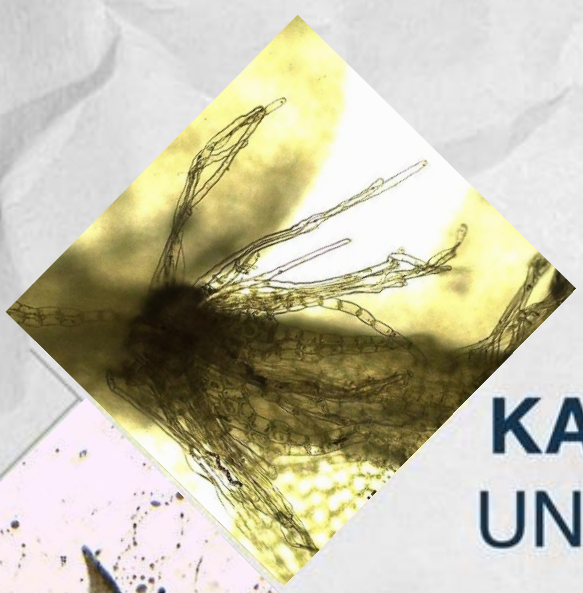

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Kapak fotoğrafı / Cover photo

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3. ***Apometzgeria pebescens*** **by Dr. Tamer KEÇELİ**
4. ***Blaphorostoma trichophyllum*** **by Dr. Tamer KEÇELİ**

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Tel.: +90 376 212 27 57 / 3261; Faks: +90 376 213 6983

E-posta:serhatursavas@gmail.com, anatolianbryology@gmail.com

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Antimicrobial and Antibiofilm Potentials of *Rhynchostegium riparioides* (Hedw.) Cardot Extracts

Cenker YAMAN[1,*], Gülcan GÖREN[2], Gizem GÜL[1], Kutay Orkun DURUKAN[2], Ezginur DUMAN[2], Dilay TURU[1], Atakan BENEK[3], Ayşe Dilek UNAN[4], Mustafa Eray BOZYEL[2], Kerem CANLI[2,3]

*[*1]Dokuz Eylül University, Graduate School of Natural and Applied Science, Department of Biology, İzmir, TÜRKİYE*
[2]Dokuz Eylül University, Faculty of Science, Department of Biology, İzmir, TÜRKİYE
[3]Dokuz Eylül University, Fauna and Flora Research and Application Center, İzmir, TÜRKİYE
[4]Zonguldak Bülent Ecevit University, Faculty of Science, Biology Department, Zonguldak, TÜRKİYE

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Abstract

In this study, antimicrobial and antibiofilm activities of extracts obtained from the moss *Rhynchostegium riparioides* using ethanol, methanol, n-hexane, and water solvents were evaluated. Standard strains, food isolates, and clinical isolates, including multidrug-resistant strains, were utilized in the tests. The efficacy of the extracts was determined using disk diffusion and minimum inhibitory concentration (MIC) methods, and their phytochemical profiles were analyzed by Gas Chromatography-Mass Spectrometry (GC-MS). The n-hexane extract showed the highest antimicrobial activity, demonstrating strong effects even at the lowest tested concentrations. This extract was predominantly composed (79.29%) of tris(2,4-di-tert-butylphenyl) phosphate. The methanol extract exhibited broad-spectrum activity, notably effective against *Enterococcus faecalis* and *Escherichia coli*, and major compounds identified included neophytadiene (21.55%), palmitic acid (18.65%), and linolenic acid (10.45%). In the antibiofilm assays, a strong inhibition of up to 95% was observed, particularly against *Listeria innocua*. These findings highlight the potential of the n-hexane extract for development as a natural antibiofilm agent. The findings underscore the potential for developing the n-hexane extracts as natural antibiofilm agents.

Keywords: Biofilm inhibation, antibacterial effect, Gas Chromatography-Mass Spectrometry (GC-MS).

Rhyncostegium riparioides (Hedw.) Cardot Ekstraktlarının Antimikrobiyal ve Antibiyofilm Potansiyelleri

Öz

Bu çalışmada, *Rhynchostegium riparioides* karayosunundan etanol, metanol, n-hekzan ve su çözücüleri ile elde edilen ekstraktların antimikrobiyal ve antibiyofilm aktiviteleri değerlendirilmiştir. Testlerde standart suşlar, gıda izolatı ve çoklu ilaç direncine sahip suşların da bulunduğu klinik izolatlar kullanılmıştır. Ekstraktların etkinliği disk difüzyon ve minimum inhibitör konsantrasyon (MİK) yöntemleriyle belirlenmiş, fitokimyasal profilleri ise Gaz Kromatografisi-Kütle Spektrometrisi (GC-MS) ile analiz edilmiştir. En yüksek antimikrobiyal aktiviteyi, test edilen en düşük konsantrasyonlarda bile güçlü etki gösteren ve içeriğinin %79,29'unu tris(2,4-di-tert-bütilfenil) fosfat bileşiğinin oluşturduğu n-hekzan ekstraktı sergilemiştir. Metanol ekstraktı geniş spektrumlu bir etki göstererek özellikle *Enterococcus faecalis* ve *Escherichia coli* üzerinde etkili bulunmuş, ekstraktta neofitadien (%21,55), palmitik asit (%18,65) ve linolenik asit (%10,45) gibi majör bileşikler tanımlanmıştır. Antibiofilm testlerinde özellikle *Listeria innocua* üzerinde %95'e varan güçlü bir inhibisyon gözlenmiştir. Bulgular, özellikle n-hekzan ekstraktının doğal antibiyofilm ajanı olarak geliştirilmesi açısından önem taşımaktadır.

Anahtar kelimeler: Biyofilm inhibisyonu, antibakteriyel etki, Gaz Kromatografisi-Kütle Spektrometresi (GC-MS).

* Corresponding author: cenkeryaman@gmail.com

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1. Introduction

The World Health Organization (WHO) and numerous scientific institutions predict that antimicrobial resistance will become one of the greatest threats to the global healthcare system in the near future (Abebe, 2020). Currently, approximately 700.000 people die annually due to antimicrobial resistance (O'Neill, 2016). Furthermore, if the rate of resistance acquisition continues at this pace, it is estimated that by 2050, 10 million people will die each year due to antimicrobial resistance (TEPAV, 2017). Multidrug-resistant (MDR) bacteria, due to their resistance to existing antibiotics, particularly act as opportunistic pathogens in hospital settings, causing increasing mortality rates and posing a serious threat to public health (Aslam et al., 2021). These examples clearly demonstrate the significant risk posed by pathogens resistant to current antibiotics to public health, explaining why antimicrobial resistance is considered one of the most critical global health challenges of the 21st century.

Biofilms are another resistance mechanism, which are microbial communities where bacteria organize themselves within self-produced extracellular polymeric matrices, adhering to surfaces (Samastı, 2021). This structure protects bacteria from antimicrobial agents and complicates infection treatment (Temel & Eraç, 2018). Detecting pathogenic microorganisms that form biofilms and determining their antibiotic resistance is crucial for disease management (Kartal, 2021). Current antibiotics used for treating biofilm-associated infections are often insufficient, highlighting the need to develop new antibiofilm agents.

As an alternative to bacteria resistant to existing antibiotics, exploring natural sources whose chemical compositions have not yet been fully elucidated offers significant advantages for discovering new antimicrobial agents. Foremost among these advantages is the rich phytochemical content developed over evolutionary processes. These natural compounds may contain unique functional groups and stereoisomeric configurations that are difficult to synthesize in laboratory settings (Newman & Cragg, 2016). Moreover, the constant interaction of these organisms with bacterial pathogens in their natural environments allows them to produce biological compounds with high specificity and efficacy against certain biological targets (Cowan, 1999). The synergistic effects of complex compound mixtures in natural extracts make it more difficult for pathogens to develop resistance compared to single compounds (Rios & Recio, 2005). Additionally, natural compounds tend to exhibit lower toxicity compared to synthetic ones, making them more attractive as potential therapeutic agents (Fabricant & Farnsworth, 2001).

Bryophytes, a group of non-vascular plants, although understudied, stand out due to their richness in secondary metabolites and bioactive compounds with therapeutic potential (Aslanbaba et al., 2017). Considering bryophytes' pioneering role in the transition and adaptation of plants from aquatic to terrestrial environments, their potential gains even greater significance (Wickett et al., 2014; Ursavaş and Ediş, 2024). It should also be noted that terrestrial ecosystems encountered by plants were already dominated by microorganisms; bryophytes, which emerged approximately 470–500 million years ago, have survived through evolutionary competition with microorganisms by developing compounds that allowed their persistence (Kenrick & Crane, 1997). This millions-of-years-long competition is a key factor contributing to the unique and rich chemical composition of bryophytes, making them attractive as therapeutic agents.

Mosses have been used ethnopharmacologically for many years across different regions such as India, China, and the Americas. This traditional use is based on the preference of local populations for mosses due to their wound healing, anti-inflammatory, and infection-preventing properties. Modern studies have reported that mosses exhibit antimicrobial, antiviral, antifungal, and neuroprotective effects (Motti et al., 2023; Şahin & Aslan, 2023). Reliable data derived from traditional use indicate a favorable toxicological profile of the plant and strengthen its potential for the development of new therapeutic agents in modern pharmaceutical research.

The plant group known as bryophytes is classified into mosses (Bryophyta), liverworts (Marchantiophyta), and hornworts (Anthocerotophyta) (Benek, 2024)[1]. The subject of the study, *Rhynchostegium riparioides* (Hedw.) Cardot, is a robust moss species exhibiting colors ranging from bright green to brownish tones, sometimes with darkish lower parts. Its shoots, which can grow up to 15 cm, are pendulous or prostrate and often leafless at the lower sections. It is typically found along stream on moist stone surfaces, acquiring a metallic sheen when dry (Smith, 2006)[1].

The species *R. riparioides* is noted for its ecological resilience. Its size and coverage vary depending on the quality and purity of the water it

inhabits; it tends to grow larger and spread more extensively in clean, cold waters (Haziri, 2018). Due to these characteristics, *R. riparioides* can be used as a biological indicator to assess the cleanliness of aquatic ecosystems (Smith, 2006; Rimac et al., 2022). Studies suggest that extracts of *R. riparioides* may exhibit antimicrobial effects against various pathogenic microorganisms (Basile et al., 1998). However, its efficacy against drug-resistant bacteria and its potential to prevent biofilm-related infections have yet to be extensively explored.

This study aims to investigate the antimicrobial and antibiofilm activities of *R. riparioides* extracts prepared using different solvents against various pathogens. The findings will contribute to identifying the antimicrobial and antibiofilm components of this moss and highlight its potential applications in pharmaceutical and medical fields. Additionally, the biochemical compositions of *R. riparioides* extracts prepared with different solvents (ethanol, methanol, and n-hexane) were elucidated through gas chromatography-mass spectrometry (GC-MS) analyses. Comparative analysis of their chemical compositions and biological activities is important for providing a solid scientific foundation for future studies.

2. Material and Methods

2.1. Moss samples

The moss *R. riparioides* was collected from Kardeşler/Zonguldak (41° 25' 07.2''N & 31° 43' 05.1''E) and identified by Ayşe Dilek Unan. The moss sample was placed in a sample bag and transported to the laboratory. Following natural air-drying under ambient conditions, tit was stored at the Fauna and Flora Research and Application Center (FAMER) of Dokuz Eylül University, located in Buca, Izmir, Turkey, under the herbarium code "FFDEU-MEB2," where it was preserved until experimental procedures were initiated.

2.2. Extraction procedure

Extraction was performed according to the method described by Canlı et al. (2015). To avoid potential toxic effects of the solvents, extracts intended for Minimum Inhibitory Concentration (MIC) and antibiofilm activity tests were freed from these solvents; the resulting dry residues were dissolved in 1% dimethyl sulfoxide (DMSO) to obtain water-based extracts. These extracts were prepared in volumes of 15 mL, with the contained substance amounts as follows: 0.661 g for the ethanol extract, 0.193 g for the methanol extract, and 0.016 g for the n-hexane extract. The aqueous extract was directly prepared in 15 mL of distilled water with a substance amount of 1.266 g.

For use in disk diffusion tests and GC-MS (Gas Chromatography-Mass Spectrometry) analyses, extracts were prepared as formulations in 25 mL solvent volumes with substance amounts of 0.452 g for ethanol, 0.682 g for methanol, and 0.062 g for n-hexane. The contents of the extracts prepared for different tests are presented in the table below.

Table 1. Extract informations.

