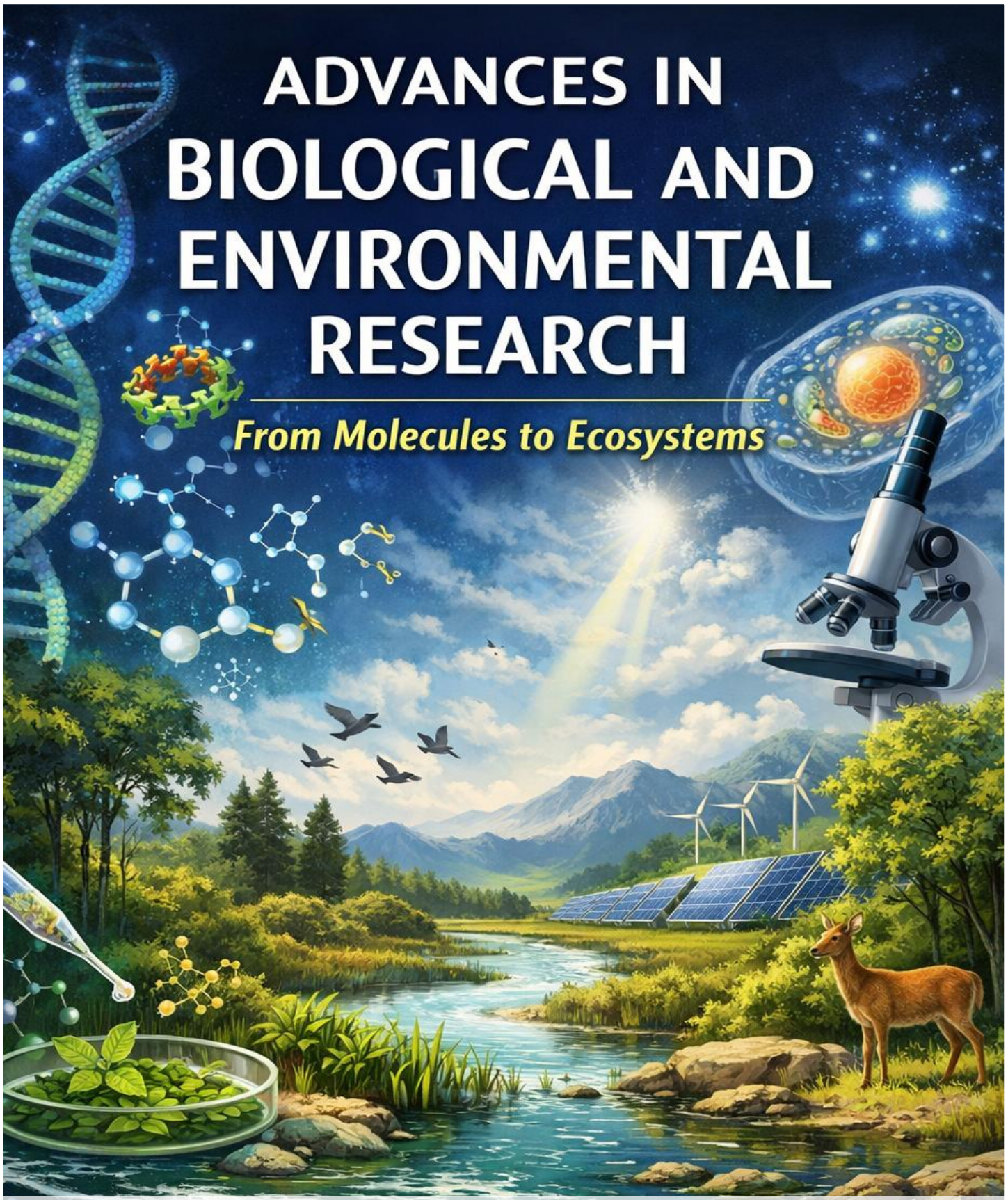
ADVANCES IN BIOLOGICAL AND ENVIRONMENTAL RESEARCH

From Molecules to Ecosystems



Dr. Gürçay Kıvanç AKYILDIZ (Editor)

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Advances in Biological and Environmental Research: From Molecules to Ecosystems

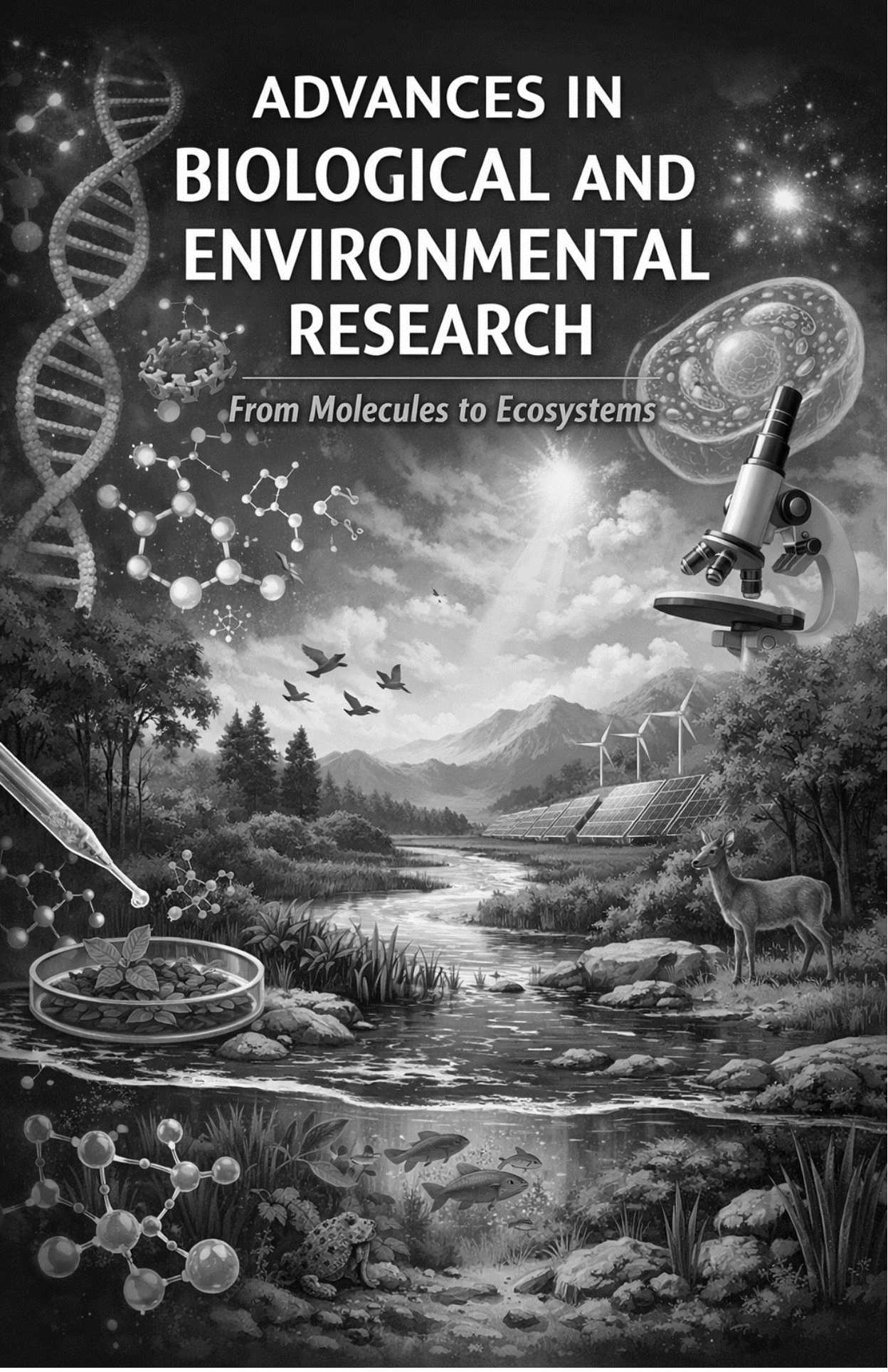
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Preface

Biological and environmental sciences have evolved into highly interdisciplinary fields that extend far beyond the understanding of natural systems alone. Today, these disciplines encompass critical issues such as sustainability, ecosystem management, biodiversity conservation, biotechnology, and human well-being. In this context, scientific research increasingly requires integrative approaches that connect molecular-level processes with ecosystem-scale dynamics. The present volume, Advances in Biological and Environmental Research: From Molecules to Ecosystems, has been prepared with this holistic perspective in mind.

This book brings together original contributions from scholars working across diverse areas of biological and environmental sciences. It aims to provide a comprehensive overview of contemporary research themes, methodological approaches, and emerging challenges in the field. By bridging fundamental and applied sciences, the volume offers valuable insights into both theoretical frameworks and real-world applications.

The chapters included in this book address a wide range of topics, from population assessment and species ecology to microbial processes, bioactive compounds, sustainable agricultural systems, and biotechnological innovations. Several contributions focus on ecological dynamics, conservation biology, and ecosystem-based approaches, while others explore molecular mechanisms and their translational potential in environmental and health-related contexts. This diversity reflects the interconnected nature of biological systems and highlights the importance of interdisciplinary collaboration in addressing complex environmental challenges.

Each chapter has been prepared with scientific rigor and reflects current developments in its respective field. The contributing authors present original findings, methodological advancements, and critical evaluations that collectively enrich the scientific discourse. As such, this volume is intended to serve as a valuable reference for researchers, graduate students, and professionals working in biology, environmental sciences, and related disciplines.

We would like to express our sincere appreciation to all authors for their valuable contributions and to the reviewers and editorial team for their dedicated efforts throughout the preparation of this volume. It is our hope that Advances in Biological and Environmental Research: From Molecules to Ecosystems will inspire further research, foster interdisciplinary collaboration, and contribute meaningfully to the advancement of biological and environmental sciences.

December, 2025

Dr. Gürçay Kıvanç AKYILDIZ

Editor

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Chapter 1

Estimating the Population Size of Sympatric Urodelan Species Using Digital Photography Technique

Eyup BAŞKALE[1] & Uğur KAYA[2]

Introduction

Mark-recapture (M-RC) techniques are useful tools for estimation of population size, which are used by biologists and ecologists (Donnelly & Guyer, 1994; Lebreton et al., 1992). These techniques have been used especially by herpetologists since 1920s to study many species of salamanders, frogs, and reptiles in different habitats (Woodbury, 1956). Beausoleil et al. (2004) and Donnelly et al. (1994) have explained various marking techniques for amphibians. Pattern mapping (Bradfield, 2004; Hagström, 1973; Loafman, 1991), tags (Donnelly et al, 1994; Elmberg, 1989; Woodbury, 1956), polymers and pigments (Nishikawa & Service, 1988; Taylor & Deegan, 1982), transponders (Donnelly et al, 1994; McAllister et al, 2004; Perret & Jolly, 2002; Schabetsberger et al. 2004), toe clipping (Gittins, 1983), and branding (Dougherty, 1976; Perret & Jolly, 2002) are the most used tools for marking amphibians. But, for amphibians some marking techniques using external tags, such as PIT tags etc. are not suitable because of their costs and the small size of the animals. The other problems are

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effects of marking techniques, i.e., tag loss, high level of injuries, and infections.

Photographic methods are used for recognizing individuals and have been improved recently. Hagström (1973) used the photographic method to recognize individuals of *Triturus cristatus* and *Lissotriton vulgaris* from their ventral patterns. Loafman (1991) described a technique of pattern mapping for recognizing individuals of spotted salamanders by their spot patterns. Doody (1995) described an inexpensive photographic technique for recognizing amphibians from their dorsal patterns. Recently Bradfield (2004) used photographic identification to recognize individual *Leiopelma archeyi*. Her study consisted of six photographs per frog and she divided *L. archeyi* into subgroups on the basis of their natural markings. Reaser (1995) expressed that polaroid pictures may be useful for recording spot patterns with the requisite technology but it can be sophisticated and expensive. Very recently digital photographic identifications were used to recognize some other animal populations such as mammals (Beausoleil et al. 2004; Bradfiels, 2004; Kelly, 2001; Markowits et al. 2003;). However, this marking techniques is newly used for amphibians (Çapar &Başkale, 2016; Yangın et al. 2017; Şirin et al. 2024).

Decline and loss of amphibian populations are increasingly becoming an international concern (Alford & Richards, 1999; Barinaga, 1990; Blaustein & Wake, 1990; Wyman, 1990). The loss of global amphibian biodiversity has been well documented recently, but concerning some populations or species, we have little information about their life cycles and population trends. Some developing countries (i.e., Turkey) have no amphibian monitoring program because they are complex, time-consuming and expensive studies for researchers. In this respect, it is required to initiate M-RC studies in open and closed populations or metapopulations of species to estimate their population sizes and densities especially for endemic, narrowly distributed and endangered amphibian species.

Ommatotriton nesterovi (Litvinchuk, Zuiderwijk, Borkin & Rosanov, 2005), Anatolian Banded Newt or Nesterov's Banded Newt, is an endemic species to Asiatic Türkiye, and is distributed along the southern coast of the Marmara at approximately Lake Ulubat, Western Black Sea, Central Anatolia and Central Black Sea regions. *O. nesterovi* inhabits stagnant waters in various forest types, including coniferous, mixed, and deciduous, extending to sub-

alpine meadows. It may also be found in slightly modified habitats. Its breeding sites include lakes, ponds, temporary pools, irrigation pools, drainage canals, small roadside puddles, ditches in meadows, and slow-flowing streams in forested areas. It has been listed as Least Concern (LC) in view of its wide distribution, presumed large population, and because it is unlikely to be declining fast enough to qualify for listing in a more threatened category (IUCN, 2025). *Lissotriton kosswigi* (Freytag, 1955), Kosswig's Smooth Newt, is endemic to Türkiye, and it's distribution covers the Kocaeli Peninsula up to the Bosphorus and reaching eastwards along the Black Sea coast to approximately the city of Bartın in the northwest of Anatolia (Wielstra et al. 2015, 2018). It lives in densely populated areas and has a very restricted distribution range (Wielstra et al. 2015). The species inhabits natural mountain forests, shrublands, and artificial waterbodies, showing adaptability in meadows, bushlands, parks, fruit gardens, and both rural and urban areas. It breeds through larval development in stagnant and slow-moving shallow waters, including irrigation ditches. *L. kosswigi* has been listed as Vulnerable (VU) because its population is considered to be severely fragmented, and there is a continuing decline in the extent and quality of its habitat (IUCN, 2025).

The aims of this study are to explain the marking technique using digital photography on individuals of *O. nesterovi* and *L. kosswigi*, and to estimate the population sizes of both species in their sympatric locality.

Materials and Methods

The study site was two separate but close irrigation pools of approximately 513 m² connected with large pipes, near Karasu in the vicinity of Sakarya, Turkey (41° 02′ N, 30° 37′ E) (Fig. 1). The maximum depth of these pools was 2 m and the elevation was 107 m above the sea level. In these pools we have found three newt species, *O. nesterovi*, *L. kosswigi* and *Triturus anatolicus*, sympatrically.



Figure 1. For agricultural irrigation purposes, man-made artificial habitats for *Ommatotriton nesterovi*, *Lissotriton kosswigi*, and *Triturus anatolicus*.

Individuals of urodelan species were captured during the day time on 21st March 2006 using a dip net. They were kept in a plastic container until they were photographed. Afterwards, they were released to the same pool.

Photographs were taken in the field using Nikon D70 and Nikon Coolpix 4600 digital cameras. Dates and image numbers were recorded as codes for all individuals. Recaptures were performed twice, on 23 and 25th of March 2006. To recognize each individual, ventral maculation (dot or spot pattern) was suitable for *L. kosswigi* and *T. anatolicus,* and lateral part of the tail and lateral body bands were suitable for *O. nesterovi* (Fig. 2). A small aquarium (2,5x20x15cm) was used for photographing *O. nesterovi*. More than one photograph was taken for each newt and later the best image selected from the monitor for recognizing each individual. All newts were photographed from a constant distance of about 15 cm.

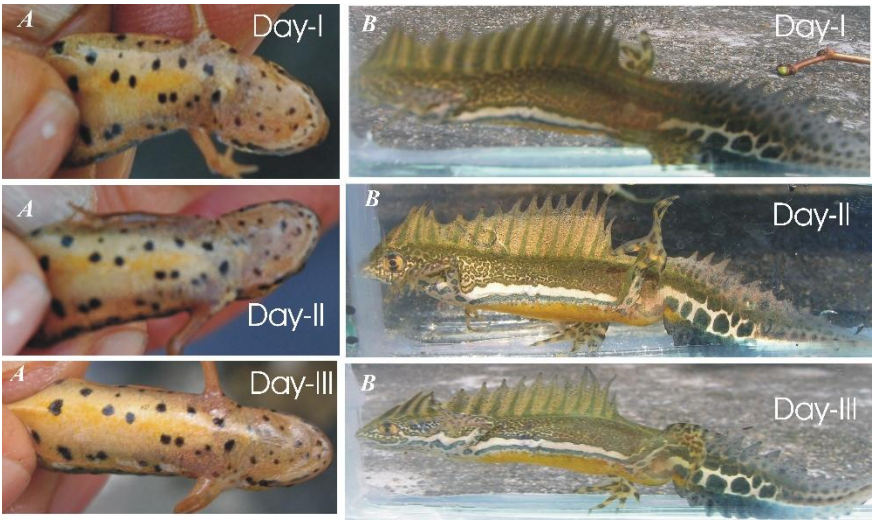


Fig. 1. Sample images of individual photographic marking; A) *Lissotriton kosswigi* B) *Ommatotriton nesterovi*. Days (I-III) indicate the number of captures.

All images were transferred to a computer and classified in different folders as 21 March, 23 March, and 25 March for *O. nesterovi* and *L. kosswigi*. Images of all individuals in folders were matched visually and the images of the same individuals from different folders were recorded using Microsoft Office Picture Manager. We performed triple catch method to estimate population sizes of *O. nesterovi* and *L. kosswigi,* using M-RC data following Begon (1979).

Results

No sign of any infections or injures were observed on the newts during capturing, handling and photographing process. The other advantages of digital photography, the best image can be chosen from the monitor of the digital camera and also many images can be recorded related to the capacity of the memory card. However, while we selected the best image from monitor, some images were still blurred. We did not observe any quality differences of images between Nikon D70 and Coolpix 4600 digital cameras. We easily recognized all recaptured specimens using Microsoft Office Picture Manager (Fig. 2).

Population size of *T. anatolicus* could not be estimated due to the fact that only two individuals (one male and one female) were captured during our three days' survey. Population sizes, survival rates, gain rates and recruitment for other species are summarized in Table 1.

Table 1: Results of triple catch method for calculating population sizes, survival rates, gain rates and recruitment for *Ommatotriton nesterovi* and *Lissotroton vulgaris*.

	$\hat{N}_1$	$\hat{N}_2$	$\hat{N}_3$	$\hat{\phi}_2 = \hat{\phi}_1$	$\hat{g}_1 = \hat{g}_2$	$SE_{\hat{N}_2}$	$SE\hat{\phi}_1$
O. nesterovi	980,87	544	301,71	0,94	-0,70	491,64	0,59
L. kosswigi	103,24	153,41	227,96	0,47	0,68	43,49	0,18

Lissotriton kosswigi; 58 individuals are captured, photographed, and released on day-1. 89 individuals were captured on day-2; 15 of which had been photographed on day-1. Of the 74 individuals captured on day-3, 3 had a day-1 image, 18 had a day-2 image, and 3 had day-1 and day-2 images.

Ommatotriton nesterovi; 36, 47, and 68 individuals were captured and photographed during the three day study. Of the 47 captured on day-2; two had a day-1 image, 68 captured on day-3; four of them had a day-1 image, four of them had a day-2 image, and one of them had day-1 and day-2 images.

It was assumed that gain rates and survival rates are constant and the interval between sample period is the same ($\hat{\phi}_2 = \hat{\phi}_1$ and $\hat{g}_1 = \hat{g}_2$) (Begon 1979). Population size ($\hat{N}$), survival rates ($\hat{\phi}_1$), gains ($\hat{g}$), standard error estimates for population size on day-2 ($SE_{\hat{N}_2}$), and standard error estimates for survival rate on day-1 ($SE\hat{\phi}_1$) are given in Table 1 for both species. According to these results, approximately 609 *O. nesterovi* and 162 *L. kosswigi* inhabit the pool.

Discussion

Increasing quantitative monitoring programs of amphibians provided new evidence that some populations or species are under decline (Alford & Richards, 1999; Gardner, 2001; Houlahan et al. 2000; Lips et al. 2005). Many types of conservation studies require the identification of specimens that is usually obtained by unique marking. M-RC data of amphibians require extensive datum collection, analysis, and is labor intensive and time consuming (Southwood, 1978). Another problem of accumulating the M-RC data is related to the techniques of marking amphibians. Different

techniques are used to mark amphibians; but none of them is accepted to be perfect. Toe-clipping is the most common method since it is less time consuming for uniquely marking, and has a low cost (Donnelly et al. 1994; Funk et al. 2005). But it may potentially affect the survival or breeding behavior of animals negatively (Bloch & Irschick, 2004; Borges-Landaez & Shine, 2003; Gittins, 1983; May, 2004; Parris & McCarthy, 2001). Fluorescent elastomers (VIE) are the most widely used alternative to toe clipping. Retention time and effect on embryonic development in salamander egg masses with fluorescent elastomers were investigated and did not detect an impact of marking and were suggested that VIE has no negative effect on salamander larvae following hatching (Regester & Woosley, 2005). Kaplan (1958) tattooed frogs by scarifying a numeral into the ventral skin and did not observe infection, redness disappeared rapidly, and the number stood out vividly against the light ventral skin. Measey et al. (2003) used Visible Implant Alphanumeric (VI Alpha) Tags and Panjet tattoos for marking caecilians. They expressed that there are no difficulties for applying, recognizing, or reading the marks, recaptured animals have no deleterious effects caused by marking, and they pursued normal activity. PIT tags are not suitable for marking newts <2 g in body mass (Fasola et al. 1993) and also a relatively expensive method for marking amphibians. Trenham et al. (2000) recorded that PIT tags are either lost or induce mortality more frequently than toe clipping in juvenile salamanders. But it can be used in long term monitoring of amphibians. According to McAllister et al. (2004), knee tagging is an unacceptable means of long-term population monitoring in Oregon spotted frogs. Perret & Jolly (2002) investigated impacts of tattooing and PIT tagging on survival and fecundity in *Triturus alpestris* and showed that both marking methods were similarly suitable for estimating population parameters. But they preferred PIT tagging because of its better long-term reliability.

Digital photographic methods have been improved recently (Kelly, 2001; Markowits et al. 2003; Mazzoil et al. 2004). The technologies depend mainly on pixel capacity of the camera, but an image with a relatively low resolution (approximately two or three megapixels) is sufficient to recognize the individuals; further, the process of archiving the images moved from binders filled with color slides to folders and files stored on a computer hard drive and backed-up on servers. In utilizing digital cameras to recognize *O. nesterovi* and *L. kosswigi* specimens in our study, we found that even some slightly blurry or fuzzy images were easily recognized and matched the

individuals. Newts were not harmed or injured during capturing, handling, and photographic processes and later they continued their normal activities. An individual's spot pattern may change with age in urodeles but in *T. cristatus*, close relative of both species. Arntzen & Teunis (1993) have reported that spot pattern is virtually stable by the end of the juvenile stage.

Thirty four amphibian species inhabit Türkiye but we lack detailed information on their population sizes and demographics (Baran & Atatür, 1998). Recently, some studies were done on populations of *Pelophylax ridibundus ridibunda* (Kaya & Erişmiş, 2001), *Bombina bombina* (Çevik et al. 2008) and *Rana holtzi* (Kaya et al. 2005, 2010). Similarly, there is no demographic study about newts in Turkey. The present study concerns two species of newts, *O. nesterovi* and *L. kosswigi*, in their sympatric habitat and it provides formative confirmation about population sizes and uniquely recognizing individual newts using digital photographic identification techniques. Even if the population sizes of day-1, day-2, and day-3 were highly different in regards to each other, means of the population sizes can give approximate conclusions on their demographic structure.

In conclusion, the successful conservation of amphibian populations is constrained by insufficient species-specific ecological knowledge and a lack of information regarding population structure. Dependable amphibian monitoring studies like this may encourage long-term monitoring initiatives and furnish valuable insights for conservation and management efforts. In this context, long-term monitoring studies are needed to reach possible fluctuations of population sizes in overtime with more localities to facilitate their conservation.

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Chapter 2

Siderophores as Specialized Metallophores in Microbial Iron Acquisition

Melike BELDEK & Caner VURAL

Introduction

Metals are indispensable elements for all living organisms, as they lie at the core of numerous fundamental biological processes ranging from redox reactions to DNA synthesis and stress responses. In particular, redox-active metals such as Fe, Cu, and Mo play critical roles in metabolic pathways (Hood et al., 2012). However, the bioavailability of metal ions is tightly constrained by environmental conditions; for example, the extremely low solubility of Fe^{3+} in oxygenated environments has compelled microorganisms to develop specialized strategies for metal acquisition. In this context, metallophores are notable as low–molecular weight organic compounds produced by microorganisms to bind and transport metal ions into the cell. Metallophore–metal interaction is a multilayered process shaped by the physicochemical properties of the metal, the structure of the ligand, and environmental factors. As a result, metallophores may occasionally complex non-target metals; they can even solubilize and incorporate into biochemical pathways metals such as Al, Pb, U, or rare-earth elements, which are toxic or metabolically irrelevant (Wolff-Boenisch and Traina, 2007).

Metallophore selectivity is governed by the compatibility between properties of the metal ion—such as hardness/softness (HSAB), charge-to-radius ratio, and coordination geometry—and ligand characteristics including the type of donor atom, rigidity, chelate ring size, and denticity (Pearson, 1963). These interactions become even more complex in the presence of competing ions and

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variations in chelate effect strength (Duckworth et al., 2009). Therefore, the target-metal preference of a metallophore cannot be attributed to a single factor; instead, it emerges from a multidimensional process in which structural complementarity, electronic compatibility, and chemical suitability are simultaneously optimized (Kraemer et al., 2015).

Because metallophores enhance metal solubility and bioavailability, they hold substantial potential in environmental applications such as phytoremediation and microbial metal recovery (Vraspir and Butler, 2009). Likewise, mechanisms such as the bacterial Zur system in zinc limitation, the role of staphylopine in zinc uptake, or metallophores that maintain copper–manganese balance in Pseudomonas species illustrate how flexible and specialized microbial systems can be in maintaining metal homeostasis. Despite this versatility, siderophores remain the best-characterized and biologically most critical group among all metallophores; their exceptional efficiency in Fe(III) acquisition renders them an evolutionarily optimized subclass.

Siderophores

Siderophores are low–molecular-weight, metal-chelating compounds secreted by prokaryotic and eukaryotic microorganisms, often in response to environmental challenges. Chemically, they typically contain ligands such as catechol, hydroxamate, or α-hydroxy acid groups, which allow them to form strong complexes with metal ions. Structurally, siderophores are highly diverse; some possess macrocyclic ring structures, while others exist as linear chains, and nearly 500 distinct siderophores have been identified across various microbial species (Miethke and Marahiel, 2007; Boukhalfa and Crumbliss, 2002). Beyond their metal-binding properties, siderophores play a critical role in microbial adaptation and competitive strategies. Moreover, their unique structural features and binding mechanisms have inspired a range of applications in biotechnology and antimicrobial research (Neilands, 1995).

The structural heterogeneity of siderophores has profound functional implications. Differences in coordination geometry, macrocyclic architecture, and hydrophobicity influence not only metal selectivity but also environmental stability, solubility, and uptake specificity. Unique siderophore families such as

pyoverdines, yersiniabactin, and petrobactin illustrate how chemical innovation drives evolutionary adaptation, interspecies competition, and pathogen virulence.

Chemical Diversity of Siderophores

In siderophore molecules, the iron atom is typically coordinated by oxygen atoms, with the most common coordination geometry being octahedral. This arrangement allows the six ligands to be positioned around the Fe center with minimal steric repulsion. The octahedral field contributes to the formation of thermodynamically stable high-spin Fe(III) complexes. Depending on the type of siderophore, this octahedral field may be distorted, and in some cases, nitrogen or sulfur atoms can be incorporated as coordinating atoms, with such variants generally exhibiting lower affinity for Fe(III) (Hider and Kong, 2010). Furthermore, Fe(III) in siderophore structures can be coordinated through bidentate functional groups such as hydroxamates, α-hydroxycarboxylates, and catecholates, as well as combinations of polydentate phenolates, nitrogen heterocycles, and carboxylates (Barry and Challis, 2009 ; Timofeeva et al., 2022).

Based on the donor groups responsible for coordinating Fe(III), siderophores are classified into four major families: hydroxamate, catecholate, carboxylate, and mixed-type siderophores (Carroll et al., 2018). Representative structures from each class are shown in Figure 1.

Hydroxamate Siderophores

Hydroxamate siderophores are predominantly produced by bacteria and fungi (Ali and Vidhale, 2013). They contain the functional group C(=O)N-(OH)R, where R typically represents an amino acid or derivative, and form bidentate coordination with Fe(III). These molecules generally act as hexadentate ligands, forming highly stable octahedral ferric complexes (Timofeeva et al., 2022). Representative compounds include desferrioxamine B, desferrioxamine E, fusarin C, ornibactin, ferrioxamine, and ferrichrome (Crosa and Walsh, 2002). **Their high stability and specificity make them essential for microbial survival under competitive environmental conditions and for potential applications in medicine and biotechnology.**

Catecholate (Phenolate) Siderophores

Catecholate siderophores chelate Fe(III) through catechol or hydroxyl groups. Chelation typically results in a hexadentate octahedral complex formed by pairs of oxygen atoms from each catechol moiety. These siderophores are derived primarily from salicylic acid or 2,3-dihydroxybenzoic acid (2,3-DHBA) (Timofeeva et al., 2022). Examples include enterobactin, vibriobactin, agrobactin, pyochelin, and yersiniabactin (Neilands, 1981).

