed:

The following key indicators were selected to assess the development of Slovak agriculture:

- Gross agricultural production compared to GDP
- Agricultural employment as a share of total employment
- Development of agricultural imports and exports (in million euros)
- Revenues from animal and crop production
- Hectare yields for selected crops (cereals, oilseeds, potatoes, and sugar beet)

Methods:

The data were processed using quantitative methods, primarily descriptive statistics (mean, percentage change, growth rates) to identify patterns, trends, and fluctuations over time. Graphical methods were applied to visualize key developments and highlight structural changes in the sector (e.g., line graphs for imports/exports trends). Comparative analyses between years were used to interpret short-term dynamics and long-term trends, especially in connection to economic modernization, EU policy impacts (e.g., CAP reforms), and environmental factors such as climate variability.

Limitations:

The research is limited by the availability of consistent data across the full monitoring period. Where possible, missing data were cross-checked with alternative official statistical reports. The study is also descriptive in nature; therefore, causal relationships were not statistically tested.

3. RESULTS

The productivity of agricultural crops is subject to significant variations influenced by multiple biophysical and economic factors. Analyzing hectare yields over the period 2013–2022 for cereals, oilseeds, potatoes, and sugar beet provides valuable insights into trends, fluctuations, and possible underlying causes affecting crop performance.

Table 1. Hectare yields of selected crops (in tons per hectare)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Cereals	**4,49**	**6,04**	**5,08**	**6,43**	**4,68**	**5,43**	**5,34**	**6,13**	**6**	**4,75**
Year on year change (in t per ha)	x	1,55	-0,96	1,35	-1,75	0,75	-0,09	0,79	-0,13	-1,25
in %	x	25,66	-18,9	21	-37,39	13,81	-1,69	12,89	-2,17	-26,32
Oilseeds	**2,42**	**3,06**	**2,3**	**3,07**	**2,66**	**2,83**	**2,61**	**2,7**	**2,71**	**2,45**
Year on year change (in t per ha)	x	0,64	-0,76	0,77	-0,41	0,17	-0,22	0,09	0,01	-0,26
in %	x	20,92	-33,04	25,08	-15,41	6,01	-8,43	3,33	0,37	-10,61
Potatoes	**18,32**	**19,64**	**17,93**	**21,46**	**20,09**	**21,9**	**22,27**	**23,75**	**24,88**	**22,78**
Year on year change (in t per ha)	x	1,32	-1,71	3,53	-1,37	1,81	0,37	1,48	1,13	-2,1
in %	x	6,72	-9,54	16,45	-6,82	8,26	1,66	6,23	4,54	-9,22
Sugar beet	**56,29**	**69,79**	**65,01**	**70,15**	**55**	**59,88**	**57,62**	**60,39**	**62,57**	**56,29**
Year on year change (in t per ha)	x	13,5	-4,78	5,14	-15,15	4,88	-2,26	2,77	2,18	-6,28
in %	x	19,34	-7,35	7,33	-27,55	8,15	-3,92	4,59	3,48	-11,16

Source: Statistical Office of SR, own processing by authors

Cereal yields exhibited the highest degree of variability, with values ranging from 4.49 t/ha in 2013 to a peak of 6.43 t/ha in 2016. The most significant year-on-year increase occurred in 2014 (+25.66%) and 2016 (+21%), while 2017 (-37.39%) and 2022 (-26.32%) experienced sharp declines. These fluctuations suggest a strong sensitivity to external factors such as climatic conditions, soil fertility, or shifts in cultivation practices.

Oilseed yields showed comparatively lower volatility, with the highest value recorded in 2014 (3.06 t/ha) and the lowest in 2015 (2.3 t/ha). The most pronounced decline occurred in 2015 (-33.04%), followed by a partial recovery in 2016 (+25.08%). However, the overall trend in the latter years indicates a slight decline, culminating in a 10.61% reduction in 2022, which may reflect adverse environmental conditions or changes in input availability.

Potatoes demonstrated the most stable yield pattern among the analyzed crops, with a consistent upward trend from 2016 to 2021, reaching a maximum of 24.88 t/ha in 2021. While fluctuations occurred, they were generally moderate, with the most notable decrease observed in 2022 (-9.22%). This relative stability suggests that potato production is less susceptible to climatic shocks compared to cereals and oilseeds, potentially due to advancements in irrigation techniques and crop management practices.

Sugar beet yields exhibited a cyclical pattern, with a peak in 2016 (70.15 t/ha) and a subsequent sharp decline in 2017 (-27.55%), possibly due to unfavorable weather conditions or soil degradation. Following a period of partial recovery, a further decline was observed in 2022 (-11.16%), reflecting a similar pattern seen in other crops. Given the high productivity potential of sugar beet, these fluctuations underscore the need for adaptive agronomic strategies to mitigate yield instability.

The observed trends highlight the inherent vulnerability of agricultural production to external stressors, particularly climatic variability, input availability, and potential market influences. The sharp declines in 2017 and 2022 across multiple crops suggest that these years faced specific challenges, which may warrant further investigation into weather patterns, soil conditions, and policy interventions. The relative stability of potato yields compared to cereals and oilseeds indicates that certain crops may be more resilient to adverse conditions, possibly due to improved agronomic techniques and technological advancements.

Overall, the findings emphasize the importance of sustainable agricultural practices, risk management strategies, and technological innovations to enhance productivity and ensure food security in the face of environmental and economic uncertainties. Future research should focus on identifying key drivers of yield fluctuations and exploring targeted interventions to improve crop resilience and stability.

The data presented in the table 2 outlines the trends in revenues from agricultural products in Slovakia, focusing on total revenues as well as the breakdown into animal and crop production. Over the 10-year period (2013-2022),

there are several key observations that provide insights into the dynamics of the agricultural sector in the Slovak Republic.

Table 2. Revenues from the sale of agricultural products from primary production (in thousand euros)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Slovak Republic	**1515658**	**1544946**	**1531500**	**1592867**	**1650217**	**1826210**	**1628177**	**1779924**	**1987012**	**2352774**
Year on year change (in ths. Eur)	x	29288	-13446	61367	57350	175993	-198033	151747	207088	365762
in %	x	1,9	-0,88	3,85	3,48	9,64	-12,16	8,53	10,42	15,55
Animal production	**710742**	**694966**	**653508**	**665634**	**729196**	**740194**	**742045**	**125280**	**728790**	**892732**
Year on year change (in ths. Eur)	x	-15776	-41458	12126	63562	10998	1851,3	-616766	603510	163942
in %	x	-2,27	-6,34	1,82	8,72	1,49	0,25	-492,31	82,81	18,36
Crop production	**804915**	**849980**	**877991**	**927233**	**921021**	**1086016**	**886132**	**1054645**	**1258223**	**146005**
Year on year change (in ths. Eur)	x	45065	28011	49242	-6212	164995	-199885	168513	203578	-1E+06
in %	x	5,3	3,19	5,31	-0,67	15,19	-22,56	15,98	16,18	-761,77

Source: Statistical Office of SR, own processing by authors

The agricultural sector in Slovakia, while showing overall growth, experienced periods of instability, particularly in animal and crop production. The positive trend in revenues from 2013 to 2022 underscores the sector's capacity for recovery, although the marked decrease in crop production in 2022 warrants further investigation. Future research should focus on understanding the underlying causes of these fluctuations, particularly with respect to climatic events, agricultural policy, and global market trends. These insights could guide strategies to enhance resilience and sustainability in Slovakia's agricultural sector, ensuring long-term growth and stability.

The comparison reveals that while Slovakia's overall economic growth (GDP) has been strong and consistent, the agricultural sector (Gross agricultural production) has faced more fluctuations. The decline in the share of Gross agricultural production in GDP indicates that the economy is becoming more diversified, with sectors outside of agriculture contributing a larger proportion to GDP growth. However, the recent recovery in Gross agricultural production in 2022 suggests that agriculture still plays a vital role in the economy, albeit with a reduced relative share.
This analysis can be expanded by investigating the specific causes behind the fluctuations in Gross agricultural production, such as changes in agricultural practices, government policy, or shifts in domestic and international markets.

Table 3. Comparison of the Development of GDP and Gross Agricultural Production from 2013 to 2022

	Gross domestic product (in mil EUR)	Year on year change	v %	**Gross agricultural production (in mil. EUR)**	Year on year change	v %	**Share of gross agricultural production on gross domestic product**
2013	**74 492,79**	x	X	**2 220,19**	x	x	2,98%
2014	**76 354,52**	1 861,73	2,44	**2 192,72**	-27,47	-1,25	2,87%
2015	**80 126,05**	3 771,53	4,71	**1 944,47**	-248,25	-12,77	2,43%
2016	**81 265,20**	1 139,15	1,4	**2 179,84**	235,37	10,8	2,68%
2017	**84 669,88**	3 404,68	4,02	**2 160,90**	-18,94	-0,88	2,55%
2018	**89 874,69**	5 204,81	5,79	**2 048,12**	-112,78	-5,51	2,28%
2019	**94 429,73**	4 555,04	4,82	**2 003,86**	-44,26	-2,21	2,12%
2020	**93 444,10**	-985,63	-1,05	**2 086,07**	82,21	3,94	2,23%
2021	**100 255,70**	6 811,60	6,79	**2 242,94**	156,87	6,99	2,24%
2022	**109 645,18**	9 389,48	8,56	**2 723,80**	480,86	17,65	2,48%

Source: Statistical Office of SR, own processing by authors

Between 2013 and 2022, the share of agricultural employees in Slovakia's total employment declined overall, reflecting broader trends of economic modernization and sectoral shifts away from agriculture. In 2013, agriculture accounted for 3.31% of total employment.The highest share in the dataset occurred in 2014 (3.50%).

After 2014, the share steadily decreased to a low of 2.29% in 2018. In 2019, there was a temporary increase back to 2.79%, likely influenced by specific economic or policy factors (such as changes in rural employment schemes or CAP subsidies). From 2020 to 2022, the share remained relatively stable, fluctuating slightly between 2.47% and 2.58%. By 2022, the agricultural sector made up only 2.54% of total employment.

Table 4. Share of agricultural employees in total employment (in thousand people)

	Total employees	Employees in Agriculture, forestry and fishing	Share of agricultural employees in total employment
2013	2 329,30	77,1	3,31%
2014	2 363,00	82,7	3,50%
2015	2 424,00	77,1	3,18%
2016	2 492,10	72	2,89%
2017	2 530,70	68,6	2,71%
2018	2 566,70	58,9	2,29%
2019	2 583,70	72	2,79%
2020	2 531,30	65,3	2,58%
2021	2 560,60	63,2	2,47%
2022	2 603,90	66,1	2,54%

Source: Statistical Office of SR, own processing by authors

Between 2013 and 2022, Slovakia's total imports (all goods) increased significantly, while imports of agricultural products (livestock, crops) also grew in absolute terms but maintained a relatively stable share of the total imports. otal imports grew from about €59.6 billion in 2013 to €107.3 billion in 2022, showing strong overall trade growth.

Agricultural product imports (livestock + crops) rose from €1.837 billion in 2013 to €3.213 billion in 2022 — a 75% increase over the decade. Share of agricultural imports relative to total imports remained fairly stable, fluctuating slightly around 2.8–3.1%. Price inflation and supply chain disruptions (especially in 2020–2022 due to COVID-19 and geopolitical tensions) could partly explain the sharp rises in 2021–2022. Despite the rise, domestic agricultural production likely absorbed much of domestic demand, keeping agriculture's share of imports stable.

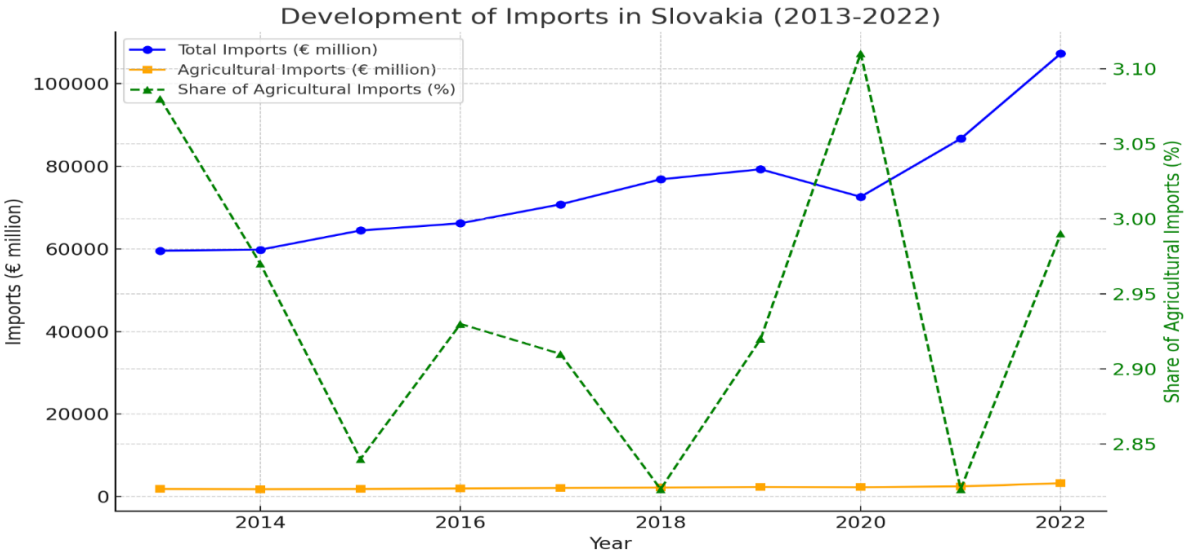

Figure 1. Development of imports in the monitored period (in million eur)
Source: Statistical Office of SR, own processing by authors

Between 2013 and 2022, Slovakia's total exports increased significantly, while exports of agricultural products also grew in absolute terms. However, the share of agricultural products in total exports declined slightly over the decade. Total exports rose from €64.1 billion in 2013 to €102.8 billion in 2022 — about a 60% increase. Agricultural exports (livestock + crops) grew from €1.796 billion in 2013 to €2.591 billion in 2022 — a 44% increase. The share of agricultural exports relative to total exports declined from 2.80% in 2013 to 2.52% in 2022. The lowest share was recorded around 2018–2019, at just under 2%. In 2022, there was a noticeable jump in agricultural exports, coinciding with a general rise in total exports. Exports grew, but agricultural products became slightly less significant relative to total exports over time.
Livestock and crop exports fluctuated, but crops contributed more to agricultural exports. 2022 saw a strong increase in agricultural exports, likely reflecting market recovery, price effects, or strong crop production.

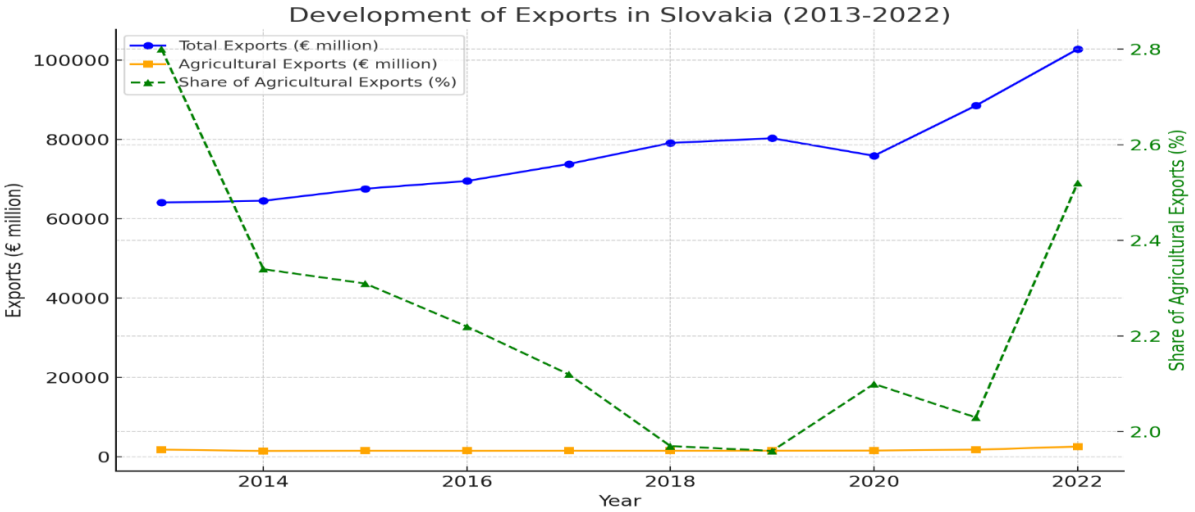

Figure 2. Development of exports in the monitored period (in million eur)
Source: Statistical Office of SR, own processing by authors

4. DISCUSSION AND CONCLUSIONS

In summary, the sustainability and performance of Slovak agriculture are influenced by a combination of economic factors, regulatory measures, competitiveness, and effective governance. Strategic integration of innovative agricultural practices and adherence to environmental standards are paramount for achieving long-term sustainability in the sector. The findings warrant continued efforts to enhance administration, promote bioeconomy principles, and ensure that Slovak agriculture can thrive amidst evolving global challenges.

The performance of the agricultural sector in Slovakia during the period 2013–2022 shows a mixed trend characterized by both growth and structural decline in relative importance within the national economy. The main findings are that gross agricultural production fluctuated throughout the observed period. Although nominal values showed a degree of recovery in 2022, agriculture's share of GDP declined, reflecting a diversification of the Slovak economy. Cereal yields exhibited significant variability, reaching a peak in 2016 (6.43 t/ha) and facing notable declines in 2017 and 2022. Oilseed and sugar beet yields followed cyclical patterns, with notable decreases attributed to climatic and input-related challenges. Potatoes displayed relatively stable and increasing yields until 2021, indicating higher resilience. Agricultural employment as a share of total employment steadily declined from 3.31% in 2013 to 2.54% in 2022, mirroring broader sectoral shifts toward services and industry. Total imports of goods increased by almost 80%, while agricultural imports grew by 75%. The share of agricultural products in total imports remained stable, around 2.8–3.1%. Total exports grew by approximately 60%. Agricultural exports increased in absolute terms by about 44%, but their relative share in total exports declined slightly from 2.8% to 2.52% over the period. Revenues from crop production showed higher volatility compared to animal production, with a notable decrease in crop revenues observed in 2022.

These findings reflect the dual nature of the sector — agriculture continues to be important for food security and rural development, but its relative economic weight is diminishing in the context of Slovakia's overall modernization.

Agricultural products account for only about 2–3% of Slovakia's total trade (both imports and exports), and this share has declined slightly. There is a need to strengthen competitiveness by supporting value-added production (processing crops, local branding), by focusing on high-quality, niche markets (organic, specialty foods) and by encouraging innovation and adoption of technology. The decline in agricultural employment from 3.31% in 2013 to 2.54% in 2022 signals a shrinking rural workforce. Policies should support young farmer programs, rural development initiatives, and training for digital and modern agricultural techniques to keep rural areas economically viable. A focus on transparent land policies, support for small and medium-sized farms, and protecting agricultural land use is needed to secure long-term sustainability.

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Conflict of Interest
The authors have no conflicts of interest to declare.

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Physicochemical Composition of Olive Pomace for a Sustainable Valorization

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Abstract: Olive pomace (OP), the solid by-product from olive oil production, represents a significant source of bioactive compounds, including polyphenols with high antioxidant properties. The growing interest in the sustainable valorisation of the olive oil production chain has driven efforts to recover high-value compounds from this low-cost byproduct. This study aims to characterise the physicochemical properties of OP obtained from different olive oil extraction systems (two-phase and three-phase), collected during the harvest seasons from 2022 to 2025. Comprehensive physicochemical analyses, including the determination of moisture, ash, dry matter, total extractives, protein content, minerals, total carbohydrates, cellulose, neutral and acid detergent fibres, and total soluble sugars, were conducted to assess the composition of OP samples. The total phenolic content and the total antioxidant activity of hydroalcoholic olive pomace extracts were quantified using the Folin–Ciocalteu method and the DPPH radical scavenging assay, respectively. Results revealed that OP samples contained high levels of crude fibres (33.6-38.5%), total carbohydrates (30% -40%), and oil (8.06 to 14.82 g/100 dry OP). OP samples from the three-phase extraction process exhibited higher protein content (5.6-7.34%), as determined by the Kjeldahl method using the N-Analyzer FOSS system. The pH, ash, minerals, and lignin contents were found to be 4.7-5.15, 1.25-3.35%, 3.8-6.02%, and 30.8-38.5%, respectively. Hydroalcoholic extracts demonstrated high phenolic content (9.56-32.59 mg GAE/g DW) and strong antioxidant activity (13.46-35.23 μmol TE/g DW). The results prove that the olive pomace studied is rich in nutrients and could be considered a valuable source for obtaining high-added-value products.

Keywords: Olive pomace, valorization, sustainable, value added products.