Test type	Solvent	Amount of substance (mg/ml)
MIC & Antibiofilm tests	Ethanol	44.066
	Methanol	12.866
	n-Hexane	1.066
	Water	84.4
Disc difusion & GC-MS analysis	Ethanol	18.08
	Methanol	27.28
	n-Hexane	2.48

2.3. Microorganisms

In this study, a total of 27 strains were analyzed, comprising 7 Food Isolates (FI), 12 Standard Isolates (ST)—including one yeast strain—and 13 Clinical Isolates (CI), of which two were yeast strains. These microorganisms were obtained from the microbiology laboratory of the Department of Biology, Faculty of Science, Dokuz Eylül University (Table 3-5).

2.4. Inoculum preparation

Bacterial strains were pre-cultured at 37°C for 24 hours, while the yeast strain was incubated at 28°C for 48 hours. To standardize microbial density, all cultures were adjusted to a turbidity of 0.5 McFarland using sterile saline (0.9% NaCl). This process resulted in approximate concentrations of 10^8 CFU/mL for bacterial suspensions and 10^7 CFU/mL for *Candida albicans*. The standardized inocula were prepared for use in all experimental studies (Gül et al., 2025).

2.5. Disc diffusion method

The antimicrobial activity of *R. riparioides* extracts was evaluated using the disk diffusion method, as described by Andrews (2003). Each solvent was tested at an equivalent volume (150 µL) and loaded onto 6 mm antimicrobial susceptibility test discs. Rather than applying the entire volume at once, these volumes were incrementally loaded in 10 µL steps. To allow for the evaporation of residual solvents, the disks were left to dry overnight, yielding disks containing 2,71 mg of substance for the ethanol extract, 4,09

mg for the methanol extract, and 0,37 mg for the n-hexane extract. Subsequently, pre-prepared microorganisms, suspended in sterile saline solution, were inoculated onto the surface of Petri dishes to ensure uniform coverage. Following inoculation, the extract-loaded disks were placed onto the agar surface, and the plates were incubated. The diameters of the resulting inhibition zones were measured in millimeters (mm) using a caliper and recorded.

Sterile blank disks and the extraction solvent (ethanol) served as negative controls, while Gentamicin and Tobramycin antibiotic disks were utilized as positive controls. All tests were performed in triplicate, and the results are presented as the mean with standard errors (Baldas & Altuner, 2018).

2.6. Minimum inhibitory concentration test

The Minimum Inhibitory Concentration (MIC) is defined as the lowest concentration of an extract that inhibits visible bacterial growth. For MIC determination, the serial dilution method recommended by Benek et al. (2024) was employed, yielding the following concentration ranges: 14,68 – 0,11 mg/ml for ethanol, 4,28 – 0,03 mg/ml for methanol, 0,35 – 0,01 mg/ml for n-hexane, and 28,13 – 0.21 mg/ml for water. Wells containing no extract served as positive controls, while wells without bacteria were used as negative controls. All assays were conducted in triplicate.

2.7. Antibiofilm activity

In this study, the antibiofilm assays were conducted by adapting the method described in Tunca-Pinarlı (2023). The experimental procedure consisted of two main stages: determination of optimal biofilm formation conditions and evaluation of antibiofilm activity. In the first stage, incubation times and culture media conditions were optimized to achieve maximal biofilm formation by the microorganisms. In the second stage, under these optimized conditions, the biofilm inhibition potential of the extracts was assessed.

2.8. Gas chromatography-mass spectrometry (GC-MC) analysis

GC-MS Analysies were carried out with adaptations from the method described by Bozkurt et al. (2024). The experiments utilized an Agilent GC 8890 coupled with an Agilent GC/MSD 5977B system (Agilent Technologies Inc., Santa Clara, CA, USA), featuring an HP5-MS capillary column measuring 30 m in length, 0.25 mm in internal diameter, and 0.25 µm film thickness. The analytical parameters were set as follows: injector temperature maintained at 350°C, helium served as the carrier gas with a flow rate of 1 ml/min. The injection was performed in split mode with a split ratio of 10:1, using an injection volume of 1 µl of the ethanol extract. The oven temperature program started at 40°C and was ramped up to 350°C at 4°C per minute, followed by a 10-minute hold at 350°C. For mass spectrometry, the transfer line and interface temperatures were both maintained at 280°C, while the ion source temperature was set to 230°C. Identification of compounds was based on matching retention times with the Wiley-NIST MS library database.

2.9. Statistics

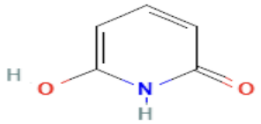
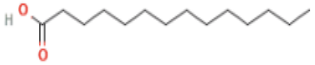
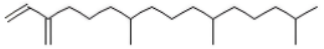
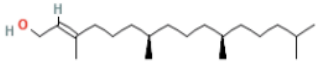
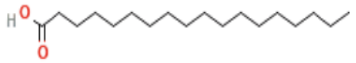
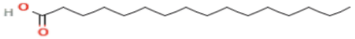
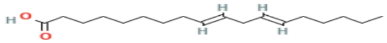
The results obtained from three independent repetitions for each activity are expressed as mean ± standard deviation (SD). Following statistical analysis of the data, values were determined using Four-Parameter Logistic Regression with a 95% confidence interval. Data were analyzed using One-Way ANOVA (Analysis of Variance) and Pearson correlation tests in R Studio (Version: 2025.05.01+513). The level of statistical significance was set at $p \leq 0.05$ (Dyakov et al., 2011).

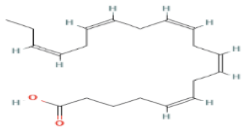
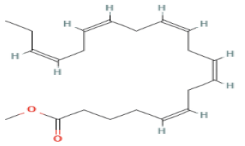
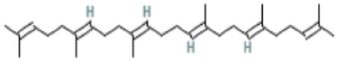
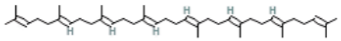
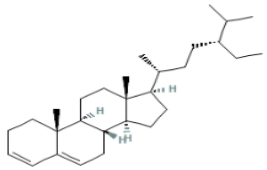
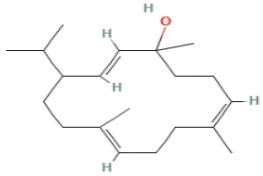
3. Results

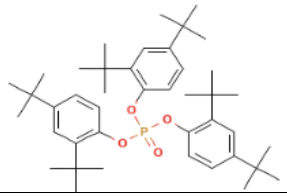
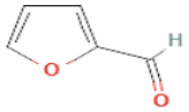
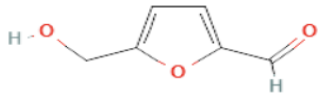
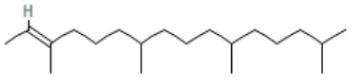
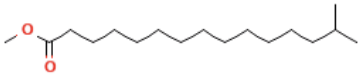
3.1. Biochemical compounds in extracts

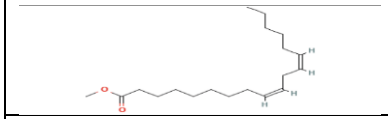
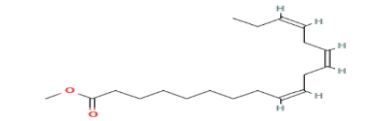
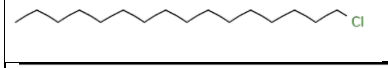
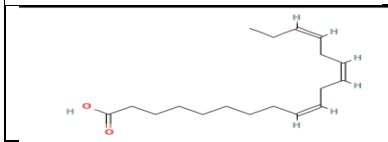
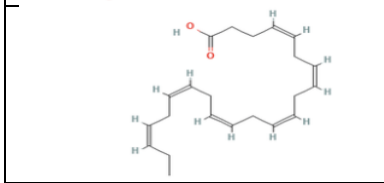
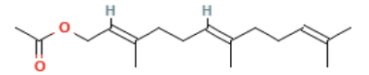
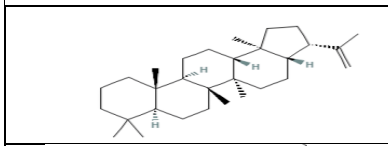
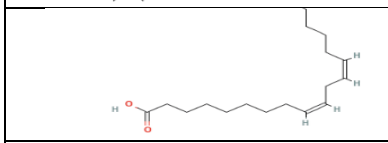
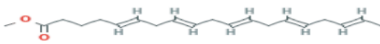
The area percentages of the compounds identified by GC-MS analysis are presented in Table 2.

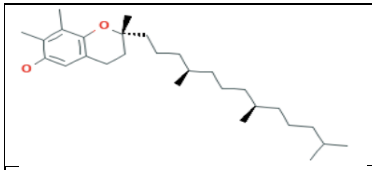
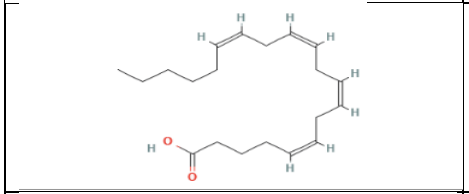
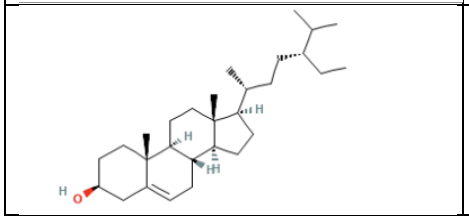
Table 2. Biochemical profiling of R. riparioides extracts.

Chemical Structure	Compound name	RT	Formula	MW (g/mol)	RR Ethanol extract	RR Methanol extract	RR n-Hexane extract	Known Activity
	2,6-Dihydroxypyridine	13.658	$C_5H_5NO_2$	111.1	1.30	-	-	-
	Tetradecanoic acid	31.101	$C_{14}H_{28}O_2$	228.37	0.81	0.62	-	Anti-inflammatory activity (Najda et al., 2021)
	Neophytadiene	32.398	$C_{20}H_{38}$	278.5	41.16	21.55	-	Antibacterial and Antifungal activity (Ceyhan-Güvensen & Keskin, 2016)
	Phytol	32.242	$C_{20}H_{40}O$	296.5	2.89	1.56	-	Antioxidant and Antimicrobial activity (Islam et al., 2018)
	Stearic acid	40.450	$C_{18}H_{36}O_2$	284.5	6.07	0.88	0.87	Antifungal and Anti-inflammatory activity (Guimarães & Venâncio, 2022; Miao et al., 2015)
	Palmitic acid	36.003	$C_{16}H_{32}O_2$	256.42	6.97	18.65	0.73	Anticancer activity (Yu et al., 2023)
	Linoelaidic acid	40.768	$C_{18}H_{32}O_2$	280.4	1.55	-	-	Carcinogenesis and Proliferative activity (Ip et al., 1994)

	Eicosapentaenoic acid	45.238	$C_{20}H_{30}O_2$	302.5	2.86	-	-	Antimicrobial activity (Chanda et al., 2018)
	Icosapent methyl	44.261	$C_{21}H_{32}O_2$	316.5	-	1.09	-	-
	Squalene	59.590	$C_{30}H_{50}$	410.7	1.39	1.07	-	Antioxidant, anti-inflammatory, and anticancer activity (Lou-Bonafonte et al., 2018)
	Lycopersene	62.543	$C_{40}H_{66}$	547	2.24	-	-	Antioxidant, Anti-inflammatory, and Anticancer activity (Lou-Bonafonte et al., 2018)
	Stigmasta-3,5-diene	66.218	$C_{29}H_{48}$	396.7	1.63	-	-	Antistaphylococcal, Antihypertensive, Antiulcer, and Antidiabetic activity (Tabassum et al., 2022)
	Thunbergol	74.875	$C_{20}H_{34}O$	290.5	1.02	-	-	Antioxidant and Anti-inflammatory activity (Shah et al., 2023)
	Nonacosane	45.207	$C_{29}H_{60}$	408.8	-	-	0.66	-
	Docosane	47.891	$C_{22}H_{46}$	310.6	-	-	1.46	Antioxidant activity (Salem et al., 2016)

	Pentacosane	50.689	$C_{25}H_{52}$	352.7	-	-	2.48	-
	Hexacosane	53.591	$C_{26}H_{54}$	366.7	-	-	2.52	Antioxidant activity (Marrufo et al., 2013)
	Heneicosane	56.580	$C_{21}H_{44}$	296.6	-	-	2.16	Antibacterial activity (Wijayanti & Dewi, 2022)
	Octacosane	59.611	$C_{28}H_{58}$	394.8	-	-	4.43	Antimicrobial activity (Khatua et al., 2016)
	Heptacosane	66.056	$C_{27}H_{56}$	380.7	-	-	0.75	Antioxidant activity (Akpuaka et al., 2013)
	tris(2,4-di-tert-butylphenyl) phosphate	73.546	$C_{42}H_{63}O_4P$	662.9	-	-	79.29	Anti-enterococcal, Antioxidant activities (AlRaddadi et al., 2024)
	Furfural	6.493	$C_5H_4O_2$	96.08	-	0.71	-	Antimicrobial activity (Chai et al., 2013)
	5-Hydroxymethyl-furfural	6.493	$C_6H_6O_3$	126.11	-	9.70	-	Anti-inflammatory activity (Kong et al., 2019)
	Phytene-2	32.672	$C_{20}H_{40}$	280.5	-	1.51	-	-
	Methyl Palmitate	34.901	$C_{17}H_{34}O_2$	270.5	-	1.99	-	Anti-inflammatory activity (El-Demerdash, 2011)