Carboxylate Siderophores

Carboxylate siderophores coordinate Fe(III) via carboxyl and hydroxyl groups. Key representatives include staphyloferrin A, mycobactin, rhizoferrin, petrobactin, pyoverdine, azotobactin, and ferribactin (Dave and Dube, 2000; Jimenez et al., 2010). **These siderophores are particularly effective in acidic environments, where their carboxylate groups enhance solubility and metal chelation efficiency.**

Mixed-Type Siderophores

Mixed-type siderophores incorporate combinations of hydroxamate, catecholate, and carboxylate ligands. Yersiniabactin exemplifies this category, displaying high iron-binding affinity and remarkable stability across diverse pH ranges due to its hybrid donor groups (Gräff and Barry, 2024). **Their structural versatility allows microorganisms to adapt to fluctuating environmental conditions and compete more effectively for metal resources.**

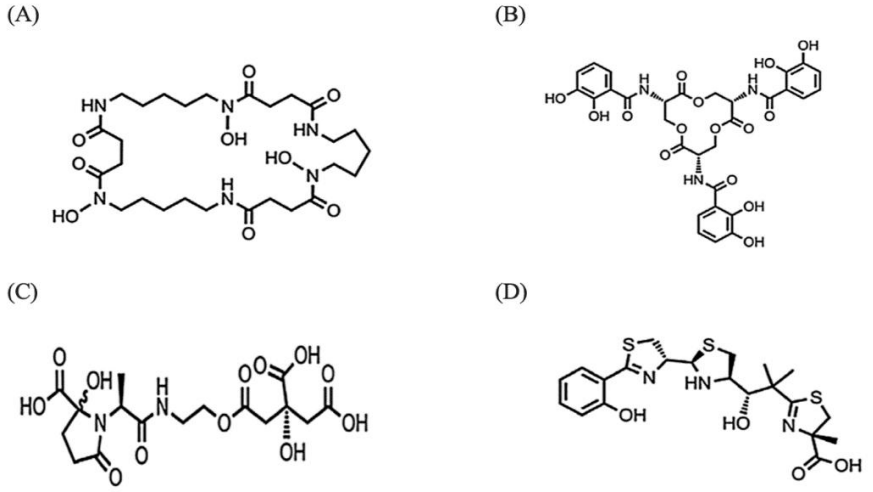


Figure 1. Structure of (A) hydroxamate siderophore: desferrioxamine; (B) catecholate siderophore: enterobactin; (C) carboxylate siderophore: vibrioferrin; (D) mixed siderophore: yersiniabactin (Khan et al., 2018).

Siderophore Producing Microorganisms

Siderophores are high-affinity metal-chelating molecules synthesized by a wide range of microorganisms to survive, maintain metabolic activity, and gain competitive advantages in environments where iron scarcity is prevalent. Among bacteria, genera such as *Pseudomonas*, *Bacillus*, *Azotobacter*, *Streptomyces*, and *Escherichia* are well-recognized for producing structurally and functionally diverse siderophores (Table 1). These molecules bind ferric iron (Fe^{3+}) with exceptional strength, enabling bacterial cells to fulfill essential metabolic requirements even under severe iron limitation. Fungi also constitute important siderophore producers; species of *Aspergillus*, *Penicillium*, and *Ustilago* secrete siderophores that not only regulate iron metabolism but also contribute to virulence, sporulation, and environmental adaptation(Saha et al., 2013; Erdem, 2013). Additionally, certain plants and invertebrate animals possess the ability to produce siderophore-like compounds that facilitate iron mobilization in a manner analogous to microbial systems. The biosynthesis of siderophores is governed by sophisticated regulatory networks capable of detecting environmental iron levels and is typically induced by factors such as iron deficiency, oxidative stress, and microbial competition.

Table 1. List of microorganisms which can produce siderophores (Saha et al., 2016).

Types of siderophore	Name of siderophore	Siderophore-producing microorganism
Hydroxamate	Ferribactin	*Pseudomonas fluorescens*
	Ferrichrome	*Ustilago sphaerogena*
	Desferrioxamine B	*Streptomyces pilosus*
	Ornibactin	*Burkholderia cepacia*
	Desferrioxamine mesylate	*Streptomyces pilosus*
Catecholate	Enterobactin	*Escherichia coli*
	Pyoverdine	*Pseudomonas aeruginosa*
	Salmochelins	*Salmonella enterica*
	Bacillibactin	*Bacillus thuringiensis*
	Vibriobactin	*Vibrio cholerae*
Carboxylate	Rhizobactin	*Rhizobium meloti*
	Staphyloferrin A	*Staphylococcus aureus*
	Rhizoferrin	*Rhizopus microsporus*
Mixed Type	Yersiniabactin	*Yersinia pestis*

Siderophore-Mediated Iron Transport

Siderophore-mediated iron uptake enables bacteria to acquire iron in a controlled and efficient manner. When intracellular iron levels are sufficient, the Fur regulatory protein represses iron acquisition genes, whereas under iron depletion this repression is relieved, activating siderophore biosynthesis and uptake pathways. Fur homologs have been identified in Escherichia coli and many other Gram-negative bacteria, highlighting the conservation of this regulatory mechanism across species. Bacteria access iron through three main mechanisms: siderophore-mediated uptake, direct transport of ferrous iron via divalent metal transporters, or acquisition from host iron-binding proteins. Siderophores bind ferric iron with exceptionally high affinity, and the resulting complexes are selectively transported into the cell via dedicated receptors. In Gram-negative bacteria, this process involves TonB-dependent outer membrane transport, while Gram-positive bacteria primarily rely on ABC transporters at the cytoplasmic membrane. Once inside the cell, iron is released from the siderophore either through reduction or enzymatic degradation, allowing ferrous iron to be trafficked into the cytoplasm and incorporated into metabolic processes (Ellermann and Arthur, 2017) (Figure 2).

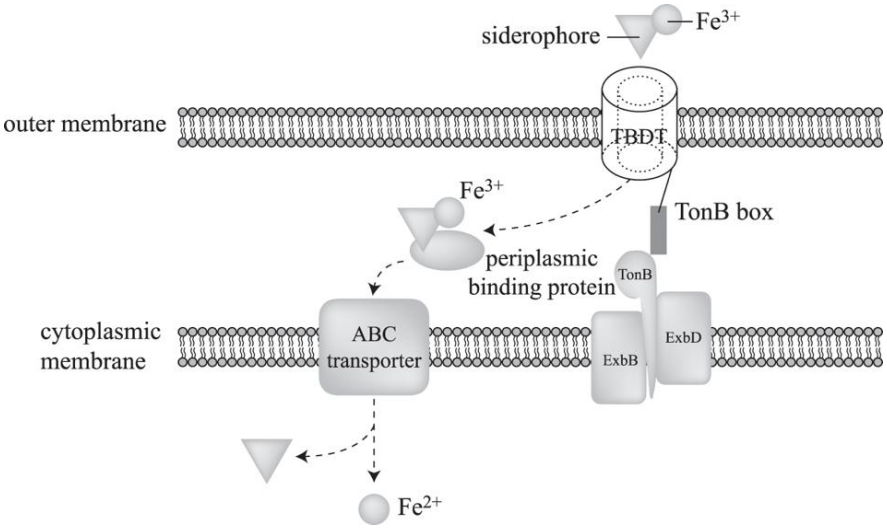


Figure 2. Transport of iron across the outer and inner membranes (Kim and Gadd, 2019).

Applications

Siderophores have gained significant attention due to their wide-ranging applications in agriculture, biocontrol, environmental remediation, and medicine (Mohandass, 2004). In agricultural systems, siderophore-producing bacteria such as *Pseudomonas putida* enhance plant growth and yield by improving iron acquisition and alleviating heavy-metal toxicity. By chelating metals accumulated in soil, siderophores reduce their harmful effects on both plants and soil microbiota (Weller, 2007; Sahu and Sindhu, 2011). Additionally, siderophore-mediated iron mobilization supports healthier rhizosphere dynamics, fostering beneficial microbial interactions. These combined effects position siderophore-producing microorganisms as promising candidates for sustainable agricultural interventions.

In the context of biocontrol, siderophores suppress the growth of numerous plant-pathogenic fungi—including *Phytophthora parasitica*, *Pythium ultimum*, *Fusarium oxysporum*, and *Sclerotinia sclerotiorum*—primarily by limiting iron availability. Reduced siderophore production consistently correlates with diminished biocontrol efficacy, underscoring their essential role in biological disease management. Moreover, siderophore-producing bacteria can outcompete pathogens in the rhizosphere, creating an iron-restricted microenvironment unfavorable for fungal proliferation.

This mechanism not only decreases disease incidence but also reduces dependency on chemical fungicides, promoting environmentally sound crop protection.

Environmental applications leverage the ability of siderophores to form stable complexes with heavy metals and radioactive elements. Major industrial contaminants such as cadmium, chromium, copper, mercury, lead, and nickel can be mobilized or immobilized by siderophores depending on their chemical properties. This versatility makes them valuable tools for soil and water remediation and even for advanced strategies targeting radioactive waste treatment (Bezbaruah and Saikia, 1998). Furthermore, siderophores can enhance the efficiency of bioleaching processes by increasing metal solubility under controlled conditions. Their integration into bioremediation technologies offers a cost-effective and eco-friendly alternative to conventional physicochemical methods.

In clinical settings, siderophore-derived chelators—most notably desferrioxamine B—play a crucial role in managing iron-overload disorders such as β-thalassemia, in which chronic transfusions lead to toxic iron accumulation. These compounds efficiently bind excess iron for excretion and are also employed in both the diagnosis and treatment of aluminum overload in dialysis patients (Krewulak and Vogel, 2008; Del Olmo et al., 2003). Recent research has also highlighted the therapeutic potential of siderophore-inspired compounds in treating infections by exploiting bacterial iron-uptake pathways. Additionally, the development of siderophore–antibiotic conjugates presents an innovative strategy for improving drug delivery and overcoming antibiotic resistance.

Conclusion and Future Perspective

Siderophores and metallophores are indispensable components of microbial metal acquisition strategies, enabling organisms to survive and thrive in environments where metal availability is severely limited. The biochemical sophistication and ecological influence of these molecules highlight their critical roles in microbial physiology, interspecies competition, and host–pathogen interactions. Siderophore production occurs across a wide range of biological systems—from bacteria and fungi to plants and even some animals—and serves as a key factor shaping community dynamics, particularly in iron-deficient ecosystems. Their growing importance in bioremediation, agriculture, antimicrobial

development, and the treatment of iron-related disorders further emphasizes their multifaceted biotechnological value. Nevertheless, several aspects, such as the environmental regulation of siderophore activity and the competitive or cooperative interactions within microbial communities, remain incompletely understood. As research progresses, metallophores and siderophores are expected to continue revealing new insights into microbial adaptation and to open expanding opportunities for innovative applications in medicine, agriculture, and environmental management.

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Chapter 3

Translational potential of caffeic acid phenethyl ester (CAPE) as a tumor microenvironment-targeted chemopreventive agent

Doğukan MUTLU[1] & Şevki ARSLAN[2]

Introduction

The intrinsic complexity of cancer and resistance to conventional therapies mandate the ongoing search for novel and effective pharmacological agents (Wu & Fu 2018). Despite significant advances in surgery, radiotherapy, and systemic therapies (including chemotherapy and immunotherapy), treatment outcomes for many solid tumors remain limited by issues such as significant systemic toxicity, acquired drug resistance, and the intricate biology of the Tumor Microenvironment (TME) (Sun 2016, Ni et al. 2021, Garg et al. 2024). Consequently, there is a strong need in oncology research to identify agents capable of simultaneously targeting multiple oncogenic hallmarks, particularly those derived from natural sources, which often exhibit favorable safety profiles (Zhang et al. 2022).

This focus on natural, multi-target agents leads to the investigation of traditionally used compounds with established safety profiles. Propolis, a resinous substance collected by honeybees from various plant sources, stands out as a prime candidate in this context (Wieczorek et al. 2022). Historically recognized for its traditional medicinal uses, modern research has confirmed its diverse

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pharmacological activities (Kuropatnicki et al. 2013, Hossain et al. 2022). Its therapeutic potential is primarily attributed to its complex phytochemical composition, which includes flavonoids, phenolic acids, terpenoids, and various essential oils (Hossain et al. 2022).

Among these components, Caffeic Acid Phenethyl Ester (CAPE), a prominent phenylpropanoid found in high concentrations in certain propolis types, is considered the major contributor to its profound anti-cancer efficacy (Cui et al. 2013, Nie et al. 2017). The chemical composition of propolis and its CAPE content vary widely depending on the bee species, geographic location, and phytogeographical origin. CAPE is particularly abundant in propolis sourced from temperate regions, such as Europe, North America, and non-tropical regions of Asia, with extracts from China, for example, showing high concentrations, typically ranging from 15–29 mg/g (Lv et al. 2021). CAPE exhibits a remarkable broad spectrum of bioactive properties, including antioxidant, anti-inflammatory, antimicrobial, antiviral, antifungal, neuroprotective, and antitumor effects (Toyoda et al. 2009, Göçer & Gülçin 2011, Meyuhas et al. 2015, Possamai Rossatto et al. 2021). Preclinical studies have demonstrated CAPE's potent, broad-spectrum anti-tumor activity against numerous cancer types, such as breast, ovarian, melanoma, prostate, and lung cancers (Kabała-Dzik et al. 2017, Liu et al. 2018, Ozturk et al. 2012).

The therapeutic efficacy of modern cancer therapies is often limited by the complexity of the TME. The TME is a dynamic ecosystem consisting of tumor cells, various immune cells, stromal cells (e.g., cancer-associated fibroblasts), and inflammatory mediators that collectively drive malignancy and resistance to treatment (Sun 2016, Wu et al. 2021). Carcinogenesis is driven by key molecular hallmarks, including metabolic reprogramming, immune evasion, and chronic inflammation (Hanahan 2022).

Chronic inflammation is perpetually present during tumor development and progression, generating a cytokine field that promotes invasion and immunosuppression (Landskron et al. 2014). Furthermore, tumors frequently experience hypoxia (low oxygen tension), which is a critical factor driving malignancy and therapeutic resistance. This state induces angiogenesis (neovascularization), a process crucial for tumor growth and metastasis (Muz et al. 2015). CAPE's unique potential as a chemopreventive agent stems from its ability to simultaneously

disrupt these TME-supporting pathways (Onori et al. 2009, Cheng et al. 2019).

CAPE modulates the inflammatory landscape primarily by acting as a potent and specific inhibitor of Nuclear Factor-kappa B (NF-kB) activation, a master transcription factor that promotes inflammation and chemoresistance (Natarajan et al. 1996, Chen et al. 2005, Lee et al. 2010). Mechanistically, CAPE blocks the phosphorylation and degradation of Inhibitor of NF-kappa B alpha (I-kB-alpha), thereby preventing the active NF-kB complex from translocating to the nucleus (Lee et al. 2010). This disruption suppresses the expression of critical pro-inflammatory cytokines, including TNF-alpha, IL-1-beta, IL-6, and IL-8, and reduces the levels of inflammatory mediators such as Tall-like Receptor 4 (TLR4) and Interleukin-1 Receptor-Associated Kinase 4 (IRAK4) (Zhang et al. 2013, Turkyilmaz et al. 2018).

CAPE is also shown to prevent Colitis-Associated Cancer (CAC) in mouse models by targeting the Nucleotide-Binding Oligomerization Domain, Leucine Rich Repeat and Pyrin Domain Containing 3 (NLRP3) inflammasome. In macrophage lineage cells (THP-1 cells), CAPE regulates NLRP3 expression at the post-transcriptional level by inhibiting Reactive Oxygen Species (ROS) production and promoting NLRP3 ubiquitination (Dai et al. 2020).

In addition to regulating inflammation, CAPE targets the metabolic reprogramming characteristic of cancer cells. Cancer cells exhibit a metabolic shift toward aerobic glycolysis—termed the "Warburg effect"—to support energy supply and precursor biosynthesis (Hanahan & Weinberg 2011). CAPE significantly inhibits proliferation and migration partly by suppressing glycolysis and lipid metabolism. It downregulates glucose transporters (GLUT1 and GLUT3) and key glycolytic enzymes, specifically Hexokinase 2 (HK2), Phosphofructokinase (PFK), Pyruvate Kinase M2 (PKM2), and Lactate Dehydrogenase A (LDHA). Furthermore, CAPE decreases the levels of lipogenic proteins, including Acetyl-CoA carboxylase (ACC), Fatty Acid Synthase (FASN), and Cluster of Differentiation 36 (CD36), suggesting its involvement in suppressing fatty acid metabolism in tumor cells (Wu et al. 2023). The anti-tumor activity of CAPE is, in fact, glycolysis-dependent.

CAPE's multi-target intervention also extends to metastasis and angiogenesis. It suppresses proliferation, migration, invasion, and angiogenesis in models, such as LPS-stimulated MDA-MB-231 cells

(Wu et al. 2023). Under hypoxic conditions, CAPE and its structural counterpart artepillin C inhibit the nuclear accumulation and promote the degradation of Hypoxia-Inducible Factor 1 Alpha (HIF-1-alpha), thereby downregulating the expression of Vascular Endothelial Growth Factor (VEGF), a key regulator of neovascularization (Choi et al. 2010, Paeng et al. 2015). Crucially for aggressive cancers like TNBC, CAPE represses Epithelial-Mesenchymal Transition (EMT) markers, notably vimentin and Vascular Cell Adhesion Molecule 1 (VCAM1), and reduces the expression of the invasion markers Matrix Metalloproteinase 2 (MMP2) and MMP9 (Chen et al. 2013, Fosu et al. 2024). The effects of caffeic acid phenethyl ester (CAPE) on tumor microenvironment are summarized in Figure 1.

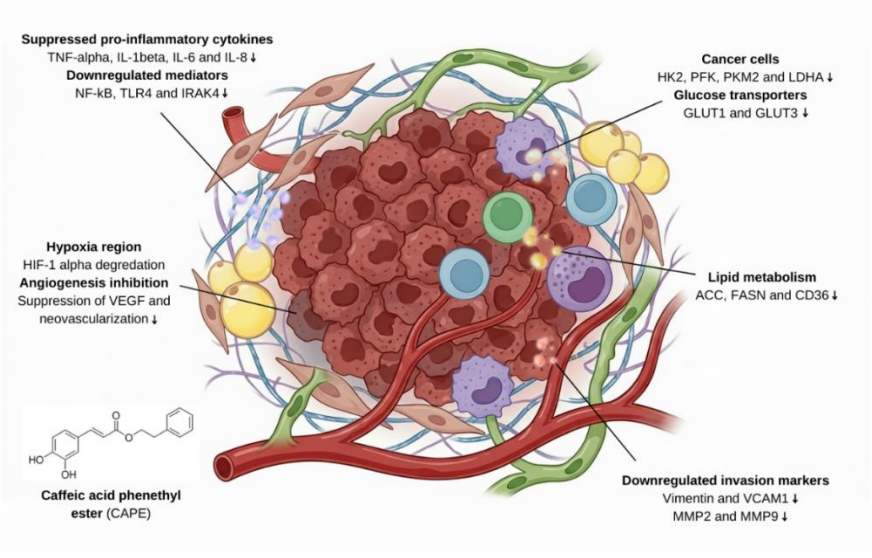


Figure 1. Molecular mechanisms of CAPE in the tumor microenvironment.

However, the translation of these promising preclinical findings to clinical practice necessitates addressing known limitations. One major barrier is CAPE's poor aqueous solubility, which severely limits its systemic bioavailability (Li et al. 2019, Kfoury et al. 2019). Consequently, advanced drug delivery systems, such as nanoparticle encapsulation, are being actively explored to enhance its efficacy and targeted delivery (Colpan & Erdemir 2021, Poyraz et al. 2023, Song et al. 2024).

Furthermore, due to the high variability of propolis composition depending on its geographical and botanical origin, chemical

standardization of CAPE-containing extracts is essential to ensure the reliability and reproducibility of clinical data.

Lastly, most current evidence relies on basic in vitro cell culture models; rigorous validation in more complex, physiologically relevant models that mimic the TME, such as organoids and humanized xenograft models, must precede clinical trials. Future research should focus on Phase I/II clinical trials to confirm CAPE's safety and efficacy when used as an adjuvant therapy in solid tumors characterized by significant inflammation and hypoxia.

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Chapter 4

Comparison of Soilless and Soiled Systems in Lettuce Cultivation: Productivity and Sustainability Analysis

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Introduction

Lettuce (*Lactuca sativa*) is among the most consumed vegetables worldwide, offering significant contributions to human health with its rich content of dietary fiber, vitamins, and antioxidants (Kim et al., 2016; Jibrin et al., 2022). Its low-calorie structure and its widespread use in salads, coupled with the increasing consumption of fresh lettuce, have made this plant species even more important in agricultural production (Koudela and Petříková, 2008; Thomas et al., 2021).

Hydroponic systems, one of the rapidly developing alternative cultivation techniques alongside traditional agricultural methods, enable more efficient use of limited agricultural land. This method stands out for its advantages, such as water conservation, reducing the risk of soil-borne diseases, and providing controlled nutrient management (Ahsan et al., 2021; Majid et al., 2021). Furthermore, their ability to produce throughout the year and their greater resilience to environmental factors make soilless systems attractive

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for sustainable agricultural practices (Velazquez-Gonzalez et al., 2022).

In contrast, soil-based agriculture, typically carried out using traditional pot culture, is still widely preferred due to its low installation cost and ease of implementation. However, yields in this method are more dependent on environmental conditions and soil structure, and inefficiencies in water and fertilizer use can be observed (Kerbiriou et al., 2016). For these reasons, a comparative study of both methods is crucial for both more efficient resource use and sustainability.

This study aimed to compare soil-based (pot culture) and soilless (hydroponic) systems for lettuce cultivation in terms of productivity, water and nutrient use efficiency, and environmental sustainability. The research findings will significantly contribute to agricultural practices that can be expanded, especially in urban areas, and will form the basis for the development of sustainable agricultural models.

Material Method

Within the scope of the study, two different cultivation systems were established for lettuce (Lactuca sativa)—soil-based and soilless (hydroponic)—to compare these systems in terms of productivity and sustainability. Experimental studies began on May 31, 2025, and both systems were conducted simultaneously (Figure 1).



Figure 1. System Setup on May 31, 2025

Seedling Placement and Trial Setup

After germination, lettuce seedlings were placed in both the soil and hydroponic systems (Figure 2).

In the soil system, pots were prepared using a homogeneous mixture of 40% garden soil, 30% peat, 20% perlite, and 10% compost.

For the soilless system, a vertical hydroponic structure based on NFT (Nutrient Film Technique) was constructed, and the seedlings were placed in mesh pots.

In both systems, the seedlings were allowed to grow under similar environmental conditions (light, temperature, humidity).



Figure 2. Lettuce in hydroponic and soil system

Nutrition and Irrigation Practices

In the soil-based system, each pot was irrigated with 200–500 mL of water at regular intervals, and fertilizer applications were made at regular intervals.

In the soilless system, a nutrient solution was initially prepared by adding 2 mL of Solutions A and B to 10 L of water. pH and EC were measured regularly over the following days, and the solution was adjusted with a pH reducer when necessary.

Target values for the nutrient solutions used:

EC: 0.8–1.2 mS/cm

pH: 6.0–7.0

Measurements were taken at regular intervals by the students participating in the project and recorded daily in a notebook. Efforts

were made to maintain EC and pH values within the target range, and interventions were made if deviations occurred.

Follow-up Process

In both systems, daily: Irrigation amounts, Nutrient applications, EC (Electrical conductivity), pH values were recorded, and differences between the systems were observed.

The targeted measurement plan was made as stated below.

Measurement Parameter	Description	Instrument/Method Used
Average Yield per Plant (g/plant)	Total weight of all harvested lettuce leaves	Scale (weighing)
Number of Leaves (leaves/plant)	Counting the total number of leaves per plant	Manual counting
Average Leaf Weight (g)	Mean weight of 10 randomly selected leaves	Precision scale
Leaf Length and Width (cm)	Measurement of leaf length and width	Ruler
Plant Height (cm)	Measurement from root base to leaf tip	Ruler or measuring tape
Root Length (cm)	Total root length	Ruler
Root Collar Diameter (mm)	Diameter at the root collar	Vernier caliper
pH	Acidity/alkalinity level of water	pH meter
EC (mS/cm)	Electrical conductivity indicating nutrient solution concentration	EC meter
Soluble Solid Content (°Brix, %)	Determination of sugar and soluble solid content	Refractometer

Findings

In both growing systems, irrigation rates, nutrient applications, EC (electrical conductivity), and pH values were recorded daily, and significant differences were observed between the systems throughout the process (Table 1). While regular interventions were made to maintain EC and pH values within target ranges in the hydroponic system, water requirements and irrigation intervals were more variable in the soil system. This suggests that the

hydroponic system offers a more controlled approach to nutrient and water management.

Table 1. Pot (Soiled Cultivation) and System (Soilless Cultivation) Follow-up Process

Date	Pot (Soil-Based Cultivation)	System (Hydroponic Cultivation)
31.05.2025	Planting done, 2l water per pot	Planting was done, 10l water and 5ml A and B nutrients were given, EC: 1, Ph: 6.3
1.06.2025	Checked	Measurement was made, EC: 1, Ph: 6.5
2.06.2025	Checked	Measurement was made, EC: 1, Ph: 6.6
3.06.2025	200 ml of water was given per pot	Measurement done, EC: 1.1, Ph: 6.5
4.06.2025	Checked	Measurement done, EC: 1.1, Ph: 6.3
5.06.2025	Checked	Measurement was made, 2ml of nutrients A and B were given, EC: 1.3, PH: 6.5
6.06.2025	Checked	Measurement was made, 1ml of A and B nutrients were given, EC: 1.2, PH: 6.2
7.06.2025	300 ml of water was given per pot	Measurement done, EC:1.1,EC:6.4
8.06.2025	Checked	Measurement was made, EC: 1, PH: 6.7
9.06.2025	Checked	Measurement was made, 1ml of A and B nutrients were given, EC: 1.2, PH: 6.2
10.06.2025	Checked	Measurement was made, 800ml water and 1ml A and B nutrients were given, EC: 1.2, PH: 6.2
11.06.2025	Checked	Measurement was made, 1ml of A and B nutrients were given, EC: 1.3, PH: 6.3
12.06.2025	Checked	Measurement done, EC: 1.6, PH: 6
13.06.2025	200 ml of nutrients were given per pot	Measurement was made, 1ml of A and B nutrients were given, EC: 1.2, PH: 6.5
14.06.2025	Checked	Measurement was made, 1l water was given, EC: 1, PH: 6.2
15.06.2025	Checked	Measurement was made, EC: 1, PH: 6.7
16.06.2025	Checked	Measurement was made, EC: 0.9, PH: 6.8
17.06.2025	The pot gave 150 ml of nutrients per pot	Measurement was made, 1l water and 1ml A and B nutrients were given, EC: 1, PH: 6.2
18.06.2025	Checked	Measurement was made, 1ml of A and B nutrients were given, EC: 1.4, PH: 6.5

19.06.2025	1 litre of water was given per pot	Measurement was made, 1.5 l of water was given EC: 1, PH: 6.5
20.06.2025	300ml of nutrients were given per pot	Measurement was made, 1l water was given, EC: 1.4, PH: 6.4
21.06.2025	Checked	Measurement was made, EC: 1.2, PH.6.3
22.06.2025	Checked	Measurement was made, 1l water was given, EC: 1.2, PH. 6.3
23.06.2025	Checked	Measurement was made, 2ml of nutrients A and B were given, EC: 1.3, PH: 6.5
24.06.2025	Checked	Measurement was made, 1l water was given, EC.1.4, PH.6.3
25.06.2025	Checked	Measurement was made, 1l water was given, EC.1.3, PH.6.6
26.06.2025	Checked	Measurement was made, 1l water was given, EC.1.4, PH.6.3
27.06.2025	500 ml of water was given per pot	Measurement was made, 2l water and 2ml A and B nutrients were given, EC: 1.3, PH: 6.5
28.06.2025	Checked	The water in the chamber was changed, 5ml of A and B nutrients were given with 10l of water, EC: 0.9, PH: 6.8
29.06.2025	Checked	Measurement was made, 1l water was given, EC.1, PH.6.4
30.06.2025	Checked	Measurement was made, 2.5 l of water was given, EC: 1.2, PH: 6.7
1.07.2025	Checked	Measurement was made, 1.5l water was given, EC: 1.2, PH: 6.5
2.07.2025	500 ml of water was given per pot	Measurement was made, 1.5l water was given, EC: 1.2, PH: 6.5
3.07.2025	Checked	Measurement was made, 1.5l water was given, EC: 1.3, PH: 6.9
4.07.2025	Checked	Measurement was made, 2l water and 2ml A and B nutrients were given, EC: 1.3, PH: 6.8
5.07.2025	Checked	Measurement was made, 1l water was given, EC: 1.3, PH: 6.6
6.07.2025	Checked	Measurement was made, 2l water was given, EC: 1.3, PH: 6.4
7.07.2025	Checked	Measurement was made, 2.5 l of water was given, EC: 1.2, PH: 6.7

Compared in terms of water and nutrient management

Soil-based system:

Generally, the process was controlled, with irrigation applied at a rate of 150–500 mL per pot on specific days. Nutrient supplementation was low and infrequent.

Soilless (Hydroponic) system:

Water and nutrient applications were more regular and controlled.

Nutrient solutions A and B were applied at frequent intervals.

pH values were generally maintained at a constant level of 6.2–6.7.

EC values also remained stable at 1.0–1.3. This supported optimal nutrient uptake.

In the soilless system, plants received more frequent and balanced nutrient administration, providing a healthier and more controlled growing environment. Regular monitoring of EC and pH values optimized nutrient uptake.

Fluctuations in EC Values:

On June 12th, the EC was measured as 1.6, and on June 13th, the EC was measured as 1.2.

The increase in the EC level to 1.6 on June 12th may indicate that the accumulated solution in the system was concentrating. However, the value decreased to 1.2 on June 13th, indicating that the system was properly diluted or that balance was achieved by water addition. This indicates that the nutrient balance in the hydroponic system was carefully monitored and that prompt intervention was taken when necessary. System management was observed to be responsive and controlled.

pH Levels:

The pH values were generally between 6.2 and 6.7, the ideal pH range for lettuce (6.0 and 6.8).

Rarely, values exceeding 6.0 or 6.9 were observed, but they stabilized quickly.

This indicates that the nutrient solution in the hydroponic system was well buffered and pH control was effective.

The hydroponic system has emerged as a system that provides a more controlled environment and manages nutrient balance through continuous measurement. The soil-based system provides sufficient water for growth, but because nutrient control and environmental parameters are not measured, it is likely to lag behind in comparative yields.

Plant Development Observations

During the following weeks of the experiment, differences in plant development were observed. Significant differences began to emerge between systems, particularly in parameters such as leaf size, plant height, and leaf count (Figure 3).



Figure 3. Significant differences between systems in parameters such as leaf size, plant height and leaf number.

Results and discussion

In this study, in order to evaluate the development of lettuce (Lactuca sativa) plants in soil and soilless cultivation systems, basic morphological and physiological parameters such as plant height, root length, leaf number, average leaf weight, leaf width and length, leaf area, root collar diameter, pH, EC, and water-soluble dry matter (TTS) ratio were measured (Figure 4). The data obtained from these measurements are presented comparatively in the table below (Tables 2, 3, 4).