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1. INTRODUCTION

The olive oil industry plays a vital economic, environmental, and social role in Mediterranean countries, which are responsible for approximately 98% of global olive oil production (Gullón et al., 2020). The growing demand for olive oil is largely attributed to its distinctive organoleptic characteristics and well-established health benefits (Di Giovacchino et al., 2017). This sector is a fundamental component of the agro-industrial economy in the Mediterranean basin, where olive mills are predominantly situated and substantial land areas are dedicated to olive cultivation (Manzanares et al., 2020). Furthermore, 75% of global olive oil production originates from Mediterranean Member States of the European Union (Lozano-Sànchez et al., 2014).

Olive oil production involves several mechanical extraction processes. In brief, olives after milling and malaxation are submitted to pressing systems, such as i) press olive oil extraction, ii) three-phase centrifugal olive oil extraction, and iii) two-phase centrifugal olive oil extraction where the press and three-phase centrifugal systems generate large volumes of liquid effluent compared to the two-phase centrifugation process, which is considered more ecological (Ochando-Pulido et al., 2020).

The virgin olive oil production chain generates significant quantities of by-products (such as olive pomace and olive mill wastewater) and wastes (including olive leaves and wood), depending on the extraction techniques used for olive oil manufacture (Abbattista et al., 2021). Currently, the generation of these by-products is high and tends to increase, posing a major environmental concern in Mediterranean regions due to the large volumes produced in short periods and their high content of organic matter and phenolic compounds (Difonzo et al., 2021; Banias et al., 2017). These by-products have diverse environmental impacts, including resource depletion, land degradation, air emissions, and waste generation (Pampuri et al., 2021).

Olive mill wastewater (OMWW) is one of the main by-products of the olive oil industry, with generation rates ranging from 1.2 to 1.8 m^3 per ton of processed olives (Haddad et al., 2017). This effluent is characterized by a high organic load, elevated levels of suspended solids and fats, acidic pH, high electrical conductivity due to its salt content, and dark coloration caused primarily by phenolic substances (García-Pastor et al., 2023; Hadidi et al.,

2021). The disposal of OMWW presents a significant environmental challenge due to its high content of phenolic compounds, which are largely responsible for its pronounced phytotoxicity and pollution potential. Additionally, the discharge of OMWW into the environment contributes to toxicity and ecological degradation, making it a pressing environmental issue with complex technological, economic, and social dimensions (Markhali, 2021). Consequently, OMWW is widely regarded as one of the most polluting effluents generated by the agro-food industry, owing to its substantial environmental load (Pikuli and Devolli, 2024a). Controlled application to agricultural soils has been shown to enhance physical, chemical, and biological soil properties (Kavdir and Killi, 2008). Despite these concerns, several studies have highlighted the potential of OMWW for beneficial reuse. These improvements are primarily attributed to the presence of valuable organic compounds in OMWW, including organic acids, alcohols, lipids, nitrogenous substances, sugars, and potassium (Roig et al., 2006). Furthermore, OMWW has been investigated as a promising substrate for biogas production, offering a sustainable and energy-efficient pathway for its valorization (Demirer et al., 2000). Additionally, when properly managed, OMWW represents an inexpensive and accessible source of natural antioxidants, primarily due to its high polyphenolic content. These bioactive compounds can be extracted and utilized as natural antioxidants in the food and pharmaceutical industries (Niaounakis and Halvadakis, 2006).

Among the various waste streams and by-products generated by the olive oil industry, olive pomace (OP) is regarded as the most significant, both in terms of volume and compositional complexity. According to Foti et al. (2022) and Cooksey (2017), one tonne of processed olives generates approximately 500 - 600 kg of OP. This by-product is a heterogeneous lignocellulosic matrix composed of olive husk, pulp, crushed stones, and residual olive mill wastewater. It typically exhibits a high moisture content of approximately 65%, although this value varies depending on the extraction technology employed (Regni et al., 2017). Specifically, pomace obtained through pressing or the traditional three-phase decanter system generally contains between 20% and 50% moisture, whereas pomace produced by the modern two-phase extraction method may exhibit moisture levels of up to 70%. The two-phase system is considered more environmentally sustainable than the conventional and three-phase extraction process of olive oil production, primarily due to its elimination of added process water, thereby significantly reducing wastewater generation (Dermeche et al., 2013).

Olive pomace, a lignocellulosic residue generated during olive oil production, is recognized as a potential source of cellulose, hemicellulose, and lignin. The efficient extraction of high-purity cellulose from OP is essential for its valorization into high-value bioproducts, including biofuels, bioplastics, and nanomaterials. Compositional analyses have shown that OP contains approximately 16.2% cellulose, 18.96% hemicellulose, and 31.7% lignin on a dry weight basis (Miranda et al., 2019). To facilitate cellulose recovery, several pretreatment strategies—such as hydrothermal treatment and enzymatic hydrolysis—have been employed. These methods have enabled the production of cellulose nanofibers from OP, which are suitable for use as reinforcing agents in biodegradable composite materials (Sagdic-Oztan et al., 2023). These developments highlight the potential of OP as a renewable raw material and underscore the importance of optimizing extraction processes to enhance its economic and environmental value.

Nowadays, olive pomace is currently utilized in various sectors, including agriculture, where it functions as a soil conditioner and organic fertilizer, bioenergy generation, and as a raw material for the extraction of bioactive compounds. These compounds include hydroxytyrosol, tyrosol, oleuropein, caffeic acid, and squalene, which are widely applied in the pharmaceutical, food, and cosmetic industries (Nunes et al., 2018; Dermeche et al., 2013). The compositional profile of OP is characterized by a rich array of bioactive substances, such as phenolic compounds, uronic acids, oily residues, and a residual oil content ranging from 3% to 4.5% on a wet basis. This biochemical complexity renders OP a promising and economically viable source of high-value compounds, including polyphenols and fatty acids, both known for their potent antioxidant properties (Nunes et al., 2021; Gullón et al., 2020). Owing to its abundance and bioactive richness, OP has attracted growing interest for its potential in sustainable, high-value applications, particularly in the formulation of functional food ingredients and nutraceuticals (Nunes et al., 2016).

The present study aims to comprehensively evaluate the physicochemical composition of olive pomace obtained from various extraction systems. Several physico-chemical analyses were conducted to determine key parameters such as moisture content, ash, dry matter, total extractives, protein content, minerals, total carbohydrates, cellulose, neutral detergent fiber (NDF), acid detergent fiber (ADF), and total soluble sugars. Additionally, the total phenolic content and antioxidant activity of hydroalcoholic extracts of olive pomace were determined to evaluate their potential as valuable sources of bioactive compounds.

2. MATERIALS AND METHODS

2.1. Sample collection and preparation

A total of 35 samples of olive pomace were obtained from the extraction of olives using two- and three-phase centrifugal systems during the harvest seasons from 2022 to 2025. Samples labeled OP1, OP2, and OP3 were collected from three olive oil processing facilities in southern and central Albania. Specifically, OP1 originated from processing the Kalinjoti olive cultivar to produce extra virgin olive oil using the three–phase extraction system. According to genetic studies, Kalinjoti is recognized as the most predominant autochthonous cultivar in southern Albania. Samples OP2 and OP3 were derived from processing various olive cultivars using two- and three-phase extraction methods, respectively. To prevent biodegradation, all collected samples were immediately stored at 4 °C. Olive pomace samples were then dried in a tray dryer at a controlled temperature of 45–50 °C for 48 hours, followed by milling with a flour mill for 10 seconds to obtain a uniform particle size of approximately 1 mm.

2.2 Analytical method for the characterisation of physico-chemical composition of OP

Protein content
The nitrogen content was determined using the Kjeldahl method with a Foss protein analyzer, based on the procedure described by Zhao et al. (2020). For the analysis, 0.3 g of dried olive pomace (OP) was subjected to acid digestion. The protein content was subsequently calculated from the nitrogen content of the dry biomass using a nitrogen-to-protein conversion factor of 6.25.

Moisture and ash content determination
Moisture content of the olive pomace samples was determined gravimetrically. Approximately 10 g of each sample was dried in a forced-air oven (LBX OVF series) at 105 ± 1 °C for 48 hours, or until a constant weight was reached, following the procedure described by Moya et al. (2010). The final weight was recorded and used to calculate the total water content, based on the difference between the initial and final weights. Moisture content was expressed as a percentage of the initial weight of the olive pomace samples or their respective extracts.

Ash content of the olive pomace was determined using a gravimetric method. Approximately 5 g of dried OP sample was placed in a pre-weighed crucible and incinerated in a muffle furnace at 650 ± 5 °C for 8 hours, or until a constant weight was reached. The residue was then cooled in a desiccator and weighed. Ash content was calculated as a percentage of the initial dry weight of the sample (Nunes et al., 2021).

Detergent Fibre
The contents of neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to the method described by Mertens (2002). NDF measures all insoluble cell wall material, including hemicelluloses, cellulose, and lignin, while ADF measures only cellulose and lignin. These fibre fractions are widely used to evaluate the structural carbohydrate content and nutritional quality of plant-based feedstuffs.

Oil Content Determination
The oil content of the olive pomace was determined using Soxhlet extraction with hexane as the solvent. A 5 g portion of dried OP was subjected to continuous extraction using a Universal Extractor, following standard procedures for lipid quantification (Azadmard-Damirchi & Dutta, 2008). Each sample was extracted through 30 complete cycles, and analyses were conducted in triplicate.

Total Carbohydrate Estimation by Difference
The total carbohydrate content was estimated by the difference method, which is commonly employed in proximate analysis, especially for plant-based materials such as olive pomace. This method involves calculating carbohydrate content indirectly by subtracting the measured percentages of moisture, crude protein, crude fat, and ash from the total composition (100%) of the sample. The formula is as follows:

$$\text{Total Carbohydrates (\%)} = 100\% - (\text{Moisture} + \text{Crude Protein} + \text{Crude Fat} + \text{Ash})$$

This approach is recommended by the Food and Agriculture Organization (FAO, 2003) and is widely used when direct carbohydrate quantification is not performed.

Determination of Total Extractives
The total extractives content in olive pomace was determined using a standard Soxhlet extraction method based on procedures described by the AOAC (920.39) and ISO 14453:2001.

Approximately 3.0 g of the dried OP sample was accurately weighed and placed in a cellulose extraction thimble. Soxhlet extraction using n-hexane as the solvent was performed for 6 hours with continuous reflux. Following extraction, the solvent was evaporated using a rotary evaporator under reduced pressure. The residue was then dried in an oven at 40 °C until a constant weight was achieved. The total extractives were calculated gravimetrically and expressed as a percentage of the dry weight OP (DW) using the following formula:

$$\text{Total Extractives (\%)} = (\text{Mass of extract residue} / \text{Mass of dry OP}) \times 100$$

Determination of Lignin Content

The lignin content in olive pomace was determined using the Klason method (TAPPI T222 om-15) with some modifications. Olive pomace samples were oven-dried at 60°C, ground to less than 1 mm, and extracted with a 2:1 ethanol–benzene solution in a Soxhlet apparatus for 6 hours. Extractive-free samples (0.5 g) were hydrolyzed with 72% H_2SO_4 at 30 °C for 1 to 2 hours, followed by dilution to 4% acid and autoclaving at 121 °C for 1 hour. The acid-insoluble residue was filtered, dried at 105 °C, and weighed. Lignin content was calculated gravimetrically and expressed as a percentage of dry weight OP using the following equation:

$$\text{Lignin (\%)} = (\text{Mass of acid-insoluble residue} / \text{Dry mass of OP}) \times 100$$

Determination of Cellulose Content

Cellulose was isolated from olive pomace following the method described by Brendel et al. (2000), with slight modifications. Approximately 250 g of dried olive pomace was treated with a mixture of 80% (w/w) aqueous acetic acid and 70% (w/w) nitric acid under continuous stirring. The extraction was carried out at room temperature to remove lignin and hemicellulose. The resulting residue was thoroughly washed with distilled water, followed by 95% ethanol, to eliminate residual nitric acid and solubilized degradation products. The residue was then dried in a hot air oven at 60 °C for 24 hours to obtain the purified cellulose fraction.

Total suluble sugar content

Total soluble sugars in olive pomace were determined using the phenol–sulfuric acid method, as described by Nielsen (2010), with slight modifications. An aliquot of 0.5 mL of the hydroalcoholic extract was mixed with 0.5 mL of 5% (w/v) phenol solution, and 2.5 mL of concentrated sulfuric acid (98% H_2SO_4) was added rapidly. The reaction mixture was incubated in a water bath at 80 °C for 15 minutes, then cooled to room temperature. The absorbance was measured at 490 nm using a UV–Vis spectrophotometer. Quantification was performed using a standard calibration curve prepared with D-(+)-glucose in the concentration range of 0.2–1.0 mg/L ($R^2 = 0.997$). Results were expressed as the percentage of total soluble sugars relative to the dry weight of olive pomace.

Determination of total phenolic content and total antioxidant activity of olive pomace extracts

The total phenolic content (TPC) of the olive pomace (OP) hydroalcoholic extracts was determined using the Folin–Ciocalteu colorimetric method, as described by Pikuli and Devolli (2024b). A calibration curve was prepared using gallic acid standards ranging from 0 to 1 mg/mL ($R^2 = 0.9996$). Absorbance was measured at 760 nm, and TPC values were expressed as milligrams of gallic acid equivalents per gram of dry wieght OP (mg GAE/g DW). Total antioxidant activity (TAA) was measured using the DPPH assay, as modified by Pikuli and Devolli (2024b). The reduction in absorbance was measured at 515 nm, using methanol as the blank. A calibration curve was prepared using Trolox as the standard, and the results were expressed in μmol Trolox equivalents per gram of dry weight olive pomace (μmol TE/g DW).

2.3 Statistical Analysis

All analyses were conducted in triplicate, and results were presented as mean ± standard deviation. Statistical analysis was performed using one-way ANOVA (Tukey's test) with a significance level of $p < 0.05$, using SPSS version 27.

3. RESULTS AND DISCUSSIONS

Table 1 presents the physicochemical composition of olive pomace (OP) samples obtained from olive oil extraction using two-phase and three-phase centrifugal systems during the 2022–2025 harvest seasons. The results are expressed as mean ± standard deviation ($n = 3$).

Moisture content was determined gravimetrically in both crude and dried olive pomace samples. Crude OP samples were dried in a forced-air oven at 40–50 °C for 48 hours to prevent the degradation of bioactive compounds. The moisture content of crude olive pomace ranged from 56.3% to 60.7% in samples obtained from the three-phase

centrifugal extraction system, while it was approximately 70% in OP samples derived from the two-phase system. A statistically significant difference ($p < 0.05$) was observed between the two extraction systems.

The results presented in Table 1 show that the ash, protein, and mineral contents of olive pomace ranged from 1.87% to 3.00%, 5.51% to 7.19%, and 4.20% to 5.89%, respectively. The lowest values for these parameters were observed in OP3 samples obtained from the three-phase centrifugal extraction system.

According to the data presented in Table 1, olive pomace samples contained 8.65% to 14.19% residual oil. This parameter is crucial for optimizing the efficiency of olive oil production. The residual oil is recovered through solvent-based extraction methods to produce "olive pomace oil." Before this extraction process, the pomace must be dried, making both residual oil and moisture content critical factors in determining its commercial value (Baysan et al., 2017; Miranda et al., 2019).

Table 1. Physico-chemical compositions of olive pomace samples

Parameters	OP1		OP2		OP3	
	mean	Std	mean	Std	mean	Std
Moisture of crude olive pomace (%)	60.67	2.62	56.33	6.94	70.00	1.63
Moisture of dried OP (% DW)	5.27	0.09	4.64	0.43	5.13	0.34
Ash (% DW)	3.00	0.27	2.69	0.20	1.87	0.44
pH	4.92	0.10	4.90	0.16	5.16	0.11
Minerals (% DW)	5.89	0.09	5.15	0.12	4.20	0.29
Oil residue (% DW)	14.19	0.76	11.23	0.24	8.65	0.43
Protein (% DW)	7.19	0.16	6.19	0.42	5.51	0.21
Total crude fibre (% for DM)	37.00	0.82	35.70	2.69	36.13	2.05
NDF (% DW)	48.43	1.52	39.95	1.92	35.97	1.96
ADF (% DW)	34.85	0.48	32.20	0.85	28.03	3.08
Total carbohydrate (% DW)	38.33	1.25	35.00	1.63	32.33	2.05
Cellulose (% DW)	26.50	0.99	18.30	4.28	20.90	2.01
Lignin (% DW)	37.33	1.03	34.33	1.25	32.10	1.10
Total extractives (% DW)	26.83	1.31	24.00	1.63	20.67	2.05
Total soluble sugars (% DW)	6.32	0.09	6.17	0.05	5.83	0.18

*Std-standard deviation

The results showed that crude fiber content ranged from 35.70% to 37.00%, total carbohydrates from 32.33% to 38.33%, cellulose from 18.30% to 26.50%, and total soluble sugars from 5.83% to 6.32%, all expressed on a dry weight basis of the olive pomace (DW) samples. The data revealed that total lignin content in the olive pomace samples ranged from 32.10% to 37.33%, while total extractives (in water and ethanol) ranged from 20.67% to 26.83%.

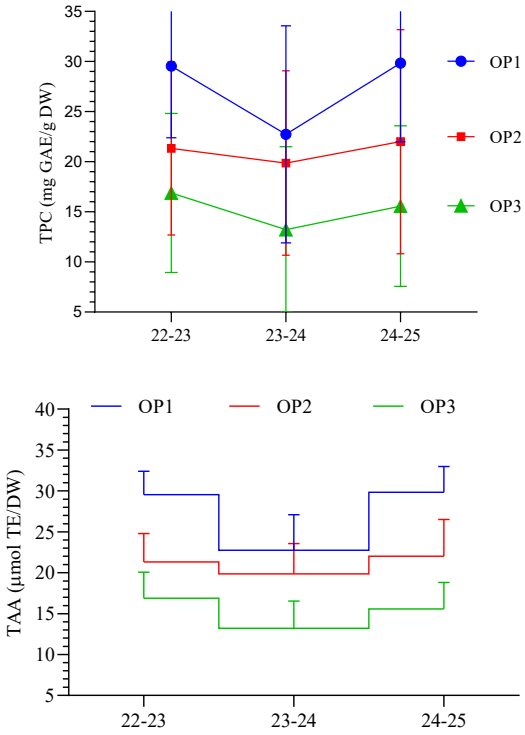

Figure 1. Total phenolic content (TPC) and total antioxidant activity (TAA) of olive pomace ethanolic extracts

The total phenolic content and total antioxidant activity of olive pomace hydroalcoholic extracts (ethanol 80%) are presented in Figure 1. The total phenolic content (TPC) and total antioxidant activity (TAA) in dry weight of olive pomace ranged from 12.09 to 31.03 mg GAE/g DW and 18.25 to 32.70 µmol TE/g DW, respectively. Among the samples analyzed, the highest levels of total phenolic content (TPC) and total antioxidant activity (TAA) were observed in the extracts of OP1 and OP2, derived from three-phase and two-phase extraction systems, respectively. Notably, the OP1 extract, obtained from the Kalinjoti cultivar, exhibited significantly higher TPC and TAA values compared to those of extracts derived from other olive cultivars (Fig. 1).

The total phenolic content and total antioxidant activity of the hydroalcoholic extracts of olive pomace obtained in the present study are in agreement with the findings of Pikuli and Devolli (2024b), who reported similar ranges in their analysis. These results align with previous studies that have consistently highlighted the significant antioxidant potential of olive pomace (Zhao et al., 2022, Nunes et al., 2018). Furthermore, the findings reinforce the nutrient-rich profile of olive pomace, reported by Cravotto et al. (2022) and Di Giovacchino et al. (2017). Additionally, the sustainable valorization of OP aligns with the principles of circular bioeconomy and sustainable food systems, offering an effective strategy for waste reduction and resource recovery within the olive oil industry.

4. CONCLUSIONS

The present study demonstrates the potential of olive pomace as a valuable source of essential nutrients and bioactive compounds. Through several physico-chemical analyses, we characterized the key components of olive pomace, including moisture content, ash, dry matter, total extractives, protein content, minerals, total carbohydrates, cellulose, neutral detergent fiber (NDF), acid detergent fiber (ADF), total soluble sugars, total phenolic content, and total antioxidant activity.

The findings revealed that olive pomace not only possesses substantial nutritional value but also exhibits significant antioxidant activity, highlighting its potential for diverse applications in the food, nutraceutical, and pharmaceutical industries. The management of olive pomace residues is crucial for environmental preservation and the sustainable utilization of agro-industrial by-products. Their valorization aligns with the growing demand for innovation and sustainability in the food system. Further research should be carried out regarding the sustainable utilization and valorization of olive pomace, contributing to the development of functional foods and bioactive-rich products.