	Methyl Linoleate	39.546	$C_{19}H_{34}O_2$	294.5	-	0.74	-	Antifungal activity (Pinto et al,2017)
	Methyl Linolenate	39.763	$C_{19}H_{32}O_2$	292.5	-	1.13	-	-
	1-Chlorohexadecane	39.987	$C_{16}H_{33}Cl$	260.899	-	0.82	-	-
	Linolenic acid	41.728	$C_{18}H_{30}O_2$	278.4	4.60	10.45	-	Anti-inflammatory and Antibacterial activity (Yan et al.,2024)
	Docosahexaenoic acid	46.568	$C_{22}H_{32}O_2$	328.5	-	4.38	-	Anticancer activity (Jiao et al., 2017)
	Farnesyl acetate	63.596	$C_{17}H_{28}O_2$	264.4	-	1.20	-	Antioxidant, Antibacterial Anticancer activity (Tian et al., 2022)
	Diploptene	72.803	$C_{30}H_5O$	410.7	4.69	2.81	-	-
	Linoleic acid	40.953	$C_{18}H_{32}O_2$	280.4	3.26	-	-	-
	Methyl eicosa-5,8,11,14,17-pentaenoate	46.123	$C_{21}H_{32}O_2$	316.5	2.89	2.21	-	Antifungal activity (Pinto et al., 2017)

	Vitamin E	68.229	$C_{29}H_{50}O_2$	430.7	1.59	-	-	Antioxidant and Anti-inflammatory activities (Aboubakr et al., 2023)
	Arachidonic acid	44.066	$C_{20}H_{32}O_2$	304.5	-	1.20	-	Anti-inflammatory activities (Das, 2018)
	Beta sitosterol	72.083	$C_{29}H_{50}O$	414.7	-	5.71	-	Anti-inflammatory activities (Mattioli et al., 2013)

3.2. Disk diffusion test results

All extracts were tested at a volume of 150 microliters, with three replicates performed. Strains for which no antimicrobial activity was observed in the disk diffusion test are indicated with a '-' symbol.

Table 3. The antimicrobial activity of *R. riparioides* against standard microorganisms (Inhibition zones in mm).

Standard Isolated Microorganisms	Ethanol	Methanol	n-Hexane	Gentamicin (10 µg)	Tobramycin (10 µg)
Bacillus subtilis DSMZ 1971	-	-	-	30	26
Candida albicans DSMZ 1386	-	-	-	12	13
Enterobacter aerogenes ATCC 13048	-	-	-	24	18
Enterococcus faecalis ATCC 29212	7.00 ± 0.00	7.00 ± 0.00	-	12	8
Escherichia coli ATCC 25922	-	-	-	22	20
Listeria monocytogenes ATCC 7644	-	-	-	28	24
Pseudomonas aeruginosa DSMZ 5071	-	-	-	15	22
Pseudomonas fluorescens P1	-	-	-	13	12
Salmonella enteritidis ATCC 13076	-	-	-	21	-
Salmonella typhimurium SL 1344	-	-	-	24	15
Staphylococcus aureus ATCC 25923	-	-	-	21	14
Staphylococcus epidermidis DSMZ 20044	-	-	7.00 ± 0.00	22	20

Table 4. The antimicrobial activity of *R. riparioides* against foodborne microorganisms (Inhibition zones in mm).

Food Isolated Microorganisms	Ethanol	Methanol	n-Hexane	Gentamicin (10 µg)	Tobramycin (10 µg)
Enterococcus durans	-	-	-	30	26
Enterococcus faecium	-	-	-	12	13
Klebsiella pneumoniae	-	-	7.00 ± 0.00	24	18
Listeria innocua	7.00 ± 0.00	-	-	12	8
Salmonella infantis	-	-	-	22	20
Salmonella kentucky	-	-	-	28	24
Escherichia coli	-	7.00 ± 0.00	-	15	22

Table 5. The antimicrobial activity of *R. riparioides* against clinical isolated microorganisms (Inhibition zones in mm).

Clinic Isolated Microorganisms	Ethanol	Methanol	n-Hexane	Gentamicin (10 µg)	Tobramycin (10 µg)
Staphylococcus aureus	-	-	-	30	26
Streptococcus mutans	-	-	-	12	13
Staphylococcus hominis	-	-	-	24	18
Staphylococcus haemolyticus	-	-	-	12	8
Staphylococcus lugdunensis	-	-	7.00 ± 0.00	22	20
Shigella boydi	-	-	-	28	24
Acinetobacter baumannii	-	-	-	15	22
Shigella flexneri	-	-	-	13	12
Staphylococcus aureus	-	-	-	21	-
Enterococcus faecalis	-	-	-	24	15
Klebsiella pneumoniae	-	-	-	21	14
Candida tropicalis	-	-	-	22	20
Candida glabrata	-	-	7.00 ± 0.00	7	8

3.4 MIC & MBC tests results

The MIC values represent the minimum concentrations of the extracts required to inhibit visible microbial growth. MBC (Minimum Bactericidal Concentration) and MFC (Minimum Fungicidal Concentration) values indicate the lowest concentrations at which the extracts exert bactericidal or fungicidal effects, respectively, by completely eliminating the tested microorganisms.

Table 6. MIC and MBC/MFC concentrations of the ethanol extract of *R. riparioides*.

Microorganisms	MIC	MBC/MFC
E. faecalis ATCC 29212	7340 µl/ml	14680 µl/ml
L. innocua (FI)	7340 µl/ml	14680 µl/ml

Table 7. MIC and MBC/MFC concentrations of the methanol extract of *R. riparioides*.

Microorganisms	MIC	MBC/MFC
E. faecalis ATCC 29212	2140 µl/ml	4280 µl/ml
E. coli (FI)	4280 µl/ml	4280 µl/ml

Table 8.MIC and MBC/MFC concentrations of the n-Hekzan extract of *R. riparioides*.

Microorganisms	MIC	MBC/MFC
S. epidermidis DSMZ 20044	350 µl/ml	350 µl/ml
K. pneumoniae (FI)	350 µl/ml	350 µl/ml
S. lugdunensis (CI)	350 µl/ml	350 µl/ml
C. glabrata (CI)	350 µl/ml	350 µl/ml

3.4.1. Results of the MIC test conducted for biofilm

Table 9. MIC and MBC/MFC concentrations of the ethanol extract of *R. riparioides*.

Microorganisms	MIC
Bacillus subtilis DSMZ 1971	14680 µl/ml
Listeria innocua (FI)	3670 µl/ml

Tablo 10. MIC and MBC/MFC concentrations of the methanol extract of *R. riparioides*.

Microorganisms	MIC
Listeria innocua (FI)	1070 µl/ml

3.4 Antibiofilm effect results

The antibiofilm activities of the extracts against the tested strains are presented in the graphs between Figure 1 and Figure 21. OD_{550} refers to the optical density measured at 550 nm, which was used for the spectrophotometric quantification of biofilm mass stained with crystal violet. The percentage of inhibition values presented in the figures were calculated relative to the positive control using the following formula: % Inhibition = [(ODcontrol – ODsamples) / ODcontrol] × 100.

In the *E. coli* strain, treatments with the ethanol extract of *R. riparioides* were found to reduce biofilm formation at all tested concentrations. The highest reduction was recorded at a concentration of 7.3450 µg/mL, with a biofilm inhibition rate of 70.02%. At other concentrations, inhibition rates of 68.72% at 14.6900 µg/mL, 67.53% at 1.8362 µg/mL, 66.07% at 0.9181 µg/mL, 64.92% at 0.4591 µg/mL, and 60.07% at 3.6725 µg/mL were observed.

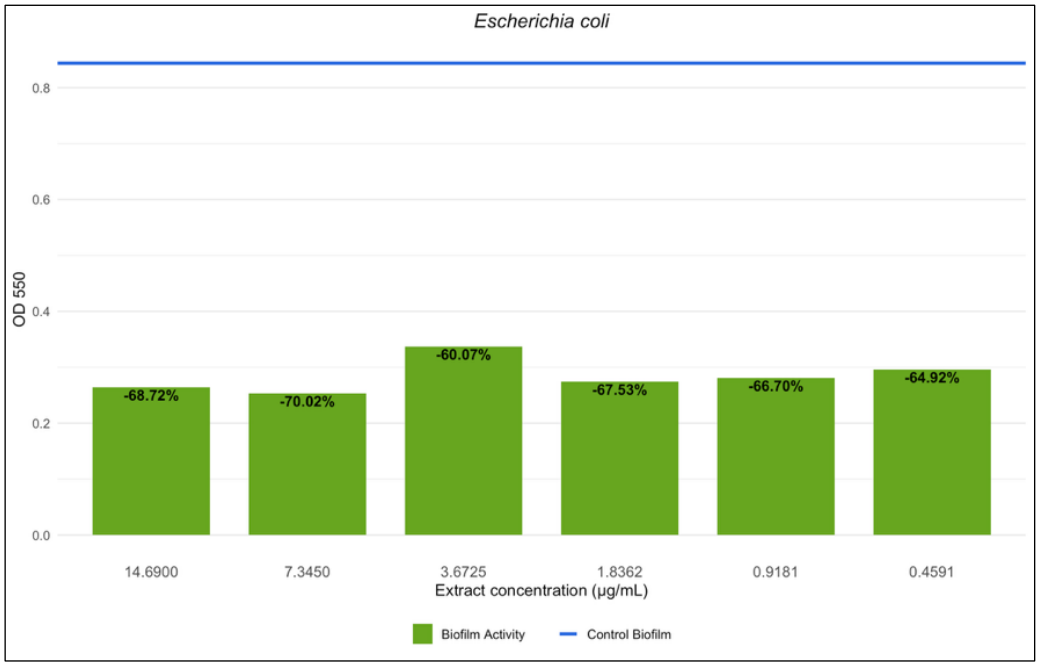


Figure 1: Graph showing the antibiofilm effect of *Rhynchostegium riparioides* ethanol extract against *Escherichia coli*

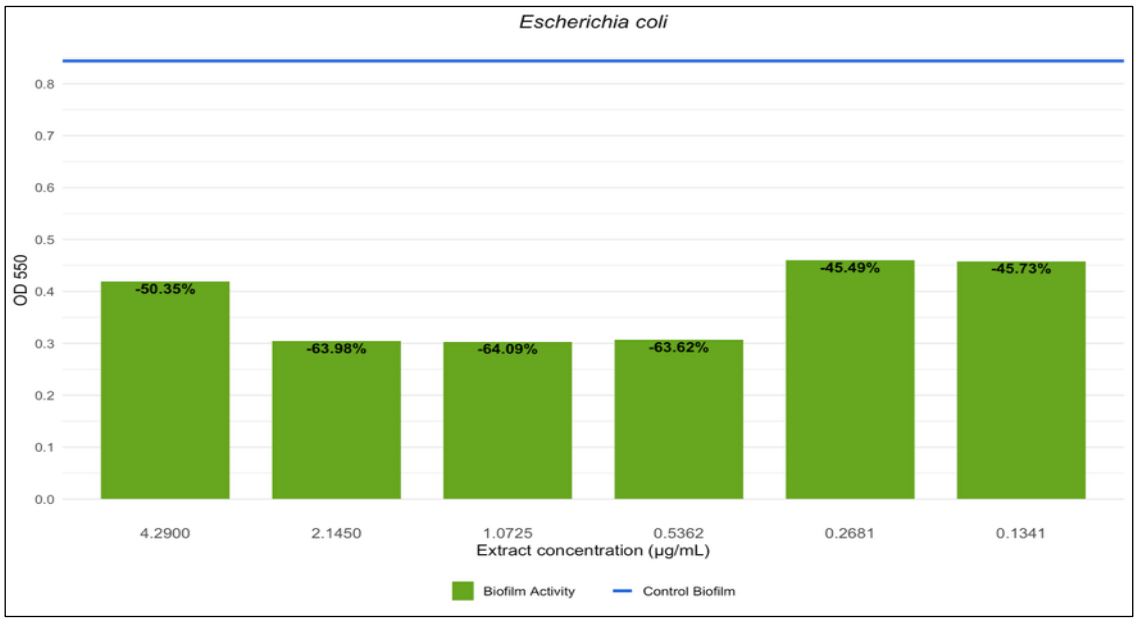


Figure 2: Graph showing the antibiofilm effect of *Rhynchostegium riparioides* methanol extract against *Escherichia coli*