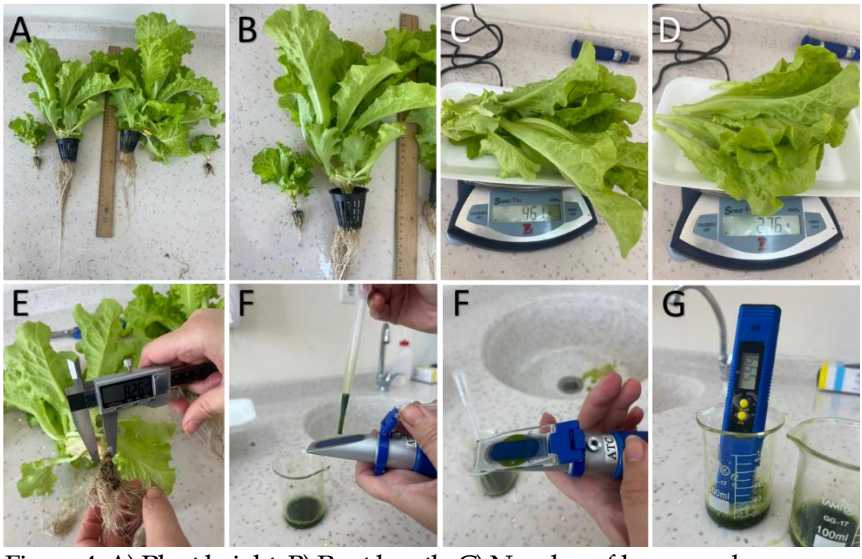


Figure 4. A) Plant height, B) Root length, C) Number of leaves and average leaf weight, D) Weight of 10 leaves, E) Root collar diameter, F) Total Soluble Solids (TSS) G) pH

Table 2. Morphological and physiological parameters measured in lettuce plants grown in soil and soilless systems

System	Recurrence	Average Yield (g/Plant)	Number of Leaves (number/Plant)	10 leaves Weight.(g/plant)	Leaf Width (cm)	Leaf Length (cm)	Plant Height (root + green parts)	Root Length (cm)	Root Collar Diameter (mm)	pH	TSS (%)
Soilless	1	47,94	20,4	27,58	9,84	17,1	50,2	22,4	6,88	5,65	2,68
	2	38,98	19,4	24,6	9,14	17,48	56,2	28,5	7,11	5,75	2,08
	3	32,44	19	18,78	8,74	16,12	50,7	21,5	6,96	5,86	2,12
Soil	1	2,86	9,8	3	3,71	5,25	10,9	3,5	5,73	6,19	2,08
	2	2,72	11,4	1,96	3,08	4,68	11,4	4,5	5,14	6,15	2,16
	3	3,46	11,6	2,58	3,99	5,67	11,98	4,7	5,46	6,11	2,24

Table 3. Average Values and Statistical Comparisons of Morphological and Quality Characteristics of Lettuce Plants in Soilless and Soil (Pot) Cultivation Systems

	Soilless	Soil	p
Average Yield (g/Plant)	39,79 ± 2,81 a	3,01 ± 0,21 b	0,000*
Number of Leaves (number/Plant)	19,60 ± 0,48 a	10,93 ± 0,46 b	0,000*
10 leaves Plant Weight.(g/plant)	23,65 ± 1,65 a	2,51 ± 0,15 b	0,000*
Leaf Width (cm)	9,24 ± 0,30 a	3,59 ± 0,11 b	0,000*
Leaf Length (cm)	16,90 ± 0,36 a	5,20 ± 0,15 b	0,000*
Plant Height (root + foliage)	52,37 ± 1,31 a	11,42 ± 0,36 b	0,000*
Root Length (cm)	24,13 ± 1,14 a	4,24 ± 0,30 b	0,000*
Root Collar Diameter (mm)	6,98 ± 0,24 a	5,45 ± 0,10 b	0,000*
pH	5,75 ± 0,04 b	6,15 ± 0,02 a	0,000*
TSS (%)	2,29 ± 0,09	2,16 ± 0,05	0,198
There is a statistically significant difference between the values indicated by different letters between the columns at the $p < 0.05$ level (Duncan multiple comparison test).			

Table 4. Correlation Analysis Results Between Morphological and Quality Characteristics of Lettuce Plant (Pearson Correlation Coefficient, n = 6)

	Average Yield (g/Plant)	Number of Leaves (number/Plant)	10 leaves Plant Weight. (g/plant)	Leaf Width (cm)	Leaf Length (cm)	Plant Height (root + foliage)	Root Length (cm)	Root Collar Diameter (mm)	pH	TSS (%)
Average Yield (g/Plant)	1									
Number of Leaves (number/Plant)	,889**	1								
10 leaves Plant Weight. (g/plant)	,986**	,859**	1							
Leaf Width (cm)	,961**	,861**	,970**	1						
Leaf Length (cm)	,961**	,907**	,960**	,982**	1					
Plant Height (root + foliage)	,919**	,910**	,914**	,943**	,981**	1				
Root Length (cm)	,892**	,859**	,907**	,929**	,957**	,979**	1			
Root Collar Diameter (mm)	,792**	,677**	,760**	,763**	,784**	,769**	,754**	1		
pH	-,917**	-,852**	-,910**	-,884**	-,898**	-,866**	-,858**	-,749**	1	
TSS (%)	,439*	0,319	,429*	,365*	0,289	0,240	0,223	0,297	-,405*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

A comparison of the morphological and physiological parameters of lettuce plants grown in soil and soilless (hydroponic) systems revealed that the soilless system generally exhibited superior performance. Average values from three replicates revealed significant advantages, particularly in terms of yield, leaf count, leaf weight, plant height, and root development.

The average yield was 39.79 g plant^{-1} in the soilless system and 3.01 g plant^{-1} in the potted (soiled) system, indicating that the hydroponic method yielded approximately 13 times higher yields ($p < 0.001$). Similarly, parameters related to photosynthetic capacity were significantly different: 19.6 leaves and 23.65 g/10 leaves in the soilless system, and 10.9 leaves and 2.51 g/10 leaves in the soil system ($p < 0.001$).

Plant height (roots + foliage) was measured as 52.36 cm in the soilless system and 11.42 cm in the pot system, while root length was 24.8 cm and 4.24 cm, respectively. These findings suggest that uninterrupted water and nutrient supply to the root zone significantly accelerates shoot and root development. The increase in root collar diameter (= 6.98 mm vs. 5.45 mm) also indicates greater mechanical strength in hydroponic plants ($p < 0.001$).

Leaf sap pH, considered a quality indicator, was 5.75 in hydroponic plants and 6.15 in soil-based plants. This value, which is in the more acidic range, has been optimized to facilitate nutrient uptake ($p < 0.001$). Although the water soluble dry matter (TSS) ratio was measured as 2.29% in the soilless system and 2.16% in the soiled system, this difference was not statistically significant ($p = 0.198$).

As a result, the hydroponic system, thanks to its controlled environment and nutrient management, demonstrated significant superiority over traditional soil-based systems in terms of productivity and plant growth. The study findings confirm that soilless cultivation represents an effective alternative for practices aiming at sustainable and high-quality lettuce production in limited spaces.

The findings in this study are in line with the general trends of a similar study by Gümüş (2023). Both studies indicate that the soilless (hydroponic) system outperforms soil-based systems in terms of yield, leaf count, and plant growth. However, the absolute values in Gümüş's study (e.g., yield of 141.0 g/plant) are higher than the results in this study. This difference may be due to the growing medium, the type of system used (e.g., NFT), climatic

conditions, or the nutrient solution applied. Both studies support the consideration of soilless cultivation as a potential alternative for lettuce cultivation.

The findings obtained in this study are generally consistent with those conducted by Al-Tawaha et al. (2018) using the NFT system. Al-Tawaha et al.'s study evaluated the effects of different water flow rates on lettuce growth, noting that yield losses were experienced due to EC increases due to salt accumulation, particularly at lower flow rates. Similarly, in this project, a sudden increase in EC was observed on June 13th, but rapid intervention ensured dilution of the solution, preventing any negative impact on yield. This similarity further demonstrates the decisive role of precise management of environmental parameters in hydroponic systems on product quality and yield.

The findings obtained in this study are consistent with the study conducted by Suharjo and Suaib (2022) on lettuce cultivation using the NFT system. In this literature, the highest fresh biomass (288.33 g) and growth parameters were reported in lettuce plants using rockwool growing medium and 5% slope conditions. Similarly, significant increases in yield parameters such as plant height, leaf count, and fresh weight were observed in the current study under the soilless farming system. Both studies demonstrate that the NFT system is an effective method for optimizing lettuce plant morphological development and productivity under controlled environmental conditions. In this regard, our study provides a successful example of the NFT system, consistent with the literature and relevant to local applications.

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Chapter 5

Reproductive Ecology of the Loggerhead Turtle on Patara Beach, Türkiye in 2024 Nesting Season

Eyup BAŞKALE[1]

Introduction

Seven species of sea turtles are recognized worldwide: *Dermochelys coriacea* (leatherback sea turtle), *Chelonia mydas* (green sea turtle), *Caretta caretta* (loggerhead turtle), *Eretmochelys imbricata* (hawksbill sea turtle), *Lepidochelys olivacea* (olive ridley turtle), *Lepidochelys kempii* (Kemp's ridley turtle), and *Natator depressus* (flatback turtle) (Lutz & Musick, 1997). All sea turtle species inhabiting the world's oceans are currently classified either as "Endangered" or "Threatened" throughout all or a substantial portion of their geographic range. These classifications reflect the severe declines observed in sea turtle populations, primarily as a consequence of anthropogenic pressures. In recent years, assessments have increasingly been conducted at both global and subpopulation levels to better evaluate conservation status and population trends (Casale & Tucker, 2015).

In the Mediterranean, *C. caretta* and *C. mydas* are the only two sea turtle species known to nest regularly along the coastline. Other species, including *D. coriacea*, *E. imbricata*, and *L. kempii*, have been recorded in the Mediterranean Basin; however, consistent nesting activity has not been confirmed. The principal nesting sites for *C. caretta* in the Mediterranean are located in Greece and Turkey, with limited nesting also occurring in Cyprus. In contrast, nesting by *C.*

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mydas is largely restricted to the eastern Mediterranean coast of Turkey. Consequently, Turkey plays a critical role in the conservation and long-term viability of Mediterranean sea turtle populations.

Both *C. caretta* and *C. mydas* utilize sandy beaches along Turkey's Mediterranean coastline for nesting, with the number of documented nesting beaches reported as 21 in recent years (Hathaway, 1972; Başoğlu, 1973b; Geldiay & Koray, 1982; Geldiay, 1983, 1984; Baran & Kasperek, 1989; Baran, 1990; Canbolat, 1991; Baran *et al.,* 1992; Lutz & Musick, 1997; Türkozan & Kaska, 2010). In addition to these established nesting sites, several beaches in Mersin Province, such as ODTÜ Beach and Davultepe Beach, as well as sporadic nesting locations including the Kuşadası coast (Aydın) and Kabak Bay (Muğla), have recently been reported as nesting habitats for sea turtles.

Both species are protected under the Bern Convention. Globally, *C. caretta* is classified as "Vulnerable" (VU); however, its Mediterranean population has recently been assessed as "Least Concern" (LC), reflecting the positive outcomes of sustained conservation efforts. In contrast, *C. mydas* is currently listed as "Endangered" (EN), and evaluations of its Mediterranean subpopulation suggest a high risk of further decline, with estimates indicating that approximately 500 adult females remain (Casale & Tucker, 2015; Türkozan & Kaska, 2010). According to the most recent assessments, the Mediterranean population of *Chelonia mydas* has been categorized as "Near Threatened" (NT) based on updated field data (Broderick *et al.,* 2024).

Patara Beach represents one of the most important nesting sites for sea turtles in Turkey (Türkozan & Baran, 1996). Previous studies have documented a declining trend in the nesting population of loggerhead sea turtles at Patara, based on long-term nesting data. Rapid tourism development in recent decades has intensified anthropogenic pressures, increasing the risk of habitat degradation and loss of nesting beaches. In this study, we examine the reproductive biology of nesting loggerhead sea turtles in 2024 breeding season at Patara Beach in order to estimate the current nesting population size. Additionally, we implemented conservation measures aimed at protecting adult turtles, hatchlings, and nests from the identified threats. The nesting trends documented at Patara may provide valuable insights applicable to other intensively monitored nesting beaches worldwide.

Materials and Methods

Study area

Patara Specially Protected Area (SPA), which covers approximately 190 km², is located within the borders of Antalya and Muğla provinces, Türkiye (Fig. 1), and includes important habitats for wild terrestrial and marine animals. Patara SPA contains residential areas, greenhouse areas, shrubland maquis areas, pastures, forests, wetlands, agricultural areas, and sand dunes. In addition to being a Special Environmental Protection Area, Patara SPA is also a first-degree natural protected area due to its rich biodiversity and an archaeological protected area because of the presence of ancient cities, such as Patara and Letoon. Patara Beach is approximately 12 km in length and consists of two subsections: the Patara section and the Karadere section. The Patara section is a dense nesting area extending for 7 km starting in the Gelemiş district (36°14.901′N, 29°18.948′E) and extending to the Eşen River (36°17.572′N, 29°15.746′E). The second section, Karadere, has a lower nest density than the Patara section and covers a 5 km-long beach, starting from the Eşen River (36°17.607′N, 29°15.691′E) and ending with the Karadere Stream (36°19.725′N, 29°13.517′E).



Figure 1. Satellite view of the Patara Specially Protected Area. The yellow line indicates the boundaries of the protected area.

Sea turtles's nest monitoring study was conducted from early May to late October following standardized protocols approved by the Turkish Sea Turtle Science Commission (Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks). Daytime and night-time surveys ensured comprehensive detection of nesting activity.

Adult female emergences were recorded daily using standardized data sheets and GPS, documenting nesting outcome, date, distance from the shoreline, proximity to permanent and semi-wet areas, and track characteristics. Total nest number (TNN) and non-nesting emergences (NNE) were recorded, and nesting success (NS) was calculated as NS = TNN / (TNN + NNE) × 100.

All nests were protected using 1 m × 1 m wire cages (10 cm mesh). In areas with intense beach use by human, prism-shaped cages were installed, accompanied by informational warning signs. Nests threatened by flooding or partial predation were relocated according to established protocols (Başkale & Kaska, 2005). Nesting density (ND) was calculated as the number of nests per kilometre (ND = TNN / 12 km). The proportion of fully protected nests (PNP) was calculated as PNP = [(TNN − predated nests) / TNN] × 100.

Nests were excavated two days after the last hatchling emergence to assess empty eggshells (EES), undeveloped eggs (UE), and dead embryos (fertilised embryos, FE) following Kaska and Downie (1999). Clutch size (CS) was calculated as CS = EES + UE + FE, with predated eggs included where applicable. Hatching success rate (HSR) was calculated as HSR = EES / (EES + FE + UE) × 100, excluding predated nests.

Results

Summary data for nests recorded during the 2024 sea turtle nesting season are presented in Table 1. The spatial and satellite-based distribution of nests along Patara Beach is illustrated in Fig. 2. The first *C. caretta* nest of the season was recorded on 11 May 2024. The mean morphometric measurements of nesting females of *C. caretta* at Patara Beach in 2024 were as follows: Straight Carapace Length (SCL) 66.08 cm, Straight Carapace Width (SCW) 57.91 cm, Curved Carapace Length (CCL) 71.70 cm, and Curved Carapace Width (CCW) 66.17 cm. In total, 1,518 emergences were recorded along the beach, of which 914 were classified as non-nesting emergences. A

total of 604 nests were recorded during the nesting season (Table 1). In this context, the nesting success rate was calculated as 39.79%.

Table 1. Nesting and egg statistics recorded at Patara Beach during the 2024 nesting season.

Nest parameters	N	%
Total nests	604	100
Fully predated nests	52	8.60
Partially predated nests	22	3.64
Completely protected nests	530	87.74
Nests with hatchling emergence	552	91.39
Nest density (nest/km)	50.33	
Egg parameters		
Total eggs	41,792	100.00
Predated eggs	3,620	8.66
Protected eggs	38,172	91.33
Hatched eggs (empty shells)	35,382	84.66
Unfertilized eggs	1,258	3.01
Dead embryos (total)	1,532	3.66
– Early stage	498	1.19
– Mid stage	150	0.35
– Late stage	884	2.11

Monthly distributions of nests and false crawls, as well as their spatial distribution according to distance from the sea and beach zones, are presented in Figures 4 and 5. Nesting activity peaked in June (258 nests), whereas the highest number of non-nesting emergences occurred in July (410 emergences). Monthly nest numbers were 118 in May, 258 in June, 202 in July, and 26 in August. False crawl numbers were 102 in May, 313 in June, 410 in July, and 89 in August. Most nests and non-nesting emergences were concentrated between 10 and 25 m from the shoreline. Due to the risk of inundation, 51 nests located too close to the sea were relocated to safer areas. Transverse analysis of nest and track distribution revealed that nesting density was highest between the dune zone and the Eşen River, followed by the area between the headland and the café

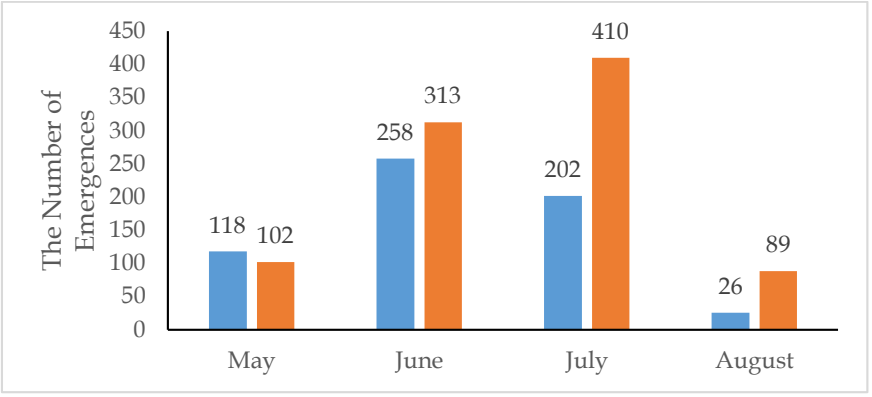


Fig. 4. Monthly distribution of nesting events and non-nesting emergences recorded at Patara Beach during the 2024 nesting season.

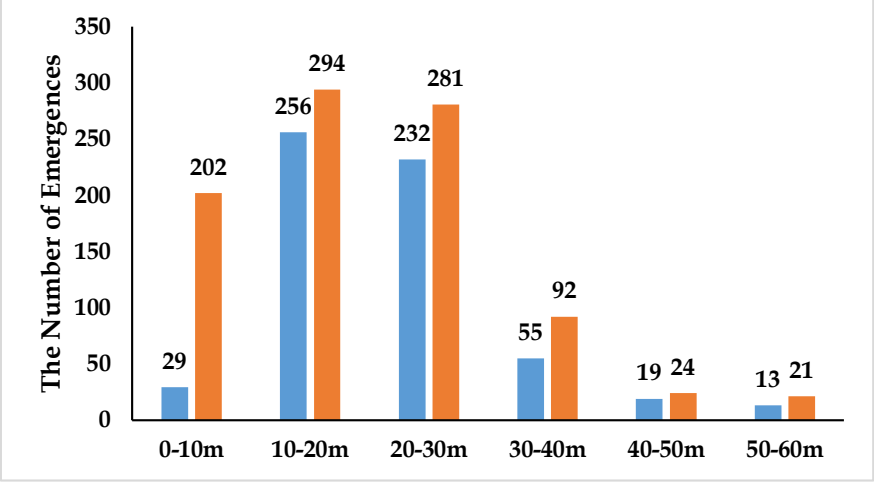


Fig. 5. Distribution of nests and non-nesting emergences according to distance from the shoreline.

All nests were protected using wire cages reinforced with 50 cm metal stakes and lateral mesh extending up to 25 cm below the sand surface. Additionally, above-sand cages were installed in areas with high human activity to enhance both public awareness and cage effectiveness. Despite comprehensive conservation measures, predation affected 74 nests (12.25%) were affected by predation (Fig. 3). Fully predated nests accounted for 52 nests (8.60%), whereas partial predation was observed in 22 nests (3.64%). Hatchling emergence was recorded in 552 nests, corresponding to 91.39% of all nests (Fig. 3). Fully predated nests were predominantly recorded in the Karadere sub-region, where night patrols could not be conducted; 40.38% of all fully predated nests occurred in this area. When Karadere Beach was excluded from the analysis, the

proportion of completely protected nests increased to 91.22%. Predation events primarily occurred on the night of nesting by foxes, and following caging, by badgers or wild boars. Overall, 3,620 eggs were lost due to predation during the study period.

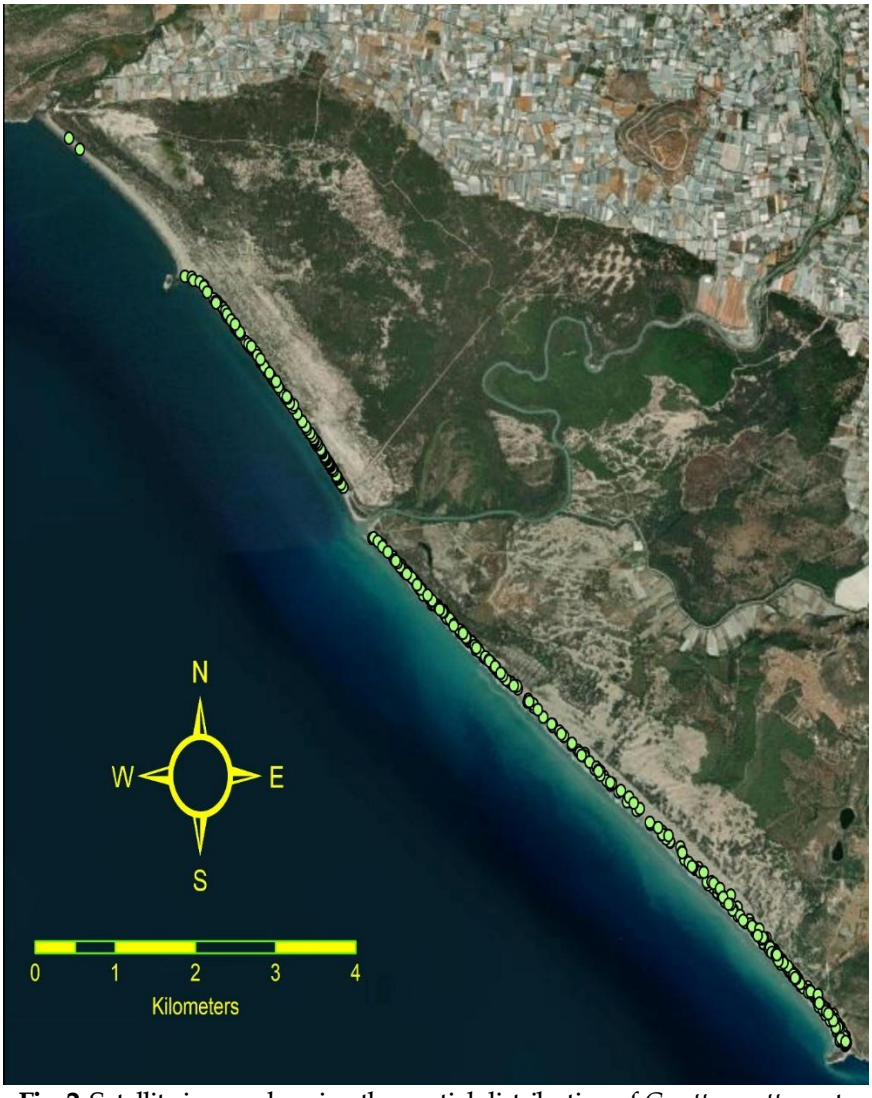


Fig. 2. Satellite image showing the spatial distribution of *Caretta caretta* nests along Patara Beach during the 2024 nesting season.

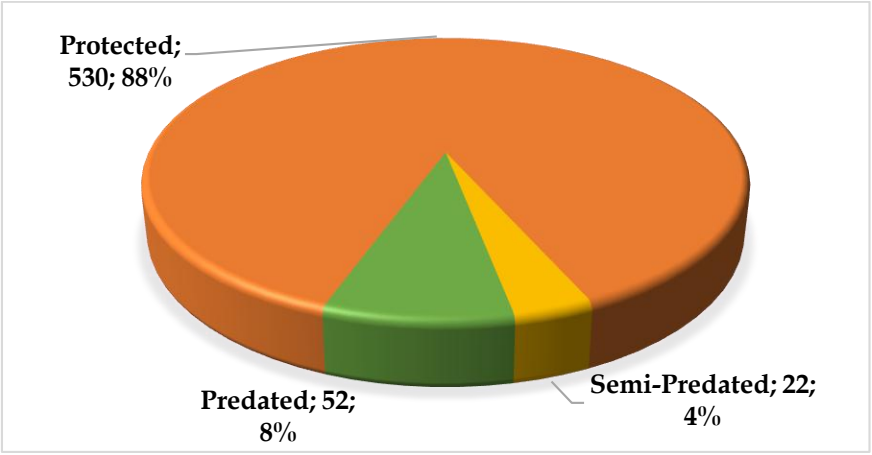


Figure 3. Predation status of *Caretta caretta* nests recorded at Patara Beach in 2024.

A total of 41,792 eggs were documented during nest excavations. Hatched eggs (empty shells) numbered 35,382 (84.66%). Unfertilized eggs accounted for 1,258 (3.01%), and embryonic mortality was observed in 1,532 eggs (3.66%), comprising 498 early-stage, 150 mid-stage, and 884 late-stage embryos.

Hatchling emergence was observed from 552 nests. Nest excavations revealed that 35,382 hatchlings successfully emerged, while 1,532 eggs died during embryonic development and 1,258 eggs were unfertilized (Fig. 4). When predated eggs were excluded from the analysis, mean hatching success was calculated as 92.69%. A total of 341 hatchlings were found dead either inside the nest or during their crawl toward the sea.

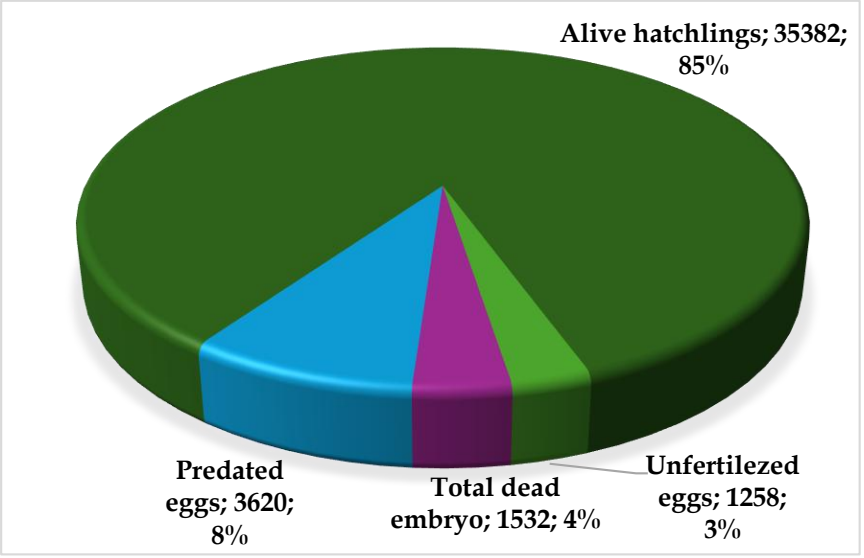


Fig. 4. Nests content information after post-emergence nest excavations.

The mean depth of the nests was determined to be 36.87 cm (minimum 30; maximum 57 cm), the mean diameter was 18 cm (minimum 16; maximum 24 cm), the mean incubation duration was 48.42 days (minimum 44; maximum 59 days), and the mean number of eggs deposited in the nests was 69.19 (minimum 33; maximum 118).

Discussion

The mean annual number of sea turtle nests across Mediterranean beaches has been estimated at 5,031 nests per nesting season, of which approximately 27.2% (n = 1,366) occur along the Turkish coastline (Margaritoulis *et al.*, 2003). Based on a synthesis of published studies and unpublished monitoring reports, the number of nests recorded in Türkiye has been estimated at 2,850 (range: 723–5,579) for *C. caretta* and 1,471 (range: 189–3,737) for *C. mydas*. Using both published and grey literature, Kaska et al. (2005) reported that within a total beach length of 178.4 km, between 1,360 and 2,710 nests were deposited annually, corresponding to approximately 700–1,150 nesting females. Inter-annual variability in nest numbers may reflect natural fluctuations in reproductive output; however, variation in survey effort, spatial coverage, and methodological approaches among studies is also likely to contribute. Consequently, actual nesting abundance is presumed to be

underestimated, particularly as small or intermittently monitored beaches are often excluded from long-term datasets.

Beyond the primary nesting beaches, recent surveys have documented nesting and non-nesting emergences on secondary beaches located in the western part of Antalya Province, including Phaselis, Kazanova, Korsan Bay, and Kaputaş (Şirin & Başkale, 2024), highlighting the broader spatial extent of nesting activity. Similarly, Sönmez (2024) reported six years (2017–2022) of nesting data for *Chelonia mydas* from Hatay Yeniyurt Beach. In addition, Yakacık Beach, a 1.7-km-long coastal stretch situated along the Antalya–Mersin provincial boundary, was recently identified as a new nesting site for *Caretta caretta*, with 201 and 197 nests recorded during the 2020 and 2021 nesting seasons, respectively (Sözbilen, 2024).

Systematic monitoring on Patara Beach began in 1989 (Yerli, 1990; Erk'akan *et al.,* 1990; Baran *et al.,* 1992; Kaska, 1993; Canbolat, 1997; Yerli ve Demirayak, 1996; Baran *et al.,* 1996, 1997; Yerli & Canbolat, 1998; Canbolat, 1999; Işık *et al.,* 2000; Öz *et al.,* 2001, 2002 and 2008; Selin İnşaat, 2004, 2005; Canbolat, 2006, 2007 Canbolat, 2007; Tarımsal Kalkınma İktisadi İşletmesi, 2009, 2011; Olgun *et al.,* 2016, 2018; EKOİZ, 2015; ENVTEK, 2016, 2017; Başkale *et al.,* 2019-2023); however, temporal differences in the length of beach surveyed have resulted in variability in reported nest numbers and nest density estimates (nests/km). Early studies documented relatively low nest numbers, such as 33 nests recorded along a 6-km section in 1994 (Yerli & Demirayak, 1996) and 35 nests in 1996 (Baran *et al.,* 1996). A notable increase in nesting activity was reported in subsequent decades, with 254 nests recorded in 2016 (Olgun *et al.,* 2016a, 2016b and 2018). Across the entire monitoring period, the long-term mean annual number of nests at Patara Beach was calculated as 115.2. However, during the period of increased nesting activity between 2012 and 2018, the mean annual nest number rose markedly to 217.