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Author Contributions
Conceptualization: P.K.; Investigation: P.K.; Material and Methodology: P.K., D.A.; Supervision: D.A.; Visualization: P.K.; Writing-Original Draft: P.K., D.A. All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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A Look Into Endemic Iberis Halophila (Brassicaceae) In The Salt Lake

BURCU YILMAZ ÇITAK *[1]

Abstract: The family Brassicaceae known as mustards is included 91 genera and 686 taxa based on the list of plants of Türkiye. The number of species of the family generally have economic importance also have aromatic and medicinal properties. The Iberis L. genus, which occupies a small place in this family, is represented by 28 taxa in the world. Only 10 species of the genus are known to be distributed in Turkey. Iberis halophila Vural & H. Duman is an endemic plant species found in the Salt Lake within the Iberis genus. This dwarf plant is perennial herb with woody at base, glabrous stems up to 10 cm. Stems are branched at base, ascending to erect with lower leaves are like spathula shaped same as smaller cauline ones in the same shape, boths are fleshy. Corymbose inflorescence is not elongated in fruit with about 15 flowered. Sepals are green at buds, purple in anthesis. Petals are pinkish-violate at base to white that lower ones bigger than upper ones. In field trips conducted from 2021 to 2025, populations of the known plant from three different localities were visited and only 450 individuals were detected in the first locality around Eskil. The populations of this endemic species in the second locality, Tersakan Lake, could not be reached. It was observed that there was an intense grazing pressure in this area. The results obtained field surveys and observations I. halophila has been suggested critically endangered.

Keywords: Cruciferae, *Iberis*, Candytufts, Morphology

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1. INTRODUCTION

Since Turkey is located in the temperate zone, it stands out with its different characteristics from many countries in the surrounding area in terms of the variety of plants it hosts. The number of plant species distributed in Turkey is approximately equivalent to the number of plant species distributed throughout the entire European region. With the addition of the findings of recent studies and research, it has been revealed that Turkey hosts nearly 12,000 plant taxa (at the level of species, subspecies and varieties) (Erik and Tarıkahya, 2004; Güner et al., 2012).

Brassicaceae known as 'the mustard family', comprised about 338 genera and 3709 species worldwide (Al-Shehbaz et al., 2006). In Turkey, this large family was accepted to include about 571 species, with 65 subspecies and 24 varieties; in other words, 660 taxa belonging to 91 genera (Al-Shehbaz et al., 2007). When the checklist of Flora of Turkey (Vascular Plants) was published (Güner et al., 2012), these numbers were updated to 91 genera and 686 species. Brassicaceae includes essential oil seeds and vegetable crops, troublesome weeds, and *Arabidopsis thaliana* Heynhold, the consensus small model plant for research in plant biology (Brown et al., 2004). The genus *Iberis*, which is represented by 10 species in Türkiye (Mutlu, 2012; Oskay, 2017; Çıtak, 2019; Çilden and Özüdoğru, 2022), is poorly known by its general morphology. Anatomical, palynological and micromorphological and molecular studies were conducted on the members of *Iberis* genus by different researchers (Çıtak, 2019; Çilden and Özüdoğru, 2022; Çıtak and Dural, 2020).

Iberis halophila Vural & Duman is a species that was identified from Salt Lake in 2012 and introduced to the scientific world. This study aimed to provide information about the current locality and populations of the species.

2. MATERIAL AND METHOD

The plant specimens in studied species collected from the natural habitats and were prepared and dried according to standard herbarium techniques. At least 10 plant specimens of *I. halophila* were observed and measured for morphological characters. Thirty morphological characters like plant and stem height, petal and sepal dimensions, basal and cauline leaves, fruit and seed sizes etc. for each character thirty or more measurement were made. Between 2021 and 2025 years, the populations of species were observed with field surveys.

3. RESULTS

***Iberis halophila* Vural & Duman**

Perennial but herbaceous at base, glabrous, 7.5-9.5 cm. Stem length 4-6 cm, branched at base. Basal leaves 1.5-3.5 cm, spatulate to oblanceolate, clearly petiolate, simple, fleshy, petiole 1 cm. Cauline leaves similar to basal leaves, but smaller, 8-13 × 2-3.5 mm. Inflorescence corymbose. Sepals purple, membranous, 3.5×2 mm. Petals white to pinkish-purple, outer petals 5-7.5 mm, inner petals 4-5 mm. Inflorescence corymbose, elongating in fruit. Filament 1.5 mm, extrorse, not toothed or expanded. Anthers yellow, 1.5 mm, stigma capitate. fruiting pedicels 4-7 mm. Fruit shape is ovoid, purple-green, 6.38×5.05 mm, wing 1.35 mm, sinus 1.19 mm, style 1 mm. Seed 3.09×1.97 mm, brown. Flowering period April-May, saline areas, 900-1000 m. (Figure 1.)

According to IUCN threat category, this endemic species should be replaced under “Critically Endangered (CR)” threat category because of the distribution area occupancy is less than 10 km^2 and there is only one known location. This endemic has less than 50 mature individuals [CR B2ab(ii, iii, v) + C2a(i)].

Figure 1. The photos of *I. halophila* in nature. a. The general view of species in flowering time b. The general view of species in fruiting time

As a result of four years of studies on this species, it has been determined that the population of the species is decreasing. During field studies conducted in the habitat of the species in the southeast of Gölyazı district, known as the type locality, the species was not encountered. 450 individuals were counted in the locality located in the northeast of Eskil district (Figure 2). Not all of these individuals are adults. Observations made in 2025 showed that changing climate conditions, especially snowfall, affected some individuals. As a result of highway works carried out in this region, it was observed that the locality with more than 600 individuals was destroyed in 2024. It was also determined during nature observations that intensive animal grazing was carried out in the region. It is obvious that the species will face the danger of extinction in the near future with such unconscious activities.


Figure 2. The habitats of *I. halophila* showed in Google Earth programme

4. DISCUSSION AND CONCLUSIONS

In this study, information is given about the morphological analysis and current status of *Iberis halophila*, which is a member of the Brassicaceae family and is distributed in Salt Lake. The number of individuals of the local endemic species is less than 500 individuals and the species is in danger of extinction in the near future. The plant needs to be monitored urgently within the scope of conservation policies and studies should be increased to improve its populations.

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The Assessement of Raw Cow Milk Chemical Parameters In North-Western Albania

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Abstract: Milk is an important source of all basic nutrients required for mammals including human beings. This study was conducted to evaluate the chemical quality of milk samples in various villages in Shkodër, Albania. The fat, solids-non-fat, and added water parameters were analyzed in the samples of fresh milk with milkanalyzer apparatus. A total of 317 samples of fresh milk were analyzed. The results were statistically processed and showed: fat 3,45% ±0,447, solids-non-fat (SNF): 7,9% ± 0,187 and added water: 5,23% ± 2,06. Significant changes were observed for added water mean %, it was significantly higher in August. The one-Way Anova analysis for ($P \leq 0.05$) showed that the means of fat, solid-non-fat and added water in the different months differ significantly from one another. Pearson correlation analysis was calculated and showed a high negative correlation between added water % and solids-non-fat % ($r = -0,938$; $P = 0,000$).

Keywords: food security; raw milk; quality standard

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INTRODUCTION

One of the oldest foods consumed by humans is milk and it is the physiological secretion of the mammary gland of mammals. Nickerson (1999). Milk is a liquid nutritive product containing 10-13% dry matter. It contains 700 kkal/l energy value. The nutritional value of milk is high because of its high protein value. Milk composition and quality are of prime concern to the dairy industry and human health because milk composition is process ability related. (Ozrenk and Selcuk, 2008) Thus, ensuring high quality and desirable physico-chemical properties of raw milk for processing is challenging because they depend on many factors like breed, pasture, etc.

Raw milk becomes spoiled easily and becomes unsuitable for processing and consumption by humans. (Food and Agriculture Organization of the United Nations, FAO 2011). Physico-chemical properties of cow's milk are dependent on solids-non-fat (SNF), total solids (TS), acidity and total bacterial count (TAC) and protein and fat content. World Health Organization and (Grimley et al., 2009) noted that milk composition should be: 3.6% fat, 28 g/l proteins, 7.71% solids-non-fat (SNF) and Lactometer Reading (LR) 1.030. The pH 6.6 ensures the milk freshness at boiling point 100oC - 117oC.(Webb et al., 1974). Milk protein, fat, and lactose are an important source of energy. A gram of milk fat provides 9.3 cal and a gram of protein and lactose provides 4.1 cal. Federal Democratic Republic of Ethiopia Central Statistical Authority (CSA), (2010). Adulteration of food is the intentional addition of foreign or inferior substance to genuine foodstuffs for various reasons. (Anagaw et al., 2024) Adulteration of milk poses critical problems to the dairy industry. It leads to financial loss, compromise on the quality of end-products and is harmful to consumers' health. Watering of milk is a common practice by farmers in certain parts of the world. (Mabrook and Petty, 2003). Albania has a rich tradition of milk production based on its suitable natural resources for cattle and small ruminants. Overall milk production is 970 thousand tons and 85,05% of them are produced by cows (Biçoku, 2023) Shkodra district has a Mediterranean climate and a positive natural potential that enable the realization of agricultural, livestock and numerous other activities. There are several factories and dairies where milk is treated and its byproducts are manufactured in Shkodra and its surroundings. The main objectives of this study was to determine the chemical composition of raw cow's milk samples in summer 2021 in Shkodër, Albania. The study evaluated the variability of fat, solid-non-fat and water addition in raw cow milk in different rmonth from nearby villages of Shkodra region.

MATERIAL AND METHODS

The area of study

The district of Shkodër includes Malësi e Madhe, Shkodër and Pukë areas. (Fig.1) Shkodër area includes Nënshkodër Lowland, Mbishkodër Upland and the mountain area. The new samples of cow's milk were collected

in the villages of Shkodër district, summer 2021. The collection of fresh milk samples was done in the villages where family farmers work hard to obtain milk for selling.

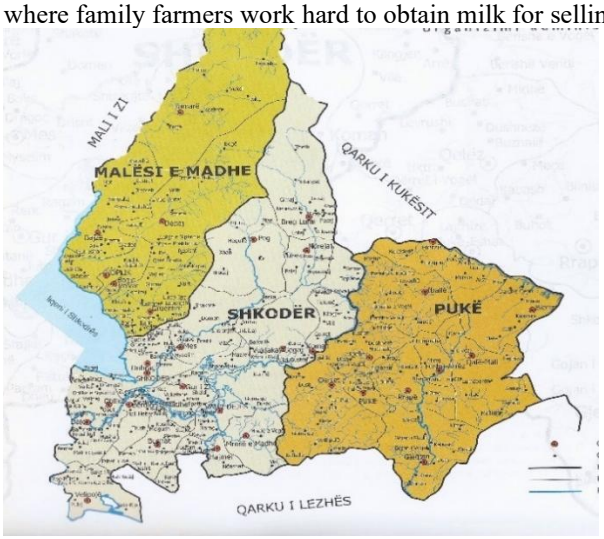

Fig.1 The district of Shkodër [https://stateweb.org]

The collection of samples

The research was carried out within a period of three months:june, july and august 2021. All the samples were collected according to the recommandations of literature. (Colorado Department of Public Health and Environment CDPHE, 2000). The samples were thoroughly agitated to ensure that the milk fat was evenly distributed prior to sampling. Submersible equipment was employed to collect the final sample. All the samples provide a mean composition of milk at the points of sampling. The polyethylene bottles utilized during the collection of milk were pre-cleaned prior to use with 30% HNO3 and spumed with distilled water and left to dry in excess. Milk samples were labeled and labeled with number, day and locality of sample milk. The ice boxes stored the samples at 4ºC and shipped the milk sample samples to the chemical milk processing factory for laboratory analysis. 317 cow milk samples were taken in the laboratory chemical high-capacity milk-processing factory of Shkodër. 3. The analyses made for the chemical factors. Automatic milkanalyzer Lactoscan calculated fat, solids-non-fat (SNF) and extra water of milk samples. The apparatus was calibrated by following the instructions of the apparatus manual. Analysis was performed for those samples which were shaken to extreme extent earlier. 25 ml of fresh milk was filled in special plastic holder and was analyzed for fat (%), solid-non-fat (%) and extra water (%) (Fig.2).

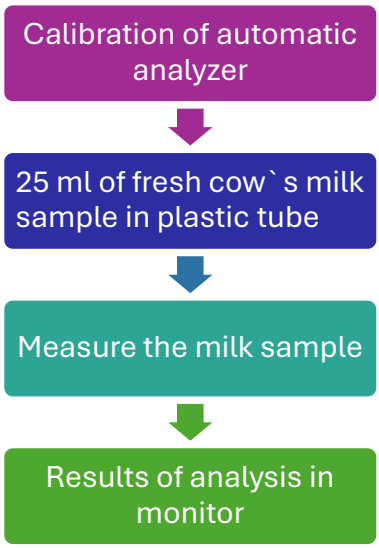

Fig.2 Scheme of the Experiment

Statistical Analysis

Statistical testing and data treatment were assessed by using the software package Minitab version 22.0, a $p<0.05$ was regarded as statistically significant. Descriptive statistics:

Variable	Mean	StDev	Min	Max	Median
Fat %	3.45	0.447	2.35	3.4	6.5
Solids-non-fat %	7.993	0.187	7.37	7.98	8.6
Added water %	5.23	2.062	0	5.3	12.5

mean and minimum, maximum, and standard deviation were calculated.One-Way Anova analyses was performed and Pearson correlations test was also used.

RESULTS AND DISCUSSION

The descriptive statistics included mean, standart deviation, maximum, minimum, median, are presented in Table 1.

Table 1 Descriptive statistics for the results of analysis

The mean value of fat (%) in the milk samples was 3,45% ±0,447 with mimimum value 2,35% and maximum value 3,4 %. As far as is known, climatic conditions and seasonal changes have influences on the milk composition. The fat is the most variable parameter among the major milk components and its synthesis is affected by many factors-especially dietary and environmental (Osama I et al., 2015). The mean of solids-non-fat (%) was 7,9 ± 0,187 with mimimum value 7,37 % and maximum value 7,98%. The added water (%) mean was 5,23 ± 2,06 with mimimum value 0% and maximum value 5,3%. The results for presence of added water in milk show that the adulteration of milk is a dangerous factor affecting poor milk quality. The mean values of fat, solids-non fat and added water in this study were compared with the results from studies published in other countries of the Balkan region: Kosovo, Macedonia, Albania. This study was refered to Albanian fat standard value for the results. (Table 2)

Table 2 Results of milk analyses from studies in different countries, Albanian Standard, this study

Chemical characteristics in milk	Xh.Hamiti et al., (2014) Albania	I.Loshi et al., (2005) Kosovo	L.Kostovska et al., (2017) Macedonia	Determination of essential nutrients in raw milk et al., (2006) Thailand	Albanian Standard (2011) STASH 1500 – 87	This study Summer (2021)
Fat (%)	3,81	3,61±..643	3,80	3.50±0.47	>3.6%	3.45 ± 0.447
Solid-non-fat (%)	8,73	8.78±.383	8,30	8.42±0.20	-	7.993 ±0.187

The fat content analysed in our study was 3,45%, it was lower than the fat% reported by (Xh.Hamiti et al.,2014), (L.Kostovska et al., 2017), and by (I.Loshi et al.,2005). Natural variation in milk of cows depends on genetic factors and other factors that affect milk composition like the race, the stage of lactation, the illness of cow, the feed. (Walstra et al., 2006). The milk from vendors is represented with a variability of cow's races. The result of solids-non-fat in this study was 7,99 %. This value was lower than the value reported by (Xh.Hamiti et al., 2014), (L.Kostovska et al., 2017), and by (I.Loshi et al., 2005). The fat content in this study was lower compared with the fat standard value published in the Albanian Regulation (2011) (>3.6%). This results is explained taking in consideration that during summer season the cows consume a lot of grazing feed, a lot of water, this is a factor that influences the decrease of fat content during summer months.

Variation of chemical parameters in milk according to month

In Figure 3 depicts graphically the mean of milk chemical characteristics by month. There were significant changes in June, July and August for added water %. It was found that the mean fat was significantly higher in July compared to August. It further found that the mean added water was significantly higher in August than in June, with the maximum mean solids-non-fat content in June and minimum in July.

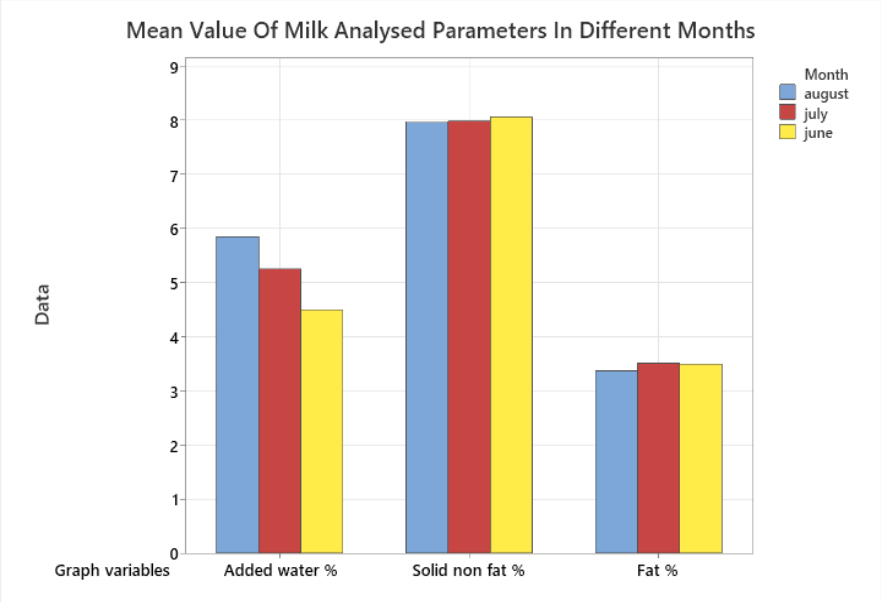

Figure 3 Mean values of fat %, solids-non-fat % and added water % according to month, in summer 2021.

One Way Anova Analysis

One-Way Anova analyses was used to investigate the influences of month of milk analysis on the composition of the milk. The means from the ANOVA analyses for fat, solid-non-fat and added water are shown in Table 3 for level of significance α=0.05. The means of fat, solid-non-fat and added water in the different months differ significantly from one another. In Fig. 4 is a detailed information on the exact period when the differences in the milk content occur, using Fisher Method and 95% Confidence Interval. The differences in fat % for the corresponding analysed samples fluctuate during the months of July-August and June-August have the greatest differences while the differences in solid-non-fat % fluctuateduring the months june-july and une-august. Added water means differ significantly among all the months

Table 3 Results of ANOVA analyses for chemical parameters of milk with month

Chemical parameters of milk	F	P
Fat (%)	3.53	0.03
Solid-non-fat (%)	9.81	0.000
Added water (%)	12.27	0.000

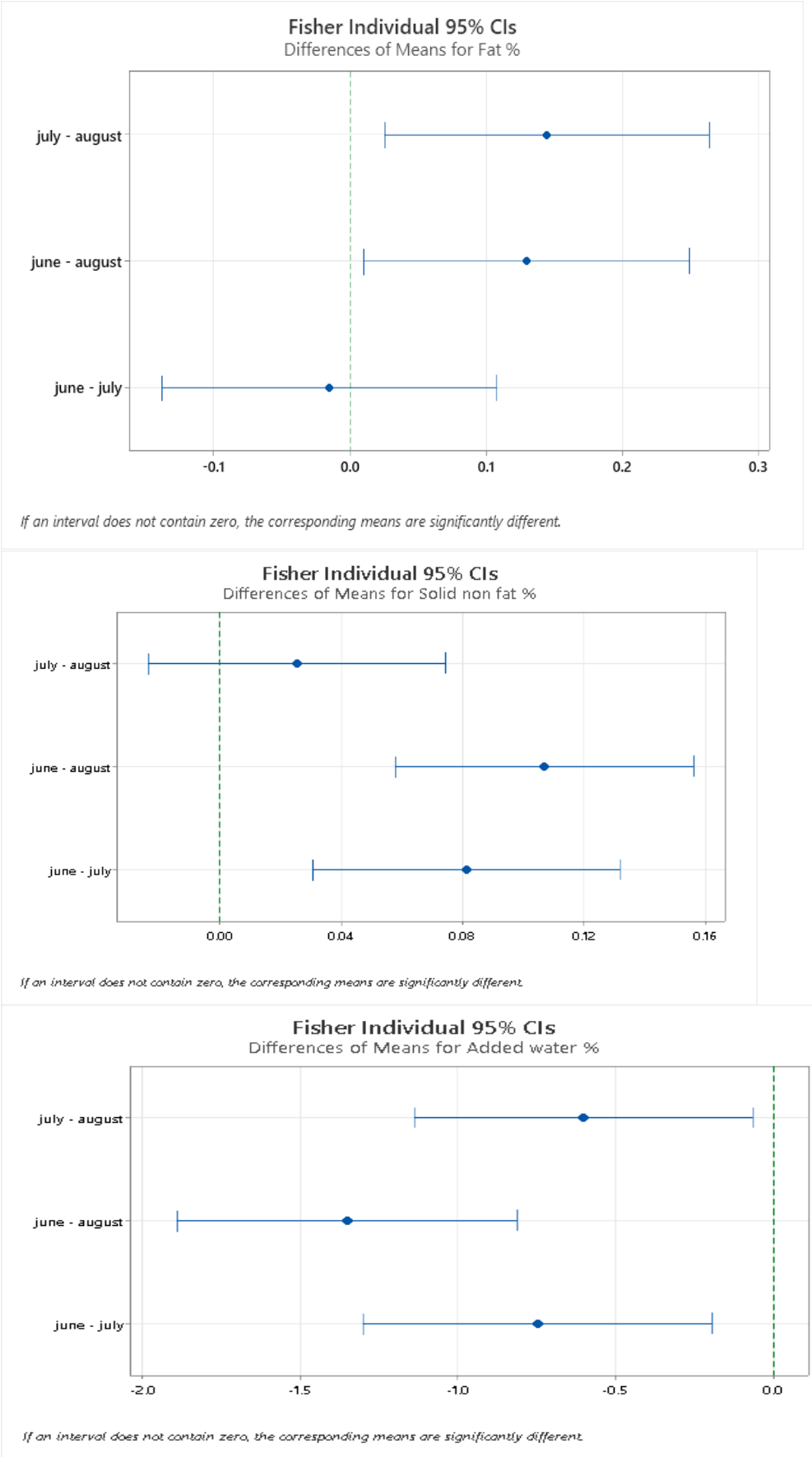

Figure.4 Changes in fat, solid-non-fat and added water means with month (ANOVA, Fisher test)

Pearson Correlation Analysis

The relationship of the original variables to the principal components was examined using Pearson's correlation. The Pearson correlation coefficients r and P value for the analyses are given in Table 4. The analysis has been conducted as shown in Table 4.