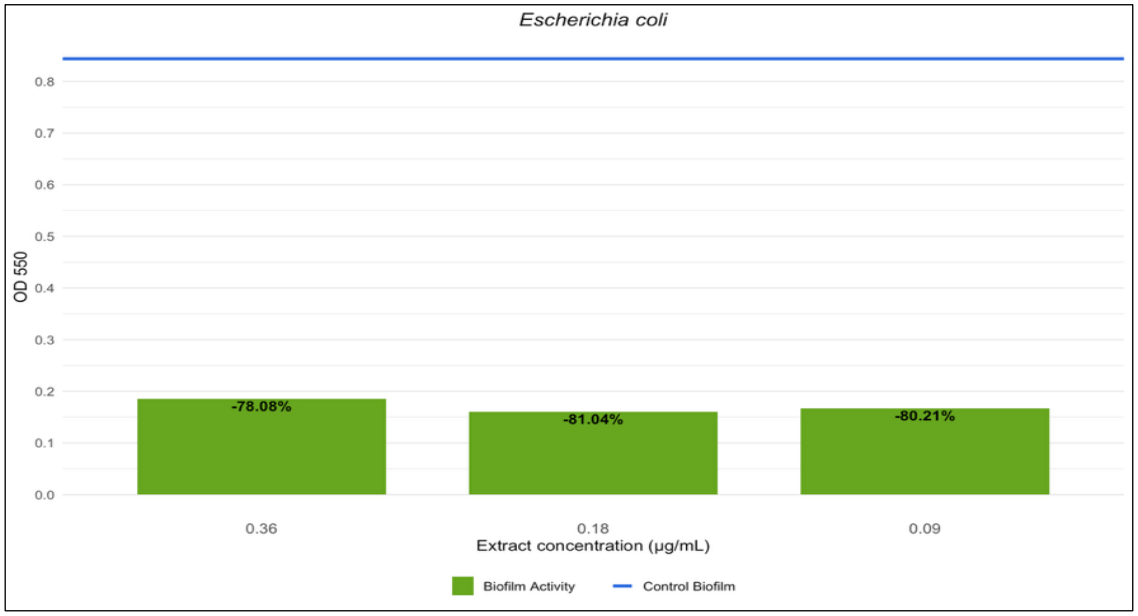


Figure 3: Graph showing the antibiofilm effect of *Rhynchostegium riparioides* n-hexane extract against *Escherichia coli*

In the *E. coli* strain, treatments with the methanol extract of *R. riparioides* were found to reduce biofilm production at all tested concentrations. The highest reduction was observed at a concentration of 1.0725 µg/mL, with a biofilm inhibition rate of 64.09%. At the other concentrations, inhibition rates of 63.62% at 0.5362 µg/mL, 63.98% at 2.1450 µg/mL, 60.35% at 4.2900 µg/mL, 45.73% at 0.1341 µg/mL, and 45.49% at 0.2681 µg/mL were recorded.

In the *E. coli* strain, treatments with the hexane extract of *R. riparioides* were found to significantly reduce biofilm formation at all tested concentrations. The highest reduction was recorded at a concentration of 0.18 µg/mL, with a biofilm inhibition rate of 81.04%. At the other concentrations, inhibition rates of 80.21% at 0.09 µg/mL and 76.08% at 0.36 µg/mL were observed.

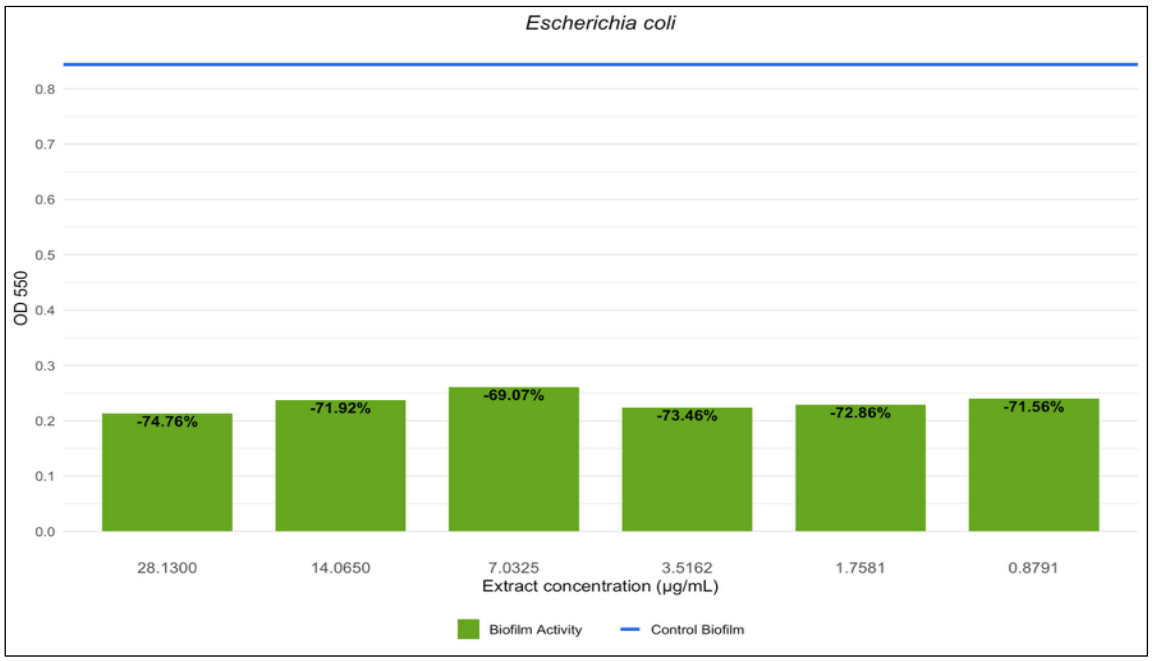


Figure 4: Graph showing the antibiofilm effect of *Rhynchostegium riparioides* water extract against *Escherichia coli*

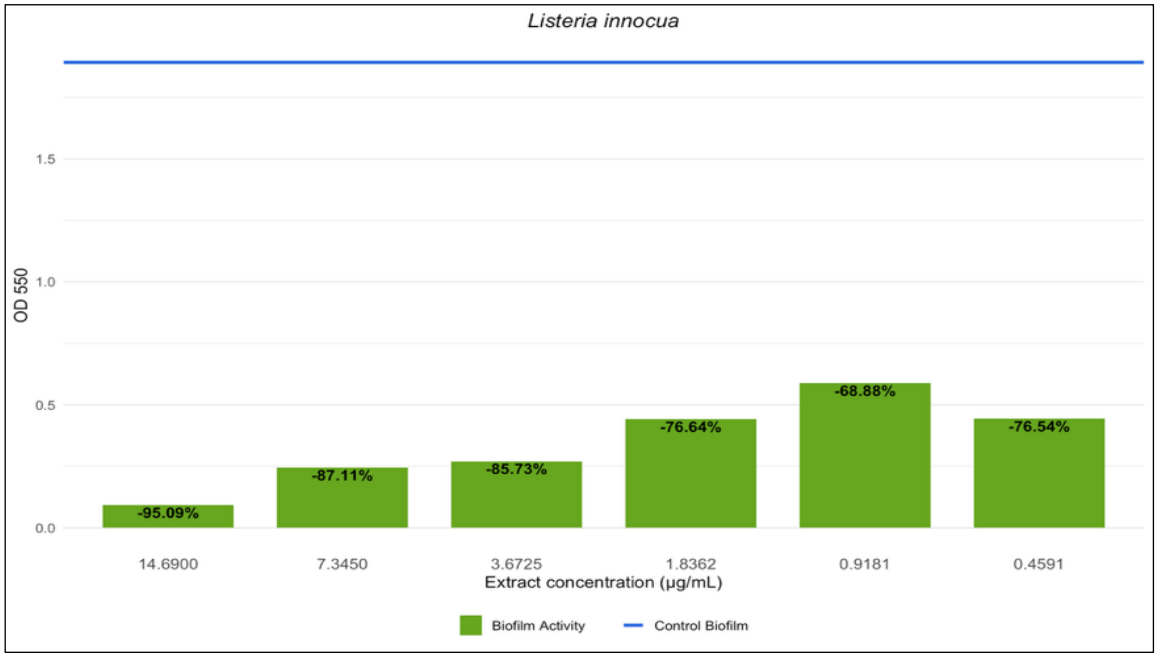


Figure 5: Antibiofilm effect of *Rhynchostegium riparioides* ethanol extract against *Listeria innocua*

In the *E. coli* strain, treatments with the water extract of *R. riparioides* were found to markedly reduce biofilm production at all tested concentrations. The highest reduction was observed at a concentration of 28.1300 µg/mL, with a biofilm inhibition rate of 74.76%. At the other concentrations, inhibition rates of 73.46% at 3.5162 µg/mL, 72.86% at 1.7581 µg/mL, 71.92% at 14.0650 µg/mL, 71.56% at 0.8791 µg/mL, and 69.07% at 7.0325 µg/mL were recorded.

In the *L. innocua* strain, treatments with the ethanol extract of *R. riparioides* were found to strongly reduce biofilm formation at all tested concentrations. The highest reduction was recorded at a concentration of 14.6900 µg/mL, with a biofilm inhibition rate of 95.09%. At the other concentrations, inhibition rates of 87.11% at 7.3450 µg/mL, 85.73% at 3.6725 µg/mL, 76.64% at 1.8362 µg/mL, 76.54% at 0.4591 µg/mL, and 68.88% at 0.9181 µg/mL were observed.

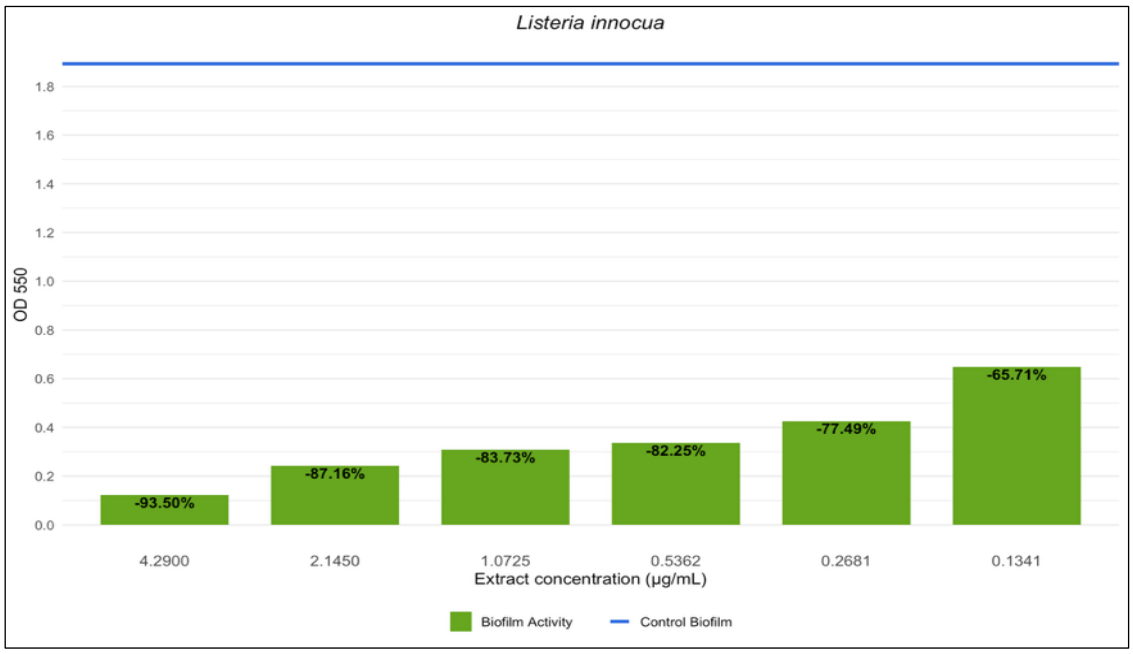


Figure 6: Graph illustrating the antibiofilm effect of the methanol extract of *Rhynchostegium riparioides* against *Listeria innocua*