In more recent years, nest numbers continued to increase, with 286 nests recorded in 2019 (Başkale *et al.,* 2019). During the 2020 nesting season, a total of 962 *C. caretta* emergences were documented, of which 434 (45.1%) resulted in successful nesting, while 528 (54.8%) were classified as non-nesting emergences (Başkale *et al.,* 2020). Nest numbers subsequently fluctuated, with 316 nests recorded in 2021, 253 in 2022, and 524 in 2023 (Başkale *et al.,* 2021, 2022 and 2023). The highest nesting activity recorded to date occurred during the 2024 nesting season, when 604 nests were documented,

representing a substantial increase relative to the long-term average.

Nest density at Patara Beach ranged from 5 to 50.33 nests/km over the monitoring period. The lowest density was observed in 1996 (5 nests/km) (Yerli & Demirayak, 1996), while the highest density was recorded in 2024 (50.33 nests/km). Since the initiation of monitoring activities, the overall mean nest density has been estimated at 14.63 nests/km. In contrast, mean nest density over the most recent decade (2015–2022) increased to 26.63 nests/km, indicating a pronounced upward trend in nesting intensity. Peak nest densities were observed during the 2023 nesting season, reaching 43.66 (Başkale *et al.,* 2024) and 50.33 nests/km for 2024 nesting period in this study.

Although Patara Beach is recognized as a major nesting site for *C. caretta*, sporadic nesting by the endangered green turtle (*Chelonia mydas*) has also been documented. Only 3–4 *C. mydas* nests have been recorded at the site over the past 30 years, with the most recent confirmed nesting event occurring in 2012 (Olgun *et al.,* 2016). Additionally, a single *C. mydas* individual was captured and tagged during field surveys conducted in 2021 (Başkale *et al.,* 2021), suggesting occasional use of the site by this species.

Analysis of a 35-year dataset revealed a mean annual nest number of 170 at Patara Beach (Yerli, 1990; Erk'akan *et al.*, 1990; Baran *et al.,* 1992; Kaska, 1993; Canbolat, 1997; Yerli ve Demirayak, 1996; Baran *et al.*, 1996, 1997; Yerli & Canbolat, 1998; Canbolat, 1999; Işık *et al.,* 2000; Öz *et al.,* 2001, 2002 and 2008; Selin İnşaat, 2004, 2005; Canbolat, 2006, 2007 Canbolat, 2007; Tarımsal Kalkınma İktisadi İşletmesi, 2009, 2011; Olgun *et al.,* 2016, 2018; EKOİZ, 2015; ENVTEK, 2016, 2017; Başkale *et al.,* 2019-2023), with pronounced inter-annual variability. In 2024, all recorded nests were attributed to *Caretta caretta*. During this season, a total of 1,518 emergences were recorded, of which 604 (39.79%) resulted in nest construction and 914 (60.22%) were classified as non-nesting emergences. The mean nest density for the 2024 season was calculated as 50.33 nests/km. This calculated nest density is the highest value recorded in the last 35 years.

Comparisons with previous years indicate that the increase in nest numbers in 2024 was accompanied by higher egg production and a reduction in predation pressure. The predation rate for the 2024 nesting season was calculated as 12.25%. Moreover, hatchling

emergence success showed a marked improvement relative to earlier years, reaching 98.81% in 2024 when predated eggs were excluded. These findings underscore the effectiveness of sustained long-term monitoring and nest protection measures at Patara Beach and highlight the site's increasing importance for the regional conservation of *C. caretta* populations.

The mean incubation period of these nests was 48.4 days (min. 44, max. 59). The incubation period is strongly correlated with nest temperature, whereby a 1°C increase in the nest shortens the incubation by 5 days (Mrosovsky *et al.*, 1999; Matsuzawa *et al.*, 2002; Kaska *et al.*, 2006).

The results of the present study indicated that the mean hatching success rate (HSR) across the study period was 84.7%, reaching a maximum value of 100%. Previous studies conducted at Patara Beach reported considerably lower HSRs, including 37% in 1992, 41% during 1993–1996 (Kaska *et al.*, 1998), 22.35% in 2000 (Kaska *et al.*, 2005), 50.78% in 2005 (Yılmaz, 2006), and 44.05% in 2010 and 2012–2014 (Olgun *et al.*, 2016). Similarly, mean HSRs recorded at other nesting beaches in Türkiye were 22.9% at Göksu in 2004 and 2008 (Durmuş *et al.*, 2011), 74.37% at Fethiye between 2011 and 2013 (Başkale *et al.*, 2016), 61.7% at Dalyan in 2004 and 2005 (Türkozan & Yılmaz, 2008), and 41.79% at Demre in 2006 (Ergene, *et al.*, 2007). Comparable values from other Mediterranean nesting beaches include 66.6% at Laganas Bay in 1984 (Margaritoulis, 2005) and 83% in northern Cyprus during 1992 and 1995 (Broderick & Godley, 1996). Overall, the HSR recorded at Patara in the present study is markedly higher than those reported in earlier investigations. This improvement can be largely attributed to intensive conservation efforts, including continuous nocturnal beach patrols throughout the nesting season, the use of protective cages to reduce nest predation, and the relocation of nests at risk of inundation.

Overall, the 2024 findings reaffirm that Patara Beach represents one of the most significant *C. caretta* nesting habitats in the Mediterranean, characterized by high nest density and strong hatchling output. Despite substantial predation pressure, continuous night patrols and effective caging methods substantially enhanced nest and hatchling survival. These results underscore the necessity of sustaining long-term habitat protection, minimizing anthropogenic disturbance, and maintaining intensive monitoring efforts to ensure the long-term viability of the Patara *C. caretta* population.

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Chapter 6

Evaluation of the Effect of Sunflower Plant Compost Formulations on Yield and Quality in Oyster Mushroom (*Pleurotus ostreatus*) Cultivation

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Introduction

The history of cultivated mushroom cultivation began in China around 2000 BC. Traditional cultivation of the first species, such as shiitake mushrooms, was observed during this period. Cultivated mushroom production became widespread in Central Asia and the Middle East around 600-800 AD, and specialized cultivation methods began to be used. During the Renaissance in Europe (14th-17th centuries), mushroom cultivation gained popularity among aristocrats in France and Italy, and was carried out using specialized methods in private gardens. In the late 19th and 20th centuries, cultivated mushroom cultivation developed, particularly with the large-scale production of *Agaricus bisporus*. Today, many countries are leaders in cultivated mushroom production, and cultivation has become a practice on an industrial scale. Technological advancements and sustainable production methods are supporting the rapid growth of the sector (Bertelsen, 2013).

Cultivating mushrooms offers a number of advantages. These include their use as an important food source, increased productivity by controlling the growth environment, year-round production without seasonal limitations in the natural

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environment, consistent yields through quality control, disease and pest control, and the ability to control specific traits for diversity and specialized medical and industrial uses. This allows for more effective and sustainable use of cultivated mushrooms in food, agriculture, medicine, and industry.

Certain mushrooms are prominent in cultivated mushroom cultivation and are among the most important species consumed worldwide. *Agaricus bisporus*, with its white and brown subspecies, is a mushroom preferred by a wide range of consumers. Shiitake has gained popularity worldwide for its delicious flavor and is particularly popular in Asian cuisine. Oyster mushrooms come in a variety of colors and forms, offering a delicious and fast-growing option. Enoki mushrooms, with their thin stems and small heads, are particularly popular in Asian cuisine. Maitake mushrooms are known for their large, horizontal heads, which are sought after for their health benefits. Crimini mushrooms are the brown version of the white champignon mushroom, and while they have similar taste and texture, they generally have a more intense flavor profile. These mushrooms offer a variety of flavors, textures, and nutritional profiles, making them appealing to a wide range of consumers and can be used in a variety of dishes (Dikeman et al., 2005).

Today, the nutritional and health value of mushrooms has become more widely understood, increasing interest in cultivated mushroom cultivation. *Pleurotus ostreatus* is the second most cultivated mushroom in the world after *Agaricus bisporus* and is valuable economically, ecologically, and medicinally. The cultivation of oyster mushrooms using a growing medium (compost) composed of unfermented materials and the low need for environmental control make them more attractive compared to other mushroom species. Furthermore, their resistance to diseases and pests is among the factors that increase oyster mushroom production (Sánchez 2010).

Pleurotus species, known by local names in our country, are known to be mushrooms that grow naturally, particularly on poplar and beech logs. Studies beginning in Germany in 1914 represented a significant step toward cultivating *Pleurotus* species on poplar logs. However, the low yields of traditional methods used during this period highlighted the challenges of mushroom cultivation. Cultivation studies on sawdust in 1959 and the use of cereal straws starting in 1970 led to significant developments in commercial mushroom production. The chemical composition of Pleurotus

species indicates that these mushrooms contain high levels of moisture, carbohydrates, crude protein, free nitrogen, fat, calcium, iron, potassium, magnesium, sodium, phosphorus, cellulose, hemicellulose, and lignin. Pleurotus spp. is rich in vitamins B1, B2, and B3, and also contains lovastatin and ergothioneine, which have antioxidant properties. These properties have inspired research on the anticancer and immunomodulatory properties of these mushrooms. Although the cultivation of Pleurotus species began in our country in the 1980s, the desired level of commercial production has not yet been reached. (Doğan et al., 2014)

Oyster mushrooms (*Pleurotus ostreatus*) are cultivated as a preferred food source due to their high nutritional value and delicious flavor. Cultivation in controlled environments allows for higher and more consistent food production. This method allows for more controlled production of oyster mushrooms, which are difficult and low-yielding in their natural environment. Furthermore, pests and diseases are controlled, ensuring product safety. Cultivated oyster mushrooms can be produced year-round, independent of seasonal constraints, allowing for the cultivation of mushrooms in a variety of colors and forms. This method is also considered a sustainable agricultural practice because it generally relies on the recycling of organic waste. Oyster mushrooms, thanks to these advantages, are cultivated and consumed worldwide as a popular mushroom (Sánchez, 2010).

Oyster mushrooms hold significant commercial value worldwide. Their delicious flavor and suitability for a variety of dishes make them a popular food staple, particularly in Asian cuisine. Their rich nutritional profile, low calorie and fat-free composition offer a healthy diet option. Their ease of cultivation makes them a convenient and efficient option for commercial cultivation. Oyster mushrooms are also used in industries such as food, medicine, and biotechnology, demonstrating their wide range of applications. Combined with sustainable cultivation methods, they also play a significant role in environmental sustainability through the recycling of organic waste. These factors are driving commercial demand for oyster mushrooms and securing their prominent market position (Rathod et al., 2021).

Compost materials used for oyster mushroom cultivation vary and are often used in combination. Materials such as wheat straw, wheat bran, coffee grounds, corn stems, wood shavings, oat hulls, cottonseed sunflower hulls, and soybean hulls are commonly used

in oyster mushroom substrate formation. These materials not only provide the nutrients the mushrooms need but also contribute to the substrate's appropriate structural properties. Factors such as sterilization of the growing medium and appropriate temperature and humidity control are also important in oyster mushroom cultivation (Mohamed et al., 2016).

Various composting strategies can be implemented to increase yields in oyster mushroom (Pleurotus ostreatus) cultivation. Combining different agricultural wastes such as wheat straw, corn stems, and rice bran, as well as animal wastes such as horse manure and chicken manure, enriches the nutritional value of compost. Organic materials, especially plant residues such as coffee grounds, improve the texture of the compost and support healthy fungal growth. Adding wood chips or sawdust can increase the compost's air permeability, allowing fungi to penetrate the substrate more effectively. Oat hulls can improve moisture control by increasing water retention capacity. Furthermore, new mushroom cultivation technologies and compost formulations can be used to achieve higher yields and healthier mushrooms. However, it is critical that these composts have balanced nutrient content and appropriate physical properties, as well as maintaining sterilization processes and hygiene standards. In any case, carefully selected and applied compost formulations can increase productivity in oyster mushroom cultivation (Girmay et al., 2016).

Yeşilhisar District is one of Kayseri's important agricultural regions, and sunflower cultivation is widespread. Sunflowers generally thrive in warm climates and prefer well-drained soils. Kayseri's continental climate can provide suitable conditions for sunflower cultivation. Sunflowers are a preferred food source for mushroom cultivation. Sunflower waste can be incorporated into compost mixtures to support mushroom growth. This type of compost is rich in nutrients and provides a suitable environment for mushroom growth. Furthermore, sunflower waste offers an economical solution for mushroom cultivation and contributes to the recycling of agricultural waste.

Using different compost materials can increase yields in oyster mushroom cultivation. Oyster mushroom (*Pleurotus ostreatus*) cultivation can be successfully achieved with appropriate compost preparation. By adding various nutrients and physical properties using different compost materials, it is possible to promote healthier mushroom growth and achieve higher yields.

This study aims to determine the effects of composts prepared from different parts of the sunflower plant on oyster mushroom yield and to develop a sustainable, economical, and applicable cultivation model by identifying the most suitable compost combination. The primary objective of the project is to demonstrate the potential use of sunflower waste as an alternative compost material and to scientifically determine the formulation that yields the highest yield.

Material method

The studies were conducted at the Application Laboratory of Kayseri University's Yeşilhisar Vocational School. In order to determine the effects of different compost formulations on yield in oyster mushroom (*Pleurotus ostreatus*) cultivation, agricultural waste parts such as sunflower stems and leafs were used. Wheat straw was used as the control group (Figure 1).

Preparation of Compost Materials

In this study, wheat straw, sunflower stems, and sunflower leafs were used in compost preparation. The sunflower stems and leafs were shredded and turned into compost material.

Materials used:

Wheat straw: Main carbon source

Sunflower stems: Fibrous structure + nitrogen additive

Sunflower leafs: Organic matter + moisture and mineral additives

Trials were conducted using four formulations.



Figure 1. Agricultural waste parts of the sunflower plant such as stems and leafs and wheat straw as the control group.

Compost Formulations

The study was conducted using the following four groups (Figure 2). Each replicate was prepared to contain 5 kg of compost.

Trial Group 1: Straw + Stem + Leafs

This group is the richest formulation, combining all suitable parts of the sunflower plant.

Wheat straw: 2,500 g (50%)

Sunflower stems: 1,500 g (30%)

Sunflower leafs: 900 g (18%)

Lime ($CaCO_3$): 50 g (1%)

Gypsum ($CaSO_4$): 50 g (1%)

Trial Group 2: Straw + Stem

In this group, only sunflower stems were added to the compost.

Wheat straw: 3,300 g (66%)

Sunflower stems: 1,550 g (31%)

Lime ($CaCO_3$): 75 g (1.5%)

Gypsum ($CaSO_4$): 75 g (1.5%)

Trial Group 3: Straw + Leafs

In this group, a mixture with a lower nitrogen content and a higher organic matter content was applied.

Wheat straw: 3,350 g (67%)

Sunflower leafs: 1,425 g (28.5%)

Lime ($CaCO_3$): 112.5 g (2.25%)

Gypsum ($CaSO_4$): 112.5 g (2.25%)

Control Group: Straw Only

Wheat straw

No sunflower-derived material was added.

Wheat straw: 4,800 g (96%)

Lime ($CaCO_3$): 100 g (2%)

Gypsum ($CaSO_4$): 100 g (2%)

Used as the primary reference group for comparisons.

Each compost formulation was prepared in 3 replicates, resulting in a total of:

4 groups × 3 replicates = 12 compost bags.

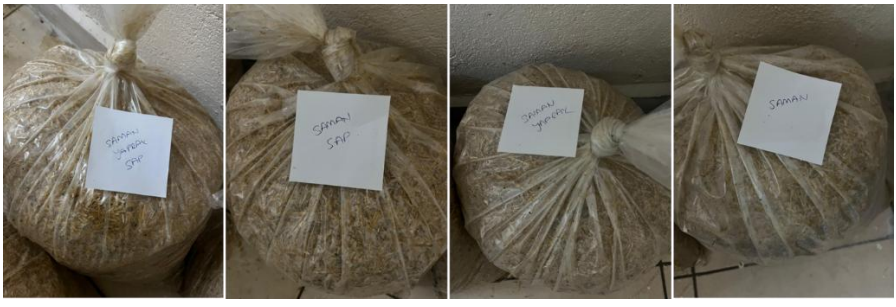


Figure 2. Compost Formulations

Preparation of the Substrate (pH Adjustment and Mixing)

Lime ($CaCO_3$) was added to the compost to maintain a pH between 5.5 and 6.5.

Calcium sulfate (gypsum, $CaSO_4$) was used to prevent clumping and increase air permeability.

Total mineral content did not exceed 1–3% of the compost weight.

Pasteurization

Compost materials were pasteurized by soaking them in hot water at 70°C for 1 hour to eliminate disease and pests (Figure 3). After pasteurization, the material was cooled to room temperature.



Figure 3. Pasteurization of compost materials

Mycelium Planting and Incubation Period

Mycelium was sown when the compost temperature dropped below 25°C. The mycelium ratio was applied at 2–5% of the compost weight (Figure 4).



Figure 4. Mycelium Planting in Compost

One hole was drilled for every 1 kg of compost filled into the bags. The bags were incubated in a dark room at 25°C and 90–95% humidity (Figure 5).



Figure 5. Incubation Stage for Mycelial Wrapping

Mushroom Formation (Fructification Period)

Approximately 15–20 days later, when mycelial wrapping was completed (Figure 6), the temperature was reduced to 15–18°C, the humidity was kept at 75–80%, the environment received light for 10–12 hours a day, and the room was ventilated 2–3 times every hour.



Figure 6. Completion of mycelial wrapping and mushroom formation

Harvest

The first flash harvest occurred approximately 30 days after the mushrooms matured. Once the mushrooms were harvested, all groups were harvested under the same conditions, and the products were weighed (Figure 7).



Figure 7. Mushroom harvesting and weighing

Yield Evaluation

The mushrooms obtained from each bag were weighed and recorded, and the average yield of each formulation was compared with the control group.

Findings

This study investigated the effects of four different compost formulations on oyster mushroom (*Pleurotus ostreatus*) yield. Three replicates of each formulation were established, each containing 5 kg of compost, and yields were calculated by averaging the three replicates. Mycelial development was completed within 15–20 days in all groups, and a homogeneous mycelial colonization was observed throughout the composts. Mushroom emergence began at different times among groups, and emergence frequency, cap size, and total yield varied depending on compost composition.

Average Yields by Flashes

The table below shows the average 1st flash, 2nd flash, 3rd flash, and total yields of different compost formulations (Table 1).

Table 1. Total yield averages of compost formulations

Grup	1. Flash (g) (Avg.)	2. Flash (g) (Avg.)	3. Flash (g) (Avg.)	Total Average Yield (g)
Straw + Stem + Leaf	825	400	100	1,325
Straw + Stem	575	300	80	925
Straw + Leaf	325	185	55	550
Control (Straw)	200	100	30	325

Evaluation of Flash Yields

The first flash was the period in which the highest yields were achieved in all groups. The highest first flash yield was measured in the Straw + Stem + Leaf group (≈825 g). The combined use of sunflower stems and leafs increased both the air permeability and organic matter content of the compost, which accelerated mycelial growth and resulted in high yields in the first flash. The Straw + Stem group (≈575 g) ranked second. Its high fiber content supported fungal growth, but it performed lower than the first group due to limited nutrient intake. Yields were significantly lower in the Straw + Leaf (≈325 g) and Control (≈200 g) groups.

In the second flash, yields decreased in all groups compared to the first flash, but the ranking remained unchanged. The second highest flash yield was again obtained in the Straw + Stem + Leaf group (≈400 g). Second-flash yields were significantly higher in the sunflower supplemented groups (Straw + Stem + Leaf and Straw + Stem), and the contribution of the sunflower material to the C/N balance also had a positive effect in this period. The Straw + Leaf group (≈185 g) yielded moderate yields, while the Control group (≈100 g) yielded the lowest.

The third flash yield was the lowest in all groups. However, the highest third-flash yield was again recorded in the Straw + Stem + Leaf group (≈100 g). While the third-flash yield of the Straw + Stem group (≈80 g) was moderate, the Straw + Leaf (≈55 g) and Control (≈30 g) groups achieved very low values.

Total Yield

Considering the total average yields of the three flashes, the ranking of the groups was as follows:

Straw + Stem + Leaf: ≈1.325 g

Straw + Stem: ≈925 g

Straw + Leaf: ≈550 g

Control (Straw): ≈325 g

These results clearly demonstrate that sunflower plants, especially when used in combination with straw and leaf, improve the physical and chemical structure of the compost, support mycelium growth, and significantly increase oyster mushroom yield.

Discussion and conclusion

This study evaluated the effects of different compost mixtures on yield in oyster mushroom cultivation and found that the Straw + Stem + Leaf group, in which sunflower stems and leafs were combined with wheat straw, yielded the highest total yield. The results are consistent with studies in the literature highlighting the impact of different lignocellulosic materials on the yield performance of Pleurotus species.

Girmay et al. (2016) reported that substrates with a balanced lignin-cellulose ratio increased biological activity (BE). In our study, mixing sunflower stems and leafs with straw enriched the fibrous structure of the compost, accelerated mycelial colonization, and increased yield. Similarly, Sharma et al. (2013) reported that materials with appropriate C/N ratios significantly increased P. ostreatus yield. The fact that the C/N ratio of the Straw + Stem + Leaf group approached the optimum range for fungal growth explains the high yields obtained.

Muswati et al. (2021) showed that substrate combinations produced higher yields than materials used alone. This study also revealed that mixed substrates provided higher overall yields than pure straw. Mohamed et al. (2016) reported that compost composition and proportions directly affect fruit body weight, a finding consistent with the Straw + Stem + Leaf group, which achieved particularly high yields in the first flush.

Shah et al. (2004) emphasized that wheat straw is the primary substrate for Pleurotus cultivation, but that enriching it with other materials can increase yield. In this study, low yields were obtained in the Control group, which used only wheat straw, indicating that straw alone provides limited nutritional and structural benefits.

An average yield of 1.3 kg was achieved in the Straw + Stem + Leaf group across three flashes, a performance close to the lower end of the 1.5–3.0 kg/5 kg compost yield range reported in the literature (Doğan et al., 2014). In all groups, the first flash accounted for 60–70% of the total yield, with yield decreasing in the second and third flashes, a finding fully consistent with the literature.

In general, it was concluded that the sunflower stem and leaf–wheat straw mixture had positive effects on mycelium development, first flash yield and total production amount and offered a suitable substrate alternative for commercial production.

This study demonstrated that sunflower agricultural waste (stems and leafs) can be used as a valuable compost component in oyster mushroom cultivation. When three different compost formulations were compared:

The straw + straw + leafs mixture yielded the highest total yield (≈1.3 kg/5 kg compost). Production increased in the straw + stem and straw + leafs groups, but the highest performance was seen in the multi-component mixture group. The control (pure straw) yielded the lowest yield. The highest production was achieved in the first flush of all groups, while the second and third flushes contributed to total production but showed lower performance.

In conclusion, the use of sunflower plant waste in oyster mushroom compost offers an important alternative in terms of both environmental sustainability and economic efficiency. These findings are consistent with current literature on the utilization of agricultural waste and highlight the importance of optimizing compost formulations for commercial production.

Acknowledgment

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Chapter 7

A New Species of Zerconid Mites (Acari: Zerconidae) from Northeastern Türkiye: *Zercon rizeensis* sp. nov.

Raşit URHAN[1] & Mehmet KARACA[2]

Introduction

The family Zerconidae belongs to the order Mesostigmata and comprises small soil-dwelling mites. Members of this family are generally around 500 micrometers in length and possess an oval, flattened body shape. Zerconid mites are primarily found in moist soils, decaying plant material, leaf litter, and fungal habitats; records also exist of some species inhabiting bird and mammal nests (Mašán and Fend'a, 2004). Most species are predatory, feeding on small nematodes and other microarthropods. Morphologically, Zerconidae are characterized by a dorsally divided idiosoma, serrated lateral edges of idiosoma, and dorsal cavities located on the posterior part of the idiosoma. These features play an important role in the taxonomic identification of zerconid mites. Ecologically, these mites act as predators in soil ecosystems, contributing to ecological balance and influencing the structure of microfaunal communities, also holding potential significance for biological control.

The genus *Zercon* represents the type genus and comprises the most species-rich genus within the family Zerconidae. It is also one of two zerconid mite genera currently recorded from Türkiye. To date, 97 *Zercon* species have been reported from various regions of the country (Urhan et al., 2026), with the majority being known

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exclusively from the country (Karaca et al., 2017). While elaborating zerconid mites based on materials collected from Rize Province in the Northeastern Türkiye (Figure 1), a new species of *Zercon* was discovered and is described herein.



Figure 1. General view of habitat for the collected materials, Handüzü Plateau in Rize Province.

Material and Methods

Soil, leaf litter, and fern samples were collected from forested areas in the Handüzü Plateau (Başköy Village, Güneysu County, Rize Province). The Altimeter GPS & Barometer application (Url-1) was used to record the geographic coordinates and elevations at the sampling location. All specimens were carried to PAU (Acarology Laboratory, Department of Biology, Faculty of Science, Pamukkale University, Denizli, Türkiye). Standart methods (Figure 2) were applied for the extraction of zerconid mites, measurement of various morphological features, and illustration procedures (Bulut et al., 2021). Terminology proposed by Sikora (2014) was followed for chaetotaxy and poroidotaxy of zerconids. All measurements of idiosomal structures and setae, including the scale bars in the figures, are presented in micrometers (µm).



Figure 2. Some photographs from field and laboratory studies. A: Collecting of biological materials, B: Zerconids arranged in a single row on a slide under a stereomicroscope and prepared for species identification, C: Placing the collected materials into the sorting device consisting of Berlese funnels for mites extraction, D: Stereomicroscopic appearance of zerconids treated with lactic acid and glycerin (weakly chitinized nymph is light colored, while strongly chitinized adults are dark colored).

Results

Family **Zerconidae** Canestrini, 1891

Genus ***Zercon*** C. L. Koch, 1836

Type species: ***Zercon triangularis*** C. L. Koch, 1836

A detailed diagnosis of the genus is given by Urhan and Karaca (2023).

***Zercon rizeensis* sp. nov.** (Figures 3-6)

Type Material. Holotype: female: Rize Province, Güneysu County, Handüzü Plateau, 40°54.136'N 40°38.705'E, 1330 m a.s.l.; 26.09.2019; in litter, soil and fern (unspecified) samples under Oriental spruce=*Picea orientalis* (Pinaceae) and Pontic oak=*Quercus pontica* (Fagaceae).

Paratypes: 1♀, 1♂: same data as holotype. Leg. M. Tataroğlu & Y. Katılmış. All material deposited in the PAU.

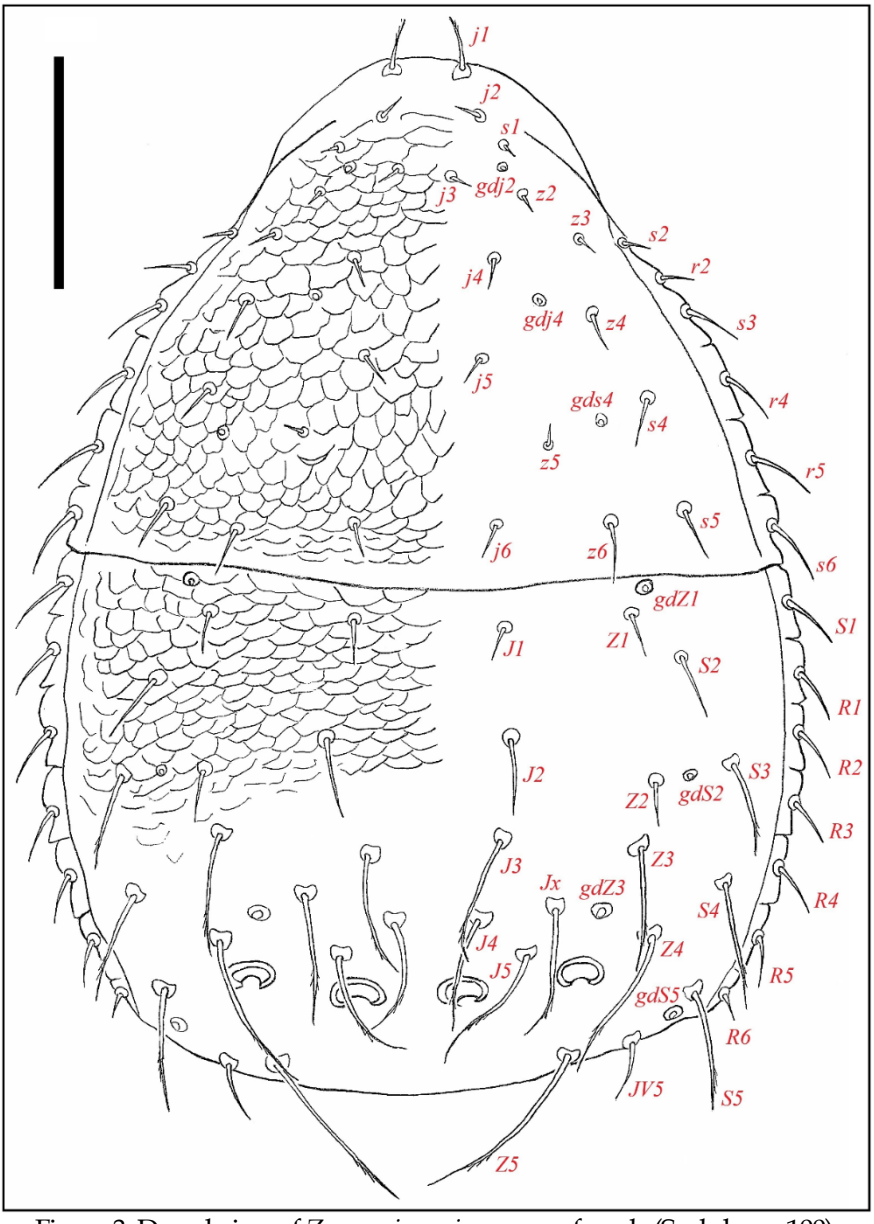


Figure 3. Dorsal view of *Zercon rizeensis* sp. nov., female (Scale bar = 100).