Table 4 Pearson correlation coefficients r and P value for parameters analysed in milk

Correlations	Fat %	Solids-non-fat %
Solid non fat %	-0,151	
	0.007	
Added water %	0,119	-0,938
	0,035	0,000

Table 4, a strong negative correlation existed for added water % and solids non-fat % (r = -0.938; P = 0.000). In addition, a moderate negative correlation for solids non-fat % and fat % was present (r = -0.151; P = 0.007).

Conclusions

Fresh cow's milk obtained in Shkoder represents a good chemical quality. In this study, the fat content in milk is lower than recommended levels from Albanian standard. The mean of added water was significantly higher in August. The one-Way Anova analysis for ($P \leq 0.05$) showed that the means of fat, solid-non-fat and added water in the different months differ significantly one from another.Pearson correlation additionally was calculated and a high negative correlation was found between added water % and solids-non-fat % (r = -0,938; P = 0,000). These results may contribute to facilitate further studies on milk quality which is a very important tool for good quality products

Recomandations

The quality of milk obtained from different dairy farms and vendors resulted adulterated, this was observed with the presence of added water content in milk. The adulteration of milk by the addition of water particularly practiced by farmers, emphasizes the importance of further investigations on milk quality as a very significant challenge to good milk quality products. These results may serve as helpful information for concerned individuals, government parties, milk producers and factory owners to address the issue of adulteration, to continue research on milk sector, to improve the quality of milk products to highest levels by monitoring the milk sector for consumers trust.

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Impacts of Nature-Based Tourism on Wildlife: Opportunities, Risks and Sustainability Approaches

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Abstract: Nature-based tourism, encompassing activities such as wildlife watching and eco-friendly excursions, has become a rapidly growing area within the global tourism sector. This type of tourism is strongly linked to wildlife conservation and sustainable development goals. However, the impacts of these activities on nature present a complex picture, with both positive and negative aspects. On the one hand, nature-based tourism contributes to local economies, creates employment, and provides financial support for conservation efforts. The alignment of tourist demands with conservation-oriented approaches offers significant opportunities for the sustainable use of natural areas. Involving local people in these processes, in particular, enables the simultaneous development of wildlife conservation and social benefits. On the other hand, uncontrolled tourism activities can pose serious threats such as habitat degradation, altered animal behavior, and disruption of ecosystem balance. These impacts are becoming even more complex with climate change, jeopardizing the sustainability of nature tourism. Therefore, the implementation of sustainability principles such as environmental impact assessments, visitor management, transportation capacity planning, and community participation is of paramount importance. Consequently, planning nature-based tourism in a way that protects ecological integrity and wildlife is a critical requirement for both the future of natural areas and the long-term sustainability of the tourism sector.

Keywords: Nature-based tourism, wildlife, sustainability, ecological impact, conservation management

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1. INTRODUCTION

Tourism is one of the most dynamic sectors worldwide in terms of its economic, cultural, and social impact (Cherkasov et al., 2017; Lusseau and Mancini, 2018). In recent decades, tourism has diversified, moving beyond traditional mass tourism to include nature-based, environmentally conscious tourism types (Xu et al., 2016; Mosammam et al., 2016). This has highlighted nature-based tourism as a form of tourism that both deepens the participant experience and supports environmental sustainability goals (Linking livelihood and biodiversity (Gidebo, 2023). The concept of nature-based tourism encompasses ecotourism, wildlife watching, bird watching, mountaineering, nature walks, and similar activities (Mosammam et al., 2016; UNWTO, 2023). Its fundamental characteristic is its interaction with local ecosystems and activities carried out in natural environments (Mosammam et al., 2016; Buckley, 2019).

This form of tourism not only provides a touristic experience but also offers multifaceted benefits such as environmental education, the protection of natural heritage, the development of local communities, and the sustainable management of biodiversity (Thapa et al., 2022). However, the realization of these benefits depends on a scientific basis for planning, implementation, and monitoring (Katon-Karagay, 2023). While nature-based tourism aims to generate economic income by utilizing natural ecosystems, practices that exceed the carrying capacity of these ecosystems can cause irreversible environmental damage (Katon-Karagay, 2023). Therefore, the opportunities offered by nature-based tourism and the risks it entails must be addressed with a holistic approach (Gidebo, 2023).

Wildlife is one of the most impacted components of nature-based tourism. Many destinations, especially natural areas with high biodiversity, attract tourists eager to observe wild animals (Lusseau and Mancini, 2018; Wolf et al., 2019). While this offers the potential to provide economic resources for conservation efforts, it also poses the risk of directly interfering with wildlife life cycles. Factors such as increased visitor density, noise, light pollution, land degradation, and direct contact with animals lead to changes in species' behavior, in some cases leading to habitat abandonment or reproductive failure (Hall, 2010).

As climate change increasingly puts pressure on ecosystems (Tekeş, 2024; Tekeş & Özkan, 2024), assessing the impacts of nature-based tourism has become even more critical (Buckley, 2019). The synergistic effects of tourism activities with climate change are a key research topic, particularly for protected areas (Buckley, 2019). Furthermore, the inadequate monitoring of the environmental impacts of some activities undertaken under the guise of ecotourism can undermine the sector's claims of sustainability (Thapa et al., 2022; Gidebo, 2023). In this context, establishing effective policies in line with sustainability principles in the tourism sector and integrating these policies with wildlife management is crucial (Gidebo, 2023).

This study aims to assess the impacts of nature-based tourism on wildlife from a multifaceted perspective. The study examines the definition and scope of nature-based tourism, and its relationship with wildlife is examined from various perspectives (Buckley, 2019; CBD guidelines, n.d.). Furthermore, how this relationship can be managed within the framework of sustainability principles is analyzed in light of current literature and exemplary practices (Katon-Karagay study, 2023; Wildlife tourism article, 2025; Thapa et al., 2022). The findings offer important insights into how environmental, social, and economic balances should be considered in nature-based tourism planning (CBD guidelines, n.d.; Gidebo, 2023). The study concludes with policy and practice recommendations on how nature-based tourism can be developed in a way that both prevents harm to natural ecosystems and contributes to the development of local communities (Gidebo, 2023; World Bank, n.d.).

2. MATERIAL AND METHOD

This study was designed as a qualitative study that aims to examine the impacts of nature-based tourism on wildlife using a multidimensional approach. Qualitative research is among the methods used to deeply understand social phenomena and stands out as an effective tool, particularly in analyzing complex human-nature relationships (Schweitzer et al., 2018). In this context, a comprehensive literature review was conducted to evaluate the impacts of nature-based tourism at both theoretical and practical levels. The primary data sources for the study consisted of nationally and internationally published scientific articles, academic reports, field research, government documents, and reports from non-governmental organizations. Databases such as Web of Science, Scopus, ScienceDirect, and Google Scholar were used for the literature review. Studies published between 2010 and 2025 were systematically examined using keywords such as "nature-based tourism," "ecotourism impacts," "wildlife tourism," "sustainability and biodiversity," and "visitor impact on habitats." The screening identified 87 publications, and 46 were included in the analysis based on their content relevance, scientific validity, and the study's objectives. The reviewed sources were thematically categorized to facilitate qualitative data analysis. Thematic analysis approach ensured data integrity under the following headings: (1) the conceptual framework of nature-based tourism, (2) economic contribution and impacts on local communities, (3) impacts on wildlife behavior, (4) habitat destruction and environmental pressures, and (5) sustainable tourism practices. This thematic classification established contextual relationships among the data, enabling multi-layered analysis of impacts on wildlife.

3. RESULT

The comprehensive literature review and case studies conducted in this study revealed that the impacts of nature-based tourism on wildlife are multidimensional. Based on the findings, it was understood that this impact should be evaluated across ecological, economic, and sociocultural dimensions. First, it was determined that the economic returns of nature-based tourism contribute to conservation efforts. Income generated through nature tourism, particularly in developing countries, provides resources for wildlife conservation projects. Safari tourism activities in Africa have enabled local communities to gain economic benefits, which in turn has fostered positive attitudes among local people toward wildlife. Large mammal viewing activities in Canada and Alaska are based on sustainable visitor management principles and aim to minimize damage to wildlife habitats. These practices are supported by carrying capacity analyses, and visitor numbers are seasonally limited. However, findings also indicate that uncontrolled nature-based tourism activities pose serious ecological threats. For example, in some natural areas where birdwatching activities are concentrated, disruptions in bird breeding cycles have been observed, and some species have been reported to abandon their habitats due to noise pollution. In Turkey, it has been determined that the number of visitors in most nature-based tourism practices conducted in national and nature parks exceeds the carrying capacity, resulting in environmental impacts such as vegetation destruction, litter pollution, and path erosion. Furthermore, in destinations such as Cappadocia, Kaz Mountains, and Yedigöller, the involvement of local people in ecotourism activities has contributed to both economic development and awareness of nature conservation. The literature also indicates that the responses of wild animals to human presence vary from species to species. While some species adapt quickly to humans, others can become more stressed and vulnerable. This diversity necessitates the development of distinct management strategies tailored to each species' behavioral characteristics. Consequently, the impacts of nature-based tourism on wildlife present both

opportunities and risks. The direction of this impact is largely shaped by the conservation policies implemented, the level of local participation, and the scientific nature of tourism planning.

4. DISCUSSION AND CONCULISION

The findings of this study reveal that the impacts of nature-based tourism on wildlife vary depending on the management method. Consistent with existing literature, these findings demonstrate that nature-based tourism can provide both ecological and economic benefits through sound planning and sustainability-based practices (Honey, 2008; Weaver, 2001). However, it is also clear that such tourism activities, if conducted uncontrolled, can cause irreversible damage to wildlife and habitats. Research by Steven et al. (2011), in particular, has examined the direct impacts of human presence on wild animals in detail. These studies emphasize that stress responses, reproductive failures, habitat abandonment, and behavioral changes in wild animals are directly related to intense visitor pressure. Similarly, a study by Geffroy et al. (2015) suggests that the processes of animal habituation to humans can have complex consequences on ecosystem balance. One of the most critical elements for the sustainability of nature-based tourism practices is the applicability of visitor management policies. Many strategies are suggested in the literature on this issue. For example, measures such as carrying capacity analyses, directing visitors to specific routes, and seasonal closures of sensitive areas can be effective in reducing direct impacts (Newsome et al., 2012). In Turkey, however, such practices generally remain at the legislative level, while field implementations lack effective oversight (Kiper, 2006). The participation of local people in tourism processes is considered a significant opportunity for both nature conservation and social development. However, for this participation to be sustainable, not only economic but also social and cultural capacity must be developed (Spenceley & Goodwin, 2007). Otherwise, expectations of short-term benefits can lead to the overuse of natural resources and the transformation of tourism into an activity that harms nature. Furthermore, the lack of environmental controls by some tourism businesses, despite operating under the label of "ecotourism," creates ethical problems in the sector. This poses the risk of nature conservation principles becoming merely a marketing tool. Honey (2008) described this situation as "greenwashing" and emphasized that the concept of ecotourism should not be stripped of its meaning. In light of all these considerations, holistic strategies that take into account not only the environmental but also the socio-economic context are needed for nature-based tourism to establish a healthy relationship with wildlife.

This study comprehensively examined the impacts of nature-based tourism on wildlife, revealing that these impacts depend on multidimensional factors such as management style, visitor density, spatial planning, and local community participation. The findings led to the following key conclusions: When properly managed, nature-based tourism activities can cease to pose a threat to wildlife and become an important tool to support conservation efforts. Controlled use, planning appropriate to carrying capacity, and visitor guidance that considers habitat sensitivity play a critical role in ensuring the sustainability of natural systems (Newsome et al., 2012; Weaver, 2001). However, field observations and literature review reveal that practices in many regions are far from ideal, with lack of oversight and tourism pressure negatively impacting habitats (Steven et al., 2011; Kiper, 2006). This can lead to behavioral changes in wildlife species, habitat abandonment, increased stress levels, and the complete extinction of some species. In this context, the following recommendations have been developed: Visitor Management Strategies: Visitor management plans based on carrying capacity analyses should be developed in wildlife areas; seasonal restrictions and zoning should be implemented.

- Education and Awareness: Educational programs that increase nature conservation awareness should be expanded for both local residents and tourists. Ecotourism activities should be supported not only by economic but also ethical and environmental responsibility (Honey, 2008).

- Field Inspections: Operating tourism businesses should be regularly inspected; nature-based tourism certificates should be awarded only to organizations that meet certain standards.

- Local Participation: Involving local people in tourism processes not only as a workforce but also as decision-makers and beneficiaries will ensure the achievement of both conservation and development goals (Spenceley & Goodwin, 2007).

- Scientific Monitoring: Continuous scientific studies should be conducted to monitor tourism impacts on wildlife, and the resulting data should be integrated into policy development processes.

- Ultimately, minimizing the negative impacts of nature-based tourism activities on wildlife and maximizing their potential benefits requires a holistic, interdisciplinary approach. In this context, a sustainable tourism model must be built that balances ecological sensitivity with economic gain.

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Assessment of Bird Diversity and Conservation Priorities in the Isparta region

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Abstract: This study examines the current state of bird diversity in Isparta, one of Turkey's biogeographically significant regions, and explores the requirements for its conservation. Located at the ecotonal intersection of the Mediterranean and Central Anatolian regions, Isparta hosts a variety of habitat types, making it an important area in terms of avian fauna richness. In this study, the effects of species' habitat preferences, climatic and topographic factors, and land-use changes on bird diversity were analyzed. Additionally, through a literature-supported approach, the contributions of wetlands, forest ecosystems, and agricultural lands to bird populations were evaluated, and conservation priorities were identified. The findings reveal that the region hosts many rare and endangered species, and that human activities disrupting habitat integrity pose a significant threat to avian species diversity. In conclusion, an increase in functional trait diversity strengthens the capacity of bird communities to maintain ecosystem functions and enhances their resilience to environmental changes, thereby positively influencing species richness.

Keywords: Bird diversity, habitat preferences, ecotone region, land use, conservation biology

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1. INTRODUCTION

Turkey boasts an exceptionally rich biodiversity of bird species due to its geographical location, ecological diversity, and location in climatic transition zones. The Anatolian Peninsula, acting as a bridge between three continents, is located at the intersection of bird migration routes, making it one of the most important ornithological centers in Europe and Western Asia (Kılıç & Eken, 2004). In this context, Isparta province, located in Turkey's Mediterranean Region, is home to a large number of bird species with its rich flora, mountainous terrain with various elevations, freshwater resources, and agricultural lands. However, while studies on bird diversity across Turkey have generated a vast literature, a significant portion of these studies have concentrated in regions such as the Western Black Sea, Central Anatolia, and Eastern Anatolia, while relatively less studied areas like Isparta have been relatively neglected. Therefore, the lack of scientific data on the current distribution, habitat use, and conservation status of bird species in Isparta increases the importance of detailed research in this area.

Isparta province is surrounded by mountainous areas that are extensions of the Western Taurus Mountains, and boasts a topography enriched with natural lakes, wetlands, and seasonal streams. This allows for the coexistence of different habitat types, providing favorable habitats for both resident and migratory birds. Lakes Eğirdir and Kovada, in particular, are among Turkey's most important wetlands and are critical for wintering and breeding waterfowl (Eken et al., 2006). Furthermore, high-altitude areas, including districts such as Sütçüler, Aksu, and Yenişarbademli, contain rich microhabitats for forest birds. Furthermore, open-land birds observed in the Isparta Plain and agricultural areas around Keçiborlu are noteworthy for assessing the impact of cultural landscapes on ornithofauna. This diversity is of strategic importance not only for bird ecology but also for sustainable nature tourism and the conservation of biodiversity. From an ecological perspective, Isparta province lies in the transition zone between the Western Anatolian Steppes and the Mediterranean Maquis zones, presenting a landscape mosaic where habitats specific to different phytogeographic regions intertwine. This transition allows bird species to utilize different habitats throughout the year. For example, many passerine species that breed in forested areas during the summer can be observed in lower-elevation wetlands or agricultural areas during the winter (Magnin & Yarar, 1997). This transition between habitats meets not only the spatial but also the functional ecological needs of birds. However, it also exacerbates the effects of threats such as habitat destruction, land use changes, and climate change (Tekeş & Cürebal, 2019; Tekeş, 2024), increasing the vulnerability of bird populations. Rural development projects, irrigation policies, and forest management practices in Isparta therefore have direct and indirect effects on bird diversity (Özesmi & Tan, 2005).

A review of the literature on bird diversity in the region reveals that existing studies are largely based on large-scale bird observation data or national bird atlases. While data provided by the bird observation network in Turkey provides important information about the general distribution of bird species, they do not provide sufficient detail on local-scale habitat preferences, population dynamics, or threat levels (Kılıç et al., 2018). The need for micro-scale studies is increasing, especially in biogeographic transition zones like Isparta. Such local studies play a critical role in determining conservation priorities, preparing area management plans, and developing species-based monitoring programs. Furthermore, the population status, migration routes, and seasonal distributions of many bird species are directly affected by regional climate change and land use transformations. Therefore, assessing bird diversity in Isparta is relevant not only to local but also to regional-scale biodiversity policies.

The assessment of Isparta's bird fauna is also important for regional conservation biology. Some habitats in the region have the status of "important natural areas" under the Bern Convention and the European Union Nature Directives, and a large portion of the bird species found in these areas are protected (Eken et al., 2006). In this context, monitoring and protecting bird species is not only a scientific necessity but also a legal imperative for the implementation of international environmental conventions to which Turkey is a party. For example, Lake Eğirdir is a potential area for Ramsar criteria and is home to many rare and endangered waterbird species (BirdLife International, 2021). However, this area is also under pressure from intensive agricultural activities, urban sprawl, and uncontrolled recreation. Therefore, bird observation data and ecological analyses should be the basis for achieving the balance between nature conservation and rural development.

The primary objective of this study is to examine the diversity, distribution patterns, and ecological requirements of bird species observed in different habitat types within the borders of Isparta province. Furthermore, the study will evaluate in detail the seasonal movements of birds, their habitat preferences, and the threats they face. This aims to develop locally applicable bird conservation strategies in Isparta province. The study's data base is based on direct field bird observations, existing literature, and resources such as the Turkey Bird Atlas (Boyla et al., 2019).

In conclusion, Isparta province constitutes a significant component of Turkey's potential for bird diversity. However, to sustainably protect this potential and ensure its future, increased scientific research conducted at the local level is necessary. In this context, the analyses presented in this paper aim to both contribute to the academic literature and establish a scientific basis for local environmental policies.

2. MATERIAL AND METHOD

This study assessed the diversity, distribution, and seasonal changes of bird species inhabiting different habitat types within the borders of Isparta province. Both qualitative and quantitative data collection techniques were used, supplemented by observational data, literature review, and geographic information systems (GIS)-assisted analyses. The methodological framework was structured in accordance with international biodiversity monitoring protocols (Bibby et al., 2000). The study area is divided into five main ecological zones within the borders of Isparta province: (i) Wetlands (especially Lake Eğirdir, Lake Kovada, and Lake Gölcük Crater), (ii) Forested Areas (Taurus Mountain forests around Sütçüler, Aksu, and Yenişarbademli), (iii) Open Agricultural Lands (Keçiborlu, Gönen, Şarkikaraağaç), (iv) High-Altitude Mountainous Areas (Dedegöl Mountain and its surroundings), and (v) Urban and Semi-Urban Habitats (Isparta city center and its surroundings). This zoning was based on the ornithological differences among habitat types.