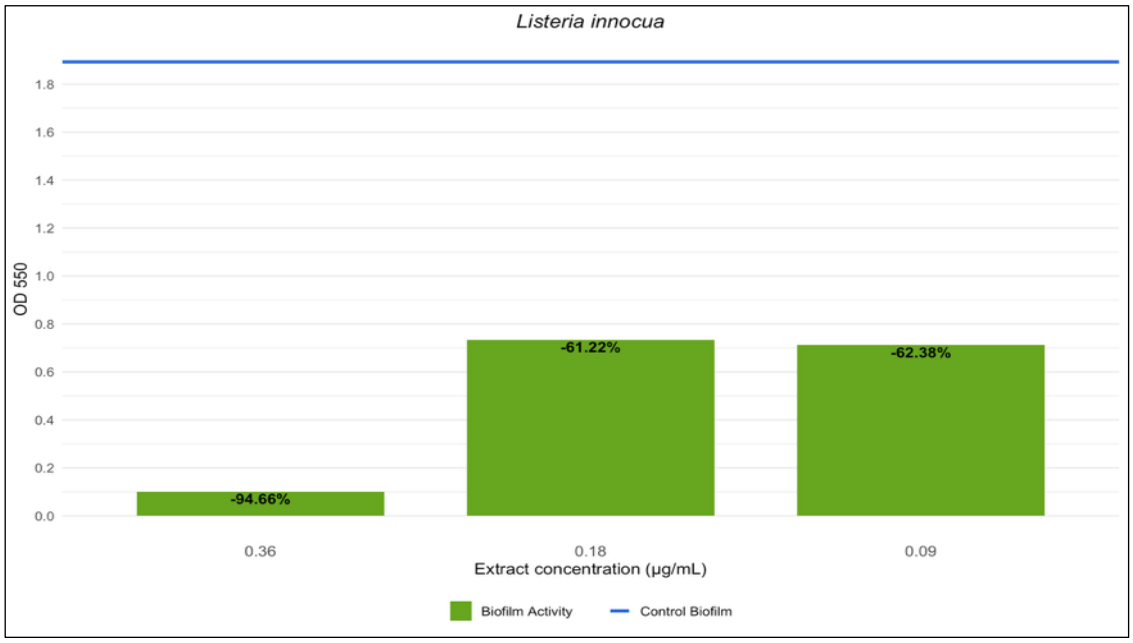


Figure 7: Antibiofilm activity graph of *Rhynchostegium riparioides* n-hexane extract against *Listeria innocua*

In the *L. innocua* strain, treatments with the methanol extract of *R. riparioides* were found to significantly reduce biofilm formation at all tested concentrations. The highest reduction was observed at a concentration of 4.2900 µg/mL, with a biofilm inhibition rate of 93.50%. At the other concentrations, inhibition rates of 87.16% at 2.1450 µg/mL, 83.73% at 1.0725 µg/mL, 82.25% at 0.5362 µg/mL, 77.49% at 0.2681 µg/mL, and 65.71% at 0.1341 µg/mL were recorded.

In the *L. innocua* strain, treatments with the hexane extract of *R. riparioides* were found to reduce biofilm formation at all tested concentrations. The highest reduction was recorded at a concentration of 0.36 µg/mL, with a biofilm inhibition rate of 94.66%. At the other concentrations, inhibition rates of 61.22% at 0.18 µg/mL and 62.38% at0.09 µg/mL were observed.

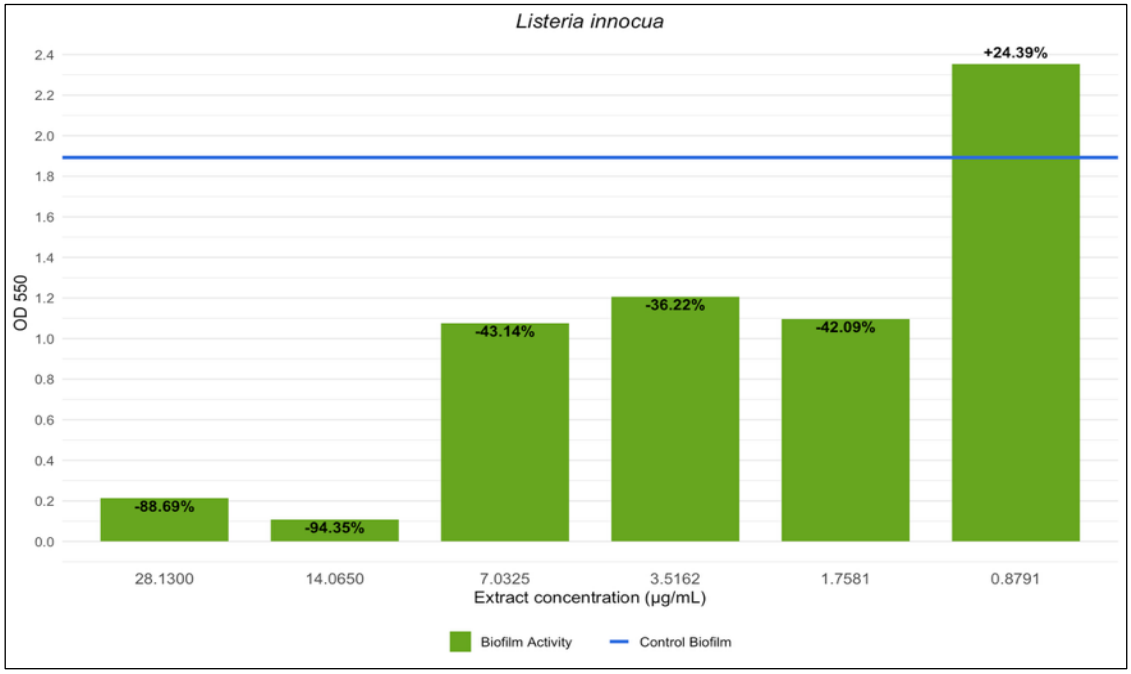


Figure 8: Graph illustrating the antibiofilm effect of the water extract of *Rhynchostegium riparioides* against *Listeria innocua*

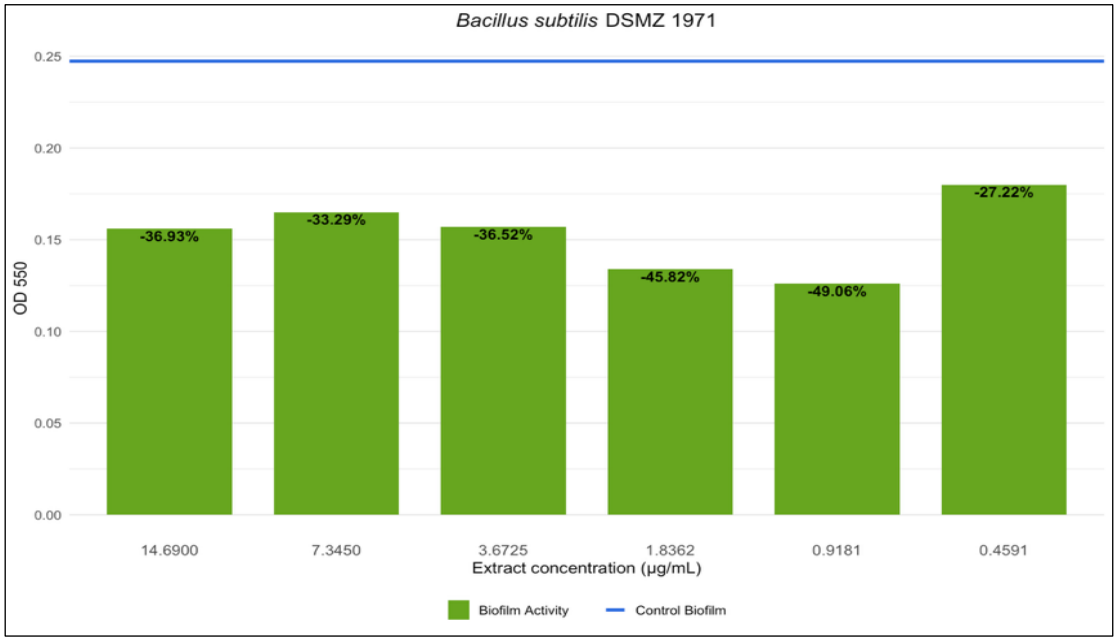


Figure 9: Graph illustrating the antibiofilm effect of the ethanol extract of *Rhynchostegium riparioides* against *Bacillus subtilis* DSMZ 1971

In the *L. innocua* strain, treatments with the water extract of *R. riparioides* resulted in both a decrease and an increase in biofilm formation depending on the concentration. The highest reduction was observed at a concentration of 14.0650 µg/mL, with a biofilm inhibition rate of 94.35%. At the other concentrations, inhibition rates of 88.69% at 28.1300 µg/mL, 43.14% at 7.0325 µg/mL, 42.09% at 1.7581 µg/mL, and 36.22% at 3.5162 µg/mL were recorded. In contrast, at a concentration of 0.8791 µg/mL, a 24.39% increase in biofilm formation was observed.

In the *B. subtilis* DSMZ 1971 strain, treatments with the ethanol extract of *R. riparioides* were found to reduce biofilm production at all tested concentrations. The highest reduction was recorded at a concentration of 0.9181 µg/mL, with a biofilm inhibition rate of 49.06%. At the other concentrations, inhibition rates of 45.82% at 1.8362 µg/mL, 36.93% at 14.6900 µg/mL, 36.52% at 3.6725 µg/mL, 33.29% at 7.3450 µg/mL, and 27.22% at 0.4591 µg/mL were observed.

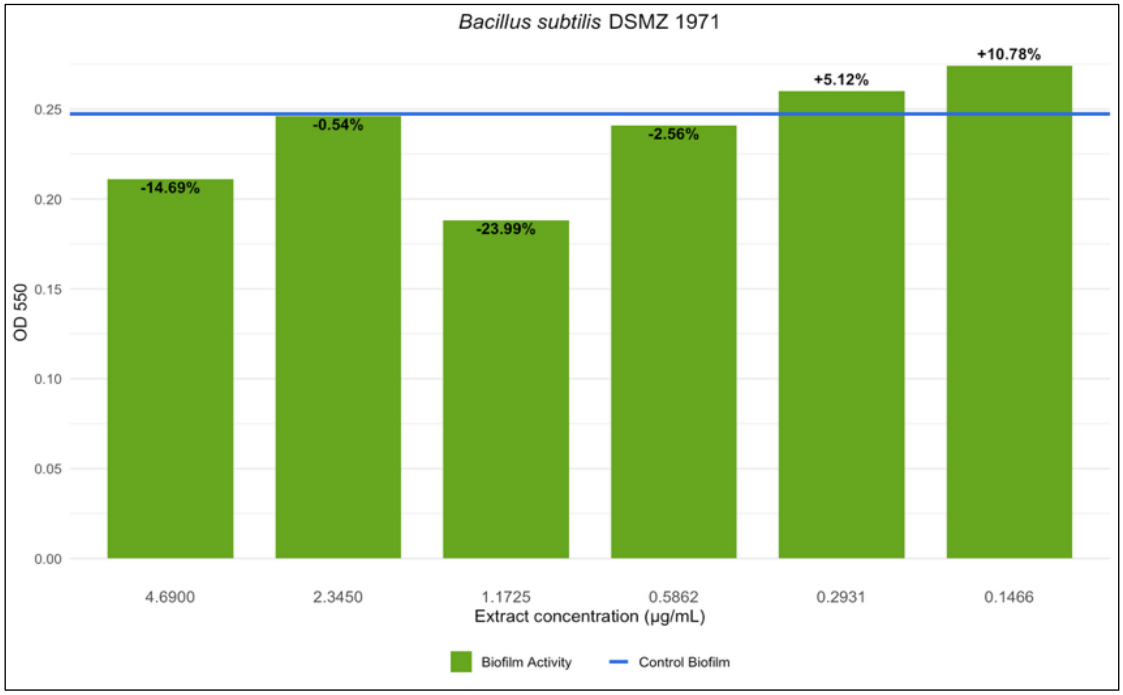


Figure 10: Graph illustrating the antibiofilm effect of the methanol extract of *Rhynchostegium riparioides* against *Bacillus subtilis* DSMZ 1971

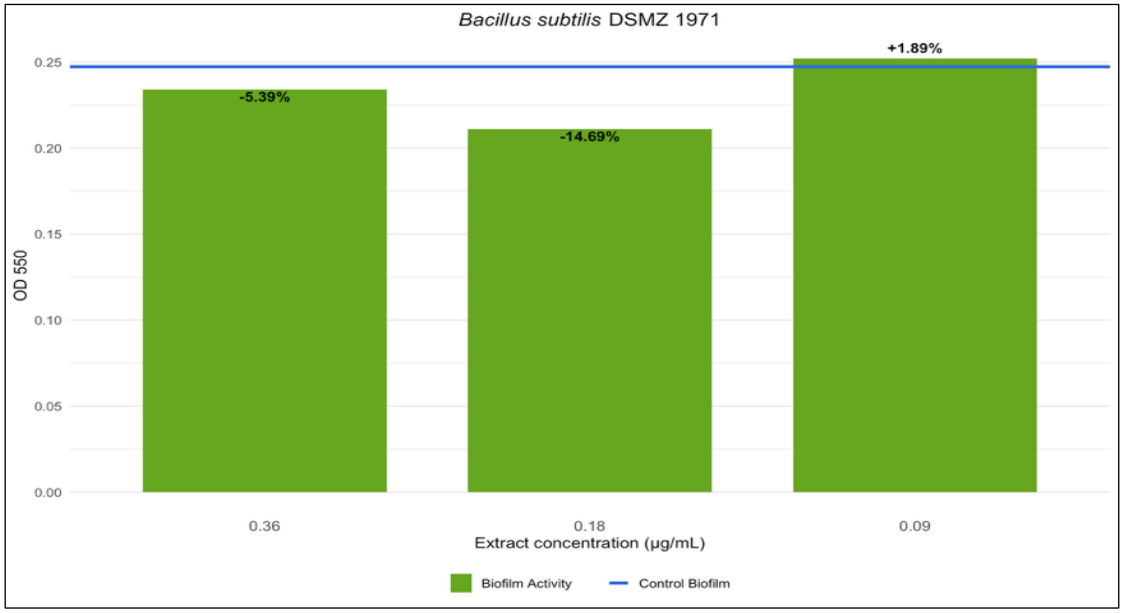


Figure 11: Graph illustrating the antibiofilm effect of the *n*-hexane extract of *Rhynchostegium riparioides* against *Bacillus subtilis* DSMZ 1971

In the *B. subtilis* DSMZ 1971 strain, treatments with the methanol extract of *R. riparioides* resulted in both increases and decreases in biofilm formation depending on the concentration. The highest increase was observed at a concentration of 0.1466 µg/mL, with a 10.78% rise in biofilm formation, followed by a 5.12% increase at 0.2931 µg/mL. In contrast, reductions in biofilm formation were recorded as 23.99% at 1.1725 µg/mL, 14.69% at 4.6900 µg/mL, 2.56% at 0.5862 µg/mL, and 0.54% at 2.3450 µg/mL.