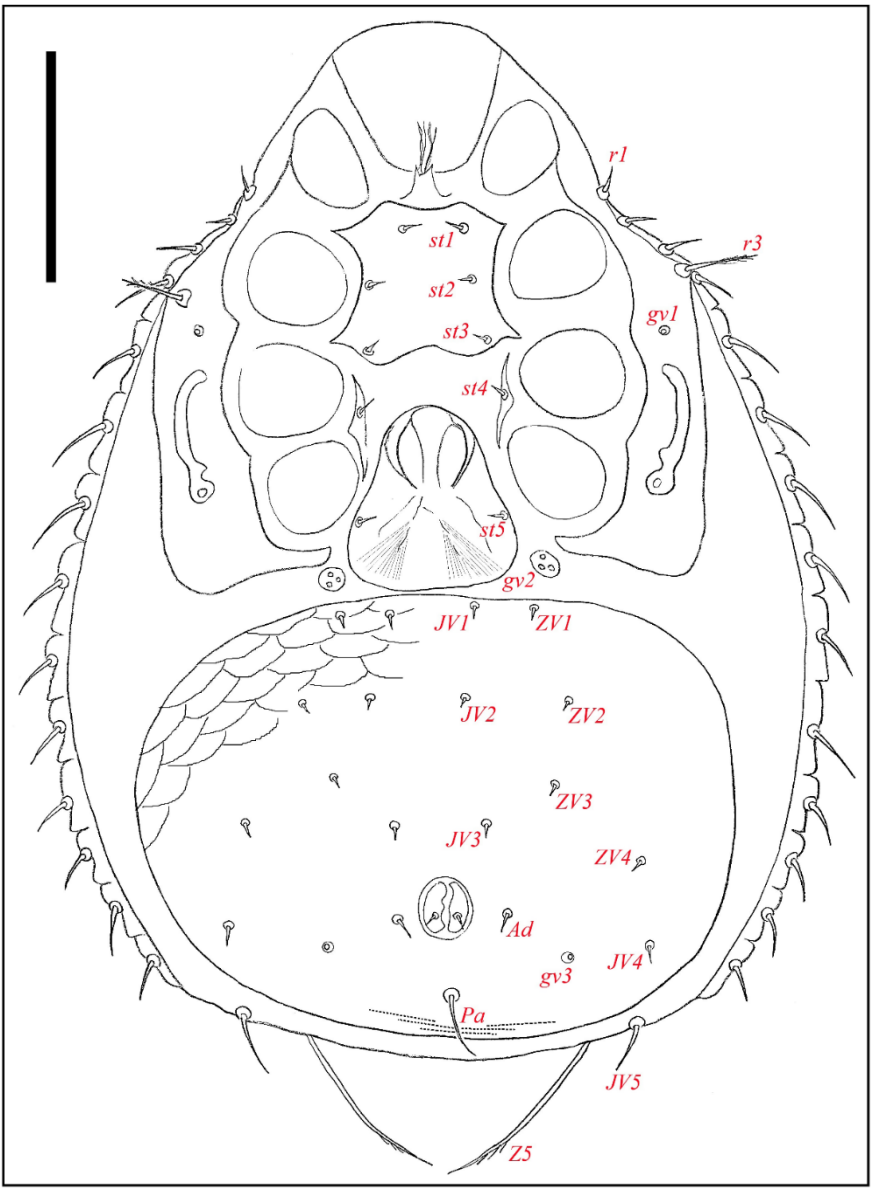


Figure 4. Ventral view of *Zercon rizeensis* sp. nov., female (Scale bar = 100).

Diagnosis. On podonotum, seta *j1* finely barbed, remaining podonotal setae smooth. On opisthonotum, setae *J3–5*, *Z3–5* and *S3–5* elongated, finely barbed without hyaline endings, other opisthonotal setae including *R*–series smooth. An extra seta (*Jx*) present among setae *J5* and *Z3*, closer to *J5* and gland pore *gdZ3*. Gland pore *gdS2* located between setae *Z2* and *S3*, *gdZ3* located between setae *Jx* and *Z4*. Dorsal cavities strongly developed and

distinct. Podonotum and anterior margin of opisthonotum covered by tile-like patterns, remaining parts of opisthonotum smooth.

Description. Female (Figures 3-4). İdiosomal length 465, width 350 in holotype (excluding gnathosoma). Measurement in one paratype: 438 × 345.

Dorsal side (Figure 3). Twenty pairs of setae on podonotal shield, including *j1–6*, *z2–6*, *s1–6*, *r2* and *r4–5*. Insertions of setae *r1* and *r3* inserted ventrally on peritrematal shields. Although podonotal setae are generally of different lengths, they are similar in shape. Only seta *j1* finely barbed on podonotum, all remaining podonotal setae smooth and needle-like. In contrary of setae *j6* and *s5*, seta *z6* reaching posterior margin of podonotal shield. Tile-like patterns present on podonotal shield. Altogether, twenty-two pairs of setae present on opisthonotal shield, including *J1–5*, *Jx*, *Z1–5*, *S1–5* and *R1–6*. Among them, *Jx* is extra (=additional=supplementary) seta among setae *J5* and *Z3*. Setae *J1–2*, *Z1–2*, *S2* and all setae in marginal row (*S1* and *R1–6*) smooth and needle-like. Setae *J3–5*, *Jx*, *Z3–5* and *S3–5* elongated, finely barbed without hyaline endings, all of these setae slender, taper toward the apex, and typically bear two or three barbs closer the apical ends. Setae *J3–4* and *Z3–4* reaching insertions of next setae in the related rows. Although seta *Z4* reaching margin of opisthonotum, setae *S4–5* reaching beyond margin of opisthonotum. Distances between setae *Z5–Z5* 120–130, *Z5–JV5* 20-25, respectively. Tile-like patterns present on anterior margin of opisthonotum to *line J2–Z2–S3*, remaining parts of opisthonotum smooth.

Pores (Figure 3). All gland pores are generally the same size. Gland pores *gdj2* situated among setae *z2* and *s1*, *gdj4* situated among setae *j4* and *z4*, *gds4* situated among setae *z5* and *s4*, *gdZ1* situated anterior to the base of seta *Z1*, *gdS2* situated among setae *Z2* and *S3*, *gdZ3* situated among setae *Jx* and *Z4*, *gdS5* situated among setae *S5* and *JV5*, closer to *S5*. Dorsal cavities as saddle-like, equal in size and shape, axes parallel to that of the body.

Ventral side (Figure 4). Ornamentation, poroidotaxy and chaetotaxy of ventral side are typical for the genus *Zercon*. The posterolateral ends of the peritrematal shield extend to the level of seta *S1*. Seta *r1* short, smooth and needle-like, *r3* elongated and finely barbed without hyaline endings on peritrematal shield. Peritreme is shaped like inverted comma. Gland pores *gv1* situated anterior to peritreme, *gv2* located at the junction point of the peritrematal,

epigynal and ventrianal shields, with three opening valves, *gv3* situated among setae *Ad* and *JV4*. All setae located on sternal shield (*st1–3*), epigynal shield (*st5*) and the soft cuticular area between these shields (*st4*) short, smooth and needle-like. There are two pairs of setae situated on anterior margin of ventrianal shield (both setae *JV1* and *ZV1* present). All of the setae (*JV1–4*, *ZV1–4*, *Ad*) on ventrianal shield short, smooth and needle-like. Postanal seta (*Pa*) is single, is noticeably longer than other setae on the ventrianal shield. Seta *JV5* smooth and needle-like, similar to the marginal setae of opisthonotum. Anterior surface of ventrianal shield covered by squamous pattern to level of setae *JV2* and *ZV2*, remaining parts of ventrianal shield smooth.

Lengths and ranges of opisthonotal setae in J, Z and S rows for female and male specimens are given in Table 1.

Table 1. Lengths and longitudinal distances between insertions of opisthonotal setae in *Zercon rizeensis* sp. nov.

Setae	♀♀	♂	Setae	♀♀	♂	Setae	♀♀	♂
J1	20-28	20	*Z1*	20	15	*S1*	23-28	22
J1–J2	53-63	40	*Z1–Z2*	60-75	40	*S1–S2*	53-58	43
J2	33-35	28	*Z2*	20-28	30	*S2*	30	28
J2–J3	43-45	33	*Z2–Z3*	30-40	25	*S2–S3*	43-48	35
J3	48-65	53	*Z3*	57-60	43	*S3*	48-50	43
J3–J4	28-38	23	*Z3–Z4*	40	28	*S3–S4*	50-55	30
J4	48-55	38	*Z4*	73-78	63	*S4*	58-63	45
J4–J5	23-25	15	*Z4–Z5*	63-69	53	*S4–S5*	40-50	35
J5	48-63	43	*Z5*	80-88	70	*S5*	63-75	55

Male (Figures 5-6). Length and width of idiosoma 338 × 245 (n=1). Shape of idiosomal setae, locations of idiosomal gland pores and ornamentation of dorsal (Figure 5) and ventral (Figure 6) shields similar to those of females, with a few exceptions. Although opisthonotal seta *Z4* reaching the margin of opisthonotum in female specimens, this seta reaching beyond of opisthonotum in male specimen. In addition, setae *J5* and *Jx* not reaching the posterior part of opisthonotum in female specimens, these setae reaching the posterior part of opisthonotum in male specimen. On the other hand, in females, four setae are present on the anterior margin of

the ventro-anal shield (both *JV1* and *ZV1* present), whereas in males, only two setae are present in this region (only *JV1* present, *ZV1* absent). Adgenital shield (gland pore *gv2*) with two opening valves Distances between setae *Z5* and *Z5* 95, between *Z5* and *JV5* 20.

Immature stages (Larva, deutonymph and protonymph). Unknown.

Differential diagnosis. The morphological characters of *Zercon rizeensis* sp. nov. are similar to *Z. bisetosus*, *Z. myriasetosus*, and *Z. trabzonensis*. The distinguishing features of these species are summarized in Table 2. The number of podonotal setae of these mites is complete (except Z. myriasetosus). However, in all of these species, there is no absence of setae in the related rows on opisthonotum. All species presented in Table 2, including the new species, have the following morphological features in common: all podonotal setae smooth (except finely barbed seta *j1* in *Z. rizeensis* sp. nov., *Z. bisetosus* and *Z. trabzonensis*). In addition, all marginal setae on opisthonotum smooth. For the opisthonotal setae *J1–2* and *Z1*, none of them reach to the base of the following setae in the same row (except Z. bisetosus, seta *J2* reach beyond of *J3* in this species). In all of these species, seta *JV5* smooth on the posterior part of opisthonotum. All dorsal cavities in these species are equal in size and appearance, saddle-like, and their axes are parallel to those of the bodies.

Etymology. The specific epithet "*rizeensis*" refers to the Rize Province where the type materials were collected.

Habitat. All biological materials containing zerconid mites were collected from forestland areas. Litter, soil and fern samples were taken under Oriental spruce=*Picea orientalis* (Pinaceae) and Pontic oak=*Quercus pontica* (Fagaceae).

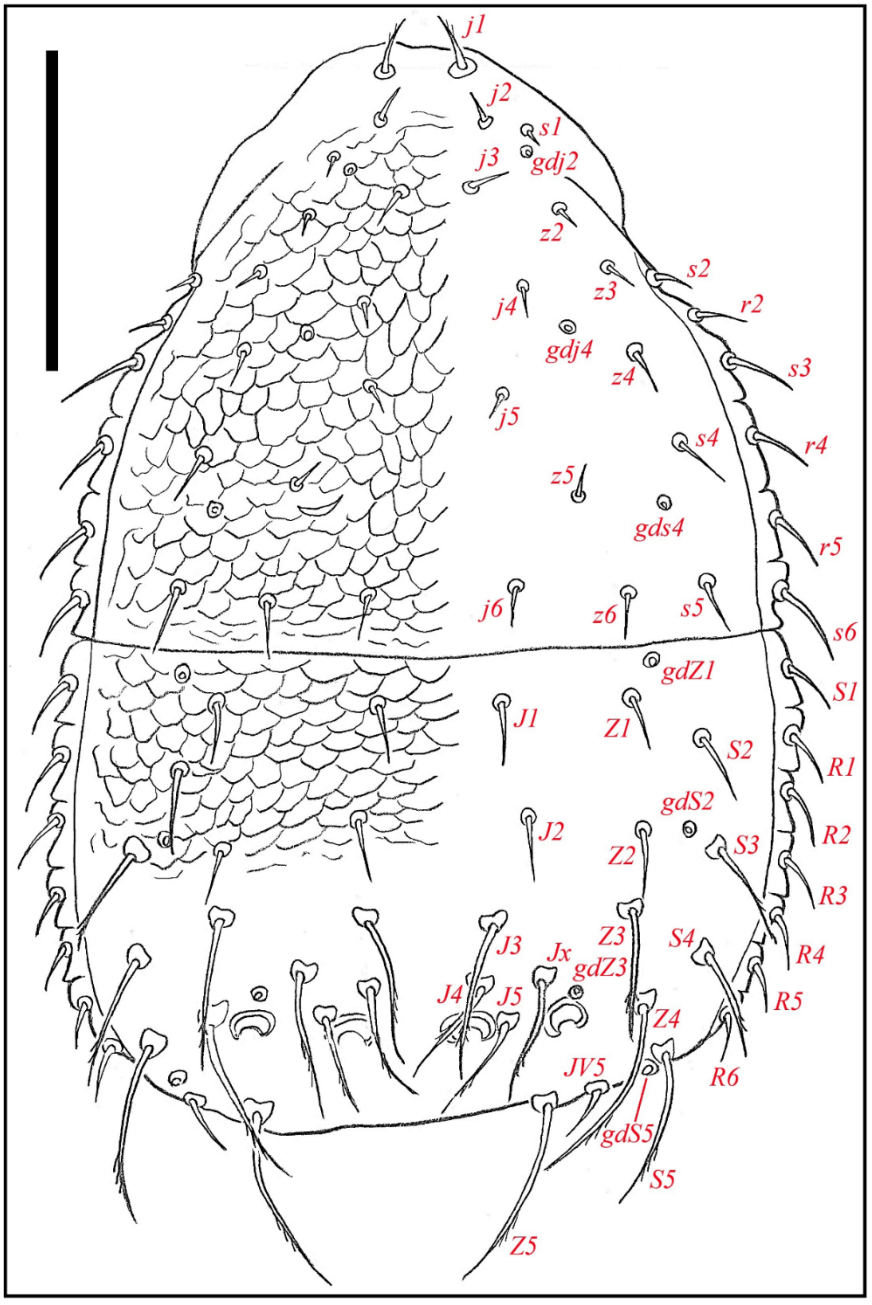


Figure 5. Dorsal view of *Zercon rizeensis* sp. nov., male (Scale bar = 100).

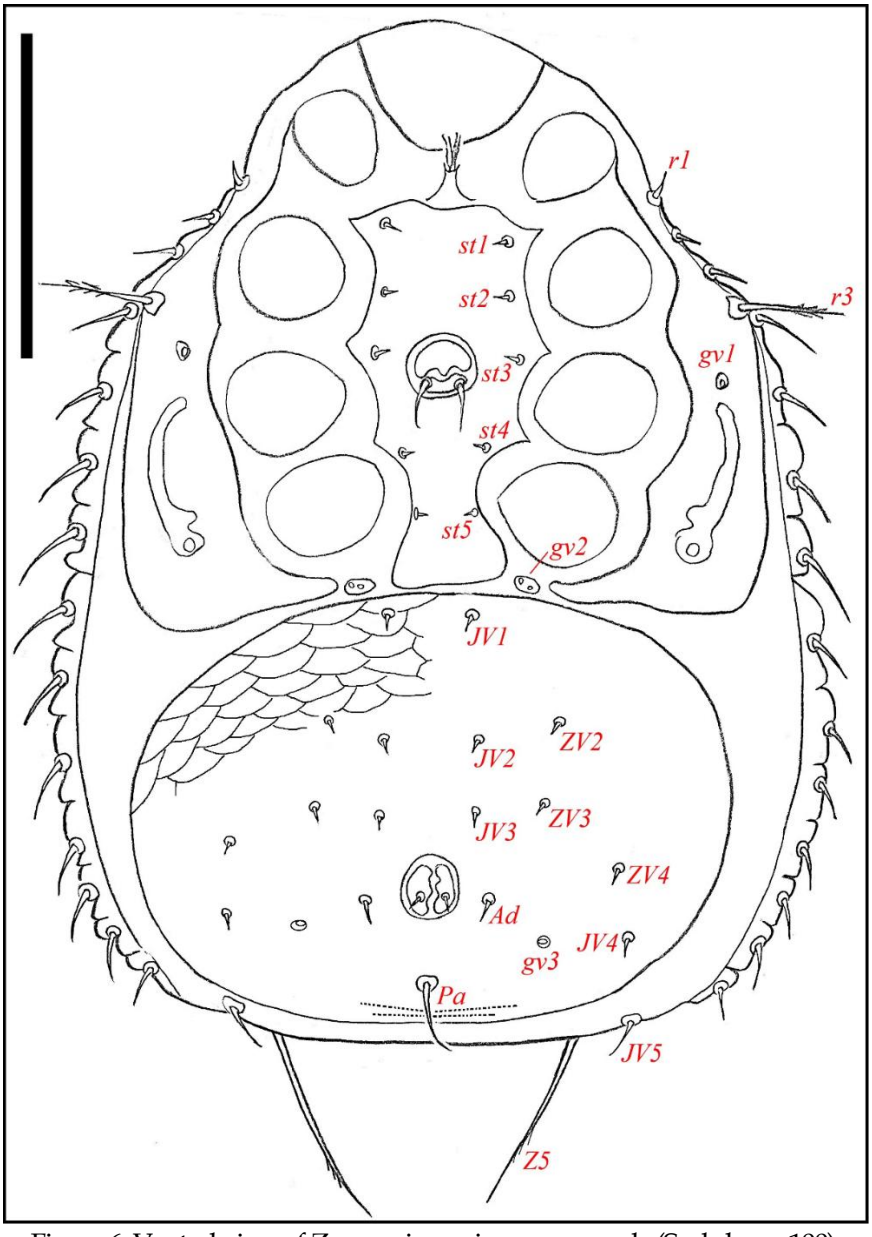


Figure 6. Ventral view of Zercon rizeensis sp. nov., male (Scale bar = 100).

Discussion and Conclusion

The occurrence of additional setae has been documented in several *Zercon* species (Ujvári, 2010). To date, seven species within this genus have been identified as neotrichous-that is, possessing various numbers of supplementary setae on the opisthonotum: *Z. aniellae, Z. armiger, Z. bisetosus, Z. echinatus, Z. myriasetosus, Z. sylvii*,

and *Z. trabzonensis*. With the new species presented in this study, the number of neotrichous *Zercon* species known from Türkiye has now increased to two.

Table 2. Comparison of the distinguishing morphological features between *Zercon rizeensis* sp. nov. and related species within the genus *Zercon*. After data in Balan (1995), Urhan (1997) and Ujvári (2010).

	Z. rizeensis sp. nov.	*Z. bisetosus* Balan, 1995	*Z. myriasetosus* Ujvári, 2010	*Z. trabzonensis* Urhan, 1997
Holotype and type locality	female, Türkiye	female, Ukraine	male, Croatia	female, Türkiye
Podonotal seta *j1*	finely barbed	finely barbed	smooth	finely barbed
Podonotal seta *s1*	present	present	absent	present
Podonotal setea *j6*, *z6* and *s5*	only *z6* reach reaching posterior margin of podonotal shield	all of them reaching posterior margin of podonotal shield	only *j6* and *z6* reaching posterior margin of podonotal shield	none of them reaching posterior margin of podonotal shield
Opisthonotal setae *J3–5*, *Z3–5* and *S3–5*	finely barbed	smooth	smooth	*J3–5* smooth, *Z3–5* and *S3–5* finely barbed
Opisthonotal setae *J2* and *Z2*	not reaching insertions of next seta	reaching insertions of next seta	not reaching insertions of next seta	not reaching insertions of next seta
Opisthonotal seta *J5*	not reaching the margin of opisthonotum	reaching beyond the margin of opisthonotum	not reaching the margin of opisthonotum	reaching beyond the margin of opisthonotum
Opisthonotal seta *S3*	not reaching the margin of opisthonotum	reaching beyond the margin of opisthonotum	not reaching the margin of opisthonotum	not reaching the margin of opisthonotum
Extra setae between *J–J* series	absent	absent	about 20 setae present	6 setae present
Extra setae between *J–Z* series	one seta present	absent	7-12 setae present	3 setae present
Opisthonotal pore *gdZ3*	between setae *Jx* and *Z4*	between setae *J3* and *Z4*	not clearly visible	between setae *J3* and *Z4*, closer to *Z4*
Opisthonotal pore *gdS2*	between setae *Z2* and *S3*	between setae *Z2* and *S2*	between setae *Z2* and *S2*	between setae *Z2* and *S3*
Anterior margin of ventianal shield	with 4 setae in females, 2 setae in male	with 2 setae in both females and males	with 2 setae in male	with 4 setae in both females and males

Türkiye has various topographic structures, climatic conditions, and rich vegetation, and it offers extensive and heterogeneous habitats for microscopic soil-dwelling mites. This remarkable habitat diversity enables the presence of numerous mite taxa across the country. Nevertheless, despite its high biological potential, many regions of Türkiye remain insufficiently explored in terms of their acarological diversity.

It is anticipated that systematic and regionally focused studies on the family Zerconidae will contribute to the discovery and description of many new species, particularly in the Mediterranean, Eastern Anatolia, Southeastern Anatolia, Black Sea, and Central Anatolia regions (Figure 7). Consequently, the species richness of Türkiye's Zerconidae fauna is expected to increase substantially in the future. This highlights the necessity for more detailed investigations of the country's mite biota and indicates that comprehensive taxonomic research will likely yield valuable new data.

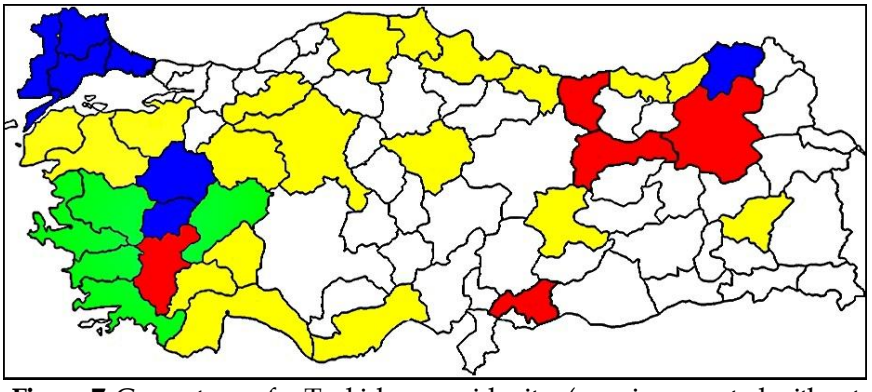


Figure 7. Current map for Turkish zerconid mites (map is presented without scale, data were compiled from systematic and taxonomic studies reported at the provincial level) (blue colors: Ph.D. theses, red colors: M.Sc. theses, green colors: long-term projects including several Ph.D. and M.Sc. theses, yellow colors: irregular records, white colors: no data).

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Disclosure Statement

The authors declare no competing interests exist.

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Url-1: https://apps.apple.com/us/app/altimeter-gps-barometer/id572227849 (Erişim Tarihi: 05/12/2025)

Chapter 8

The Ecological and Biotechnological Importance of Endophytic Fungi

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General Definition and Characteristics of Endophytic Fungi

Plant endophytes consist of fungal and bacterial communities that colonize plant tissues, spending all or part of their life cycles within these tissues, and generally do not harm their hosts (Petrini and Fisher, 1990; Hardoim et al., 2015). The term "endophyte" is of Greek origin, derived from the combination of the words "endo," meaning "within," and "phyte," meaning "plant." Microorganisms that live symbiotically within internal plant tissues and establish mutualistic relationships with these plants exhibit a wide range of diversity.

These organisms can be found in various tissues, including roots, stems, leaves, and even seeds. Evidence of plant-associated microorganisms found in the fossilized tissues, stems, and leaves of land plants suggests that endophyte-plant relationships may have co-evolved alongside the evolution of higher land plants (Krings et al., 2007). It has been established that nearly all vascular plant species examined harbor endophytic bacteria and/or fungi (Rodriguez et al., 2009; Hardoim et al., 2015). These microorganisms are found in almost all organs of a host plant, and some have been identified as being seed-borne.

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Endophytes generally provide significant benefits to their host plants; specifically, endophytic fungi can contribute substantially to physiological traits such as plant growth, development, and stress tolerance (Rodriguez et al., 2009; Hardoim et al., 2015). Secondary metabolites produced by these microorganisms exhibit health-improving effects on plants and hold great potential for biotechnological applications (Kusari et al., 2012; Venieraki et al., 2017). Particularly in recent years, the discovery of bioactive compounds produced by endophytic fungi and their diverse biological activities—offering antibacterial, antifungal, and antioxidant properties—has become a prominent research topic in medical, agricultural, and industrial fields.

These fungi hold vast potential for ecological and biotechnological research, representing a critical area of study for gaining a better understanding of plant-fungal interactions and their utilization in sustainable agriculture and forestry practices.

Discovery and History of Endophytic Fungi

The discovery and identification of endophytic microorganisms have a long-standing history within the fields of plant microbiology and pathology. The origin of the term "endophyte" dates back to 1809, when German botanist Heinrich Friedrich Link utilized the concept of "Entophytae" to describe a specific group of fungi that were partially parasitic to plants (Link, 1809). Subsequently, this term was expanded by Anton de Bary in 1866 through microscopic observations and was defined as "any organism growing within plant tissues" (De Bary, 1866).

During the late 19th century, when Robert Koch formulated his postulates, it was widely believed that healthy plant tissues were entirely devoid of microorganisms. However, advancements in microscopy and sterilization techniques demonstrated that endophytic microorganisms live asymptomatically within plant tissues; it was realized that these communities comprise bacteria, fungi, actinomycetes, protists, and algae (Hardoim et al., 2015). Studies conducted in the early 20th century questioned the effects of these organisms on plant health, and some species were initially considered latent pathogens (Wilson, 1995; Stone et al., 2000). Research gaining momentum in the 1960s and 1970s revealed that endophytic fungi establish mutualistic relationships with plants,

thereby increasing the host's growth rate and strengthening its stress tolerance (Carroll, 1988).

Since the 1980s, the development of molecular biology and genetic techniques (such as DNA analysis, barcoding, etc.) has facilitated the species-level identification of endophytes and the understanding of their phylogenetic relationships (Arnold et al., 2000; Rodriguez et al., 2009). These advancements have highlighted not only the ecological significance of endophytic fungi but also their biotechnological potential. As of the 21st century, research has focused on the utilization of these organisms in fields such as the development of biopesticides, biofertilizers, and pharmaceutical products (Saikkonen et al., 2004). Furthermore, it is emphasized that endophytic fungi can play a critical role in environmental bioremediation projects due to the stress tolerance they confer to plants (Redman et al., 2011; Porras-Alfaro & Bayman, 2011).

Approaches to the Classification of Endophytic Fungi

The classification of endophytic fungi is too complex to be addressed through a one-dimensional approach due to the inherent nature of these microorganisms. While various definitions and classification criteria have been proposed in the literature, current and widely accepted approaches tend to define endophytes primarily based on their habitats, while evaluating their functional roles atop this fundamental framework (Hardoim et al., 2015; Mishra et al., 2021). Therefore, in this study, endophytic fungi are considered as microorganisms residing within plant tissues regardless of their functions, and the classification is structured based on ecological continuity and context-dependent functions.

Classification According to Life Cycle and Colonization Continuity

Endophytic fungi do not exist at the same level or in the same manner throughout the plant's life cycle. While some species establish long-term and stable relationships with the host plant and can be found within the tissues throughout its entire life cycle, others become more prominent only during specific developmental stages or under particular environmental conditions (Arnold et al., 2000; Porras-Alfaro & Bayman, 2011). Mishra et al. (2021) view this distinction as a reflection of the dynamic nature of the endophyte-host relationship and emphasize that endophytes may follow systemic or transient/seasonal colonization strategies within the plant.

Classification According to Propagation Methods

The transmission of endophytic fungi between plants primarily occurs through vertical and horizontal propagation. In vertical transmission, the endophyte is transferred to the next generation via the seeds of the host plant, which facilitates the establishment of a long-term relationship with the plant; asexual *Epichloë* species are cited as prominent examples of this model (Christensen and Voisey, 2007). In horizontal transmission, however, endophytes transition to the plant from environmental sources (soil, air, water), and their colonization success is closely linked to environmental conditions (Haskett et al., 2021). This distinction provides a fundamental framework for understanding the ecological continuity and distribution patterns of endophytes within the plant.

Ecological and Functional Roles

While the habitat-based definition delineates the boundaries of the endophyte concept, the impacts of endophytic fungi on the plant and the ecosystem are mostly discussed through their functional roles. In this context, endophytes are categorized as groups that promote plant growth, contribute to processes related to stress tolerance, or assume roles associated with plant defense mechanisms (Porras-Alfaro & Bayman, 2011). Within this framework, conceptual subgroups such as classical endophytes, latent pathogens, and systemic endophytes have been defined in the literature (Schulz & Boyle, 2005; Slippers & Wingfield, 2007; Rodriguez et al., 2009). However, Mishra et al. (2021) emphasize that these functional roles do not replace the definition of an endophyte; rather, the endophyte–plant relationship consists of contextual characteristics shaped by environmental conditions, host genotype, and microbial interactions. Therefore, functional classification should be evaluated as an explanatory layer that complements the habitat-based definition of endophytes.

Tissue Specificity and Ecological Context

Different tissues of the plant (such as roots, stems, and leaves) provide distinct microhabitats for endophytic fungi, which in turn influences the composition of endophyte communities (Rodriguez et al., 2009; Beram and Akyol, 2025). Studies conducted on Pinus species have demonstrated that endophytic fungal communities can differentiate significantly across various tissues (Rim et al., 2021). These findings reveal that tissue specificity is a crucial

component of the ecological context in the classification of endophytes.

In addition to these factors, endophytic fungi can exhibit diverse metabolic profiles depending on the biochemical products they produce, such as secondary metabolites and enzymes; these characteristics provide an important framework for assessing their biotechnological and pharmacological potential (Gong et al., 2022). Moreover, their adaptation capabilities against environmental stress factors—such as drought, salinity, and temperature fluctuations—serve as a complementary criterion for understanding the roles of endophytes within plant ecosystems (Arnold & Lutzoni, 2007).