Because Isparta’s elevation spectrum ranges from sea level to 3,000 meters, analyzing the elevation preferences of bird species constituted one of the key sub-topics of this study. The region's climate exhibits characteristics of a semi-arid Mediterranean climate, while more continental climate influences are observed in the northern districts (MGM, 2023). Field studies were conducted from March 2023 to March 2024, covering a total of four seasons. Fixed sampling points were identified in each habitat zone (50 points in total), and the standard point count method was used at these points in the morning hours (between 05:30 and 09:30) (Ralph et al., 1995). Point counts were conducted within a 50-meter radius for 10 minutes, and individual numbers were recorded based solely on visual and auditory observations.

In addition, telescopic observations were made in wetlands using telescopes and binoculars, documenting waterbird behavior, group sizes, and habitat use in detail. Canon 10x42 L IS WP binoculars and a Leica APO-Televid 82 telescope were used during bird observations. The coordinates of all observation points were recorded using a GPS device (Garmin GPSMAP 64s) and entered into a database for map analysis.

The Collins Bird Guide (Svensson et al., 2010) was used to identify species identified in the field, and local nomenclatures and observation notes were compared with data from the Turkish Birdwatching Society. BirdLife International Red List and IUCN databases were used to assess species' conservation status and population trends (BirdLife International, 2021). Only species directly observed or identified by sound during sampling were included in the list; data based on indirect tracks (such as nest remains, feathers, feces, etc.) were considered limited. To minimize observer bias, at least two experienced birdwatchers were present at each location, and observations were cross-checked.

Collected data were analyzed using SPSS 26.0 and R (version 4.3.1) statistical software. Species richness, the Shannon-Wiener diversity index, and the Pielou index of equality were calculated. Kruskal-Wallis H test and Tukey HSD post-hoc tests were applied to analyze differences in diversity among habitats. Additionally, repeated-measures analysis of variance (ANOVA) was used to assess seasonal variation. Multivariate statistical analyses (Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) were applied to analyze the clustering of species according to their habitat preferences, and the results were visualized spatially using ArcGIS Pro software. For GIS analyses, the spatial distributions of species were mapped using ArcGIS Pro 3.2 and QGIS 3.34, and species densities observed in different habitats were compared. CORINE land cover data and Landsat 8 satellite images were used in mapping (Copernicus Land Monitoring Service, 2022). No physical intervention was made on any bird species in the study, and all observations were conducted using passive monitoring. Practices such as sound recording devices, calling methods, or nest inspections that could harm the birds were avoided. Observation sites were selected in collaboration with local residents and were selected to prevent potential human-wildlife conflicts. Limitations of the study include reduced audibility of bird calls, particularly in forested areas, due to environmental noise or topographical obstacles; the inability to observe some nocturnal species during daytime counts; and seasonal variations due to the limited number of observation days. These limitations were taken into account in the interpretation of the results. Of course. Below, I present the Findings section, written in an academic style and with APA in-text citations, consistent with the previous sections. This section analyzes species diversity, habitat preference, seasonal variation, and distribution data obtained during the fieldwork.

3. RESULT

Systematic observations conducted within the provincial borders of Isparta during the study period resulted in the identification of a total of 178 bird species. These species belong to 18 different families and 42 genera and were classified into four main groups: resident, summer migrant, winter migrant, and passage migrant, based on their ecological functions. Of the identified species, 52% were passerines (Passeriformes), 21% were waterbirds (Anseriformes, Podicipediformes, Charadriiformes, etc.), and the remaining 27% were diurnal and nocturnal raptors and other groups such as open-land birds. When bird diversity was assessed by habitat, the areas with the highest species richness were identified, respectively, as wetlands (144 species), forested areas (121 species), agricultural lands (94 species), mountainous areas (87 species), and urban and semi-urban habitats (56 species). The wetlands around Lake Eğirdir and Lake Kovada support significant numbers of waterbirds, especially during the winter months. More than 10,000 individuals have been reported to be observed simultaneously in these regions during the winter months (Eken et al., 2006). The most frequently encountered species in wetlands included Anas platyrhynchos (Gallery Head), Fulica atra (Eurasian Eurasian Coot), Podiceps cristatus (Great Grebe), and Ardea cinerea (Grey Heron). However, globally threatened species such as Pelecanus crispus (Dutch Pelican) and Aythya nyroca (Hungarian Duck) were also encountered. A few individuals of Pelecanus crispus were observed, particularly in the reed beds southwest of Lake Eğirdir (BirdLife International, 2021). In forested areas, resident species such as Parus major (Great Tit), Certhia brachydactyla (Short-toed Creeper), Sitta europaea (Nuthatch), and Dendrocopos syriacus (Syrian Woodpecker) are particularly common. These areas also serve as temporary stopover areas for small passerines such as Turdus philomelos (Warbler Thrush) and Phylloscopus collybita (Chicken Chiffchaff) during migration. In open agricultural areas, species such as Alauda arvensis (Meadow Harrier), Motacilla flava (Yellow Wagtail), and Corvus frugilegus (Black Crow) are significantly dominant. These areas also serve as hunting grounds for predators such as Falco tinnunculus (Hawk-headed Falcon). While species diversity observed in urban areas was more limited, species such as Columba livia (Pigeon Pigeon), Passer domesticus (Sparrow), and Apus apus (Black Swallow) were prominently represented. On a seasonal basis, species diversity reached its highest levels in summer (164 species), followed by spring (151), autumn (119), and winter (94). Of the species observed during the summer, 43% were migratory, and the majority of these species breed in forests and wetlands. Species such as Hirundo rustica (Swallow), Merops apiaster (Bee-eater), and Lanius collurio (Red-tailed Shrike) were observed frequently in late spring and exhibited breeding behavior throughout the summer. In winter, despite an increase in the number of individuals observed in wetlands, there was a decrease in species diversity. Species such as Anas clypeata (Spokebill), Aythya ferina (Pochard Pochard), and Tachybaptus ruficollis (Lesser Grebe), which winter in Lakes Eğirdir and Kovada, are prominent winter migrants. However,

some species have been observed to become permanent residents in the region during the winter months; this may be related to thermal shifts due to climate change in the region (Şekercioğlu et al., 2011). According to the findings, 12 of the 178 species identified are listed as "Vulnerable (VU)," "Endangered (EN)," or "Village of Extinction (CR)" under the IUCN Threat Category. Aythya nyroca, Clanga pomarina (Lesser Spotted Eagle), and Pelecanus crispus are among the species considered in this category. In addition, a total of 46 species listed on Appendix II and Appendix III of the Bern Convention have conservation priority under international nature conservation agreements to which Turkey is a party (Eken et al., 2006). The most significant threat factors identified during field observations include agricultural land expansion, drying of wetlands, destruction of reed habitats, hunting activities, and anthropogenic noise pressure. Illegal reed cutting, particularly around Lake Eğirdir, directly impacts the breeding success of reed birds and waterfowl. Furthermore, the use of chemical pesticides in rural areas is another threat to the food chain of open-land birds (Özesmi & Tan, 2005). According to the Shannon-Wiener diversity index calculated according to land use types, the highest values were recorded in wetlands (H'=2.91), followed by forests (H'=2.63), open agricultural lands (H'=2.17), mountainous areas (H'=2.03), and urban areas (H'=1.44). These results indicate that wetlands have a particularly high ecological carrying capacity for birds. According to the Pielou evenness index, the most balanced individual distribution was observed in forests (J=0.81), indicating a relatively homogeneous distribution among species. In mountainous and urban habitats, species distribution is more heterogeneous, with a few species dominating.

4. DISCUSSION AND CONCULISION

The findings of this study clearly demonstrate that Isparta province is one of Turkey's most important ornithological regions in terms of bird diversity. The observation of a total of 178 bird species demonstrates that the region has a rich potential for both resident and migratory species. Factors such as habitat heterogeneity, elevation gradient, abundance of water resources, and its location at the intersection of different climatic transition zones are among the main reasons for this diversity (Şekercioğlu et al., 2011; Kılıç & Eken, 2004).

The high species richness of the wetlands around Lakes Eğirdir and Kovada further confirms the critical role of wetlands in bird communities. As noted in the literature, wetlands serve not only as temporary stopover areas for migratory birds but also as breeding and wintering habitats for many species (Mitsch & Gosselink, 2015). In this context, wetland protection is essential for the sustainability of not only individual species but also entire bird communities. Globally threatened species, such as Pelecanus crispus observed around Lake Eğirdir in Isparta, support the area's status as an internationally recognized "important bird area" (BirdLife International, 2021).

Species observed in forested areas have shown that Mediterranean forest ecosystems harbor unique bird communities. The high frequency of species such as Dendrocopos syriacus, Sitta europaea, and Parus spp., in particular, indicates that the natural structure of the habitat is being preserved. However, it is also known that forestry activities in forested areas pose a risk of disrupting habitat structure. The long-term effects of activities such as wood production and road construction on forest bird communities have been documented in numerous studies, particularly in Europe and the Mediterranean basin (Fuller, 2000; Donald et al., 2001).

Bird diversity observed in open agricultural lands suggests that agricultural landscapes can be important secondary habitats for birds. However, intensive agricultural techniques used in these areas, particularly monoculture practices and pesticide use, limit both the food sources and breeding grounds of birds (Benton et al., 2003). Species such as Alauda arvensis, frequently encountered in Isparta agricultural lands, are among those experiencing population losses due to agricultural intensification across Europe (BirdLife International, 2021). This suggests that regional agroecological measures can be decisive in preserving bird diversity.

When seasonal variations are examined, the high diversity in summer reveals that the region serves as a breeding ground for many bird species. This highlights the importance of forested and semi-open habitats, particularly in the Mediterranean climate zone, for summer migrants. Despite the decline in species numbers in winter, the fact that wetlands still host a high number of individuals suggests that these habitats are functional year-round. This finding is consistent with regional studies that similarly emphasize the importance of wetlands for winter migrants in the Mediterranean basin (Green & Elmberg, 2014).

Data on diversity indices also provide strong indicators of habitat quality and ecological carrying capacity. Wetlands and forested habitats with the highest Shannon-Wiener indexes stand out not only in terms of species numbers but also in terms of functional diversity. High Pielou evenness values in forested areas indicate that species dominance levels are close to each other, indicating a balanced ecological structure in the habitat (Magurran, 2004).

The threats observed in the study pose serious risks to bird diversity. Uncontrolled cutting of reeds, in particular, directly threatens the breeding success of wetland birds, while agricultural chemicals disrupt food webs and weaken ecological relationships (Özesmi & Tan, 2005). Furthermore, construction pressures and anthropogenic noise pollution resulting from the expansion of rural settlements also negatively impact bird behavior (Francis et al., 2009).

This study is one of the most comprehensive studies assessing bird diversity in different habitats within the borders of Isparta province. The findings clearly demonstrate that the region is a significant biodiversity hub for both resident and migratory bird species. Wetlands and forested areas play a critical role, particularly as habitats for rare and threatened species.

The results have important implications for local governments and nature conservation organizations. Priority strategies should include protecting wetlands such as Lake Eğirdir and Lake Kovada in accordance with Ramsar criteria, preventing the destruction of reed habitats, and combating illegal hunting. Furthermore, the adoption of bird habitat-sensitive practices in forest management plans, such as selective felling, the use of deadwood, and the preservation of habitat connections, should be expanded.

In agricultural areas, sustainable agricultural techniques should be encouraged and agroecological practices that protect biodiversity should be supported. Practices such as the controlled use of chemical pesticides, increasing hedgerows, and preserving mosaic landscapes will contribute to the preservation of bird diversity. For the success of conservation policies developed specifically for Isparta, it is crucial to include local residents in this process. Expanding ecotourism and birdwatching activities will both increase environmental awareness and create economic alternatives. Such practices will raise conservation awareness and indirectly protect bird habitats.

Ultimately, this research aims to contribute to nature conservation efforts at both the national and local levels by documenting the ecological characteristics of bird communities in Isparta. Future studies are recommended to explore topics such as long-term monitoring programs, the impact of climate change on bird populations, and interspecies interactions.

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Conflict of Interest
The authors have no conflicts of interest to declare.

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Ecological Characteristics and Conservation Priorities of Mount Honaz

AYŞEGÜL TEKEŞ DÜDÜKÇÜ*[1]

Abstract: Mount Honaz, the highest peak in Western Anatolia (2571 m), hosts an important biological wealth thanks to its topographic, climatic and geological diversity. In this study, the floristic and faunistic diversity and climatic sensitivity of Mount Honaz were evaluated comprehensively and conservation priorities were addressed based on literature. According to research findings, there are approximately 993 plant taxa on the mountain, 128 of which are endemic species specific to Türkiye. Red pine, black pine forests, juniper communities and subalpine meadows observed in different elevation zones reveal both the horizontal and vertical habitat diversity of the mountain. Endemic and relict species, especially concentrated in microclimatic transition zones, are highly sensitive to the effects of climate change. As temperature and humidity gradients change with elevation, the risk of "local extinction" of these species increases, which can lead to disruptions in ecosystem services. The study offers suggestions for species distribution modeling in Honaz Mountain, identification of microreserve areas, establishment of long-term ecological monitoring systems, and development of nature-based sustainable tourism policies. As a result, the protection of Mount Honaz is important for the sustainability of regional biodiversity and the continuity of mountain ecosystems resilient to climate change.

Keywords: climate change, conservation biology, endemism, floristic diversity, Mount Honaz

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1. INTRODUCTION

Mountainous areas stand out as ecologically critical habitats that often host high levels of biological diversity, thanks to their topographic, microclimatic and geological diversity. These areas are of strategic importance in the context of ecosystem management, not only in terms of biodiversity conservation, but also due to the sustainability of the ecosystem services they provide and their resilience to climate change (Körner, 2004; Perrigo et al., 2020; Acarer & Mert, 2025). In this context, Mount Honaz, the highest peak of Western Anatolia, constitutes one of the important examples of this biological diversity (Erinç, 1955).

Mount Honaz (2571 m) is located within the borders of Denizli province in the Aegean Region and contains different plant communities due to climatic and edaphic factors changing from north to south and from lower to higher altitudes (Özhatay et al., 2008). Mount Honaz gained national park status in 1995 and has been protected to a significant extent thanks to this status (Anonymous, 2025). However, in recent years, threats such as increasing human pressure, climatic changes and habitat destruction have created serious pressure on the biological integrity of this area (Prakash, & Verma, 2022).

Studies on the flora and vegetation structure of Mount Honaz reveal that this area hosts a significant number of endemic and rare plant species. As a matter of fact, approximately 13.7% of the species identified in the area consist of endemic taxa. The plant communities that develop along the mountain's elevation gradient provide a remarkable example of ecological diversity. Typical Mediterranean maquis forests consisting of species such as *Quercus coccifera*, *Arbutus* sp., *Olea europaea*, *Pistacia terebinthus*, *Erica arborea*, *Myrtus communis* and *Cistus* sp. are distributed along with *Pinus brutia* forests at lower elevations. While *Pinus nigra* forests are seen in the mid-altitude zone, a transition to subalpine-alpine meadows is observed in higher elevations with juniper species such as *Juniperus oxycedrus* and *Juniperus foetidissima*. This structural and floristic diversity makes Honaz Mountain not only a rich species shelter but also an important genetic reservoir on a regional scale and a center of ecological diversity (Büyükoğlan, 2010).

Climate change is a factor that seriously threatens mountain ecosystems, especially those at high altitudes and with microclimatic sensitivity (Beniston, 2003; Negi et al., 2012). A large portion of the endemic plant species spread in mountainous areas are extremely sensitive to climatic changes due to their limited distribution areas and narrow ecological tolerances. These species face risks such as habitat shift, population shrinkage and local extinction due to their existence in niches specific to elevation-dependent microhabitats (Thuiller et al., 2005; Yadav et al., 2021). In this context, Mount Honaz is considered one of the ecologically sensitive mountain areas where expected changes in temperature and humidity regimes along elevation gradients may cause shifts in species composition (Büyükoğlan, 2010).

In this context, the floristic and faunistic diversity of Mount Honaz and its ecological sensitivity to climate change were evaluated in line with the existing scientific literature (Figure 1). In addition, it is aimed to develop recommendations that will contribute to the sustainable management of the region from a conservation biology perspective and to present adaptation strategies against climate change. Thus, it is aimed to both contribute to the literature and offer suggestions for area-based conservation and management policies.

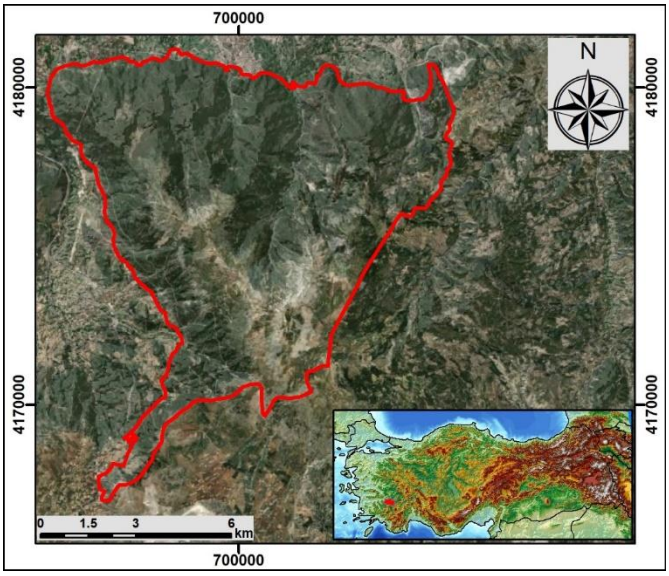

Figure 1: Location map of the study area (Honaz Mountain national park)

2. 2. BIODIVERSITY: FLORISTIC AND FAUNISTIC ASSESSMENT

Mount Honaz is one of the richest mountain masses in Anatolia in terms of floristics and hosts a high level of species diversity due to its location in the floristic transition zone of Western Anatolia. The mountain is located at the intersection of different biogeographic elements, creating an ecotone between the Mediterranean phytogeographic region and the Irano-Turanian phytogeographic region (Atalay, 1994). This location, together with the intertwining of different climatic and geological effects, significantly enriches the plant species composition in the region and also increases the diversity of endemic taxa (Özhatay et al., 2008).

Mount Honaz is among the 122 Important Plant Areas (IPA) identified in Türkiye and attracts attention due to its high floristic diversity. As a result of the floristic inventory studies carried out so far on Mount Honaz, approximately 993 different taxa have been recorded. 128 of these are endemic species specific to Türkiye (Özhatay et al., 2008). It is also known that 20 taxa endemic to Türkiye and the Eastern Aegean Islands are found on Mount Honaz. A significant portion of the taxa distributed in the area consist of endemic and rare species, and approximately 50 of them are considered rare at the country level. Among these taxa, *Pinguicula crystallina* and *Comperia comperiana* are protected under the Bern Convention and are classified as endangered species throughout Europe (Özhatay et al., 2008). According to the IUCN Red List category, *Pinguicula crystallina* is classified as NT (Near Threatened) (Bazos et al., 2011) on the European scale, while *Comperia comperiana* is classified as EN (Endangered) (Rankou, 2011). In addition, *Verbascum chrysorrhacos*, a local endemic species specific to Mount Honaz, further reveals the biogeographical uniqueness of the region.

Mount Honaz contains many taxa that have been recorded in only three or fewer localities throughout Türkiye. This situation shows that the area has a high level of endemism density in a limited geography (Özhatay et al., 2008). Particularly the high altitude parts of the mountain stand out as hotspots where mostly endemic and relict species with narrow ecological tolerances are concentrated and dependent on the altitude. These species, seen in subalpine and alpine zones, are generally isolated taxa with narrow ecological tolerances depending on altitude.

Another striking aspect of the floristic structure is the plant zones that change depending on the altitude. The following zones were determined approximately on Honaz Mountain (Büyükoğlan, 2010):

- **Lower zone (800–1200 m):** Pinus brutia forests, Mediterranean maquis communities (Quercus coccifera, Pistacia terebinthus, Phillyrea latifolia, Arbutus, Olea europaea, Erica arborea and Cistus sp.)

- **Middle zone (1200–1800 m):** Pinus nigra, Cedrus libani and Juniperus oxycedrus, Juniperus excelsa forests
- **Upper zone (>1800 m):** Subalpine meadows, herbaceous endemics and rare relict taxa

The change in floristic composition along this elevation gradient reveals the richness of the mountain in terms of vertical biodiversity (Rawat et al., 2021). In addition, the influence of continental-humid climate transitions has led to the concentration of micro-endemic species on certain ridges, valleys and slopes. Some species have limited distribution, particularly in microhabitats specific to this mountain. For example, *Verbascum chrysorrhacos* is an endemic species and is seen only on Honaz Mountain in Türkiye. Mount Honaz hosts particularly local taxa that are recorded in three or fewer locations throughout Türkiye. This situation shows that there are many endangered and endemic plant species in the area (Özhatay et al., 2008). The future of such species is directly related to the protection of the species' habitat.