In the *B. subtilis* DSMZ 1971 strain, treatments with the hexane extract of *R. riparioides* resulted in both decreases and increases in biofilm formation at lower concentrations. The highest reduction was recorded at a concentration of 0.18 µg/mL, with a biofilm inhibition rate of 14.69%. A 5.39% reduction was observed at 0.36 µg/mL, while a 1.89% increase in biofilm formation was detected at 0.09 µg/mL.

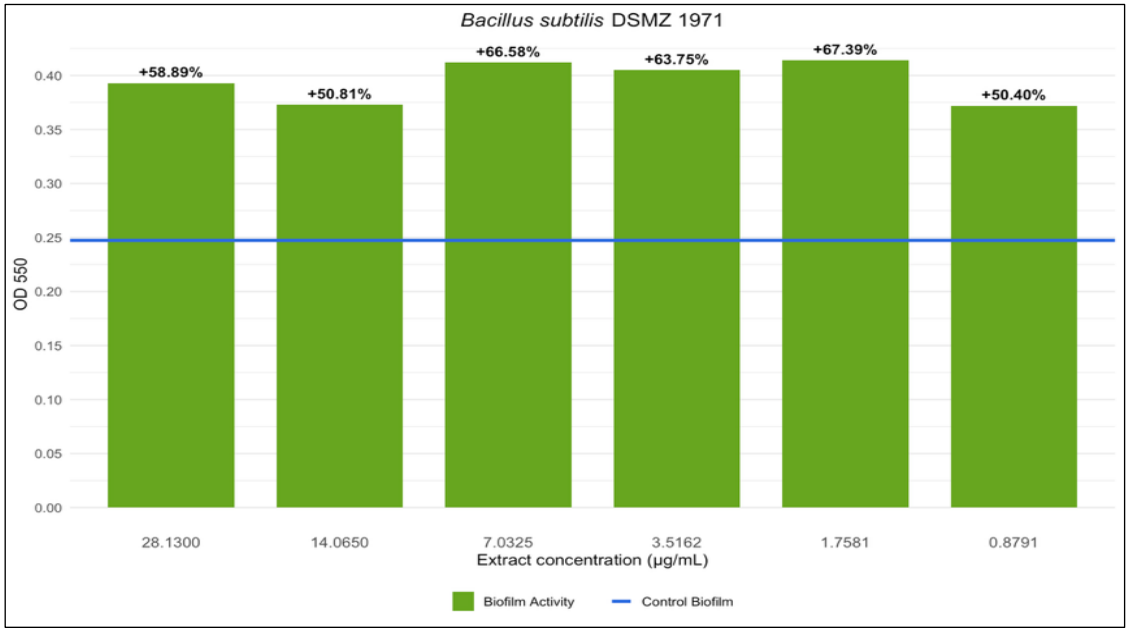


Figure 12: Graph illustrating the antibiofilm effect of the water extract of *Rhynchostegium riparioides* against *Bacillus subtilis* DSMZ 1971

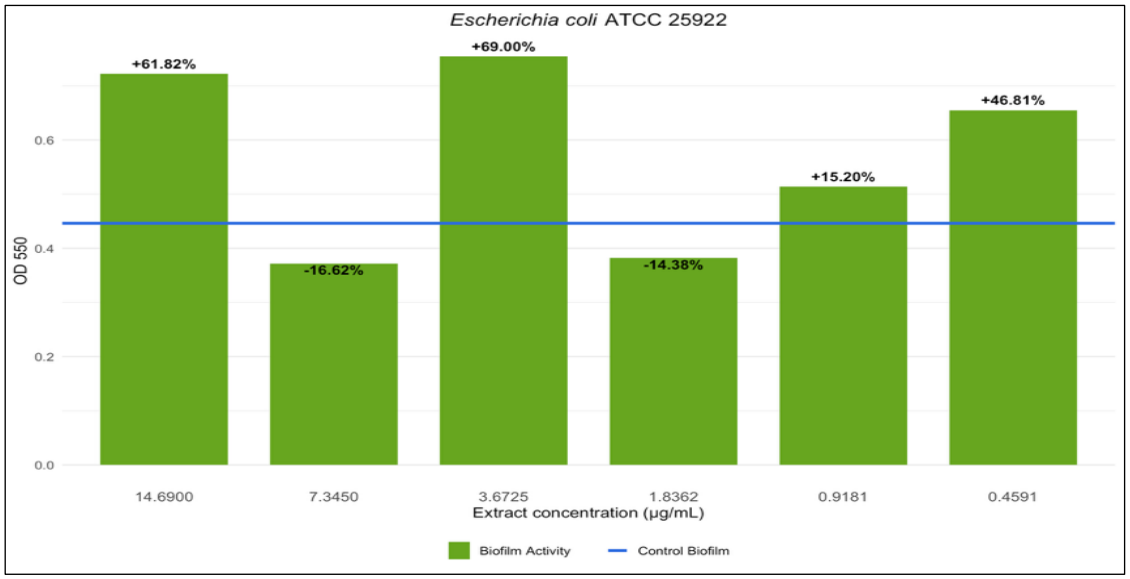


Figure 13: Graph illustrating the antibiofilm effect of the ethanol extract of *Rhynchostegium riparioides* against *Escherichia coli* ATCC 25922

Biofilm formation was found to increase at all tested concentrations. The highest increase was recorded at a concentration of 1.7581 µg/mL, with a 67.39% rise in biofilm formation. At the other concentrations, increases of 66.58% at 7.0325 µg/mL, 63.75% at 3.5162 µg/mL, 58.89% at 28.1300 µg/mL, 50.81% at 14.0650 µg/mL, and 50.40% at 0.8791 µg/mL were observed.

In the *E. coli* ATCC 25922 strain, treatments with the ethanol extract of *R. riparioides* resulted in concentration-dependent variations in biofilm formation levels. While an increase in biofilm production was observed at certain concentrations, a decrease was recorded at others. The highest increase was observed at a concentration of 3.6725 µg/mL, with a 69.00% rise in biofilm formation. At the other concentrations, increases of 61.82% at 14.6900 µg/mL, 46.81% at 0.4591 µg/mL, and 15.20% at 0.9181 µg/mL were recorded. In contrast, reductions of 16.62% at 7.3450 µg/mL and 14.38% at 1.8362 µg/mL were observed.

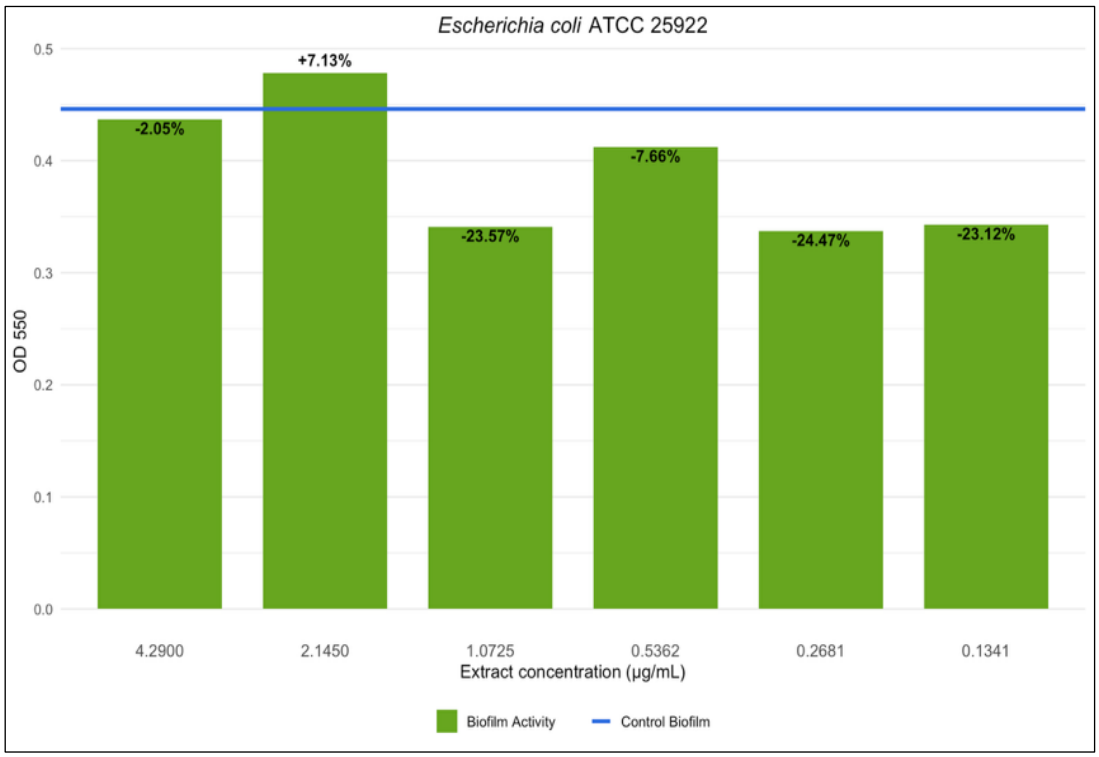


Figure 14: Graph illustrating the antibiofilm effect of the methanol extract of *Rhynchostegium riparioides* against *Escherichia coli* ATCC 25922

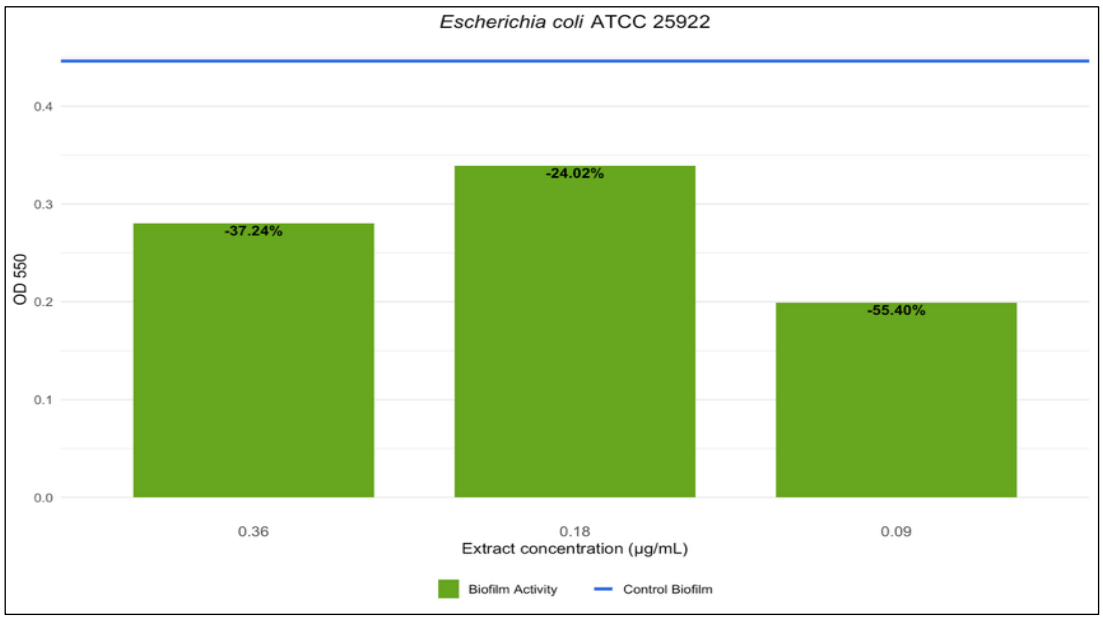


Figure 15: Graph illustrating the antibiofilm effect of the *n*-hexane extract of *Rhynchostegium riparioides* against *Escherichia coli* ATCC 25922

Both increases and decreases in biofilm formation were observed at different concentrations. The highest increase was recorded at a concentration of 2.1450 µg/mL, with a 7.13% rise in biofilm formation. In contrast, inhibition was detected at the other concentrations, with reductions of 2.05% at 4.2900 µg/mL, 23.57% at 1.0725 µg/mL, 7.68% at 0.5362 µg/mL, 24.47% at 0.2681 µg/mL, and 23.12% at 0.1341 µg/mL.