The composition and diversity of endophytic fungal communities can vary significantly depending on geographical location, habitat type, climatic conditions, and host plant characteristics (Hawksworth & Lücking, 2017; Zhou & Hyde, 2001; Glynou et al., 2017; Huang, 2020). Indeed, it has been established across various plant systems that different geographical regions, altitudinal differences, precipitation regimes, and seasonal variations are decisive factors for endophytic fungal diversity and the emergence of dominant groups (Göre and Bucak, 2007; Zamora et al., 2008; Yuan et al., 2018; Oliveira et al., 2020; Debbarma, 2024).

Ecological Importance of Endophytic Fungi

Endophytic fungi play numerous significant roles in plant health and ecosystem functions. While residing within plant tissues, they provide critical benefits in combating pathogens, adapting to stress conditions, and promoting plant growth. Recent research has highlighted the potential for utilizing these organisms in biotechnology and ecosystem management. Particularly in agricultural systems, they offer significant contributions to the conservation of biodiversity and the development of sustainable agricultural practices (Saikkonen et al., 2004). The ecological importance of endophytic fungi can be summarized under the following headings:

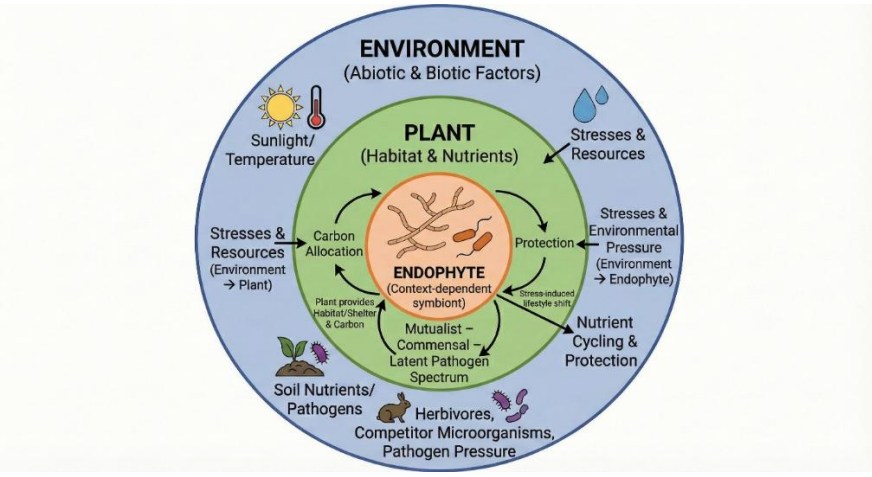


Figure 1. Multifaceted interactions within the Endophyte-Plant-Environment triangle. The diagram illustrates the impact of environmental stresses, carbon allocation, and protection mechanisms on the symbiotic lifestyle of endophytes.

Plant Growth Promotion

Endophytic fungi utilize evolved symbiotic mechanisms to optimize the growth potential of host plants within natural ecosystems. These fungi increase root surface area and, consequently, water and mineral uptake capacity by modifying root architecture in the rhizosphere region. Under natural conditions, signaling molecules such as auxin and gibberellin-like compounds secreted by endophytes trigger plant cell division, thereby facilitating an increase in biomass (Waqas et al., 2012). Furthermore, their ability to solubilize soil-bound nutrients and make them bioavailable for plant use provides a critical ecological advantage in nutrient cycling. This symbiotic support constitutes a fundamental component of the plant's survival strategy, particularly under stressful environmental conditions (Porras-Alfaro et al., 2014).

Enhancing Plant Stress Tolerance

Endophytic fungi play a significant role in enhancing plant resistance against various environmental stresses. These stresses include abiotic factors such as drought, salt stress, high temperature, and heavy metal contamination. Endophytes produce protective metabolites to increase the durability of plants against these adverse conditions. For instance, certain endophytic fungi

provide specialized metabolites that strengthen plants against challenging environmental conditions like drought and salt stress (Porras-Alfaro et al., 2014). This supports the overall health of ecosystems by increasing the ability of plants to adapt to stress conditions (Chen et al., 2016).

Furthermore, endophytic fungi can confer resistance to abiotic stress factors while providing protection against diseases, insects, and other pathogens in plants. This effect is achieved through the production of bioactive natural products such as phytohormones (auxins and gibberellins) that promote plant growth and development (Ortega et al., 2020). Consequently, by enhancing plant stress tolerance, endophytic fungi support agricultural productivity and the sustainability of ecosystems.

It has been emphasized that the plant immune system plays a key role in the formation and colonization of the endophytic microbiota (Liu et al., 2017). Next-generation sequencing technologies have provided a better understanding of the mechanisms by which the microbiome assembles and functions. Recently, it has been understood that the plant immune system modulates the microbiome through various pathways, and this modulation ensures the formation of the microbiome community (Lebeis, 2014; Liu et al., 2017). The suppression of host immunity is of critical importance for the colonization of both beneficial and pathogenic microorganisms (Lebeis, 2014). Interestingly, it has been found that many free-living rhizospheric microorganisms have the potential to suppress root immune responses, which is necessary for establishing a continuous relationship between beneficial endophytes and plants (Yu et al., 2019). It has also been observed that alterations in plant defense hormone levels effectively enable the colonization of the microbiome at the community level (Lebeis, 2014).

Protecting the Plant Against Pathogens

Endophytic fungi play a critical role in protecting plants against pathogens through various biochemical and ecological strategies. These protection mechanisms are primarily categorized into two main groups: "direct" and "indirect." Direct protection involves endophytes inhibiting pathogen development through the secretion of antimicrobial metabolites and lytic enzymes. Indirect protection, on the other hand, is achieved through competition for nutrients

and space, the formation of physical barriers, and the triggering of the plant's immune system (induced resistance). The ecological success of endophytes relies on microscopic competition strategies against pathogens. Foremost among these strategies is mycoparasitism; for instance, certain endophytes such as Trichoderma species degrade pathogen cell walls by secreting enzymes like chitinase and glucanase. In another strategy known as the principle of competitive exclusion, the endophyte occupies niches within plant tissue, thereby preventing the establishment of the pathogen. Additionally, endophytic colonization stimulates the plant immune system (priming), enabling the plant to deliver a faster defense response against potential attacks.

Direct Protection Mechanisms: In this mechanism, endophytic fungi directly target pathogens with the bioactive compounds they produce. For example, *Neotyphodium* (now renamed *Epichloë*) species establish a powerful chemical defense line against both herbivores and pathogens in grasses through alkaloid-derived compounds (Saikkonen et al., 1998). Similarly, some endophytic species synthesize specific antimicrobial metabolites that inhibit pathogen proliferation by disrupting their cell walls (Khan et al., 2012). Specifically, endophytic isolates belonging to the genus *Trichoderma* degrade the pathogen cell wall by secreting hydrolytic enzymes such as chitinase and glucanase; by colonizing the root zone, they physically and chemically prevent the entry of soil-borne pathogens into the plant (Harman et al., 2004).

Another unique protection mechanism of endophytes is Mycofumigation. Some endophytic fungi produce low-molecular-weight Volatile Organic Compounds (VOCs), which can inhibit pathogen growth in the gas phase without physical contact (Stinson et al., 2003; Kaddes et al., 2019). For instance, compounds such as isobutyric acid esters produced by *Muscodor albus* exhibit broad-spectrum antimicrobial activity by disrupting pathogen cell membrane integrity or acting through mechanisms like DNA methylation (Yee et al., 2009).

Indirect Protection and Competition: Endophytes provide indirect protection by competing with pathogens for ecological niches (habitats) and nutrient resources. Endophytes that pre-colonize plant tissues limit the sites available for pathogen establishment and reduce the risk of infection through the principle of "competitive exclusion" (Arnold et al., 2003). Furthermore, endophytes

strengthen mechanical barriers by promoting lignification in plant cell walls or by altering the structure of the extracellular matrix (Carroll, 1988). Moreover, one of the most significant indirect effects of endophytes is the stimulation of the host defense system. Endophytic colonization enhances the expression of plant defense genes, ensuring that the plant remains in a "primed" state. Consequently, the plant develops a much faster and more robust immune response against potential pathogen attacks (Arnold et al., 2003; Harman et al., 2004).

Impact on Ecosystem Dynamics: The plant-pathogen-endophyte triangle is of paramount importance for the sustainability of ecosystem health. Endophytic fungi contribute to the continuity of ecosystem functions by extending plant lifespans and supporting biomass production (Porras-Alfaro et al., 2014). Specifically, the dual protection (against both biotic and abiotic stresses) provided by species such as *Neotyphodium* maintains ecosystem balance by increasing the resilience of plant populations (Saikkonen et al., 1998). In conclusion, endophytic fungi hold great potential as biological control agents, serving as viable alternatives to chemical pesticides in agricultural production.

Supporting Biodiversity

Endophytic fungi contribute significantly to the general balance and functionality of ecosystems by supporting biodiversity within plant communities. These microorganisms ensure the presence of diverse endophytic species across different plant types, which enhances the species diversity of plant communities and maintains the dynamic equilibrium of ecosystems (Arnold, 2007). The symbiotic relationships established between endophytic fungi and plants contribute to the conservation of biodiversity in both natural areas and agricultural lands by supporting essential ecosystem functions.

Interestingly, many endophytic fungal species are found only in specific hosts due to specialized conditions such as leaf tissue phytochemistry and micro/macro nutrient content (Arnold et al., 2003). This indicates that endophytes exhibit host specificity among plant species. Furthermore, endophytic fungal communities within the same plant species are highly dynamic; the taxonomic diversity and richness of these communities are shaped by both biotic and abiotic factors (Reis et al., 2022). This dynamic structure

demonstrates the critical role endophytes play in supporting the biological diversity of ecosystems.

Ecosystem Functions and Nutrient Cycling

Endophytic fungi exert critical impacts on ecosystem functions not only within living plant tissues but also after the plant dies or undergoes senescence. When the host plant ages and dies, endophytes alter their life strategies by transitioning to a "saprotrophic" (decomposer) phase, serving as pioneer microorganisms that initiate organic matter decomposition (Promputtha et al., 2010). This process is vital for the "carbon cycle"; endophytes accelerate the transformation of organic carbon and nutrients back into the soil by breaking down complex carbon compounds, such as cellulose and lignin, within plant tissues (Osono, 2006).

This decomposition process initiated by endophytes indirectly enhances the humus content and nutrient quality of the soil. Consequently, the diversity of soil microbial communities is enriched, leading to a more balanced biological structure within the ecosystem (Purahong et al., 2016). Additionally, certain root endophytes, specifically Dark Septate Endophytes (DSE), can perform mycorrhiza-like functions by assisting plant roots with water and mineral uptake under harsh environmental conditions. By increasing the resilience of the root system, they also contribute to erosion control (Mandyam & Jumpponen, 2005).

Sustainable Ecosystem Management

Endophytic fungi utilized in agriculture contribute to sustainable farming practices by reducing the necessity for chemical pesticides. By helping plants become more resilient, these fungi increase productivity in agricultural production while minimizing environmental damage (Bamisile et al., 2018). Furthermore, they offer an eco-friendly alternative for protecting plant health when used as biological control agents (Vega, 2008). A better understanding of the ecological roles of endophytic fungi holds significant potential for both the conservation of natural ecosystems and the improvement of agricultural production systems.

Biotechnological Importance of Endophytic Fungi

Endophytic fungi are organisms of increasing importance in the field of biotechnology. Due to the symbiotic relationships they establish with plants, they not only support plant health but also produce bioactive components that can be utilized in various industrial and agricultural applications. These fungi carry immense potential in numerous biotechnological applications, such as eco-friendly biological control agents and the production of pharmaceuticals and biofuels. Understanding the biotechnological potential of endophytes enables the optimization of current applications and the development of new solutions, thereby contributing to the advancement of sustainable and environmentally friendly technologies (Schulz et al., 2002).

Production of Bioactive Compounds

Endophytic fungi produce a variety of bioactive components with great potential in the pharmaceutical, cosmetic, and agricultural industries. These bioactive substances may possess antimicrobial, antifungal, antiviral, and anticancer properties. In particular, the extraction of Taxol, a significant anticancer compound, from the endophytic fungus *Taxomyces andreanae* associated with *Taxus spp.* (specifically *Taxus brevifolia*) (Stierle et al., 1993), has drawn the attention of the scientific community to the capacity of these microorganisms to produce bioactive molecules and has pioneered new research (Strobel & Daisy, 2003; Reis et al., 2022). The discovery of bioactive components from endophytic fungi provides eco-friendly alternatives to chemical synthesis methods in biotechnological production processes and is recognized as a novel resource in drug development studies.

Biological Control Agents

The biocontrol potential of endophytic fungi is increasingly being commercialized as "microbial biopesticides" within the agricultural industry. Specifically, entomopathogenic endophytes, such as Beauveria bassiana, are utilized as viable alternatives to chemical pesticides to combat insect pests and pathogens. These agents, produced via industrial fermentation techniques, regulate pest populations through the action of toxic metabolites. The primary objective in the development of these biological products is to enhance sustainable agriculture by extending shelf life and

engineering formulations that are resilient to environmental stressors, such as UV radiation and humidity.

Biofuel Production

Endophytic fungi possess significant potential to play a transformative role in biofuel production. These microorganisms are instrumental in the synthesis of enzymes required for the degradation of lignocellulosic biomass. Lignocellulosic biomass is composed of complex polymers, primarily lignin and cellulose, located within plant cell walls. The efficient decomposition of these recalcitrant components is a prerequisite for the overall efficiency of biofuel production processes (Sunitha et al., 2013).

Endophytic fungi are particularly notable for their capacity to produce cellulase and ligninase enzymes. Cellulase facilitates the conversion of cellulose into glucose, which provides the fermentable sugars that serve as the fundamental feedstock for biofuel production. Concurrently, ligninase enables the breakdown of the lignin matrix, allowing for more effective biomass processing. Deriving these enzymes from endophytic fungi renders biofuel production processes more sustainable and environmentally compatible (Sunitha et al., 2013).

Conventional methods utilized in biofuel production are frequently associated with high energy consumption and adverse environmental impacts. The integration of endophytic fungi can transition these processes toward greater efficiency and ecological safety. Specifically, endophyte-derived enzymes enable the rapid and effective processing of biomass, resulting in a substantial improvement in biofuel yields. This approach offers both economic and ecological advantages in biofuel synthesis, thereby contributing to the advancement of renewable energy resources (Sunitha et al., 2013).

Industrial Enzyme Production

Endophytic fungi are regarded as a substantial resource for the production of enzymes utilized in various industrial processes. These microorganisms can efficiently produce enzymes that play critical roles in several sectors—including the food, textile, paper, and biofuel industries—in an environmentally friendly manner. Enzymes derived from endophytic fungi hold significant potential

in industrial biotechnology by offering both economic and environmental advantages (Wang et al., 2012; Sharma et al., 2013).

Amylase enzymes obtained from endophytic fungi are vital biocatalysts that convert starch into glucose. In the food industry, they are employed in the processing of bread, confectionery, and other starch-based products. Amylases sourced from endophytes provide high yields and cost-effective production (Yadav et al., 2018; Pandey et al., 2000). Lipase enzymes catalyze the hydrolysis of lipids. Within the textile industry, lipases are used for fabric cleaning and the formulation of biodegradable detergents, which mitigates environmental pollution by reducing reliance on chemical detergents (Ghosh et al., 2013; Zambare et al., 2011).

Proteases are enzymes that degrade proteins into amino acids and play a pivotal role in paper and biofuel manufacturing. Proteases derived from endophytic fungi facilitate the more effective processing of plant materials in the kraft processes of the paper industry and in biofuel production (Rao et al., 1998; Sunitha et al., 2013).

Bioremediation

Endophytic fungi play a significant role in bioremediation efforts aimed at mitigating environmental pollution. These microorganisms contribute to the restoration of both soil and water resources by effectively removing environmental pollutants through plants (phytoremediation) (Doty, 2008). Particularly in environments contaminated with pollutants such as heavy metals, petroleum derivatives, and toxic chemicals, the utilize of endophytic fungi emerges as an effective biotechnological approach.

Endophytic fungi promote various biochemical processes within the rhizosphere environment around plant roots and inside the tissues. These processes enable the uptake, binding, or transformation of heavy metals into less toxic forms. For example, some endophytic fungi facilitate the chelation and bioaccumulation (sequestration in vacuoles) of heavy metals that leach into the soil through plant roots (Jiang et al., 2013).

These microorganisms are also effective in the degradation of petroleum derivatives and hydrocarbons. Endophytic fungi accelerate natural processes without harming the environment,

ensuring the more rapid elimination of pollutants. For instance, in the cleanup of oil spills, certain endophytic fungi (such as *Cladosporium* or *Aspergillus* species) decompose petroleum components by utilizing them as a carbon source, thereby supporting the survival of plants in these contaminated soils (Soleimani et al., 2010; Khan et al., 2013). This biotechnological approach to bioremediation provides sustainable solutions for the reduction of environmental pollution (Ali et al., 2013).

Plant Growth-Promoting Substances

The plant growth-promoting properties of endophytic fungi allow for the development of "bio-fertilizer" formulations as viable alternatives to chemical fertilizers in modern agriculture. In biotechnological processes, products aimed at increasing plant yields are developed by utilizing the phytohormone (gibberellin, IAA, ABA) production capacities of endophytes (Khan et al., 2012). The bioactive components obtained through these processes are converted into commercial products in the form of seed coatings or granular fertilizer additives. Specifically, the production of stress hormones such as abscisic acid (ABA) by endophytes is utilized as a biotechnological tool to enhance the tolerance of agricultural plants against abiotic stresses, including drought and salinity (Liu et al., 2017).

Myconanotechnology and Green Synthesis

Endophytic fungi are utilized as eco-friendly "bio-factories" in the production of metal nanoparticles through the "Green Synthesis" method (Dikshit et al., 2021). In this process, fungi biochemically reduce metal ions (Ag^+) into metallic nanoparticles and stabilize them via reductase enzymes secreted into the extracellular environment (Sawalha et al., 2025; Lacava et al., 2022). Silver (AgNPs) and gold (AuNPs) nanoparticles synthesized using this method possess potent antimicrobial, anticancer, and antioxidant properties, holding significant application potential in medical and industrial fields (Govindappa et al., 2016; Akther et al., 2019).

Conclusion

Endophytic fungi offer a highly potent and versatile biological potential for enhancing plant health, increasing stress tolerance, and developing sustainable agricultural practices. Through their mutualistic relationships with plants, these microorganisms support natural defense mechanisms, promote growth and productivity, and confer significant advantages to plants against environmental stresses. Given these characteristics, endophytic fungi are among the fundamental biological components of eco-friendly and nature-compatible agricultural systems. Research conducted to date has clearly demonstrated the capacity of endophytic fungi for bioactive compound production, biocontrol efficiency, and plant growth-promoting effects. With the increasing body of knowledge, the integration of these microorganisms into agricultural applications is becoming more systematic and effective each day. In particular, advancing biotechnological methods and formulation approaches enable endophytes to remain active for longer periods under field conditions and to provide sustainable contributions to plant–environment interactions.

The success of endophytic fungi within the ecosystem stems from their dynamic and harmonious interactions with both the plant and the soil microbiota. The "holobiont" approach, which considers the plant and its associated microbial community as a single unit, has provided a new perspective for endophyte research. This system-based approach has made it possible to better understand endophyte–host relationships and to develop biological solutions specific to various plant genotypes. Today, endophyte research is evolving beyond classical descriptive studies into an innovative field of science supported by advanced molecular techniques and synthetic biology approaches. The design of programmable microbial communities (SynComs) allows for the development of functionally optimized endophyte consortia. Furthermore, the widespread adoption of advanced identification methods such as Multilocus Sequence Typing (MLST) and Whole Genome Sequencing (WGS) contributes to a more accurate and reliable revelation of the functional potential of endophytes.

The application areas of endophytic fungi extend beyond agricultural biocontrol to include innovative biotechnological solutions. Their evaluation as biological production platforms in the green synthesis of metal nanoparticles within the field of myconanotechnology, and mycofumigation approaches that enable

contactless plant protection via Volatile Organic Compounds (VOCs), highlight the multi-disciplinary usage potential of these microorganisms. In conclusion, endophytic fungi stand out as biological agents that play a key role in the development of sustainability-oriented agricultural systems, compatible with ecological principles and supported by modern biotechnological tools. Future studies conducted through interdisciplinary approaches will allow for the more effective utilization of the natural potential of these microorganisms and provide a strong scientific foundation for the eco-friendly agricultural and biotechnological applications of the future.

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Chapter 9

Species List of Zerconid Mites (Acari: Mesostigmata: Zerconidae) in the Marmara Region (Türkiye)

Mehmet KARACA[1] & Raşit URHAN[2]

Introduction

The Marmara Region, located in northwestern Türkiye, represents a transitional zone between Europe and Asia and is characterized by a heterogeneous landscape shaped by plains, plateaus, mountain ranges, and extensive coastal areas surrounding the Sea of Marmara. This geomorphological diversity includes fertile lowlands, river valleys, and a complex coastline with gulfs and straits, notably the Bosphorus (İstanbul Strait) and the Dardanelles (Çanakkale Strait). The region experiences a transitional climate influenced by Mediterranean, Black Sea, and continental climatic regimes, resulting in mild to warm summers and cool, relatively wet winters. These climatic and physiographic conditions support a wide range of vegetation types, including deciduous and mixed forests, maquis formations, agricultural lands, and wetlands, which sustain diverse flora and fauna, including endemic plant species, migratory birds, and freshwater fish communities. The Marmara Region is one of the most industrialized and agriculturally productive areas of Türkiye, with major agricultural products including wheat, sunflower, rice, olives, and various fruits. Furthermore, the region contains several significant protected

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areas, such as Uludağ National Park, İğneada Floodplain Forests National Park, and Manyas Bird Paradise National Park (Url-1). Despite its high biodiversity, the region faces threats from urbanization, industrialization, and habitat fragmentation, emphasizing the importance of continued conservation efforts (Url-1).

Türkiye harbors a rich and diverse fauna, with invertebrates representing a substantial portion of its biodiversity. Among these, soil-dwelling mites are of particular ecological significance, playing essential roles in nutrient cycling, soil formation, and the regulation of microbial communities. The varied habitats across the country, including forests, wetlands, grasslands, and agricultural lands, provide numerous microhabitats that support high species richness and endemism within invertebrate groups. Many soil mite species are found only in limited areas, which makes them particularly important for ecological research and for designing conservation strategies aimed at protecting Türkiye's soil biodiversity. In addition, some soil mite species are known to have potential applications in biological control and biological monitoring programs, a factor that makes acarological studies especially compelling and valuable.

Zerconid mites (species of the family Zerconidae) are a diverse group of soil-dwelling Acari that are widely distributed across various terrestrial habitats in the Holarctic region. They are primarily predators, feeding on nematodes and other small arthropods, and thus play a key role in regulating soil microfauna populations. Their diversity and ecological functions make them an important component of soil biodiversity and a subject of interest in both taxonomic and ecological studies.

In recent years, regional species inventories (the Black Sea, Mediterranean, Central Anatolia, Eastern Anatolia, and Aegean regions) have been compiled to establish a comprehensive species checklist of Zerconidae mites in Türkiye (Karaca & Urhan, 2024a-b, 2025a-c) (Figure 1). Various systematic and ecological studies have previously been conducted in the provinces of the Marmara Region (Balıkesir, Bilecik, Bursa, Çanakkale, Edirne, İstanbul, Kırklareli, Kocaeli, Sakarya, and Tekirdağ). Within the scope of these studies, several new species and new records have been added to the acarofauna of Türkiye. The present study, however, focuses on the Marmara Region, for which a detailed and integrated species checklist has not previously been compiled.

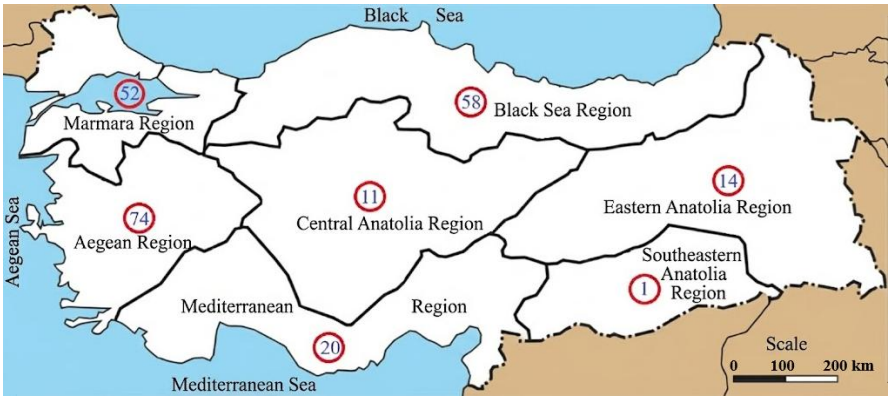


Figure 1. The numerical distribution of zerconid mites across the geographical regions of Türkiye (Url-2, map not to scale).

Material and Methods

In order to provide a comprehensive and up-to-date inventory of Zerconidae mites reported from the Marmara Region of Türkiye, various literature sources was examined, including articles, symposium and conference proceedings, as well as master's and doctoral theses. All species of the family Zerconidae recorded from the provinces of the region were systematically documented and organized alphabetically by genus and species. In addition, their national and global distributions were compiled and presented.

Results

All literature records reported from the Marmara Region at different times can be grouped into three main categories: (1) data reported in a doctoral thesis conducted in Turkish Thrace (Çanakkale, Edirne, İstanbul, Kırklareli, and Tekirdağ provinces), (2) data reported in a master's thesis conducted in the İstanbul province, and (3) short-term or irregular records reported from the provinces located in the Anatolian part of the region. A total of 52 zerconid mite species reported from the provinces of the region are listed in Table 1 and are presented in alphabetical order in this section. In addition, the national and global distributions of all reported species are provided based on the most up-to-date literature.

Table 1. Species list of the Marmara zerconids (All data are based on the literature records. *There are no records in Yalova province yet). Abbreviations for references_[1]: Karaca and Urhan, 2023a; [2]: Karaca and Urhan, 2025d; [3]: Urhan, 2008a; [4]: Urhan, 2007; [5]: Urhan, 2008b; [6]: Karaca et al., 2017; [7]: Karaca and Urhan, 2023b; [8]: Duran and Urhan, 2017; [9]: Karaca and Urhan, 2023c; [10]: Urhan, 2008c; [11]: Urhan, 2008d; [12]: Urhan, 2008e; [13]: Karaca and Urhan, 2023d; [14]: Karaca, 2025; [15]: Karaca and Urhan, 2017.

Species / Provinces	Balıkesir[1-2]	Bilecik[2-3]	Bursa[2-4-5,15]	Çanakkale[2-6]	Edirne[7,14]	İstanbul[8]	Kırklareli[9,14]	Kocaeli[2-3,10-12]	Sakarya[2]	Tekirdağ[13-14]	Yalova*
P. balikesirensis	●		●			●					
P. banazensis										●	
P. bulbiferus				●	●		●			●	
P. buraki						●		●			
P. carpathofimbriatus			●		●	●	●			●	
P. demirsoyi	●					●		●			
P. elifae										●	
P. esati					●					●	
P. fimbriatus						●	●				
P. gamzeae							●				
P. graecus							●			●	
P. kafkasoricus									●		
P. luxtoni								●			
P. martae	●			●	●					●	
P. miraci	●										
P. morazae					●					●	
P. satapliae						●					
P. sultani						●					
P. sellnicki	●										
P. tataroglui							●				
P. tragardhi						●	●	●	●	●	
P. yavuzi	●	●	●	●		●					
Z. anatolicus							●	●	●		
Z. apladellus	●										
Z. bulgaricus							●				
Z. cabylus										●	
Z. carpathicus	●		●				●			●	
Z. colligans	●	●		●	●	●	●	●	●	●	

Z. cretensis						●					
Z. delicatus	●										
Z. denizliensis	●										
Z. filiformis							●				
Z. foveolatus							●	●		●	
Z. geliboluensis				●			●			●	
Z. inonunensis		●				●		●			
Z. istanbulensis						●					
Z. juvarae							●				
Z. laczii						●					
Z. lepurus						●		●			
Z. longisetosus								●			
Z. magdae				●			●			●	
Z. marinae	●			●	●	●	●			●	
Z. nemoralis						●					
Z. osmaneliensis	●	●						●		●	
Z. similifoveolatus							●			●	
Z. sklari					●		●				
Z. sklarsimilis							●				
Z. tekirdagensis										●	
Z. thracicus					●		●			●	
Z. turcicus							●				
Z. uludagicus			●								
Z. yusufi	●										
TOTAL	14	4	4	7	9	17	22	11	4	20	0

Family: **ZERCONIDAE** G. Canestrini, 1891

Genus: ***Prozercon*** Sellnick, 1943

Type species: ***Zercon fimbriatus*** (C. L. Koch, 1839)

For detailed diagnosis of the genus, see Urhan and Karaca (2023).

1. *P. balikesirensis* Urhan, 2008

Turkish records: Balıkesir, Bursa, Isparta, İstanbul, Kütahya (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

2. *P. banazensis* Urhan, Karaca & Duran, 2015

Turkish records: İzmir, Kütahya, Tekirdağ, Uşak (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

3. *P. bulbiferus* Ujvári, 2011

Turkish records: Aydın, Çanakkale, Denizli, Edirne, Kırklareli, Kütahya, Muğla, Tekirdağ (Karaca and Urhan, 2025a).

Known distribution: Greece, Türkiye (Karaca and Urhan, 2025a).

4. *P. buraki* Urhan, 2008

Turkish records: Bolu, Giresun, İstanbul, Kocaeli (Karaca and Urhan, 2025d).

Known distribution: Türkiye (Karaca and Urhan, 2025d).

5. *P. carpathofimbriatus* Mašán & Fend'a, 2004

Turkish records: Bursa, Edirne, İstanbul, Kırklareli, Tekirdağ (Karaca, 2025).

Known distribution: Croatia, Czechia, Greece, Poland, Slovenia, Türkiye (Karaca, 2025).

6. *P. demirsoyi* Urhan & Ayyıldız, 1996

Turkish records: Artvin, Aydın, Balıkesir, Bolu, Giresun, İstanbul, Kocaeli (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

7. *P. elifae* Karaca, 2025 (Figure 2A)

Turkish records: Tekirdağ (Karaca, 2025).

Known distribution: Türkiye (Karaca, 2025).

8. *P. esati* Karaca, 2025 (Figure 2B)

Turkish records: Edirne, Tekirdağ (Karaca, 2025).

Known distribution: Türkiye (Karaca, 2025).

9. *P. fimbriatus* (C. L. Koch, 1839)

Turkish records: Artvin, Giresun, İstanbul, Kırklareli (Karaca, 2025).

Known distribution: Algeria, Austria, Belgium, Bulgaria, Caucasia, Croatia, Czechia, Germany, Hungary, Italy, Poland, Romania, Slovakia, Slovenia, Spain, Switzerland, Türkiye (Karaca, 2025).