Mount Honaz is home not only to a variety of plants but also to important wild animals. The mountain goat (*Capra aegagrus*) and the snow mouse (*Chionomys nivalis*) are examples of these species. In addition, the endangered yellow-spotted skipper (*Thymelicus acteon*) is also found in this area (Özhatay et al., 2008). According to the IUCN Red List category, *Capra aegagrus* is classified as NT on a global scale (Weinberg and Ambarli, 2020) and VU (Vulnerable) on a Mediterranean scale (Weinberg et al., 2010). *Chionomys nivalis* is recorded to be in the LC (Least Concern) class on a global scale (Krystufek, 2016) and on a European scale (Krystufek and Amori, 2007). *Thymelicus acteon* is classified as NT on the European scale (van Swaay et al., 2010) and LC on the Mediterranean scale (Van Swaay et al., 2014).

In conclusion, the floristic structure in Mount Honaz is not only due to quantitative richness, but also to qualitative factors such as high endemism rate, ecological sensitivity and phytogeographic transition feature. However, the area is also of critical importance in terms of faunism, as it hosts not only plant diversity but also wild animals with conservation priorities such as *Capra aegagrus*, *Chionomys nivalis* and *Thymelicus acteon*. This situation necessitates that Mount Honaz be considered as a holistic biodiversity focus at both local, national and regional scales and be ranked high among conservation priorities.

3. CLIMATIC FACTORS AND ECOLOGICAL SENSITIVITY

Mount Honaz stands out as an area with great climatic diversity, as it is the natural border separating the Aegean and Mediterranean Regions and is the highest mountain in the Aegean Region. This mountainous system is located in the interaction area of the Mediterranean climate and the semi-arid continental climate, and microclimatic differences caused by elevation, aspect, wind direction and topography play a decisive role in the distribution of vegetation (Büyükoğlan, 2010).

3.1. Elevation and Microclimate Effects

At Mount Honaz, elevation causes significant changes in climate parameters such as temperature and humidity. With increasing altitude, temperature decreases by approximately 0.5–0.6°C per 100 meters, while relative humidity may tend to increase. This enables different plant communities to develop in certain altitude zones . For example, while maquis with Mediterranean characteristics are common at lower altitudes, floristic elements specific to subalpine meadows and nival areas are seen at upper altitudes. Whether the slopes face south or north also creates differentiating effects on the daily temperature regime, soil moisture and snow cover duration. While snow cover remains longer on north-facing slopes, drought-tolerant species dominate on south-facing slopes (Körner, 2004; Büyükoğlan, 2010; Pauli et al., 2012).

3.2. Climate Change and Ecological Sensitivity

In mountainous ecosystems, most species are more vulnerable to the effects of climate change because they are organisms with narrow distributions, limited ecological tolerances and high-altitude niches (Thuiller et al., 2005; Pauli et al., 2012). Similarly, it is known that the distribution areas of endemic and relict species, especially in the upper zones, are quite limited in Honaz Mountain. Global temperature increases are shifting the optimum habitats of these species towards higher altitudes, but once the mountain peak is reached, these species have no opportunity to migrate further up. This situation brings up “local extinctions” (Wiens, 2016). In addition, increasing temperatures and changing precipitation regimes can shorten snow cover periods and disrupt soil moisture cycles, disrupting phenological cycles and changing pollination timing. This situation threatens not only the distribution of species but also their reproductive success and population continuity (Inouye, 2022).

3.3. Modeling and Future Projections

Species Distribution Modelling (SDM) studies conducted to reveal the sensitivity of mountainous areas to climate change are of great importance for areas with high biodiversity such as Mount Honaz. Projections, particularly using models such as MaxEnt, predict that many alpine plants will lose their current distribution areas and will survive only in limited microrefugia areas (Guisan & Thuiller, 2005; Miller, 2010). Similar studies conducted in Türkiye have also revealed that species in high mountain zones are at great risk (Acarer, 2025; Tekeş et al., 2025).

3.4. Ecological Risk Factors and Management Challenges

The climatic sensitivity of Mount Honaz may have serious consequences not only at the species level but also in terms of ecosystem services. Changes in vegetation cover lead to the weakening of essential services such as carbon storage capacity, water regulation functions and soil protection. Additionally, degradation of habitat structures can create suitable environments for the spread of invasive species. In this context, climate change should be considered not only as a matter of temperature increase, but as a complex pressure regime that threatens ecosystem integrity (Tariq et al., 2024).

Mount Honaz is an ecologically extremely sensitive area due to its climatic gradients, microclimatic mosaics and elevation-dependent habitat zones (Özhatay et al., 2008). This sensitivity, combined with the effects of climate change, puts the area at high risk for its biodiversity. Therefore, protection strategies for Mount Honaz need to be developed with adaptable and data-based approaches that take into account climate change projections.

4. CONCLUSION

Mount Honaz stands out as one of the most important mountain ecosystems in Türkiye in terms of biodiversity with its rich floristic diversity, high endemism rate, different plant formations and habitat mosaics depending on the elevation. Its location at the intersection of Mediterranean and continental climate zones makes it unique not only in terms of species diversity but also in terms of ecosystem transitions and climatic sensitivity.

In this study, the floristic structure, habitat diversity and climatic sensitivities of Mount Honaz were evaluated based on literature. In the light of current information, the ecological values of the region that need to be protected and the risks it may face in the future are discussed. As a result of the study, the following findings and recommendations were developed:

- • Approximately 993 plant taxa have been identified on Mount Honaz, approximately 128 of which are endemic species specific to Türkiye. This shows that the mountain is a priority conservation area on a national scale in terms of floristics.
- • The mountain ecosystem consists of a wide variety of habitats such as red pine, black pine, maquis and cedar forests, juniper communities, subalpine meadows and nival zones. These habitats show great variability over short distances, both horizontally and vertically.
- • Microclimatic conditions, which are formed by factors such as altitude, aspect and soil properties, make Honaz Mountain an ecological laboratory containing a large number of microhabitats.
- • Climate change poses a significant threat, especially to high-altitude endemic species. The tendency for species to migrate upwards only increases the risk of “local extinctions” as they reach the mountain summit limit.

Suggestions

- Zones of high biological value within the borders of the Honaz Mountain National Park should be redefined as "protection zones" or "biological reserve areas" and designated as microreserve areas.
- Special management plans should be prepared for microhabitats with high endemic species density.
- Climate-adaptive conservation priorities should be determined by modeling the potential distribution changes of endemic and relict species under climate scenarios using species distribution modeling (SDM) techniques.
- Ecological corridors should be created to increase habitat connectivity, and spatial strategies to prevent genetic isolation should be implemented.
- Certain boundaries and rules should be determined for transhumance, mountaineering and rural recreation activities.
- Local people should be informed about nature conservation awareness and the ecological importance of the mountain; participatory conservation approaches should be encouraged.

- Regional environmental education programs should be organized in cooperation with universities and non-governmental organizations.

In order to sustainably protect the ecological values of Mount Honaz, a holistic and adaptive conservation approach should be adopted. The floristic richness of the area is not only of scientific interest, but also one of the fundamental building blocks of ecosystems resilient to climate change. In this context, both local governments and national nature conservation policies should place areas like Mount Honaz at the center of their strategic conservation plans.

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Modeling of the Brutian Pine Species Using the GAM Method: The Case of the Sütçüler District

ÖZDEMİR ŞENTÜRK*[1]

Abstract: Forest ecosystems hold strategic importance in terms of nature conservation and sustainable resource management due to their ecological functions and the ecosystem services they provide. In this context, determining the current and potential distribution areas of ecologically and economically valuable species such as Brutian pine (Pinus brutia Ten.) is of great importance for developing effective conservation and management strategies. This study was conducted to reveal the potential distribution of Pinus brutia in the Sütçüler district of Isparta province, located in the Mediterranean Region. The presence-absence data obtained from 1040 sample areas in field studies and environmental variables produced with the help of geographic information systems were modelled using the Generalised Additive Model (GAM) method. As a result of the modeling, it was determined that Pinus brutia potentially occurs in areas especially within the elevation range of 700–950 m, and where conglomerate, limestone, and sandstone bedrock types are dominant. The AUC values of the resulting model (training: 0.946; test: 0.944) indicate a high level of explanatory power. The study provides an opportunity to evaluate the site properties of Brutian pine in an ecological context and contributes to species distribution modeling-based applications.

Keywords: Ecological modelling, Environmental variables, Species distribution modeling, Site factors.

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1. GİRİŞ

Orman ekosistemleri, sahip oldukları geniş ekolojik işlevler ve ekonomik potansiyellere rağmen, günümüzde küresel ölçekte artan çevresel ve antropojenik baskılar nedeniyle ciddi tehditlerle karşı karşıyadır. Küresel ısınma, kuraklık, çölleşme, düzensiz yağış rejimleri, taşkınlar, hızlı nüfus artışı, kontrolsüz arazi kullanımı, erozyon ve orman yangınları gibi faktörler, orman alanlarının önemli ölçüde tahribine yol açmaktadır (Curtis et al., 2018). Bu sistemlerin tahrip edilmesi, biyolojik çeşitlilik kaybı, atmosferdeki karbon miktarında artış, toprak erozyonunun hızlanması ve su kaynaklarının kalitesinde bozulma gibi çok yönlü çevresel sonuçlara yol açmaktadır (Houghton, 1995). Bu durum, ormanların sunduğu ekosistem hizmetlerinin sürdürülebilirliğini ciddi şekilde tehdit etmekte ve bu sistemlerin korunması ile bozulan alanların restorasyonu gerekliliğini giderek daha belirgin hâle getirmektedir. Bu bağlamda, Türkiye'de de son yıllarda orman alanlarının korunması, iyileştirilmesi ve ekolojik fonksiyonlarının yeniden kazandırılmasına yönelik uygulamalar önemli ölçüde artış göstermiştir (Özkan et al., 2015).

Türkiye ormanlarının yaklaşık %58'i normal kapalı, %42'si ise boşluklu kapalı orman statüsünde yer almaktadır. Türkiye'deki orman alanlarının yaklaşık 13,6 milyon ha saf meşcerelerden, 9,3 milyon ha ise karışık meşcerelerden oluştuğu bilinmekte olup, tür bazında meşe (yaklaşık 6,7 milyon ha), kızılçam (yaklaşık 5,2 milyon ha) ve karaçam (yaklaşık 4,2 milyon ha) en fazla yayılış gösteren asli orman ağaç türleri olarak karşımıza çıkmaktadır (OGM, 2020). Bu türler arasında yer alan kızılçam (*Pinus brutia* Ten.), hem ekolojik hem de ekonomik ve sosyokültürel açıdan öne çıkan bir türlerin içerisinde yer almaktadır. Yüksek büyüme hızı, odun ve kereste kalitesi nedeniyle ormancılık endüstrisinde önemli bir yer tutmakta, aynı zamanda karbon depolama, erozyon kontrolü, rekreasyon, temiz su üretimi ve yaban hayatına sağladığı katkılar bakımından da çok yönlü işlevler sunmaktadır (Erten & Taşkın, 1985; Taş, 2017; Keten ve Gülsoy, 2020).

Bu çerçevede, kızılçam türünün mevcut ve potansiyel yayılış alanlarının belirlenmesi hem türün ekolojik gereksinimlerinin anlaşılması hem de sürdürülebilir orman yönetimi ve koruma stratejilerinin etkin biçimde planlanabilmesi açısından stratejik bir önem taşımaktadır. Bu gereksinimi karşılamaya yönelik olarak geliştirilen tür dağılım modelleme yaklaşımları, çevresel değişkenlerle tür varlığı arasındaki ilişkileri nicel olarak analiz ederek mekânsal düzeyde potansiyel dağılım alanlarını öngörebilmektedir (Elith & Leathwick, 2009; Guisan & Zimmermann, 2000). Özellikle doğrusal olmayan, kompleks ekolojik ilişkilerin modellenmesinde etkin bir yöntem olan Genelleştirilmiş Eklemeli Modeller (GAM), esnek yapısı sayesinde farklı çevresel değişkenlerin etkilerini açıklamada yüksek başarı oranları sunmakta ve ekolojik uygulamalarda son yıllarda yaygın olarak tercih edilmektedir (Guisan et al., 2002; Wood, 2017).

Bu çalışma, Akdeniz Bölgesi'nde yer alan Isparta ili Sütçüler yöresinde kızılçam türünün potansiyel dağılım alanlarını farklı bir istatistiksel yöntem kullanılarak belirlemek amacıyla gerçekleştirilmiştir. Arazi envanter çalışmalarıyla toplanan var–yok verileri ile yöreye ait çevresel değişkenler kullanılarak Genelleştirilmiş Eklemeli Model yöntemi aracılığıyla potansiyel dağılım modellemesi yapılmıştır.

2. MATERYAL VE YÖNTEM

2.1 Çalışma alanı

Bu çalışma, Akdeniz Bölgesi Göller Yöresi sınırları içerisinde yer alan Isparta ilinin Sütçüler yöresinde gerçekleştirilmiştir. Yörenin yükseltisi 200 – 2545 m arasında değişmekte olup yaklaşık olarak 128000 ha büyüklüğe sahiptir. Sütçüler yöresinin büyük bölümü yüksek eğimli ve engebeli bir arazi yapısına sahiptir. Çalışma alanı içerisinde en düşük yükseltilerin rastlandığı bölümde Yazılı Kanyon ve orta yükselti kuşağına yakın yerde Köprüçay Kanyonu bulunmaktadır. Yörede farklı yükseltilere sahip alanlar içerisinde Sarp Dağı (2545 m) ve Tota Dağı (2200 m) yüksek zirvelerdir. Çalışma alanı, Akdeniz iklimi ve karasal iklim özelliklerinin görüldüğü bir geçiş kuşağında yer almaktadır. Köppen iklim sınıflandırmasına göre tipik Akdeniz iklim özelliklerine sahip Csa (Kışı ılık, yazı çok sıcak ve kurak) ve Csb (Kışı ılık, yazı sıcak ve kurak iklim) iklim sınıflarına girmektedir (Rubel vd., 2017). Yörede yıllık ortalama sıcaklık 14,1 ºC ve yıllık ortalama toplam yağış miktarı 950,1 mm'dir (Şentürk, 2012). Sütçüler yöresi bitki tür çeşitliliği bakımdan zengin bir yapıya sahiptir. Yörede asli orman ağacı türlerinden kızılçam, karaçam, boylu ardıç, diken ardıcı, kısmen Toros sediri, kermes meşesi ve saçlı meşe türlerine rastlanmaktadır. Çalışma alanı karstik bit arazi yapısına sahip olup kireçtaşı başta olmak üzere konglomera ve kumtaşı anakaya tipleri yaygın olarak görülmektedir.

2.2 Arazi ve Büro Çalışmaları

Hedef türün potansiyel dağılım modellemesi amacıyla 20x20 m (400 m^2) büyüklüğe sahip 1040 örnek alandan var – yok verileri toplanmıştır. Arazi envanter çalışmasından elde edilen veriler Küresel Konumlama Sistemi (GPS: Global Position System) enlem ve boylam değerleriyle birlikte envanter karnesine işlenmiştir. Hedef türün dağılım modellemesinin gerçekleştirilmesinde arazi envanter çalışmalarıyla var – yok verilerinin elde edilmesinin ardından büro ortamında açıklayıcı değişkenlerin üretilmesi süreçlerine geçilmiştir. İlk olarak çalışma alanının sınırı dikkate alınarak bir Sayısal Yükseklik Modeli (SYM) oluşturulmuştur. SYM esas alınarak bakı, eğim ve yükselti değişkenleri üretilmiştir. Daha sonrasında arazi yapısını ortaya koymak amacıyla Jennes (2006) tarafından kullanıma sunulan eklenti yardımıyla Topografik Pozisyon İndeksi (TPIN) değişkeni oluşturulmuştur. Elde edilen değişkenin negatif değerleri vadi, vadi tabanı ve kanyon gibi yerleri, pozitif değerler daha çok tepeler, sırtlar ya da dağlar gibi yüksek yerleri ve sıfıra yakın değerleri ise düzlük, ova ve alt yamaç arazileri temsil etmektedir. Topoğrafik Nemlilik İndeksi (TNI), eğim derecesi ve havza alanları arasındaki belirli noktaların oransal ifadesi olarak tanımlanmaktadır. Bu değişkende yüksek pozitif değerler nemliliği temsil ederken, düşük eksi değerleri ise kuraklığın göstergesi olarak kabul edilmektedir (Wilson ve Gallant, 2000). Maden Tetkik Araştırma Müdürlüğünden alınan jeoloji haritası çalışma alanı sınırı esas alınarak sayısallaştırılmıştır. Sayısallaştırılan anakaya tipleri (konglomera, marn, radyolerit, bazalt, ofiyolitli melanj, dolomit, kireçtaşı ve kumtaşı) öznitelik tablosuna tanıtılarak anakaya tipleri haritası üretilmiştir. Son aşamada ise, Radyasyon İndeksi, Sıcaklık İndeksi ve Bakı Uygunluk indeksi değişkenleri üretilmiştir. Radyasyon indeksi ve Bakı Uygunluk İndeksi, bakı değişkeninin dönüştürülmesiyle elde edilmektedir (Denklem 1, Denklem 2). Sıcaklık indeksi, diğer iki indeksten farklı olarak bakı değişkeninin yanında eğim değişkeni kullanılarak dönüştürülmektedir (Denklem 3).

$$RADIN = \left[1 - \cos\left(\left(\pi/180\right)x(\theta - 30)\right)\right]/2 \quad (1)$$

$$SCIN = \cos\left(radyan\left((\theta) - \theta_{maks}\right)\right)x\ (\tan(radyan(\Delta))) \quad (2)$$

$$BUIN = \cos(radyan(\theta_{maks} - \theta) + 1 \quad (3)$$

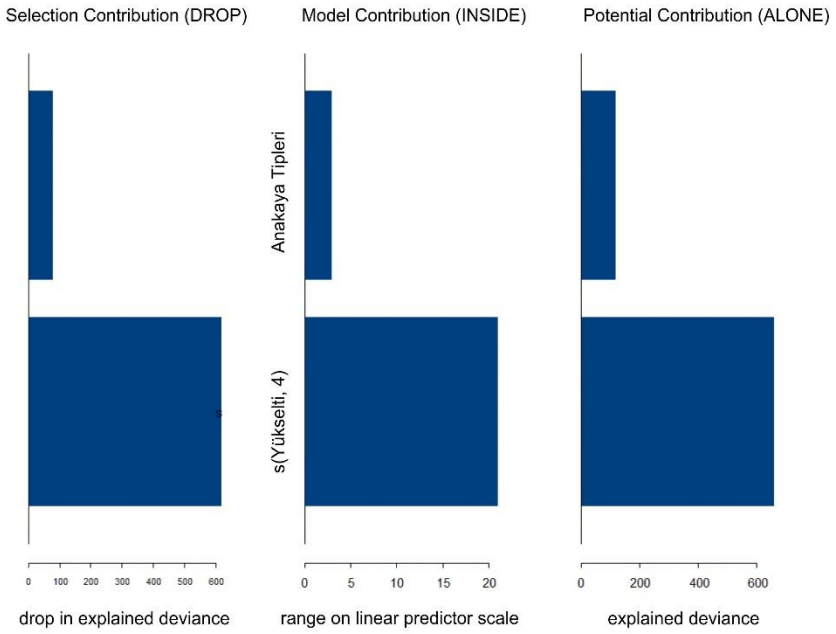
Burada, θ bakı değişkenini, θ_{maks} 202,5 değerini ve Δ eğim değişkenini temsil etmektedir. Elde edilen RADIN değişkeni 0 – 1 değerleri arasında değişiklik göstermektedir. Sıfır ve sıfıra yakın değerler kuzey ve doğu veya kuzeydoğu arazilerdeki gölgeli bakıları temsil ederken, 1 değerine yakın yerler güney ve batı gibi sıcak veya kurak bakıları temsil etmektedir (Roberts ve Cooper 1989). Diğer taraftan, SCIN değişkeni -1 – 1 değerleri arasında değişiklik göstermektedir. Bu değişkende -1 değerine yakın yerler gölgeli bakıları, 1 değerine yakın yerler sıcak yada kurak bakıları göstermektedir (Parker, 1988; Olsson et al., 2009). Son olarak, BUIN değişkeni 0 – 2 değerleri arasında değişiklik göstermektedir (Roise ve Better, 1981).