In the *E. coli* ATCC 25922 strain, treatments with the water extract of *R. riparioides* were found to reduce biofilm formation at all tested concentrations. The highest inhibition rate was recorded at a concentration of 0.09 µg/mL, with 55.40% inhibition. At the other concentrations, inhibition rates of 37.24% at 0.36 µg/mL and 24.02% at 0.18 µg/mL were observed.

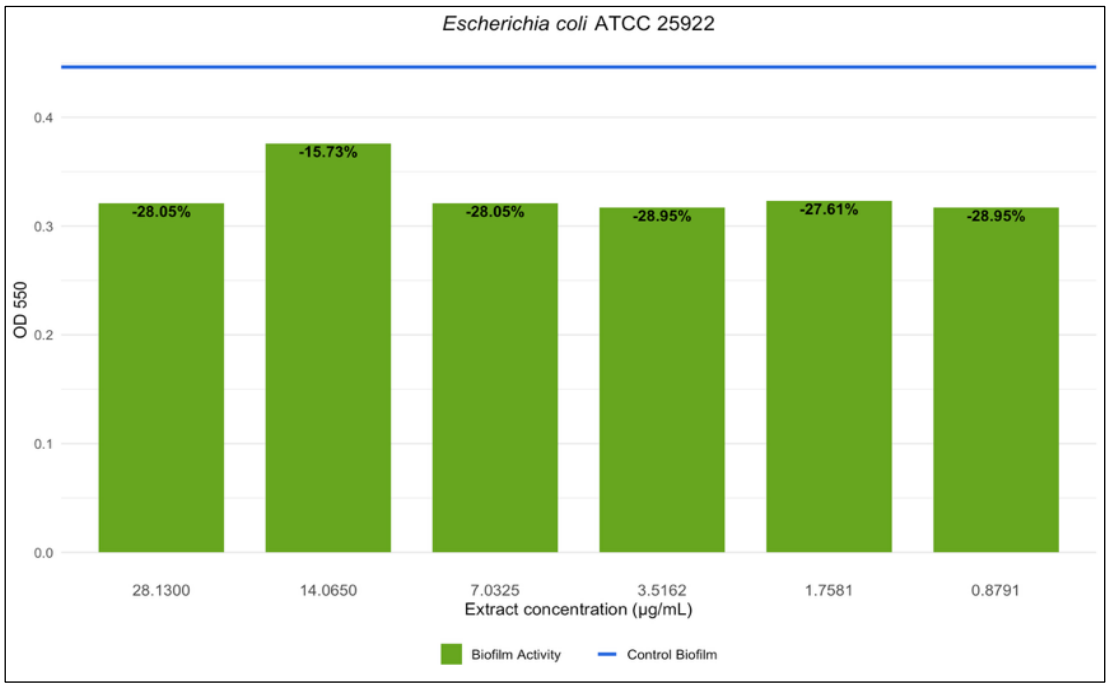


Figure 16: Graph illustrating the antibiofilm effect of the water extract of *Rhynchostegium riparioides* against *Escherichia coli* ATCC 25922

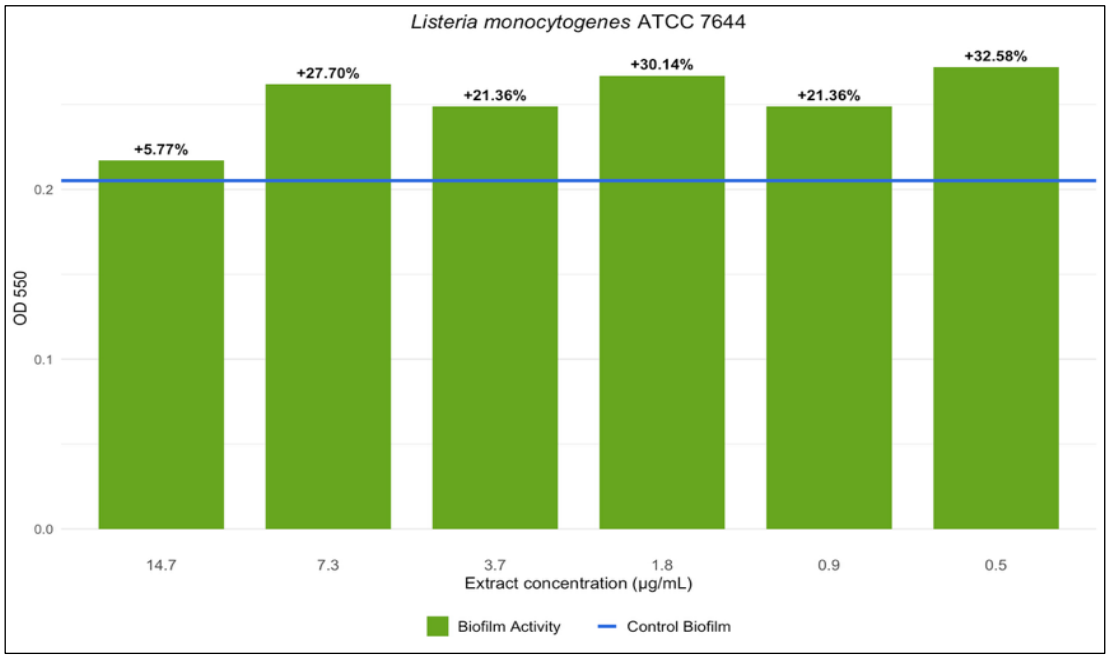


Figure 17: Graph illustrating the antibiofilm effect of the ethanol extract of *Rhynchostegium riparioides* against *Listeria monocytogenes* ATCC 7644

In the *E. coli* ATCC 25922 strain, treatments with the water extract of *R. riparioides* were found to reduce biofilm formation at all tested concentrations. The highest reduction was recorded at concentrations of 3.5162 µg/mL and 0.8791 µg/mL, with a biofilm inhibition rate of 28.95%. At the other concentrations, inhibition rates of 28.05% at 28.1300 µg/mL, 28.05% at 7.0325 µg/mL, 27.61% at 1.7581 µg/mL, and 15.73% at 14.0650 µg/mL were observed.

In the *L. monocytogenes* ATCC 7644 strain, treatments with the ethanol extract of *R. riparioides* were found to increase biofilm formation at all tested concentrations. The highest increase was observed at a concentration of 0.5 µg/mL, with a 32.58% rise in biofilm formation. At the other concentrations, increases of 30.14% at 1.8 µg/mL, 27.70% at 7.3 µg/mL, 21.36% at 0.9 µg/mL, 21.36% at 3.7 µg/mL, and 5.77% at 14.7 µg/mL were recorded.

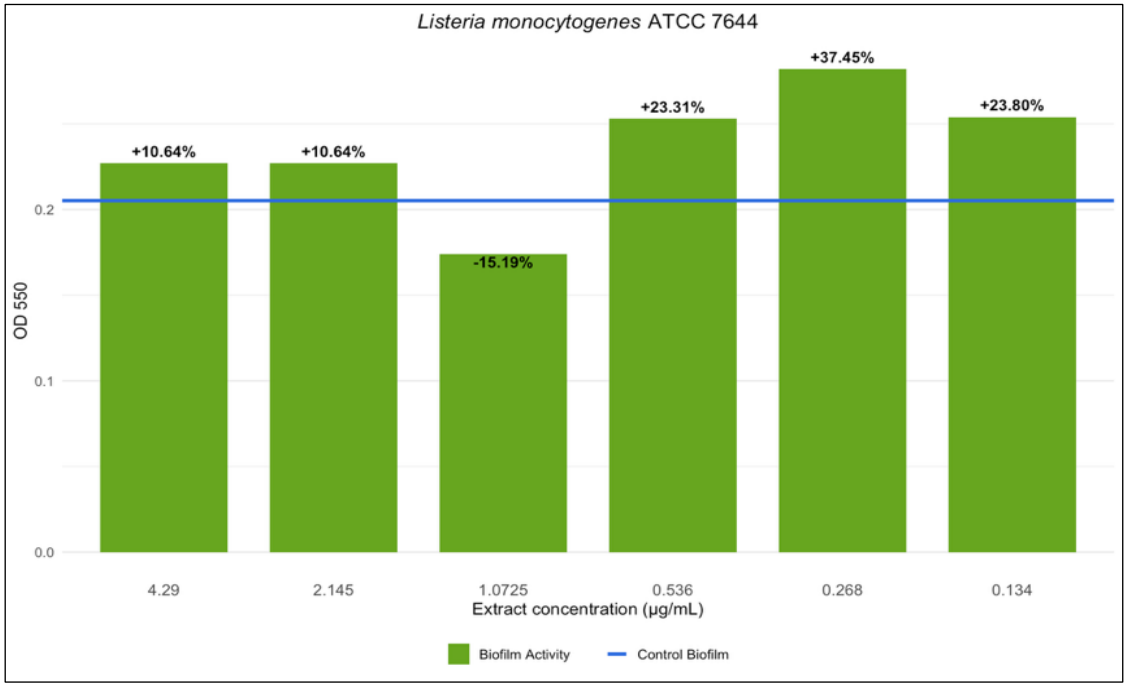


Figure 18: Graph illustrating the antibiofilm effect of the methanol extract of *Rhynchostegium riparioides* against *Listeria monocytogenes* ATCC 7644

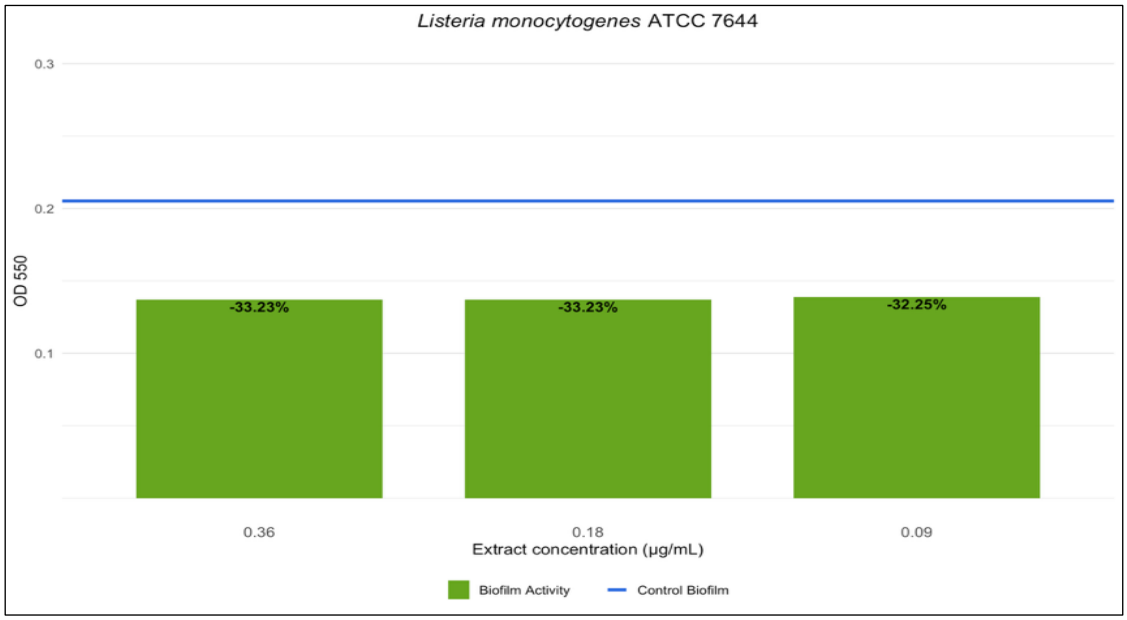


Figure 19: Graph illustrating the antibiofilm effect of the *n*-hexane extract of *Rhynchostegium riparioides* against *Listeria monocytogenes* ATCC 7644

The highest biofilm inhibition was observed at a concentration of 1.0725 µg/mL, with an inhibition rate of 15.19%. In contrast, biofilm formation increased at all other concentrations. The highest increases were recorded as 23.31% at 0.536 µg/mL, 23.80% at 0.134 µg/mL, 10.64% at 4.29 µg/mL, and 10.64% at 2.145 µg/mL.