10. *P. gamzeae* Karaca, 2025 (Figure 2C)

Turkish records: Kırklareli (Karaca, 2025).

Known distribution: Türkiye (Karaca, 2025).

11. ***P. graecus*** Ujvári, 2011

Turkish records: Bolu, Kırklareli, Kütahya, Tekirdağ, Uşak (Karaca and Urhan, 2025a).

Known distribution: Greece, Türkiye (Karaca and Urhan, 2025a).

12. ***P. kafkasoricus*** Urhan, 1998

Turkish records: Artvin, Rize, Sakarya (Karaca and Urhan, 2025d).

Known distribution: Türkiye (Karaca and Urhan, 2025d).

13. ***P. luxtoni*** Urhan & Ayyıldız, 1996

Turkish records: Artvin, Kocaeli, Rize (Karaca and Urhan, 2025d).

Known distribution: Türkiye (Karaca and Urhan, 2025d).

14. ***P. martae*** Ujvári, 2010

Turkish records: Balıkesir, Çanakkale, Edirne, Tekirdağ (Karaca, 2025).

Known distribution: Croatia, Türkiye (Karaca, 2025).

15. ***P. miraci*** Urhan, Karaca & Duran, 2020

Turkish records: Balıkesir, İzmir, Manisa (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

16. ***P. morazae*** Ujvári, 2011

Turkish records: Edirne, Kütahya, Tekirdağ (Karaca and Urhan, 2025a).

Known distribution: Greece, Türkiye (Karaca and Urhan, 2025a).

17. ***P. satapliae*** Petrova, 1977

Turkish records: Artvin, Erzincan, Giresun, İstanbul (Karaca, 2025).

Known distribution: Russia, Türkiye (Karaca, 2025).

18. ***P. sultani*** Duran & Urhan, 2015

Turkish records: Bolu, İstanbul (Karaca, 2025).

Known distribution: Türkiye (Karaca, 2025).

19. *P. sellnicki* Halašková, 1963

Turkish records: Aydın, Balıkesir, İzmir, Manisa (Karaca and Urhan, 2025a).

Known distribution: Croatia, Czechia, Germany, Latvia, Poland, Slovakia, Türkiye, Ukraine (Karaca and Urhan, 2025a).

20. *P. tataroglui* Karaca, 2025 (Figure 2D)

Turkish records: Kırklareli (Karaca, 2025).

Known distribution: Türkiye (Karaca, 2025).

21. *P. tragardhi* (Halbert, 1923)

Turkish records: Ankara, Artvin, Aydın, Bolu, Çorum, Denizli, Erzincan, Erzurum, Giresun, Hatay, İstanbul, Kars, Kırklareli, Kocaeli, Kütahya, Muğla, Ordu, Rize, Sakarya, Tekirdağ, Trabzon (Karaca and Urhan, 2025a).

Known distribution: Austria, British Isles, Bulgaria, Czech Republic, Croatia, England, Germany, Hungary, Iceland, Ireland, Latvia, Lithuania, Poland, Romania, Russia, Slovakia, Slovenia, Sweden, Switzerland, Türkiye, Ukraine (Karaca and Urhan, 2025a).

22. *P. yavuzi* Urhan, 1998

Turkish records: Antalya, Aydın, Balıkesir, Bilecik, Bursa, Çanakkale, Denizli, İstanbul, İzmir, Manisa, Muğla, Uşak (Karaca and Urhan, 2025a).

Known distribution: Greece, Türkiye (Karaca and Urhan, 2025a).

Genus: ***Zercon*** C. L. Koch, 1836

Type species: ***Zercon triangularis*** C. L. Koch, 1836

For detailed diagnosis of the genus, see Urhan and Karaca (2023).

23. *Z. anatolicus* Urhan, 2008

Turkish records: Kırklareli, Kocaeli, Kütahya, Sakarya (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

24. *Z. apladellus* Błaszak, 1979

Turkish records: Balıkesir, Bitlis (Karaca and Urhan, 2025d).

Known distribution: Iran, Türkiye (Karaca and Urhan, 2025d).

25. *Z. bulgaricus* Balogh, 1961

Turkish records: Artvin, Giresun, Kırklareli (Karaca and Urhan, 2024a).

Known distribution: Bulgaria, Russia, Türkiye (Karaca and Urhan, 2024a).

26. *Z. cabylus* Athias-Henriot, 1961

Turkish records: Artvin, Bolu, Kütahya, Tekirdağ (Karaca and Urhan, 2025a).

Known distribution: Algeria, Türkiye (Karaca and Urhan, 2025a).

27. *Z. carpathicus* Sellnick, 1958

Turkish records: Balıkesir, Bursa, Kırklareli, Kütahya, Tekirdağ (Karaca and Urhan, 2025a).

Known distribution: Latvia, Poland, Romania, Slovakia, Türkiye, Ukraine (Karaca and Urhan, 2025a).

28. *Z. colligans* Berlese, 1920

Turkish records: Afyonkarahisar, Amasya, Antalya, Artvin, Aydın, Balıkesir, Bilecik, Çanakkale, Denizli, Edirne, Erzincan, Erzurum, Eskişehir, Giresun, Hatay, Isparta, İstanbul, İzmir, Kayseri, Kırklareli, Kocaeli, Kütahya, Manisa, Mersin, Muğla, Sakarya, Samsun, Sinop, Tekirdağ, Uşak (Karaca and Urhan, 2025a).

Known distribution: France, Iran, Italy, Russia, Sweden, Switzerland, Türkiye (Karaca and Urhan, 2025a).

29. *Z. cretensis* Ujvári, 2008

Turkish records: Aydın, İstanbul (Karaca and Urhan, 2025a).

Known distribution: Greece, Türkiye (Karaca and Urhan, 2025a).

30. *Z. delicatus* Urhan & Ekiz, 2002

Turkish records: Afyonkarahisar, Artvin, Balıkesir (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

31. ***Z. denizliensis*** Urhan, 2011

Turkish records: Afyonkarahisar, Aydın, Balıkesir, Denizli, Eskişehir, Giresun, İzmir, Kütahya, Manisa (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

32. ***Z. filiformis*** Karaca & Urhan, 2016 (Figure 2E)

Turkish records: Kırklareli (Karaca and Urhan, 2016).

Known distribution: Türkiye (Karaca and Urhan, 2016).

33. ***Z. foveolatus*** Halašková, 1969

Turkish records: Bolu, Kırklareli, Kocaeli, Manisa, Tekirdağ (Karaca and Urhan, 2025a).

Known distribution: Hungary, Romania, Slovakia, Türkiye, Ukraine (Karaca and Urhan, 2025a).

34. ***Z. geliboluensis*** Karaca & Urhan, 2016 (Figure 2F)

Turkish records: Çanakkale, Kırklareli, Manisa, Tekirdağ (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

35. ***Z. inonunensis*** Urhan, 2007

Turkish records: Afyonkarahisar, Bilecik, Eskişehir, İstanbul, Kocaeli, Kütahya, Manisa (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

36. ***Z. istanbulensis*** Duran & Urhan, 2015

Turkish records: İstanbul (Karaca and Urhan, 2016).

Known distribution: Türkiye (Karaca and Urhan, 2016).

37. ***Z. juvarae*** Ivan & Călugăr, 2004

Turkish records: İzmir, Kırklareli, Kütahya (Karaca and Urhan, 2025a).

Known distribution: Romania, Türkiye (Karaca and Urhan, 2025a).

38. ***Z. laczii*** Ujvári, 2010

Turkish records: Afyonkarahisar, Bolu, İstanbul, Kütahya (Karaca and Urhan, 2025a).

Known distribution: Croatia, Türkiye (Karaca and Urhan, 2025a).

39. *Z. lepurus* Błaszak, 1979

Turkish records: Bolu, İstanbul, Kocaeli (Karaca and Urhan, 2025d).

Known distribution: Türkiye (Karaca and Urhan, 2025d).

40. *Z. longisetosus* Urhan, 2008

Turkish records: Bolu, Kocaeli, Kütahya (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

41. *Z. magdae* Ivan & Călugăr, 2004

Turkish records: Çanakkale, Kırklareli, Kütahya, Tekirdağ, Uşak (Karaca and Urhan, 2025a).

Known distribution: Romania, Türkiye (Karaca and Urhan, 2025a).

42. *Z. marinae* Ivan & Călugăr, 2004

Turkish records: Afyonkarahisar, Antalya, Balıkesir, Çanakkale, Edirne, İstanbul, Kırklareli, Kütahya, Manisa, Tekirdağ, Uşak (Karaca and Urhan, 2025a).

Known distribution: Romania, Türkiye (Karaca and Urhan, 2025a).

43. *Z. nemoralis* Urhan, 2001

Turkish records: Artvin, İstanbul (Karaca and Urhan, 2024a).

Known distribution: Türkiye (Karaca and Urhan, 2024a).

44. *Z. osmaneliensis* Urhan, 2008

Turkish records: Afyonkarahisar, Balıkesir, Bilecik, Denizli, İzmir, Kocaeli, Kütahya, Manisa, Tekirdağ, Uşak (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

45. *Z. similifoveolatus* Ivan & Călugăr, 2004

Turkish records: Kırklareli, Kütahya, Manisa, Tekirdağ (Karaca and Urhan, 2025a).

Known distribution: Romania, Türkiye (Karaca and Urhan, 2025a).

46. *Z. sklari* Balan, 1992

Turkish records: Edirne, Kırklareli (Karaca and Urhan, 2023b-c).

Known distribution: Ukraine, Türkiye (Karaca and Urhan, 2016).

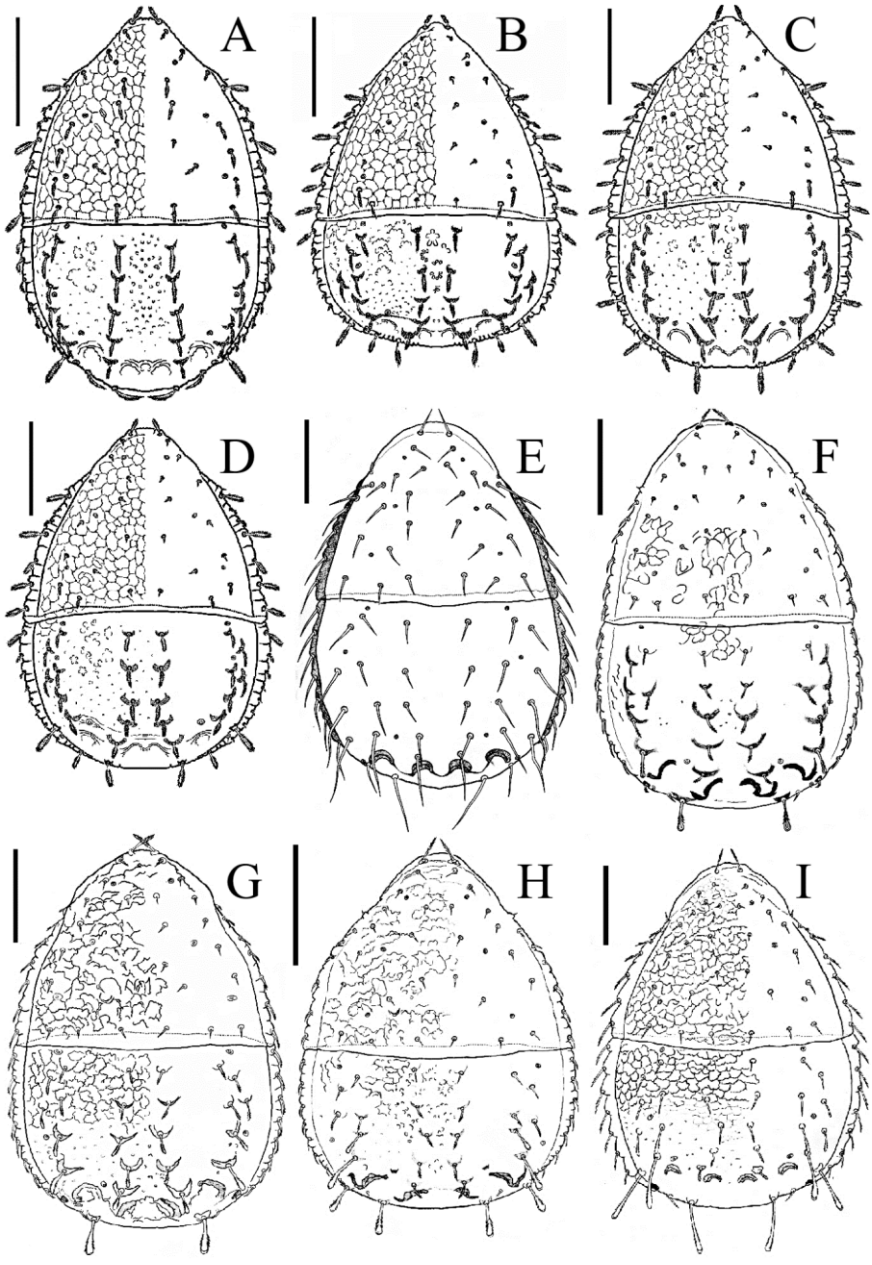


Figure 2. Some of the zerconid mite species whose type localities are in the provinces of the Marmara region and which are considered endemic to Türkiye: A=P. elifae, B=P. esati, C=P. gamzeae, D=P. tataroglui, E=Z. filiformis, F=Z. geliboluensis, G=Z. sklarsimilis, H=Z. tekirdagensis, I=Z. thracicus (All scale bars equal to 100 micrometers. After data in Karaca and Urhan, 2016; Karaca, 2025).

47. *Z. sklarsimilis* Karaca & Urhan, 2016 (Figure 2G)

Turkish records: Kırklareli (Karaca and Urhan, 2016).

Known distribution: Türkiye (Karaca and Urhan, 2016).

48. *Z. tekirdagensis* Karaca & Urhan, 2016 (Figure 2H)

Turkish records: Tekirdağ (Karaca and Urhan, 2016).

Known distribution: Türkiye (Karaca and Urhan, 2016).

49. *Z. thracicus* Karaca & Urhan, 2016 (Figure 2I)

Turkish records: Edirne, Kırklareli, Tekirdağ (Karaca and Urhan, 2016).

Known distribution: Türkiye (Karaca and Urhan, 2016).

50. *Z. turcicus* Urhan & Ayyıldız, 1994

Turkish records: Afyonkarahisar, Aydın, Denizli, Erzincan, Erzurum, Kırklareli, Muğla, Yozgat (Karaca and Urhan, 2025a).

Known distribution: Iran, Türkiye (Karaca and Urhan, 2025a).

51. *Z. uludagicus* Urhan, 2008

Turkish records: Bursa (Urhan, 2008b).

Known distribution: Türkiye (Urhan, 2008b).

52. *Z. yusufi* Urhan, 2010

Turkish records: Afyonkarahisar, Balıkesir, Bolu, Kütahya (Karaca and Urhan, 2025a).

Known distribution: Türkiye (Karaca and Urhan, 2025a).

Discussion and Conclusion

In this study, the diversity of species belonging to the family Zerconidae recorded from 11 provinces in the Marmara Region was examined, and the national and global distribution records of all species were presented. The Marmara Region, represented by 52 zerconid species following the Aegean (74 species) and Black Sea (58 species) regions of Türkiye, is considered a highly rich area in terms of flora and fauna due to its location along the transition corridor to the European continent. Although the diversity of zerconid species in Turkish Thrace (the European part of Türkiye) has been relatively well investigated, the records from the provinces

located in the Anatolian part of the region remain insufficient to reflect the actual biodiversity.

When the provinces in the region are compared in terms of zerconid diversity, Kırklareli (22 species), Tekirdağ (20 species), İstanbul (17 species), and Balıkesir (14 species) rank highest. To date, no zerconid species have been recorded from Yalova Province, while Bursa, Bilecik, and Sakarya (4 species each) represent the provinces with the lowest recorded diversity. Some of the zerconid mite species reported from the region have their type localities (terra typica) in various provinces within the study area (Figure 2). These species are considered endemic to Türkiye. Consequently, long-term and systematic studies, particularly in provinces that have not yet been investigated in detail, are expected to enrich knowledge of the Zerconidae fauna of the Marmara Region and contribute significantly to the overall diversity of the acarofauna of Türkiye.

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Chapter 10

Lichens in the Biomonitoring of Atmospheric Microplastics: A Comparative Review of Findings from Türkiye with the Global Literature

Zekiye KOCAKAYA[1], Mustafa KOCAKAYA [2]

Introduction

The dramatic increase in plastic production in recent years has made the environmental spread of microplastics (MP; <5 mm) and especially microfibers (microfibers, MF) a significant problem on a global scale. Initially considered limited to marine and freshwater ecosystems, microplastic pollution has now been shown to be widespread in the atmospheric environment and capable of long-distance transport (Loppi et al., 2021; Rosati et al., 2024). Atmospheric microplastics are transported to different ecosystems via wind, precipitation, and dry deposition; in this process, they become a pollution component that directly affects both natural areas and human life. A significant portion of microplastics in the atmosphere are in fiber form, and their main sources are synthetic textiles, tire wear particles, packaging materials, and industrial plastic waste. Polymers such as polyester (PET), polypropylene (PP), and polyethylene (PE) are predominantly reported in atmospheric samples (Loppi et al., 2021; Khodabakhshloo et al., 2024; Grifoni et al., 2025). The aerodynamic properties of these fibers enable long-distance transport, leading to the detection of microplastics even in remote and protected areas.

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The potential impacts of atmospheric microplastics on human health are also gaining increasing importance. Studies have shown that atmospheric microplastics can accumulate on plant surfaces and be transported into the food chain, with microplastic fibers detected in lettuce grown in urban vegetable gardens (Canha et al., 2023). The literature discusses how inhaled microplastics can pose potential health risks through processes such as inflammation and oxidative stress, and may play a role in the transport of toxic additives (Rosati et al., 2024). It is also noted that microplastics are not only a physical pollutant but can also function as a carrier (vector) for heavy metals, PFAS, and other organic pollutants, which can increase environmental and health risks (Rahman et al., 2023). In this context, monitoring the spatial and temporal distribution of atmospheric microplastics is critical for environmental risk assessments.

Lichens and Mosses in the Biomonitoring of Atmospheric Microplastics

The use of biomonitor organisms in monitoring atmospheric pollutants has been a common approach for many years. Lichens and mosses, in particular, are considered ideal biomonitors reflecting the accumulation of airborne pollutants due to their lack of root systems, high surface area/mass ratios, and direct nutrient uptake from the atmosphere. These characteristics also offer significant advantages in monitoring particulate pollutants such as microplastics (Rosati et al., 2024).

Use of Lichens as Microplastic Biomonitors

The use of lichens in atmospheric microplastic biomonitoring is a relatively new approach. One of the pioneering studies in this field is research conducted around a landfill in Italy, evaluating the microplastic accumulation of the species Flavoparmelia caperata. In this study, it was reported that microplastic fibers and fragments were significantly increased in lichen thalli in areas close to the landfill; the dominant polymer type was polyester (PET) (Loppi et al., 2021).

Subsequent evaluations have shown that lichens can reflect not only the presence of pollutants but also variations in microplastic size and density depending on the distance to the sources. The decrease in maximum fiber length with distance at sampling points at

different distances suggests that large particles tend to settle in areas close to the sources (Loppi et al., 2021). Furthermore, it has been reported that microplastic-lichen interaction is not limited to passive retention; some lichen species can directly grow on plastic surfaces and colonize PET surfaces (Gomez et al., 2023).

Transplant Experiments and Active Biomonitoring

The use of natural lichen samples has limitations such as the unknown age of the thallus and the uncertainty of the exposure time. Therefore, transplant experiments offering controlled exposure times have come to the forefront in recent years. In a study conducted in Milan, Italy, the species Evernia prunastri was moved from a rural area to urban and semi-urban areas and exposed for a period of three months; atmospheric microplastic accumulation was quantitatively evaluated. This study showed that the fibrous form was dominant, microplastic accumulation was higher in urban areas, and deposition rates could be calculated (Jafarova et al., 2022).

Similarly, studies directly comparing moss and lichen transplants have reported that mosses retain smaller fibers more effectively, while lichens tend to accumulate longer fibers (Capozzi et al., 2023; Grifoni et al., 2025). These findings highlight the need for careful biomonitor selection based on the research objectives.

Lichen-Moss Comparisons and Methodological Discussions

Significant differences in microplastic retention capacity have been reported between lichens and mosses. It has been stated that moss species such as Hypnum cupressiforme can better capture small fibers due to their looser and more branched structures; whereas foil-like lichens such as Pseudevernia furfuracea retain larger and longer fibers (Capozzi et al., 2023). In addition, it has been emphasized that the net or bag systems used in transplant experiments may affect microplastic accumulation; and that exposure without a net ("bare") may provide higher susceptibility.

Studies involving simultaneous sampling have reported that algae accumulate more microplastics per unit mass, while lichens show a more pronounced tendency to capture long fibers (Jafarova et al., 2023). These findings indicate that the morphology of the biomonitor organism and the experimental design are crucial in interpreting the results obtained.

At this point, there is also an important conceptual debate in the literature: Are the microplastics observed in the lichen thallus truly "accumulated" particles, or do they represent fibers and fragments retained on the surface? This distinction is critical for evaluating the extent to which data from microplastic biomonitoring reflect environmental deposition and clearly highlights the need for standardized and comparable methodologies (Rosati et al., 2024).

Methodological Approaches and Conceptual Framework

In monitoring atmospheric microplastics using biomonitor organisms, the reliability of the results obtained largely depends on the methodology applied and the correct definition of the conceptual framework used. Although the detection of microplastics in biomonitor thalli is often expressed in the literature with the concept of "accumulation," whether this term always represents a true intracellular uptake in a biological sense is increasingly debated.

Concepts of Accumulation, Deposition, and Retention

It is thought that a significant portion of the microplastics observed in lichen and moss thalli are particles mechanically retained on the surface rather than through intracellular uptake. Therefore, some researchers suggest using the terms "retention" or "interception" instead of "accumulation" (Rosati et al., 2024). Studies based on controlled experiments emphasize that microplastics detected in lichen thalli do not always represent biologically accumulated particles; it is necessary to differentiate between precipitated and retained fibers and true biological accumulation (Nistal et al., 2025).

Microplastics, particularly those in fibrous form, can be retained on the surface via the rough surface of the thallus, hyphal structure, and extracellular polysaccharides. This suggests that the presence of microplastics observed in biomonitors is often an indicator of atmospheric deposition occurring in the environment, but does not exhibit the behavior of a biochemically processed or metabolized pollutant within the organism. This distinction is critical for interpreting the results.

In this context, microplastic biomonitoring differs methodologically from classical heavy metal and polycyclic aromatic hydrocarbon (PAH) biomonitoring, in which lichens have long been successfully

used. While heavy metals and PAHs can exhibit biochemical binding or intracellular accumulation in biomonitoring organisms, microplastics are largely detected through physical retention and surface interactions.

Passive and Active Biomonitoring Approaches

Two main approaches stand out in the literature: passive biomonitoring (use of naturally growing organisms) and active biomonitoring (transplant experiments). While passive biomonitoring offers significant advantages in terms of providing long-term environmental integration, the unknown age of the thallus and the duration of exposure constitute a significant source of uncertainty (Capozzi et al., 2023).

In active biomonitoring, lichens or mosses are taken from low-pollution areas and placed in target sites for a specific period, and the exposure time is controlled. Transplant studies conducted in Milan, Siena, and Campania have shown that this approach allows for the calculation of daily or monthly microplastic deposition rates (Jafarova et al., 2022; Grifoni et al., 2025). However, the literature also emphasizes that the mesh, bags, or support materials used in transplant systems can affect microplastic retention and cause bias in the results.

Analytical Methods and the Standardization Problem

Different analytical approaches are used in the isolation and identification of atmospheric microplastics from biomonitors. The most common methods include wet peroxide oxidation (WPO), fluorescent staining, FT-IR, and Raman microspectroscopy. While the WPO method is effective in removing the organic matrix, it is reported that it can lead to the loss of very small particles. In contrast, FT-IR and Raman techniques enable reliable identification of polymer types (Loppi et al., 2021; Çobanoğlu & Özen, 2024).

One of the key problems highlighted in the literature is the lack of methodological consistency among different studies. Differences in digestion protocols, filter sizes, visual identification criteria, and reporting units make it difficult to directly compare results obtained in different geographical areas. This clearly demonstrates the need for standardized and harmonized methodologies for monitoring atmospheric microplastics on a global scale (Rosati et al., 2024).

Atmospheric Microplastic Biomonitoring in Turkiye: The Case of Yozgat Çamlık National Park

Although studies on the evaluation of atmospheric microplastics using biomonitor organisms in Türkiye are still limited, an increasing scientific interest in this field has been observed in recent years. In particular, studies centered in Istanbul, carried out on a megacity scale, reveal the impact of intense human activities on atmospheric microplastic accumulation; while research conducted in protected areas shows that microplastics are not limited only to local sources and can reach relatively pristine ecosystems through long-distance atmospheric transport (Çobanoğlu & Özen, 2024).

In this context, the study conducted in Yozgat Çamlık National Park holds a unique position in the literature as it is one of the rare examples in Türkiye of evaluating atmospheric microplastic pollution using lichens at the scale of a national park. In the study, the presence, size distribution, and polymer composition of microplastic fibers were determined using lichen samples collected from areas with different levels of anthropogenic pressure within the park. It has been reported that microplastics were reliably identified thanks to multi-stage analytical approaches such as wet peroxide oxidation (WPO), fluorescent staining, and FT-IR/Raman spectroscopy (Kocakaya et al., 2025).

The findings have shown that anthropogenic microfibers are widespread even in a protected area like Yozgat Çamlık National Park. Examination of the polymer profile revealed that synthetic textile and industrial polymers, particularly polyurethane (PU), acrylonitrile butadiene styrene (ABS), and polyethylene terephthalate (PET), are dominant. This polymer distribution largely coincides with findings reported in similar studies conducted in Europe and the Middle East (Loppi et al., 2021; Khodabakhshloo et al., 2024).

These results suggest that microplastics reach protected areas not only from local emission sources but also through long-distance atmospheric transport processes. Indeed, studies conducted around the city of Shiraz in Iran have shown that large microplastics decrease with distance from the city center; however, microplastics in the form of fine fibers can be transported over long distances (Khodabakhshloo et al., 2024). The fiber-dominant microplastic profile obtained in Yozgat Çamlık National Park can be considered a reflection of this global trend on a Türkiye scale.

Comparative Analysis of Studies in Turkiye and Around the World

Studies on the evaluation of atmospheric microplastics using biomonitor organisms, although employing similar methodological approaches in different geographies, yield results that vary depending on the sampling environment, biomonitor type, exposure time, and level of anthropogenic pressure. However, when the existing literature is evaluated together, some common trends repeated in different regions are noteworthy.

Microplastic Morphology: Dominance of Fibers

In the vast majority of atmospheric microplastic biomonitoring studies conducted in Türkiye and worldwide, the dominant morphology of detected microplastics has been reported as fiber form. In a study conducted around a landfill in Italy, approximately 70% of the microplastics detected in lichen thalli were reported to be in fiber form (Loppi et al., 2021). Similarly, lichen and moss transplant experiments conducted in the Milan, Siena, and Campania regions also showed that fibers were the most common particle type (Capozzi et al., 2023; Grifoni et al., 2025).

Studies conducted in Istanbul and Yozgat Çamlık National Park in Türkiye have also determined that microplastics are largely in fiber form (Çobanoğlu & Özen, 2024; Kocakaya et al., 2025). This finding suggests that the main source of atmospheric microplastics is synthetic textiles and daily human activities. Furthermore, the aerodynamic properties of fibers, making them more suitable for long-distance transport, explain the detection of microplastics in different ecosystems, including protected areas. In this respect, fiber dominance is considered an important indicator of the regional and global transport potential of atmospheric microplastics.

Polymer Profiles and Source Relationships

When examining the polymer profiles reported in atmospheric microplastic biomonitoring studies, it is seen that polyester (PET), polypropylene (PP), and polyethylene (PE) types are dominant in almost all geographies. The detection of high rates of PET and PP fibers in studies based in Italy and Canada reveals that synthetic textiles and plastics associated with household use are significant

sources of microplastics on a global scale (Loppi et al., 2021; Grifoni et al., 2025).

In addition, studies conducted in areas with high traffic density have detected microrubber particles as well as microplastic fibers, indicating that emissions from tire wear make a significant contribution to the atmospheric particulate load. A study conducted in Shiraz, Iran, clearly demonstrated the impact of traffic-related pollution on the atmospheric microplastic profile by showing the presence of microrubbers (Khodabakhshloo et al., 2024).

Polymer profiles obtained in Yozgat Çamlık National Park in Türkiye show that polymers associated with synthetic textiles and industrial plastics (e.g., PET, PU, and ABS) are dominant (Kocakaya et al., 2025). This distribution largely overlaps with polymer profiles reported in Europe and the Middle East, suggesting that microplastic sources are largely associated with regional and long-distance transport, even in protected areas. In this context, polymer profiles are considered an important tool not only for detecting the presence of microplastics but also for identifying potential emission sources.

Spatial Gradients: Urban, Rural and Protected Areas

When the spatial distribution of atmospheric microplastic accumulation is examined, it is seen that microplastic density generally follows a decreasing gradient from urban centers to rural and protected areas. Urban centers and areas with intense human activity constitute the main sources of microplastic emissions; this is also reflected in the microplastic densities measured in biomonitor organisms. Indeed, in lichen and moss transplant experiments carried out in urban areas such as Milan, Siena and Naples, it was reported that microplastic accumulation in commercial and residential areas was significantly higher compared to rural or semi-natural areas (Jafarova et al., 2022; Capozzi et al., 2023).

However, studies conducted in protected areas reveal that atmospheric microplastic pollution is not limited to local sources. Findings from Yozgat Çamlık National Park have shown that microplastic fibers can be detected even in an area with limited human activity. Similar results have been reported in samples taken in Iran from high-altitude regions far from urban centers (Khodabakhshloo et al., 2024). These findings clearly demonstrate

that microplastics have long-distance atmospheric transport capacity and are an effective pollutant on a regional and even global scale. In this respect, spatial gradient analyses are considered a critical tool in understanding microplastic sources and transport processes.

Differences Depending on Biomonitor Type

The literature frequently emphasizes that there are significant differences in microplastic retention capacity depending on the type of organism used in atmospheric microplastic biomonitoring. In general, it is reported that algae, thanks to their looser, branched, and three-dimensional structures, can more effectively retain small and short fibers; while lichens, due to their more compact and layered thallus structures, tend to capture longer fibers and relatively large particles (Capozzi et al., 2023; Grifoni et al., 2025). These differences are directly related to thallus morphology, surface roughness, and the growth mode of the organisms.