2.3 İstatistiksel Değerlendirme

Hedef türün potansiyel dağılım modellemesinin gerçekleştirilmesinde Genelleştirilmiş Eklemeli Model (GEM) kullanılmıştır. GEM, genelleştirilmiş doğrusal modelin parametrik olmayan durumu olarak ifade edilmekte olup doğrusal olmayan dağılımların yani eğrisel ilişkilerin tespit edilmesinde kullanılan yöntemlerden birisidir. Bu yöntem, bağımlı değişkenler ile bağımsız değişkenler arasındaki karmaşık ilişkilerin belirlenmesinde yumuşatma fonksiyonunu kullanarak tahmin kabiliyetini artırmaktadır. Böylece elde edilen modeller daha anlamlı sonuçlar ortaya çıkarmaktadır (Guisan vd., 2002; (Lehmann et al., 2002; Moisen vd., 2006). Elde edilen modeller çapraz geçerlilik yöntemiyle teyit edilmektedir. BU kapsamda modellerin geçerlilikleri ROC eğrisi altında kalan alan (AUC) ile değerlendirilmiştir.

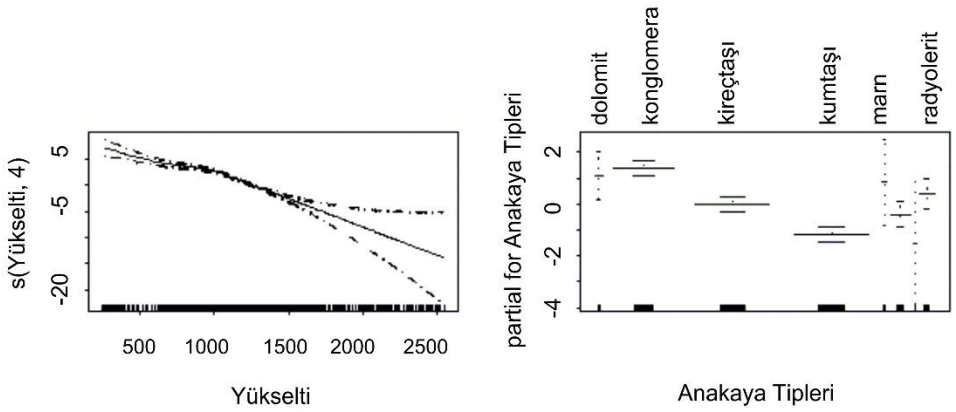
3 BULGULAR

Hedef türün arazi envanter çalışmalarında 1040 örnek alanda toplanan var – yok verileri ile büro ortamında üretilen çevresel değişkenler (Yükselti, Eğim, SCIN, RADIN, BUIN, TPIN, TNI, Anakaya Tipleri) GEM yöntemi kullanılarak potansiyel dağılım modellemesi gerçekleştirilmiştir. Yapılan modelleme işleminde çapraz geçerlilik yöntemiyle elde edilen en iyi modeli yükselti ve anakaya tipleri değişkenleri yapılandırmıştır (Şekil 1). Elde edilen modelin AUC değerlerine göre eğitim veri seti 0,946 ve test veri seti 0,944 olarak bulunmuştur.



Şekil 1. Modeli yapılandıran değişkenlerin katkı durumları

Modeli yapılandıran değişkenlerden yükseltiye göre kızılçam yöredeki düşük yükseltilerden başlayarak 700 – 950 m arasındaki yükseltilere kadar potansiyel olarak en uygun alanlarda dağılım göstermektedir (Şekil 2). Çalışma alanında kızılçam için 1000 m yükseltinin üzerindeki alanlarda potansiyel olarak dağılımının gittikçe azaldığı görülmektedir. Öte yandan, modeli yapılandıran diğer bir değişken olan anakaya tiplerine göre özellikle konglomera başta olmak üzere kireçtaşı ve kumtaşı kızılçam türünün dağılımında önemli rol oynadığı tespit edilmiştir (Şekil 2).



Şekil 2. Modelde yer alan değişkenlerin açıklayıcı grafikleri

4 TARTIŞMA ve SONUÇ

Sütçüler yöresinde kızılçamın potansiyel dağılım modellemesinin gerçekleştirilmesi amacıyla 1040 örnek alandan var – yok verisi toplanmıştır. Daha sonrasında oluşturulan çevresel değişkenler GEM yardımıyla modelleme aşaması gerçekleştirilmiştir. GEM sonucunda elde edilen modeli yükselti ve anakaya tipleri değişkenleri yapılandırmış olup elde edilen AUC değerleri oldukça tatmin edici değerler vermiştir. Modeli sonuçlarına göre kızılçam için en uygun dağılım alanlarının 700 – 950 m arasındaki yükseltiler olduğu tespit edilmiştir. Bu değerlerin üzerine çıkan yükseltilerde potansiyel olarak dağılımın giderek azaldığı tespit edilmiştir. Modelde yer alan anakaya tipleri değişkenine göre başta konglomera olmak üzere kireçtaşı ve kumtaşının kızılçamın dağılımında önemli olduğu belirlenmiştir. Buna göre çalışma alanının güneybatı kısmında yer alan Yazılı Kanyon ve çevresi, Yeşilyurt, Şehler ve Müezzinler ile yörenin güneydoğu hattında yer alan Kesme ve Çukurca kızılçam için en uygun potansiyel dağılım alanlarını oluşturmaktadır. Kızılçamın dağılımında yükseltinin belirleyici bir değişken olduğu bilinmekte olup yapılan birçok literatür çalışmasında benzer sonuçların elde edildiği görülmüştür. Atalay (2008), tarafından Akdeniz ekosistemleri üzerine yapılan çalışmada özellikle Toros dağlarında kızılçamın yöreye bağlı olarak 800 – 1200 m arasındaki yükseltilerde üst sınırı oluşturduğunu ifade etmiştir. Ancak, Gölhisar yöresinde kızılçamın dağılımı üzerine yapılan bir çalışmada türün yaklaşık 1350 m yükseltinin altındaki alanlarda yayılış gösterdiğini tespit edilmiştir (Şentürk, 2024). Özellikle Gölhisar yöresinde kızılçamın lokal olarak üst yükselti kuşaklarına kadar yayılış gösterdiği yerlerde bulunmaktadır (Kılıç and Güner, 2000). Sütçüler yöresinde gerçekleştirilen arazi envanter çalışmalarında da kızılçamın yaklaşık 1400 m yükseltilerde küçük meşcereler kurduğu gözlemlenmiştir. Bu durum kızılçamın belirtilen yükseltilere yetişme ortamı özelliklerinin imkan tanımasıyla bu tip lokal alanlarda var olabileceğini göstermektedir.

Diğer taraftan, modeli yapılandıran diğer bir değişken anakaya tiplerine göre konglomera, kireçtaşı ve kumtaşı değişkenleri kızılçamın dağılımında belirleyici olmuştur. Bilindiği üzere kızılçam ülkemizde başta Akdeniz ve Ege Bölgeleri olmak üzere Marmara Bölgesi, Orta ve Batı Karadeniz'de Akdeniz ikliminin hakim olduğu alanlarda lokal olarak yayılış göstermektedir (Şentürk vd., 2019). Özellikle esas yayılış gösterdiği Akdeniz ve Ege Bölgelerinde farklı anakaya tipleri üzerinde yayılış gösterdiği bilinmektedir. Bu dağılım içerisinde en iyi geliş gösterdiği bazı anakaya tipleri marn, fliş, kireçtaşı ve bazalt olarak ifade edilmektedir (Atalay ve Efe, 2015). Bunun yanı sıra yapılan farklı çalışmalara bakılacak olursa Şentürk (2024) Gölhisar yöresinde kızılçamın dağılım modellemesi ve haritalaması üzerine gerçekleştirdiği çalışmada kumtaşı, kireçtaşı, çört ve serpantin anakaya tiplerinin türün dağılımında önemli rol oynadığını tespit etmiştir.

Sütçüler yöresinde kızılçamın dağılım modellemesi üzerine gerçekleştirilen bu çalışmanın sonuçları ormancılık faaliyetlerine yön vermesi ve yapılacak uygulamalarda doğru kararların alınması noktasında uygulamacılara bilgi vermesi bakımından değerli bir çalışmadır. Öte yandan, bu çalışmada farklı bir istatistik yaklaşım kullanılmış olup özellikle araştırmacılara yapacakları çalışmalarda farklı bakış açısı kazandırmasına hizmet edeceği düşünülmüştür.

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Rising Nature-Based Tourism Trends Within The Framework Of Forest Ecosystem Services

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Abstract: Forests provide a diverse array of ecosystem services essential to environmental stability and human well-being. Beyond their ecological functions, such as carbon sequestration, water regulation, and biodiversity conservation, forests also offer critical cultural services, including opportunities for recreation, emotional renewal, and psychological restoration. In response to growing urbanization, mental health challenges, and ecological crises, nature-based tourism (NBT) has emerged as a transformative model that integrates forest ecosystem services with sustainable tourism, public health, and cultural revitalization. This review synthesizes recent conceptual and empirical developments in NBT, highlighting emerging practices such as forest bathing (Shinrin-yoku), therapeutic forests, wellness retreats, slow and regenerative tourism, digital detox initiatives, biophilic tourism, wildlife wellness tourism, and Indigenous-led experiences. These models reveal the evolving role of forests as spaces of healing, reflection, and regeneration. The review emphasizes the need to align tourism strategies with ecosystem service frameworks to ensure both environmental sustainability and human flourishing. It concludes that NBT not only supports ecological resilience and rural economies but also fosters ethical and emotional relationships with the natural world, offering a compelling pathway toward regenerative, inclusive, and future-oriented tourism development.

Keywords: Nature-based tourism; Forest ecosystem services; Biophilia; Regenerative tourism; Therapeutic forests; Cultural ecosystem services; Human-nature connection; Wellness tourism

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INTRODUCTION

Forests are among the most vital ecosystems on Earth, providing essential ecological functions such as carbon sequestration, water regulation, soil stabilization, and biodiversity conservation (Ali, 2023; Brockerhoff et al., 2017; Führer, 2000). Beyond these biophysical services, forests also offer important cultural ecosystem services, including aesthetic, recreational, and spiritual values that are critical to human well-being (Ali, 2023; Daniel et al., 2012; Everard, 2018). These intangible benefits increasingly influence tourism development strategies and offer a powerful entry point for integrating sustainability and well-being into tourism planning (Bachinger & Rau, 2019).

As urbanization, mental health challenges, and environmental crises intensify, forests have gained renewed attention not only as recreational spaces but as restorative environments offering critical ecosystem services. Likewise, there is a growing demand for restorative experiences in nature.(Fredman and Margaryan, 2021; Lin et al., 2014; Yıldızbaş et al., 2025). This societal shift has given rise to new forms of tourism that engage forest landscapes not merely as sites for recreation, but as spaces of healing, reflection, and emotional renewal (Bachinger & Rau, 2019; Bowler et al., 2010; M. H. Chun et al., 2017; Han et al., 2016; Joschko et al., 2023; Pouso et al., 2021). As global concerns about sustainability, well-being, and mental health intensify, nature-based tourism (NBT) is emerging as a transformative model that integrates environmental stewardship with personal and societal health benefits.

Activities like forest bathing and nature therapy exemplify this trend that underscores the ability of forests to improve emotional well-being and mental health via deep engagement with nature (Bachinger & Rau, 2019; Balmford et al., 2009; Han et al., 2016; Hansen et al., 2017; Jimenez et al., 2021; Muro et al., 2022). As these practices continue to gain attraction, understanding their benefits will be vital for developing effective tourism strategies that promote both health and sustainability.

Within this framework, nature-based tourism is increasingly recognized as a strategic avenue for advancing sustainability, public health, and ecosystem conservation. The integration of forest ecosystem services into tourism planning offers opportunities not only for enhancing visitor well-being but also for supporting local economies, preserving biodiversity, and strengthening human-nature relationships. This review aims to summarise emerging

nature-based tourism models intersect with forest ecosystem services, offering innovative pathways to enhance human well-being, biodiversity conservation, and sustainable development through forest-centred experiences.

2. MATERIAL AND METHOD

This review follows a narrative approach, aiming to bring together key literature on nature-based tourism within the context of forest ecosystem services. Rather than using a systematic or bibliometric method, sources were selected for their conceptual relevance, diversity, and contribution to current debates. The focus is on integrating recent academic and policy insights to explore emerging tourism trends linked to ecological and social sustainability.

3. NATURE-BASED TOURISM

Nature-based tourism refers to a form of travel that emphasizes the appreciation and exploration of natural environments (Avecillas-Torres et al., 2025; Fredman & and Margaryan, 2021; Joschko et al., 2023; Mehmetoglu, 2007). This type of tourism often involves activities that allow individuals to engage directly with nature, such as hiking, birdwatching, wildlife observation, and eco-friendly adventures. It is characterized by a focus on sustainability, aiming to minimize environmental impact while promoting conservation and the protection of natural habitats.

The essence of nature-based tourism lies in its ability to provide travellers with authentic experiences that foster a deeper connection with the natural world. This can include visiting national parks, nature reserves, and pristine landscapes, where visitors can immerse themselves in the beauty and diversity of ecosystems. Nature-based tourism often encourages cultural interactions as many destinations are home to indigenous communities whose traditions and practices are closely tied to their natural surroundings as awareness of environmental issues grows, nature-based tourism has gained popularity among travellers seeking not only recreation but also a responsible way to explore the planet (Lee et al., 2013; Mandić & McCool, 2023; Vespestad & Mehmetoglu, 2010). For instance birdwatching tourism has been shown to pose significant potential to enhance the economic and ecological welfare of indigenous populations, facilitate the dissemination of knowledge regarding the importance of biodiversity among local residents, and establish both local and national motivations for the effective conservation and safeguarding of natural habitats (Liu et al., 2021; Schwoerer & Dawson, 2022; Sekercioglu, 2002). By choosing this type of tourism, individuals contribute to the conservation of natural areas, support local economies, and promote sustainable practices that benefit both the environment and local communities (Kiper, 2013; Lee et al., 2013; Liu et al., 2021; Mandić & McCool, 2023; Sandbrook, 2010; Schwoerer & Dawson, 2022; Vespestad & Mehmetoglu, 2010).

Scientific research provides robust frameworks for understanding the psychological benefits of NBT. The Attention Restoration Theory (R. Kaplan & Kaplan, 1989; S. Kaplan, 1995) suggests that natural environments restore depleted cognitive resources by offering effortless attention through "soft fascination" and a psychological sense of escape from routine stressors. Ulrich's psycho-evolutionary theory (Ulrich, 1983) complements this by explaining that humans have evolved to respond positively to certain natural features, such as water, greenery, and open spaces, because they signalled safety and survival. Exposure to such features activates the parasympathetic nervous system, promoting stress recovery, emotional regulation, and physiological calm. Indeed, the appeal of NBT is rooted in humanity's deep connection to nature, a concept captured by biologist E. O. Wilson's biophilia, the innate tendency to seek connections with the natural world (Wilson, 1986). Biophilia, combining the Greek words for "life" (bio) and "love" (philia), suggests that our desire to engage with forests and wilderness is embedded in our biology, shaped by millennia as hunter-gatherers in resource-rich landscapes (Barbiero & Berto, 2021). The word "biophilia" was coined twice independently by German psychologist Erich Fromm and American biologist E. O. Wilson. Fromm used the term to describe the psychological orientation of being attracted to all that is alive and vital (Fromm, 1964), adopting a predominantly ontogenetic perspective focused on individual development. Wilson, in contrast, framed biophilia as an evolutionary adaptation, a phylogenetic trait rooted in humanity's survival in natural environments(Barbiero & Berto, 2021). Later, Wilson and Kellert (1995) expanded this concept into the Biophilia Hypothesis, proposing that the human dependence on nature extends beyond physical sustenance to aesthetic, intellectual, and spiritual needs (Kellert & Wilson, 1995). They argued that this innate affinity for natural systems supports psychological well-being and is essential for emotional and cognitive development. This perspective has profound implications for NBT: it provides a scientific rationale for why modern individuals, despite living in urbanized, technology-saturated environments, are drawn to natural settings for restoration, healing, and meaning. As Barbiero & Berto (2021) emphasize, the evolutionary imprint of nature remains deeply embedded in the human psyche, shaping our behaviours, preferences, and even our capacity for

psychological resilience. In this sense, NBT is not merely a recreational trend but a response to deep-rooted biological and psychological needs for interaction with living systems.

As the foundation of NBT becomes increasingly recognized across disciplines, it is equally important to explore how this conceptual understanding is evolving through contemporary trends and applications. The following section delves into emerging models and practices within nature-based tourism that reflect its growing relevance in addressing today's psychological, ecological, and cultural needs.

3.1. Emerging Trends in Nature-Based Tourism

As global interest in sustainability, well-being, and ecological resilience continues to grow, nature-based tourism (NBT) is evolving beyond conventional outdoor recreation. Emerging trends reflect a deeper integration of health, culture, and conservation goals within tourism experiences—particularly in forested landscapes, which offer unique sensory, emotional, and ecological value (Balmford et al., 2009; Fredman et al., 2024; Haukeland et al., 2023; Sandbrook, 2010).

These new directions in NBT include diverse models such as forest bathing, therapeutic forests, slow and regenerative tourism, biophilic design, wildlife wellness, and Indigenous-led journeys. While each trend is distinct, they share common ground in promoting immersive, low-impact, and meaningful interactions with natural environments. Many of these practices are rooted in the recognition of forests not only as recreational spaces but also as sources of healing, cultural continuity, and ecosystem stewardship.

3.1.1 Forest Bathing (Shinrin-Yoku)

One of the most widely recognized trends in nature-based tourism is forest bathing, or "Shinrin-yoku" in Japanese, a therapeutic practice that originated in Japan in the 1980s as a preventive health measure involves immersing oneself in a natural forest environment to promote physical, mental, and emotional wellbeing (Hansen et al., 2017). It involves slow, mindful walks in forested environments, engaging all five senses to promote relaxation and psychological restoration (Hansen et al., 2017; Keller et al., 2024; Muro et al., 2022, 2023).

Scientific studies have demonstrated that forest bathing can reduce cortisol levels, lower blood pressure, strengthen autonomic and immune functions (Hansen et al., 2017; Li, 2022; Li et al., 2007; B. Oh et al., 2017; Yau & Loke, 2020). Forest bathing interventions have also been shown to reduce pulse rate, increase heart rate variability (HRV), improve cardiopulmonary and metabolic function, elevate mood, reduce anxiety, and enhance quality of life, particularly among pre-hypertensive or hypertensive individuals(Yau & Loke, 2020). In particular, Shinrin-yoku has been shown to increase natural killer (NK) cell activity and anti-cancer protein levels, enhance parasympathetic nervous system activity, and lower stress-related hormones such as adrenaline and cortisol. It also contributes to better sleep, improved mood, and elevated levels of beneficial biomarkers like adiponectin and DHEA-S(Li et al., 2007). These effects suggest a preventive role against non-communicable diseases and even potential resilience against infections such as COVID-19 (Hansen et al., 2017; Li, 2022; Li et al., 2007; Muro et al., 2022, 2023; Yau & Loke, 2020). Moreover, forest bathing has been proven to have psychological effects of alleviating depression and anxiety, improving mental health improve emotional stability and mental clarity (M. H. Chun et al., 2017; Furuyashiki et al., 2019). By slowing down and engaging with forests, visitors can counter the alienation of modern life, finding meaning in their surroundings. This practice fosters a sense of presence and connection, countering the alienation of modern life and aligning with the existential quest for meaning. Its growing acceptance as a therapeutic intervention underscores its potential not only to enhance mental well-being but also to increase the appeal of forest-based tourism destinations (Karaşah, 2022).

3.1.2 Therapeutic Forests and Clinical Integration

Forest therapy refers to a set of structured, nature-based practices designed to enhance physical and psychological well-being through immersive engagement with forest environments. It is closely associated with the Japanese concept of Shinrin-yoku (forest bathing), which emphasizes mindful, sensory immersion in forest settings to reduce stress and promote mental clarity. While forest bathing is typically used in preventive health and public wellness contexts, forest therapy is a more formalized approach that integrates guided, therapeutic use of forests into clinical and rehabilitative care (Immich & Schuh, 2021).

One of the most innovative applications of forest therapy is the creation of therapeutic forests; green spaces intentionally designed and located near hospitals, rehabilitation centres, or wellness institutions to support structured, nature-based interventions. These environments are tailored to meet the needs of patients recovering

from neurological conditions, chronic diseases, mental health disorders, and stress-related illnesses(H. Chun et al., 2023; Häggström, 2019). Evidence shows that such settings offer significant psychological and physiological benefits, including reduced cortisol levels, improved mood, and enhanced rehabilitation outcomes. For example, stroke patients involved in forest-based recovery programs showed better cognitive and emotional recovery than those in conventional urban care settings (Heckmann et al., 2023). Several countries, including Japan, South Korea, China, and Germany, have begun formally integrating forest therapy into their public health systems. This includes developing policy frameworks, certifying forest therapy sites, training facilitators, and including nature-based interventions in clinical protocols (Bae et al., 2014; Khil et al., 2023; Mazzoleni et al., 2024; Zhang & Ye, 2022). In these countries, therapeutic forests are increasingly recognized not as ancillary wellness spaces but as complementary infrastructure within mainstream healthcare. Meanwhile, in many European nations, forest therapy is gaining momentum as part of a broader movement toward ecotherapy and integrative medicine, aligning public health goals with environmental and community well-being (Mazzoleni et al., 2024).