Studies conducted in Türkiye have shown that epiphytic foliose lichens (e.g., Xanthoria parietina) are effective biomonitors in monitoring atmospheric microplastics (Çobanoğlu & Özen, 2024). Similarly, lichen species used in Yozgat Çamlık National Park have also yielded successful results in detecting fibrous microplastics (Kocakaya et al., 2025). These findings highlight that the data obtained in Türkiye are consistent with global trends regarding microplastic uptake by lichens and mosses, and emphasize the importance of selecting biomonitor species according to the study objective.

The Mitigating Effect of Urban Green Spaces and Ecosystem-Based Approaches

While it is known that atmospheric microplastics (MPs) are concentrated in urban areas, scientific evidence has been increasingly strengthened in recent years that urban green spaces can reduce this burden. In this context, a transplant-based study conducted using Evernia prunastri, through a comparison of parking lots–urban parks–remote (reference) areas, revealed that urban parks (greenspaces) can significantly reduce airborne microplastic accumulation and opened the discussion of the "green infrastructure" approach in the context of microplastic pollution (Basile et al., 2025).

This study highlighted that lichens, thanks to their morphological characteristics, can effectively trap airborne particles; the physical barrier created by the vegetation and its effect on regulating air currents can reduce microplastic deposition. Furthermore, the demonstration that transplanted samples can maintain viability after short-term exposure supports the applicability of lichen-based biomonitoring in urban environments. These findings indicate that managing microplastic pollution requires not only measurement and monitoring approaches but also mitigation strategies developed through ecosystem services (e.g., the filtration and retention capacity of vegetation).

Demonstrating the microplastic-reducing effect of urban green spaces presents a significant opportunity in Türkiye to integrate biomonitoring data into decision-making processes in areas such as urban planning, campus and settlement landscaping. In this respect, biomonitoring studies serve as a scientific tool not only for detecting environmental pollution but also for supporting sustainable and ecosystem-based urban design approaches.

The "Moss Bag" Approach in Active Biomonitoring and the Need for Standardization

While lichens are frequently preferred in atmospheric microplastic biomonitoring, moss bags offer a strong alternative in active biomonitoring applications in terms of field applicability and the production of comparable data between studies. In a moss bag study conducted using Pleurozium schreberi, it was shown that microplastics (MP) were detected in all sampling areas after a 45-day exposure period; accumulation increased significantly in areas with high traffic and population density, and the results could be quantitatively reported in terms of microplastic number per unit mass (MP g^{-1}) (Bertrim & Aherne, 2023). In addition, estimating deposition with area and time-based metrics (MP m^{-2} day^{-1}) offers a significant methodological advantage in terms of directly converting biomonitor data into atmospheric deposition indicators.

This approach provides a critical breakthrough in terms of "inter-study comparability," one of the fundamental problem areas of the compilation. The fact that bag design, exposure time, and sampling protocols used in moss bag systems are more easily standardized compared to natural lichen samples makes this method particularly attractive for regional and international monitoring programs.

Indeed, the current literature particularly emphasizes the need to establish regional-scale biomonitor networks and develop harmonized protocols for monitoring atmospheric microplastics (Jafarova et al., 2025). In this context, the moss bag approach has significant potential in terms of both methodological standardization and long-term monitoring strategies.

Local–Regional Resources, Agricultural Plastics, and Rural Background Sites

While long-distance transport processes are frequently emphasized in the atmospheric microplastic (MP) literature, recent studies have revealed that local and regional resources are often the primary factors determining microplastic accumulation, even in rural background sites. A large-scale study conducted in 33 background sites in rural Tuscany using pleurocarp mosses reported that microplastic accumulation was predominantly fiber-based (mostly textile-derived) and that polymer diversity pointed to local sources such as agricultural plastics (e.g., plastic mulch applications) (Jafarova et al., 2025).

These findings demonstrate that atmospheric microplastics in areas with intensive agricultural production should not be considered solely as an "urban" problem. In the context of Türkiye, inputs such as greenhouse activities, plastic mulch use, irrigation infrastructure, and agricultural packaging waste should be considered as potential contributors to the atmospheric microplastic load. Furthermore, this study emphasizes that microplastic concentrations may be related to human activities on a scale of approximately 10–100 km, reinforcing the importance of buffer zones and impact zones in the design of biomonitoring studies (Jafarova et al., 2025).

Intercontinental Similarity: Urbanization Gradient with Ramalina celastri in Argentina

The fact that lichen transplant applications produce similar spatial patterns in different geographies in the global literature strengthens the generalizability of atmospheric microplastic biomonitoring. In a transplant study conducted using Ramalina celastri in Argentina, it was reported that microplastic accumulation increased significantly as the level of urbanization increased; in particular, the fragment morphotype showed a stronger relationship with urban areas

(Gollo et al., 2025). The dominance of fragments suggests that mechanical abrasion and secondary plastic degradation processes are more effective in urban environments.

These findings demonstrate that focusing solely on the total amount of microplastics is insufficient in atmospheric microplastic studies conducted in Türkiye (for example, in megacities like Istanbul or in transition zones heavily impacted by road traffic). Instead, considering the distribution of different morphotypes, such as fibers, fragments, and tire wear particles, together will allow for the separation of potential sources and a more accurate interpretation of spatial gradients. In this respect, the results obtained in Argentina offer a strong conceptual and methodological basis for comparison in studies in Türkiye.

The "Photograph or Film?" Debate: The Accumulation-Deposition Distinction and the Methodological Backbone of the Compilation

One of the most critical methodological questions of the compilation is to what extent and under what conditions the atmospheric deposition of microplastics detected in lichen talus can be represented. At this point, the "photograph or film?" approach put forward by Bargagli and Rota clearly frames the conceptual ambiguity in the literature. According to the authors, while data obtained with bioindicators in most cases present a "photograph" of environmental conditions at a specific time, true biomonitoring should produce a "film" that includes temporal integration and reliable representation (Bargagli & Rota, 2025).

Bargagli and Rota (2025) emphasize that lichen–microplastic interaction may be weaker compared to heavy metals or some persistent organic pollutants; the retention of microplastic fibers and particles is highly dependent on environmental factors such as wind, precipitation, and morphological characteristics. Therefore, it is stated that the assumption that microplastics observed in lichen talus directly reflect bulk atmospheric deposition quantitatively should be treated with caution. The same study points out that in many cases, epigeic algae can show higher microplastic accumulation compared to lichens in both active and passive biomonitoring applications.

This methodological framework is also guiding in evaluating the position of the findings from Türkiye discussed in this review

within the world literature. If the aim is to reveal proximity to resources, urban-rural gradients, or spatial distribution patterns, lichens can be considered as strong bioindicators. In contrast, when the goal is to quantitatively determine deposition flows or track temporal trends, it is clear that algae-based approaches, active biomonitoring applications, and calibration with instrumental measurements where possible are necessary.

Bridge with Türkiye Literature: National Visibility and Conceptual Depth

Studies on monitoring atmospheric microplastics in Türkiye through biomonitoring organisms have shown a significant increase in both quantity and methodological maturity in recent years. Review and field-based studies published in the Türkiye literature not only increase awareness on a national scale but also enable the conceptual, terminological, and methodological linking of research conducted in Türkiye with the international literature. This situation shows that microplastic biomonitoring in Türkiye is beginning to become a holistic research field, moving away from scattered individual applications.

One of the studies that strengthens the conceptual basis of this process is the Türkiye review published by Özbey and Yıldız (2025). This study addresses the potential of lichens in microplastic biomonitoring from a holistic perspective, within the framework of sampling strategies, oxidative digestion approaches, fluorescent staining techniques (Rose Bengal and Nile Red), and spectroscopic verification methods (FT-IR). Systematizing the methodological information, which is scattered across different studies in the international literature, into Türkiye terminology has created a common conceptual ground on a national scale and has made a significant contribution to the design of field studies conducted in Türkiye in a manner compatible with the global research language.

This conceptual framework is supported by concrete and comparable data from a lichen-based field study conducted by Çobanoğlu and Özen (2024) on the Asian side of Istanbul. This research, conducted using the species Xanthoria parietina, enabled the evaluation of atmospheric microplastics at an urban scale for the first time in Türkiye using both chemical (FT-IR) and visual (fluorescence microscopy) verification methods. The findings revealed that microplastic components are not limited to areas with

high traffic and tourism; they can also be transported to forested and semi-natural areas. These results are highly consistent with findings related to urban-semi-natural transition zones reported in different geographies such as Italy and Iran.

This national literature framework has been further expanded with a study conducted in Yozgat Çamlık National Park, which includes a lichen-supported multi-stage analytical validation approach. This research, conducted on a protected area scale, has shown that atmospheric microplastic biomonitoring in Türkiye is not limited to urban centers; long-distance atmospheric transport processes should also be considered on a national scale (Kocakaya et al., 2025). In this respect, the study provides a reference example that increases the direct comparability of data obtained in Türkiye with the international literature.

When these studies are considered together, it is seen that microplastic biomonitoring in Türkiye has evolved from being merely a "local application" into a research field directly linked to methodological and conceptual discussions conducted on a global scale. In particular, issues such as the limitations of lichen-based passive biomonitoring approaches, the deposition-accumulation distinction, and the need for multi-stage verification have begun to be addressed in the Türkiye context, in parallel with discussions in the international literature.

In conclusion, the combined evaluation of compilation studies and national-scale field research enhances the scientific visibility of atmospheric microplastic biomonitoring studies conducted in Türkiye and helps these studies gain a clearer position within the world literature. This accumulated knowledge provides a solid scientific foundation for future development of national monitoring networks, long-term biomonitoring programs, and comparative regional studies.

Evaluation of Lichen-Based Atmospheric Microplastic Biomonitoring in Turkiye in a Global Context

When the studies examined in this review are evaluated together, it is seen that the lichen-based atmospheric microplastic biomonitoring study conducted in Türkiye is highly comparable to the global literature, but has a distinctive position in some aspects. While atmospheric microplastic accumulation is mostly discussed in international studies through urban centers, industrial areas and

traffic-congested regions, the fact that the study conducted in Türkiye focuses on Yozgat Çamlık National Park, a protected area, reveals an important difference in terms of spatial context (Kocakaya et al., 2025). Passive biomonitoring studies comparing urban, natural and protected areas reveal that microplastic fibers can be detected even in protected areas, and the findings obtained in Yozgat Çamlık National Park are consistent with this global trend (Taurozzi et al., 2024).

The detection of microplastic fibers in rural and semi-natural area studies conducted in Iran, Italy, and South America indicates that the findings obtained in Türkiye are not exceptional but consistent with globally observed atmospheric transport processes. This supports the idea that microplastic pollution is not limited to local sources; regional and long-distance transport mechanisms play a decisive role.

From a methodological perspective, the combined use of wet peroxide oxidation (WPO), fluorescent staining, and FT-IR/Raman verification techniques in the study conducted in Türkiye aligns with the multi-stage verification approaches proposed in the literature. In this respect, the study offers a more reliable analytical framework compared to approaches based solely on visual identification, which have been limited in some early research. The obtained polymer profiles and fiber morphologies are largely parallel to the trends reported in lichen transplantation and passive biomonitoring studies in Europe and South America.

When evaluated in terms of biomonitor selection, the ability of the lichen species used to effectively capture microplastics in fiber form supports the idea that textile-derived emissions are a common dominant source globally. In this context, the results obtained in Türkiye serve as a local confirmation of the general patterns identified in the global literature.

When evaluated in light of the "photo or film?" approach put forward by Bargagli and Rota, the study in Türkiye presents a spatial cross-section of atmospheric microplastic accumulation over a specific time period. However, this does not limit the value of the study; rather, it highlights a clear research gap in Türkiye for long-term monitoring, active biomonitoring, and studies based on standardized protocols. In this respect, the study is not only a comparative example but also a starting point that forms the scientific foundation for future national monitoring studies.

Conclusion and Future Perspectives

This review clearly demonstrates that atmospheric microplastics are a widespread, persistent, and inter-ecosystem transport environmental pollutant on a global scale. The studies examined show that microplastics are predominantly present in fiber form, with synthetic textiles emerging as a primary source, and that these pollutants are not limited to urban areas but extend to rural and protected areas.

Lichens and algae stand out as effective biomonitors in monitoring atmospheric microplastics due to their direct feeding from the atmosphere and high particle sequestration capacity. Both passive and active biomonitoring approaches offer significant advantages in determining the spatial distribution of microplastics and comparing different environmental contexts.

The lichen-based study conducted in Türkiye produces results consistent with the global literature, but fills a significant gap in the national literature due to its implementation at the protected area scale. This study demonstrates that atmospheric microplastic pollution cannot be considered merely a local environmental problem; it is a multi-scale problem linked to regional and long-distance transport processes.

Future research is recommended to focus on long-term and standardized monitoring designs that integrate passive and active biomonitoring approaches. Furthermore, evaluating biomonitor data in conjunction with meteorological parameters and land-use characteristics will contribute to more accurate identification of microplastic sources.

In conclusion, lichen and algae-based biomonitoring approaches offer cost-effective, feasible, and environmentally friendly tools for monitoring atmospheric microplastic pollution. Studies supported by BAP (Scientific Research Projects Association) in Türkiye demonstrate the applicability of these approaches on a national scale and provide a solid scientific foundation for future national atmospheric microplastic monitoring strategies.

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9	Saka Raji Audu	Issues in 2003 general elections	2003	Yale University Library, ABD	8	JQ3098 .A78 2003 (LC)
10	C. West Churchman, Leonard Auerbach, Simcha Sadan	Thinking for decisions : deductive quantitative methods	1975	Princeton University Library, ABD	6	HD69.D4C49
11	Dennie L. Van Tassel	The Compleat computer	1976	Princeton University Library, ABD	6	QA76 .C547q
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13	Siegfried Engelmann	Corrective reading. Decoding B2 : Decoding strategies	1988	Toronto University Library, Canada	18	428.42 C824 B2 1988
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25	Howard M. Carlisle	Management essentials: concepts and applications	1979	National University of Singapore Library, Singapur	25	HD31 Car
26	Harold T. Smith & William H. Baker	The administrative manager	1978	National University of Singapore Library, Singapur	25	HF5547 Smi
27	Solutions Manual	Thinking for decisions : Deductive quantitative methods	1975	LMU Munich Library, Almanya	32	1006/QH 233 C563-2
28	Henry F. Ledgard & Michael Marcotty	The Programming Language Landscape	1981	Australian National University, Avusturya	50	QA76.7.L44
29	Robert F. McNown & Dwight R. Lee	Economics in our time: macro issues	1976	Australian National University, Avusturya	50	HB171.5.M173
30	Lavette C. Teague & Christopher W. Pidgeon	Structured analysis methods for computer information systems	1985	Australian National University, Avusturya	50	QA76.9.S88T4
31	Paul T. Heyne	The economic way of thinking	1976	Australian National University, Avusturya	50	HB171.5.H46
32	Stanley Rothman & Charles Mosmann	Computers and society: the technology and its social implications	1976	Australian National University, Avusturya	50	QA76.9.C66.R67
33	Stephen Murray Pizer	Numerical computing and mathematical analysis	1975	Australian National University, Avusturya	50	QA297.P59
34	Fran Goertzel Gustavson & C. William Gear	Applications and algorithms in business	1978	Australian National University, Avusturya	50	HF5548.2.G87

NOT: Yayınevimiz tarafından yayınlanan tüm akademik e-kitaplara tüm üniversite kütüphaneleri üzerinden "WorldCat" aracılığı ile ulaşılabilmektedir.

Ek 2: Doçentlik Alanlarına Göre Ayrıştırılarak Seçilmiş Kitap Listeleri

EĞITIM BILIMLERI TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	Leyla Akbaş	Eğitim ve Sosyal Bilimler Araştırmaları
2	Turhan Çetin, Bahadır Kilcan, Yusuf İnel & Osman Çepni	New Horizons in Social Studies Education
3	Neriman Aral, Emel Sardohan Yildirim & Rıdvan Karabulut	Current Trends in Special Education
4	Ali Gül & Nurcan Uzel	Current Researches in Environmental Education
5	Fatma Alisinanoğlu, Vedat Bayraktar & Ali İbrahim Can Gözüm	New Horizons in Early Childhood Education
6	Herman Mundia	Multiple Intelligence Capabilities for Early Childhood Development
7	Amelia Christenson & Magdalena Leslie	Problem Solving Skills of Teachers
8	Sakineh Laila	The Effective School: New School Paradigm
9	Paul Alisa & Stephem Timoty	Teachers' Perceptions of Classroom Behaviour and Working Memory
10	Elegbeleye Trasten	Understanding Anxiety of Secondary School Students
11	Richard Bosire	The Right to Education
12	Sinan Adeyemi	Explanation and Critique of the Principles of Postmodern Moral Education
13	John Tracy	Teaching Dissent and Persuasion
14	Anita Graham	Adult college students' perceptions on science education
15	Brian Martin	Personal science and its implications for science education
16	Tara Coffin	Science Education in the Early Childhood & Special Education Setting
17	Jessica Gale	Comprehensive School Reform and Elementary Science Education
18	Joseph Davis	The historical foundations of modern earth science education
19	Sher Thao	Early Childhood Special Education
20	Lauren Arend	The current state of early childhood education programs
21	Teresa Aligbe Ngozi	Equal access and quality in early childhood education
22	Madeline Madrigal	Special education or special placement?
23	Nancy Ann Hudson	Evaluation of special education teachers
24	Deborah Schumacher	Special education teacher education teacher preparation
25	Raymond Francis Russell	Opinions toward and knowledge of special education law

FEN BILIMLERI VE MATEMATIK TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	Lütfiye Özalemdar	Educational Studies in Science and Mathematics
2	Andrew Komlan Ghoneim	Benefit-Cost Analysis for Sustainable Water Management
3	Harpreet Alina	New Hypoglycemic Agents from Plants
4	Kathleen Walsh	The relationships among mathematics anxiety
5	Shumaila Khan	Computational chemistry and mechanistic modeling of atmospheric chemistry
6	D. Michael Donaher	Honors mathematics education
7	Jamie Smith James	Science, Technology, Engineering, and Mathematics (STEM) Curriculum
8	Iris Clark-Bland	Teaching mathematics strategies
9	James M. Calhoun	An analysis of mathematics interventions
10	Tina Louise Johnston	Pushing into advanced mathematics classes
11	Jillian Know	Brief relational mathematics
12	Samia Hamza Al Farra	The private tuition phenomenon in mathematics
13	James Joseph	Mathematics and nursing
14	Rick Anderson	Mathematics, meaning, and identity
15	Nisha Parmar	Achievement and Persistence in Science
16	Brittany Porter	Mathematics Anxiety, and Teaching Mathematics Efficacy
17	Nathan Bunch	Oral Fluid Method Validation
18	Glen Smith	Achievement and Attitudes in Mathematics
19	Patricia Davis	Is science in danger?
20	Bill Brent	The achievements of "Chemistry in the Community"
21	Carol Wood	Theoretical Studies of Inorganic Molecules
22	Ahmet Akdeniz	Sensing of enantiomeric excess in chiral carboxylates
23	Donald H. Lorenz	Hydrogenolyses with Triaryltin Hydrides
24	Kenneth Muir	Organic and Organometallic Compounds
25	Jules Alan Shafer	Hydrolytic Enzyme Models

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MÜHENDISLIK TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	Abdullah Demir,& İlker Turgut Yılmaz	Current Science and Engineering Research
2	Hasan Öktem	Mühendislik ve Fen Bilimlerinde Yeni Gelişmeler
3	Ali Öz	Academic Perspectives for Engineering Science Metaphors
4	Elizabeth Eden May	Engineering Design Education
5	Chinedu Okonkwo & Simon Odularu	Energy Consumption and Economic Performance
6	Nichole Ramirez	Motivation of Students Who Switch from Engineering to Engineering Technology
7	Xiaofeng Tang	Engineering Knowledge and Student Development
8	Willem Johannes & Cornelis Bakkeren	Computer-integrated structural engineering
9	Theresa Lynn Ceccarelli	Computer -mediated communication in graduate engineering classroom
10	Paul Robert Stalf	Adapting global engineering concepts
11	Guy Savage	Holacratic Engineering Management
12	Sidney E. Martin	Improving Inclusion and Diversity in Engineering
13	Matthew William Ohland	Engineering by Design
14	Daniel Galván	Engineering My Community Cultural Wealth
15	Manuel Poitras	Engineering genomes, engineering societies
16	Wesley A. Carpenter	Engineering creativity and engineering design
17	Brett A. Benowitz	Modeling and Simulation of Random Processes
18	Brett Lougheed	Drafting an archival blueprint for engineering
19	Peter Korfiatis	Development of a virtual concept engineering process
20	Betsy Morrow Aller	Writing practices in the engineering workplace
21	Karimkhan Hirji	Concurrent engineering across distance and time
22	Mi Y. Kwon	Engineering the Interface
23	Jongmin Lee	Engineering the Environment: Regulatory Engineering
24	Brunel Paling	Industrial relations in the building and civil engineering
25	Atte Eerikki Kinnula	Software process engineering in a multisite environment
26	Bayram Kiliç	Pragmatic Approaches to Science and Engineering Studies

MIMARLIK, PLANLAMA VE TASARIM TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	Murat BAŞ	Current Approaches in Engineering and Architecture
2	Nicola Chard	Indeterminate drawings of architecture
3	Reem Al Rawi	The Architecture of War: A Conflict Generated Architecture
4	Jussi Sakari Jauhiainen	Urban planning, urban redevelopment and urban policy
5	Yun Li	Research on the Guiding Role of Industrial Planning in Urban Planning
6	Choi Shan Yeung	Environmental policies and urban planning strategies
7	Guang Yue Zhu	Research on planning discretion in urban planning
8	Michael O'Rourke	Urban and regional planning: Sustainable urban development
9	Basim Sulaiman Al Atni	The Internationalisation of Urban Planning Strategies
10	Agrippa Spence Kellum	On the design-build of small pavilions
11	Rebecca Snyder	The Power of Architecture
12	Erin McDade	Building Language
13	Andrew Phillip Payne	Understanding change in place
14	Katelin Marie Posthuma	A new framework for post-industrial transformation
15	Nicholas Groves	The engagement of architecture & landscape
16	Ulla Salmela	Urban space and social welfare
17	Nicole Beattie-Vallespir	Understanding Design Responsibility in Human Health
18	Robert Kevin Rodriguez	Community design centers on the upsurge
19	Chia-Hui Wang	Evidence-based design for childbirth environments
20	Charles Jason Woodard	Architectural strategy and design evolution in complex engineered systems
21	Nkiruka Nicole Mokwe	Mobile Transactions Architecture
22	Jamil Binabid	Vertical Garden
23	Read Adam	Building towards an identity
24	Cathryn Core	Architecture, Identity, and Performance
25	Adel Bakheet Alzahran	Understanding Outdoor Social Spaces
26	Dilek Erdirençelebi	Sanat, Tasarım ve Mühendislik Alanında Akademik Değerlendirmeler

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SOSYAL, BEŞERI VE İDARI BILIMLER TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	Ömer Kürşad Tüfekci	İş Dünyası Metaforları: Akademik Değerlendirmeler
2	Gürkan Kalkan	Human and Business Oriented Academic Research
3	Sezgin Demir & Fatma Deniz	Riske Dayalı Finansal Iç Kontrol Sistemi ve Bir Model Önerisi
4	Ömer Aydinlioğlu	Ideology in Communication Studies
5	Haşim Özüdoğru, Turhan Çetin & İrfan Yazicioğlu	Current Issues in Economy and Social Sciences
6	Jateen Raoof Mahmood	Tekstil Sektöründe Pazar Yönlülük ve Müşteri Temelli Kurumsal Marka Değeri
7	Hatice Aztimur & Baran Arslan	Teknoloji ve . . .
8	Nezihe Tüfekci	Felsefi ve Toplumsal Eksende Akademik Diyalektik
9	Hasan Göksu	Selected Social Sciences Research with Global and Local Approach
10	Oktay Kızılkaya & Emrak Koçak	Energy and Sustainability: Theoretical and Applied Perspectives
11	Ayşe Çiğdem Mercanlıoğlu	Bankaların Performansında Üst Yönetimin Önemi ve Etkisi
12	Jack Nilson & Marry Harrison	Price Discovery, Trading Costs and Insider Trading
13	Richard Tefera & Stephen Eddie	Ethical Behaviour and Organizational Performance
14	Veronica Jacob & Zainabu Bakalikwira	Immigrant Women's Entrepreneurship
15	Josephat Foroutan	Exploring Human Capital in Tourism
16	Ahiauzu Xin & Kezzie Mwenje	Real Exchange Rate and International Fund Flows
17	Jacob Eliasu & Isaac Vincent	Audit Risk and Corporate Governance
18	Gerardo Piccolo	Population Growth, Urban Expansion and Housing Scenario
19	Elijah Obamuyi	The Relationship between Interest Rates and Economic Growth
20	Ali Firooz Zarea	Managing the Capital Requirement of Business
21	John Brickson	Political Risk and Economic Growth
22	Suresh Folorunso	Green Banking and Sustainability
23	Suzan Woldekidan	The Role of Foreign Aid in Reducing Poverty
24	Isaya Maana, Anne Kamau & Kethi Kisinguh	Volatility and Economic Changes
25	George Grande Regina	Entrepreneurship Complication

ZIRAAT, ORMAN VE SU ÜRÜNLERI TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	K. Matte Rahman	Tenancy and production behaviour in agriculture
2	Linda Joanne Hawk	Distance education in agriculture extension
3	Stephanie Marie Bostic	Fish and Seafood Provisioning
4	Eric Zeldis	Urban agriculture
5	Bruce Alan Larson	The role of agriculture in resource management
6	Kyle Colton Flynn	Local food and agriculture awareness
7	Tewodros Taffese Assefa	Experimental and Modeling Evaluation of Conservation Agriculture
8	Brian Robertson	Geographic Information Systems Used for Precision Agriculture
9	Crane Slater Miller	Agriculture in an Urbanizing Environment
10	Raju Babu Shrestha	Ngos and sustainable agriculture
11	Adam Daigneault	Fire, carbon, timber, and trees
12	Sijia Zhang	Trade, production and exchange rate volatility
13	Sarah E. Quinn	Locally defined measures of successful forest co-management
14	Trevor Anthony Woollery	Tropical forest depletion
15	William Leroy Wagner	Privateering in the public forest
16	Lip Khoon Kho	Carbon cycling in a bornean tropical forest
17	Aaro Ravila	Radiocesium in the forest and forest industry
18	Cara Meghan Starbuck	Examining forest recreation demand
19	Alicia Ushijima Elsholz	Seafood labeling and consumer behavior
20	Brian S. Bennett	Consumer preferences for genetically modified fish and seafood
21	Joanna Beyers	The forest unbundled
22	Hillary Sparks	Benefits of seafood consumption
23	Emily Evmorfopoulos	Chemical and biological aspects of mercury in seafood
24	Mary Catherine Sheehan	Risk of developmental neurotoxicity due to methylmercury in seafood
25	Ellen P. Preece	Detection of the cyanotoxin, microcystin, in seafood

SPOR BILIMLERI TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	Napaporn Candure	Sports Marketing and Advertising Strategies in Sport
2	Rhonda Cohen	Personality, sensation seeking, reaction time and sport participation
3	A. Reppold Filho	Physical education, sport science and the field of human movement studies
4	George William Colpitts	Science, streams and sport
5	Jeffrey Graddy	The future of sport psychology
6	Parissa Safai	Origins, development, and institutionalization of sport medicine
7	Tatjana Riba	Applied sport psychology
8	Michelle Bartlett	Intense training in sport
9	Ryan Sacko	New Insight for Activity Intensity Relativity
10	Andi Johnson	Human performance
11	Isabel Granada Ferrero	The socioeconomic potential of physical and sport activities sector
12	Bang-Chool Kim	Sport, politics and the new nation
13	Rachael Irene Marie Sofie	Fueling sport performance
14	Mindy M. Mayol	Exploring Sport Motivation and Multi-Dimensional Wellness
15	Stephanie M. Eckert	High performance sport versus participatory sport and physical activity
16	Amanda A. Metcalf	History, philosophy, and sociology of sport recommendations
17	Ian Lyle Reade	Managing collaborative relationships between sport organizations
18	Ronald William Quinn	Sport administration program directors at institutions of higher education
19	Shut-yee Jessica Yeung	Performance recovery from exercise
20	Andrée Claude Gaudet LaRocque	Mental Toughness, Competitive Anxiety, and Team Cohesion
21	Andreas Stamatis	Mental Toughness in Sport
22	Cathleen Graham	Popular sport and the practice of development
23	João Paulo Duarte Ramos	Complex Networks Analysis in Team Sports Performance
24	Philip Veliz	The Role of Interscholastic Sport in Public High Schools
25	Lindsey Hamilton	Stress mindset, cognitive appraisals, and sport injury

HUKUK TEMEL ALANI		
S.No	**Yazar(lar)**	**Kitabın Adı**
1	Mark Macguigan	Law, Morals and Natural Law
2	Richard Ross Stacey	The Rule of Law and the Right to Water
3	Dirk Voorhoof	Media law and freedom of communication
4	Bengt Lindell	Matters of fact and matters of law
5	Emma Claridge	Marrying lon fuller to customary international law
6	Abdulrahman Al-Subaihi	International commercial arbitration in islamic law
7	Manfred Schuttengruber	Use of data processing in law
8	Zhi Ming Feng	The identity of international law and national law
9	Julian Nowag	Competition law, state aid law and free-movement law
10	Xin Ren	Tradition of the law and law of the tradition
11	William Franklin Mabe	Shareholder rights laws, financial disclosure laws and insider trading laws
12	Arwa Ibrahim Aljallal	The duty of good faith in insurance law
13	Yvonne Jeannette Chandler	Professional preparation competences for law librarianship
14	Ying-Jun Lin	Balancing and sovereignty in international law
15	Alia Saho	The system of law of damages for breach of contract
16	Randall Kheng Juan Tan	Fulfilling the law apart from the law
17	Bin Yi Yang	Freedom of expression and rule of law on media
18	Ariel Zemach	The relationship between international law and morality
19	Scott Douglas Makar	Essays in law and economics
20	Francisco Javier Andrade	Contractual expansion of judicial review of arbitral awards
21	Sarah Dromgoole	Law and the underwater cultural heritage
22	Nikhil Moro	Freedom of expression and the information society
23	Amandine Decoux	The arbitration agreement and the reality of international trade
24	Beth A. Porterfield	International Environmental Law
25	Laura Ann Foster	Patent Law and Epistemic Citizenship