Successful clinical integration of forest therapy relies on interdisciplinary collaboration and service design innovation. Healthcare professionals, ecotherapists, and environmental planners must work together to design accessible, evidence-based forest therapy programs that cater to diverse patient needs(Mazzoleni et al., 2024; Pálsdóttir et al., 2014; Rosa et al., 2021; Siah et al., 2022; Vujcic Trkulja et al., 2021). Incorporating tools such as user journey mapping and multi-sensory design can improve the therapeutic experience and ensure that interventions are both clinically effective and emotionally engaging (M. Wang & Cheng, 2022; X. Wang et al., 2022).

Ultimately, therapeutic forests represent a shift toward holistic healthcare models that treat humans as part of broader ecological systems. As recognition grows for the role of green infrastructure in health promotion and disease prevention, forest therapy offers a scientifically grounded, cost-effective, and human-centred solution to some of today's most pressing health challenges.

3. 1. 3 Wellness-Oriented Activities in Forest Environments

Wellness-oriented activities such as yoga, meditation, and breathwork have emerged as integral components of contemporary nature-based tourism, offering complementary benefits to forest therapy and forest bathing. These practices aim to cultivate physical vitality, emotional regulation, and psychological resilience through structured engagement with mind-body techniques in natural environments. Increasingly, these wellness practices are being integrated into forest-based wellness retreats, where sustainable accommodations are paired with immersive activities such as yoga sessions, guided meditation, herbal therapy, and forest rituals. When embedded within forested settings, these wellness modalities harness the therapeutic potential of nature to enhance mental clarity, reduce stress, and support holistic well-being (Lyu et al., 2019; Sathyanarayanan et al., 2019; Yeo et al., 2024). These retreats leverage the calming ambiance of forest environments, characterized by low sensory pollution, natural sounds, and biophilic aesthetics, to amplify the restorative effects of wellness activities. Wellness-oriented tourism thus contributes not only to individual flourishing but also to broader efforts in building adaptive, health-oriented, and ecologically sustainable communities.

Yoga, in particular, has been widely studied for its mental health benefits. Systematic reviews have shown that regular yoga practice leads to reductions in symptoms of anxiety, depression, and stress (Brinsley et al., 2020; Gothe et al., 2019; Hernando et al., 2019). It promotes parasympathetic nervous system activation, improving autonomic balance and cognitive functioning (Vancampfort et al., 2012). These physiological changes are accompanied by improved mood and mindfulness, with benefits documented across diverse populations, including individuals undergoing cancer treatment and those experiencing severe mental illness (Desai et al., 2023; Patel et al., 2021). In such cases, yoga contributes to emotional stability, pain management, and enhanced quality of life, particularly by alleviating existential distress and fostering hope (Sathyanarayanan et al., 2019).

Meditation, particularly mindfulness-based practices, further complements yoga by promoting emotional awareness and attentional control. A growing body of evidence supports its efficacy in reducing generalized anxiety and depressive symptoms (Cramer et al., 2016; Yeo et al., 2024; Zeidan et al., 2010). By enhancing self-regulation, meditation fosters a deeper connection to the present moment and greater psychological resilience, especially when practiced in nature-rich environments.

Breathwork techniques, including yogic pranayama, play a crucial role in facilitating physiological relaxation and emotional balance. These practices regulate respiratory rhythms and increase heart rate variability—an indicator of stress adaptability and nervous system health (Gothe et al., 2019; Yamamoto-Morimoto et al., 2019). Breath-

focused interventions have been shown to reduce psychological distress, promote emotional equilibrium, and enhance cognitive function across clinical and non-clinical populations.

The fusion of wellness practices with forest settings reflects a growing convergence between global wellness culture and ecological consciousness, transforming nature-based tourism into a vehicle for psychological healing and sustainable living.

3.1.4 Slow Tourism, Silence Trails, and Digital Detox Retreats

As urban life accelerates and digital saturation intensifies, alternative forms of nature-based tourism are gaining momentum (Floros et al., 2019; Guiver et al., 2016; H. Oh et al., 2016; Upendra & Kaur, 2024). Among these, slow tourism, silence trails, and digital detox retreats have emerged as restorative models that respond to contemporary psychological and ecological challenges(Gong et al., 2023; Guiver et al., 2016, 2016; Talukder et al., 2024). These trends prioritize mindful travel, deep environmental engagement, and intentional disconnection from digital technologies, qualities that position them as meaningful extensions of forest-based tourism and wellness.

Slow tourism promotes a deliberate and immersive approach to travel that contrasts with the fast-paced, consumption-driven tendencies of mass tourism. Originating from the Slow Food movement of the 1980s, slow tourism emphasizes quality over quantity, advocating for extended stays, low-impact transportation, and meaningful engagement with local cultures and ecosystems (Balletto et al., 2020; Walker et al., 2021). Within forest landscapes, slow tourism enables visitors to appreciate biodiversity, cultural traditions, and ecosystem services more fully. It supports sustainability by reducing ecological footprints and strengthening local economies, particularly in rural or under-visited regions (Lee & Jan, 2019). This immersive style fosters a deeper appreciation for environmental stewardship and aligns with the therapeutic ethos of NBT by encouraging reflection and connection to place (Lu et al., 2023; Shang et al., 2020).

Silence trails are specialized routes designed to cultivate tranquillity and introspection through quiet immersion in nature. Often developed within forested areas, these trails minimize external noise to enhance sensory perception and mindfulness. Participants are encouraged to engage in contemplative walking, breathing exercises, or silent observation, which contribute to reduced stress and heightened psychological restoration (Crosswell et al., 2022). As an extension of slow tourism, silence trails exemplify the therapeutic potential of natural environments and support mental health objectives by providing spaces for calm and introspective engagement with nature.

Digital detox retreats aim to counteract the mental fatigue and emotional strain associated with constant digital connectivity(Cai & McKenna, 2021; Stäheli & Stoltenberg, 2024; Talukder et al., 2024). These retreats typically take place in natural, often forested settings, where participants temporarily disconnect from electronic devices and instead engage in nature-based activities such as guided walks, meditation, yoga, and communal experiences (Blasche et al., 2021; Giridharan, 2024). By fostering mindfulness and present-moment awareness, digital detox retreats promote emotional resilience and stress reduction (Cvijanović et al., 2025; Gaafar, 2021). Studies have shown that such retreats improve psychological well-being, interpersonal relationships, and attentional control, making them valuable components of holistic tourism and wellness strategies (Arenas-Escaso et al., 2024; Upendra & Kaur, 2024).

In addition to individual health benefits, digital detox retreats contribute to broader sustainability goals. Participants often report increased appreciation for the natural world and a desire to support conservation efforts, aligning with NBT's emphasis on ecological consciousness (Stäheli & Stoltenberg, 2024). These retreats also stimulate local economies by attracting visitors to rural areas and promoting the use of locally sourced products and services(Bozan & Treré, 2023; Cai & McKenna, 2021).

Together, slow tourism, silence trails, and digital detox retreats illustrate a broader shift toward experiential, health-centred, and ecologically attuned travel. They reflect growing interest in travel practices that prioritize well-being, sustainability, and cultural authenticity. As these models gain traction, they present valuable opportunities for integrating forest-based tourism into public health, conservation, and regional development strategies. In this way, they extend the core principles of NBT, reconnection with nature, psychological renewal, and sustainability, into diverse and inclusive tourism frameworks.

3.1.5. Regenerative Tourism

Regenerative tourism represents a transformative shift in tourism development, moving beyond sustainability to actively restore degraded ecosystems and revitalize local communities impacted by tourism (Becken & Kaur, 2021; Bellato et al., 2023; Bellato & Pollock, 2025; Dredge, 2022). It redefines the role of tourists as active co-stewards of ecological and cultural regeneration, emphasizing participation, reciprocity, and restoration (Duxbury et al., 2021; Owen, 2007). Key practices in regenerative tourism include rewilding, forest restoration, agroecological engagement, and community-based initiatives, all designed to enhance biodiversity, ecosystem services, and socio-economic resilience. Rewilding refers to ecological restoration initiatives aimed at returning ecosystems to their natural, uncultivated state, primarily through the reintroduction of native species and the removal of invasive species (Mathisen et al., 2022). This not only helps to restore biodiversity but also enhances the ecosystem's ability to manage natural processes autonomously (Sawu et al., 2024). As noted by Mathisen et al. (2022), incorporating such small-scale regenerative activities can significantly contribute to the flourishing of regenerative tourism, transforming the relationship between tourism and nature by fostering a more symbiotic interaction.

Forest restoration is another crucial aspect of regenerative tourism, focusing on rehabilitating degraded forest landscapes to restore ecological functioning and improve carbon sequestration capabilities (Derizal et al., 2024). Activities might include planting native trees, control invasive species, and implementing sustainable management practices to ensure the long-term health of forest ecosystems. This restoration is essential not only for biodiversity recovery but also for enhancing the aesthetic and recreational value of forested areas, thus attracting responsible tourists who support these initiatives(Khorshed et al., 2024).

Agroecological tourism integrates sustainable agricultural practices with tourism, promoting biodiversity, soil health, and local food sovereignty while supporting rural livelihoods (Amloy et al., 2024). Tourists can engage directly with local producers, fostering immersive experiences that align with environmental values(Ateljević & Sheldon, 2022).

A defining feature of regenerative tourism is its community-centred approach, which prioritizes participatory governance and knowledge co-production. This ensures that local stakeholders are not only beneficiaries but also key actors in tourism planning and implementation (Khorshed et al., 2024; Sharma & Tham, 2023). Initiatives may include cultural heritage programs, stewardship projects, and voluntourism, where visitors contribute to ecological restoration or social development efforts (Islam et al., 2024; Tomassini & Cavagnaro, 2022).

In forest and nature-based contexts, regenerative tourism fosters stronger partnerships among communities, tourists, conservationists, and policymakers. It revitalizes degraded landscapes, enhances cultural continuity, and promotes shared responsibility for ecosystem health and community well-being (Gültekin, 2022; Saputra & Kamilah, 2024). These outcomes align with broader sustainability frameworks such as the UN Sustainable Development Goals by promoting environmental justice, circular economies, and local resilience (Luković et al., 2022; Sawu et al., 2024).

Importantly, regenerative tourism resonates with emerging traveler values, particularly among millennials, who seek meaningful, authentic, and low-impact experiences (Ating et al., 2024; Hui et al., 2023). As post-pandemic recovery efforts provide a chance to rethink tourism, regenerative models offer a compelling path toward a more equitable, ecologically grounded, and future-oriented tourism sector.

3.1.6. Biophilic Tourism

Biophilic tourism is an emerging strand of nature-based tourism that integrates immersive nature experiences with the psychological and evolutionary principles of biophilia, a concept introduced by biologist Edward O. Wilson to describe humanity’s innate affinity for life and lifelike processes (Kellert & Wilson, 1995; Wilson, 1986). It builds upon the understanding that human well-being is deeply connected to the natural world, not only for physical sustenance but also for emotional, cognitive, and spiritual fulfilment (Barbiero & Berto, 2021; Trevisam & Silva Oliveira, 2024). Rooted in both ontogenetic and phylogenetic dimensions, the concept of biophilia reflects a deep-seated psychological orientation to seek connection with nature, shaped by our evolutionary past as hunter-gatherers and reinforced through positive emotional responses to natural environments (Barbiero & Berto, 2021; Farkić et al., 2025).

Biophilic tourism operationalizes these insights by fostering direct, meaningful engagement with natural environments, particularly forests, through activities that enhance emotional well-being and strengthen environmental stewardship. These experiences extend beyond visual appreciation to include multi-sensory,

embodied interactions such as forest walks, wildlife observation, forest bathing (Shinrin-yoku), and mindfulness practices, which contribute to reduced stress, improved mood, and enhanced cognitive function (Gaekwad et al., 2022; Guardini et al., 2023). Importantly, biophilic tourism is not merely recreational but has therapeutic potential. It emphasizes the design of tourism experiences, often in forested or wilderness settings, that restore the human–nature connection and promote pro-environmental attitudes (Fredman et al., 2021; Meltzer et al., 2020). It aligns with principles of ecotourism and nature-based tourism, both of which advocate sustainable resource use and cultural sensitivity (Komossa et al., 2018; Phumsathan et al., 2017).

Forests, as biodiversity-rich and culturally symbolic landscapes, serve as ideal environments for biophilic tourism. They offer opportunities for ecological learning, physical restoration, and cultural immersion (Mäntymaa et al., 2017; Tyrväinen et al., 2021). In Nordic countries, for example, biophilic tourism is increasingly tied to community-led initiatives that blend conservation, recreation, and cultural heritage (Fredman et al., 2021; Schweinsberg et al., 2012). Furthermore, the architectural and design dimensions of biophilic tourism are gaining attention. Incorporating natural materials, daylight, green infrastructure, and organic forms into lodges, trails, and visitor centres enhances the immersive quality of the experience (Farkić et al., 2025). Such design elements foster "biophilic environments" that deepen the psychological and aesthetic connection between visitors and place.

The economic and conservation benefits of biophilic tourism are also noteworthy. By promoting low-impact tourism practices and encouraging emotional attachment to place, it contributes to local livelihoods while incentivizing ecosystem preservation (Henri et al., 2017; Nugroho et al., 2021). Additionally, as interest in biophilic experiences grows, especially among urban populations seeking digital detox and emotional renewal, this tourism model offers pathways for sustainable destination development rooted in both science and sentiment.

In summary, biophilic tourism reflects a paradigm where nature is not only the setting but the therapeutic agent. Grounded in evolutionary psychology, ecological sustainability, and cultural reverence for natural systems, it provides a compelling rationale for why forests and other natural landscapes remain vital in fostering well-being, conservation, and meaningful travel. As such, biophilic tourism contributes not only to the flourishing of individuals but also to the resilience of the ecosystems and communities that host them.

3.1.7. Wildlife Wellness Tourism

Wildlife wellness tourism which blends ethical wildlife encounters with mindfulness and reflective engagement (Sachin & Dash, 2022; Tu, 2022) is an emerging subcategory of wildlife tourism that integrates animal welfare, conservation ethics, and human well-being. It promotes responsible, emotionally resonant encounters with wildlife—particularly in rehabilitative or sanctuary settings—that prioritize both ecological integrity and the psychological benefits for tourists (S. Curtin & Kragh, 2014; Speiran, 2025). Central to this approach is the notion that wildlife are not just attractions, but stakeholders in tourism experiences. Wildlife wellness tourism avoids exploitative practices, emphasizing respectful, non-invasive interactions that support species conservation, habitat restoration, and public education. For example, wildlife sanctuaries may provide opportunities for species reintroductions and therapeutic visitor experiences, linking animal care with ecosystem healing (Speiran & Hovorka, 2024).

This form of tourism responds to growing tourist demand for immersive, meaningful nature experiences. Visitors increasingly seek emotional and spiritual connection with wildlife, and such encounters have been shown to improve mental well-being, foster empathy, and encourage conservation-oriented behaviours (Ballantyne et al., 2011; Leurs et al., 2024). These benefits are enhanced when animals are ethically treated and local communities are engaged in tourism governance (Karanth et al., 2012; Thomsen et al., 2021).

By integrating wellness, ethical engagement, and sustainability, wildlife wellness tourism offers a holistic alternative to conventional wildlife viewing. It exemplifies how tourism can promote healing, both for people and for the planet, through responsible interaction with the natural world.

3.1.8. Indigenous-Led Tourism and Ancestral Wisdom Journeys

Indigenous-led tourism and ancestral wisdom journeys are also gaining traction, offering culturally rich and respectful interactions grounded in traditional ecological knowledge, such as the use of medicinal plants and forest-based spiritual practices (Carr et al., 2016; Shrestha et al., 2025, Vandermale & Mason, 2024). Indigenous-led tourism refers to tourism initiatives designed, controlled, and operated by Indigenous communities. These efforts prioritize cultural preservation, self-determination, and socio-economic development while resisting the commodification of Indigenous heritage. When Indigenous peoples manage tourism on their own terms, it becomes

a tool for achieving autonomy, cultural revitalization, and community resilience (Fletcher et al., 2016; Porsani et al., 2024). This model also responds to growing global interest in authentic, place-based experiences that centre Indigenous worldviews. A key component of Indigenous-led tourism is the concept of Ancestral Wisdom Journeys, immersive experiences that facilitate knowledge sharing between Indigenous hosts and visitors. These journeys foreground traditional ecological knowledge, oral histories, spiritual practices, and lifeways that have been passed down through generations. Such experiences not only offer deep cultural engagement for tourists but also contribute to the intergenerational transmission of Indigenous knowledge (Hsieh et al., 2017; Reddy & Sailesh, 2024).

Empowering Indigenous communities to define how their culture is presented ensures that tourism reinforces cultural integrity rather than exploitative narratives. As Vandermale and Mason (2024) note, tensions often arise between environmental conservation goals and commercial tourism pressures, particularly in Indigenous territories (Vandermale & Mason, 2024). Genuine Indigenous tourism initiatives, however, are rooted in local agency, reciprocity, and consent(N. Curtin & Bird, 2021). Economically, Indigenous-led tourism can provide vital income streams, infrastructure development, and employment opportunities while instilling cultural pride and identity validation (Zamani et al., 2023).

In summary, Indigenous-led tourism and Ancestral Wisdom Journeys offer powerful frameworks for fostering cultural continuity, sustainable livelihoods, and cross-cultural understanding. When grounded in Indigenous knowledge systems and values, these initiatives can become catalysts for empowerment and regeneration.

4. DISCUSSION AND CONCLUSIONS

Forest ecosystems provide a broad array of ecosystem services that are foundational to the development and sustainability of nature-based tourism. These services, as categorized by the Millennium Ecosystem Assessment (2005), include provisioning (e.g., fresh water, medicinal plants, wild foods), regulating (e.g., climate regulation, air purification, flood mitigation), supporting (e.g., nutrient cycling, soil formation, habitat provision), and cultural services (e.g., recreation, spiritual values, aesthetic experiences) (Millennium Ecosystem Assessment (Program), 2005; Booi et al., 2022; Daniel et al., 2012; Everard, 2018; Miller, 2024; Romanazzi et al., 2023; Willis, 2015; Avecillas-Torres et al., 2025; Miller, 2024; Willis, 2015; Booi et al., 2022; Daniel et al., 2012). While provisioning and regulating services are essential for maintaining the ecological infrastructure that supports tourism such as clean air, scenic landscapes, and climate stability, it is the cultural services that directly shape the tourist experience (Booi et al., 2022; Daniel et al., 2012; Everard, 2018; Miller, 2024; Romanazzi et al., 2023; Willis, 2015).

In this context, nature-based tourism can be seen as both a beneficiary of forest ecosystem services and a mechanism to reinforce their protection. Aligning tourism strategies with the full spectrum of forest ecosystem services ensures that tourism remains both ecologically viable and socially enriching. By recognizing forests not just as destinations, but as complex, service-providing systems, it is possible to design NBT models that promote biodiversity, climate resilience, and human well-being in tandem (Avecillas-Torres et al., 2025; Barbiero and Berto, 2021; Farkić et al., 2025; Gray et al., 2024; Joschko et al., 2023; Lumber et al., 2017; Miller, 2024; Bachinger and Rau, 2019; Romanazzi et al., 2023)

Nature-based tourism (NBT) represents a paradigm shift, redefining our engagement with forest landscapes as spaces of healing and renewal. Far beyond their ecological roles in carbon sequestration and biodiversity conservation, forests serve as sanctuaries that nurture psychological resilience, foster cultural connections, and support rural economies. Guided by ecosystem service frameworks and sustainability principles, NBT harnesses these cultural services, recreation, aesthetic inspiration, and spiritual enrichment, to advance public health and environmental stewardship. Through activities like forest bathing, slow tourism, and regenerative travel, NBT transforms tourism into a catalyst for wellbeing and ecological vitality. This shift invites us to reconnect with nature, moving beyond consumption to embrace our innate bond with the living world, as captured by the concept of biophilia. Similarly, NBT rekindles our instinctual connection to forests, reviving weary souls and degraded landscapes alike. This aligns with deep ecology's call for biocentric equality, recognizing the intrinsic value of all living beings, and Aldo Leopold's Land Ethic, which envisions humans as members of a broader ecological community, tasked with its care. These perspectives challenge the historical view of nature as a mere resource, promoting a reciprocal relationship that fosters ethical responsibility and personal fulfilment.

Looking forward, NBT holds the promise of a harmonious future where tourism nurtures both human wellbeing and the health of our planet. By weaving together scientific insights NBT invites us to see forests not as commodities but as living tapestries of interdependence. As we engage with these landscapes, we cultivate a deeper

awareness of our place within the natural world, ensuring that tourism becomes a restorative force, one that heals individuals, strengthens communities, and safeguards the ecosystems that sustain us all.

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