In the *L. monocytogenes* ATCC 7644 strain, treatments with the n-hexane extract of *R. riparioides* were found to reduce biofilm formation at all tested concentrations. The highest inhibition rate was recorded at concentrations of 0.36 µg/mL and 0.18 µg/mL, both showing a 33.23% reduction in biofilm formation. At the lowest concentration of 0.09 µg/mL, a 32.25% decrease in biofilm formation was observed.

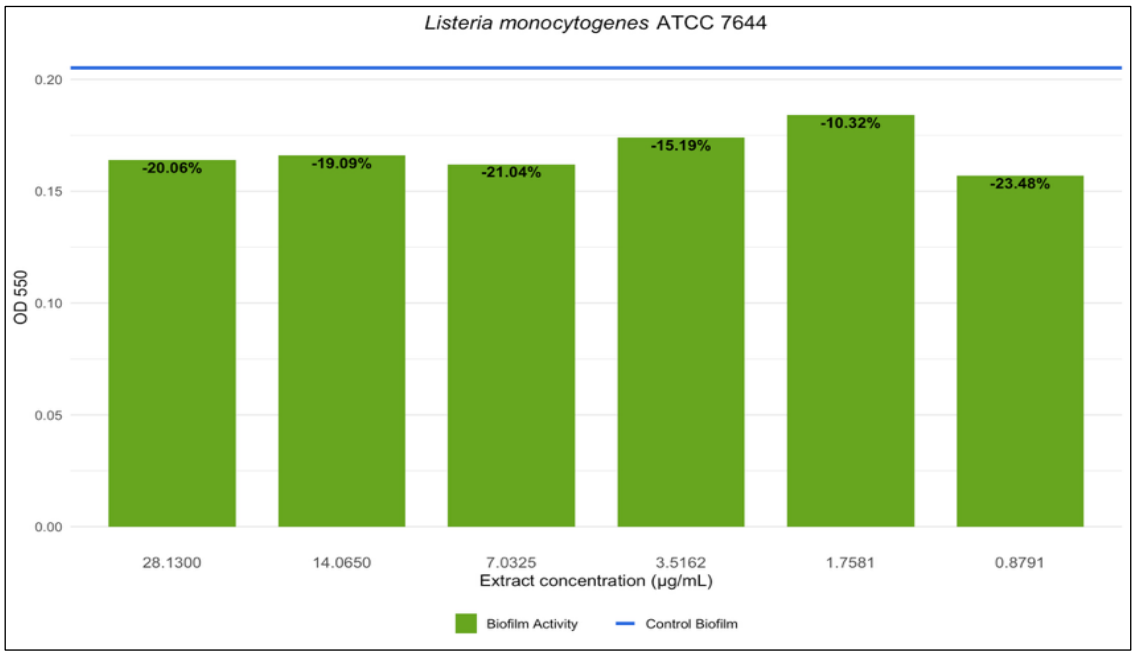


Figure 20. Graph illustrating the antibiofilm effect of the water extract of *Rhynchostegium riparioides* against *Listeria monocytogenes* ATCC 7644

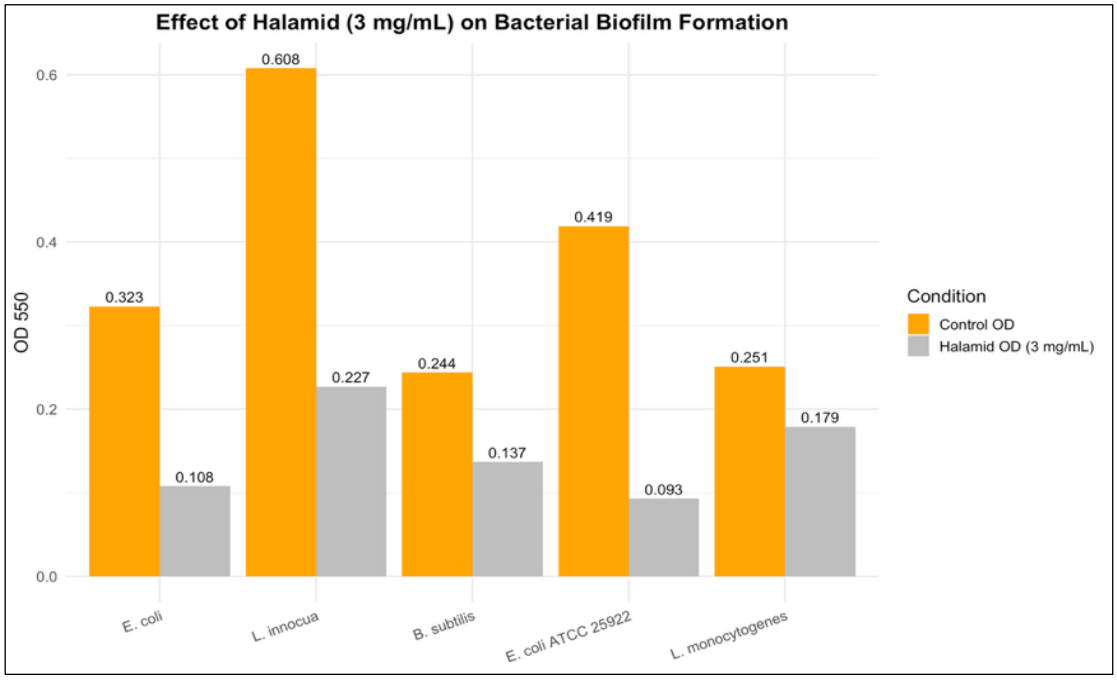


Figure 21. Biofilm graph showing the antibiofilm effect of Halamid (control group) at a concentration of 3 mg/ml

In the *L. monocytogenes* ATCC 7644 strain, treatments with the water extract of *R. riparioides* were observed to reduce biofilm formation at all tested concentrations. The highest inhibition rate was recorded at a concentration of 0.8791 µg/mL, with 23.48% inhibition. At the other concentrations, inhibition rates of 20.06% at 28.1300 µg/mL, 19.09% at 14.0650 µg/mL, 21.04% at 7.0325 µg/mL, 15.19% at 3.5162 µg/mL, and 10.32% at 1.7581 µg/mL were observed.

At a concentration of 3 mg/mL, treatment with Halamid resulted in a decrease in the optical density (OD_{550}) value of the *E. coli* strain from 0.323 in the control group to 0.108 in the treatment group. For *Listeria innocua*, these values were 0.608 and 0.227, respectively; for *Bacillus subtilis* DSMZ 1971, 0.244 and 0.137; for *E. coli* ATCC 25922, 0.419 and 0.093; and for *Listeria monocytogenes* ATCC 7644, 0.251 and 0.179, respectively.

4. Discussions and Conclusions

4.1. Biochemical compounds

In this study, the phytochemical contents of *R. riparioides* extracts obtained using different solvents (ethanol, methanol, and n-hexane) were evaluated based on percentage area data from GC-MS analysis. The findings indicated that solvent polarity significantly influenced both the diversity of extracted compounds and their relative abundance within the extracts. Across all three extracts, palmitic acid and stearic acid were identified as common major compounds. Stearic acid was found in the highest concentration (6.07%) in the ethanol extract, whereas palmitic acid was most abundant (18.65%) in the methanol extract.

The ethanol and methanol extracts displayed similar compositional profiles, sharing numerous common compounds. Notably, tetradecanoic acid, neophytadiene, phytol, squalene, methyleicosapentaenoate, and diploptene were detected in both extracts. These components are known to be widespread in moss species and are thought to play important roles in the chemical defense mechanisms of these plants (Benek, 2024)[2]. The methanol extract presented a more balanced profile in terms of compound diversity and concentration, with significant amounts of neophytadiene (21.55%) and linolenic acid (10.45%). Meanwhile, the ethanol extract was characterized by a particularly high proportion of neophytadiene (41.16%), although other compounds were present at lower percentages. This suggests that the methanol extract may possess a broader spectrum of biological activity, while the ethanol extract may exhibit its effects based on a few major compounds.

In the n-hexane extract, unlike the other extracts, a large majority of the total peak area (79.29%) was dominated by a single compound, tris(2,4-di-tert-butylphenyl) phosphate. Tris(2,4-di-tert-butylphenyl) phosphate (Irgafos 168) is an organophosphorus antioxidant and stabilizer widely used in the plastics industry due to its ability to reduce oxidative degradation and enhance polymer stability (Chen et al., 2020). This finding suggests that the biological activity of the n-hexane extract may largely depend on the presence of this specific compound. Additionally, the effective biofilm inhibition observed at the lowest tested concentration of 0.4 µg/ml for the n-hexane extract is thought to be related to the presence of its major compound, tris(2,4-di-tert-butylphenyl) phosphate. The data indicate that the methanol extract exhibits a more favorable profile in terms of phytochemical diversity and balanced percentage distribution compared to other solvent extracts. Furthermore, GC-MS analyses revealed greater compound diversity and richness in the methanol extract compared to the n-hexane extract. This rich chemical profile explains why the methanol extract showed the second highest biofilm inhibition rate after the n-hexane extract. Therefore, the synergistic effect of multiple active compounds in the methanol extract appears to play a significant role in inhibiting biofilm formation. While the ethanol extract is characterized by dominance of a few main compounds with high biological activity potential, the n-hexane extract displays limited diversity and an imbalanced compound distribution.

These results underscore the direct impact of solvent choice on the resulting phytochemical profile and biological activity, highlighting the need to optimize extraction strategies according to the targeted biological activity.

4.2. Antibiofilm effects

This study evaluated the antibiofilm activities of *R. riparioides* extracts prepared with ethanol, methanol, n-hexane, and water solvents against standard bacteria (*Bacillus subtilis* DSMZ 1971, *Escherichia coli* ATCC 25922, *Listeria monocytogenes* ATCC 7644, clinical isolate *Escherichia coli*, and food isolate *Listeria innocua*. The results demonstrated that the biofilm inhibition potential of the extracts varied depending on the solvent type and the target bacterial species.

Other than the n-hexane extract, all other solvent extracts induced biofilm formation in at least one strain, whereas the n-hexane extract exhibited varying degrees of biofilm inhibition across all strains. GC-MS analysis revealed that its compound profile was predominantly composed (79.29%) of tris(2,4-di-tert-butylphenyl) phosphate, an organophosphorus antioxidant widely used in the plastics industry for its oxidative degradation prevention and polymer stabilization properties (Chen et al., 2020). This compound likely explains the observed high inhibition rates. The use of a nonpolar solvent like hexane facilitated the extraction of lipophilic secondary metabolites, which are thought to contribute to the biofilm inhibition effect observed here, potentially including terpenoids, sterols, or lipophilic phenolic compounds. Future studies are recommended to isolate the active components, elucidate biofilm inhibition mechanisms, and perform extensive testing on different pathogenic species.

The methanol extract was characterized by the presence of active compounds such as palmitic

acid, phytol, linoleic acid, and oleic acid according to GC-MS analysis. Given the reported antimicrobial properties of these compounds, it is expected that the methanol extract provides strong biofilm inhibition at low concentrations against various bacteria. For instance, fatty acids like linoleic and oleic acid are known to disrupt cell membrane permeability in gram-positive bacteria, exhibiting antimicrobial effects, while phytol has demonstrated significant antibacterial and antibiofilm activity particularly against *P. aeruginosa* (Desbois & Smith, 2010; Saini et al., 2016). These findings align well with the suppressive effects on biofilm formation observed for the methanol extract. For L. monocytogenes, a distinct behavior was observed (Figure 18). Although biofilm formation was induced, a 15% inhibition was recorded at a concentration level of 1.0725 µg/mL. This finding further emphasizes the critical importance of the dose–response relationship.

Significant biofilm inhibition rates of the ethanol extract were demonstrated. Compounds detected by GC-MS, such as stearic acid, may have indirect effects on biofilm inhibition. Polar solvents like ethanol are effective in extracting phenolic compounds, flavonoids, and certain alkaloids. Thanks to its biofilm inhibitory properties, the ethanol extract of *R. riparioides* holds potential as a natural agent for biotechnological, industrial hygiene, and possible medical applications. Future work should focus on isolating active constituents, investigating molecular mechanisms of biofilm inhibition, and assessing activity under varied environmental conditions.

When evaluating the antibiofilm effects of the water extract of *R. riparioides* against different bacterial species, marked strain-specific differences were observed. The extract exhibited strong biofilm suppression across all tested concentrations in *E. coli*, with inhibition rates ranging from 69.07% to 74.76%, indicating that the extract can effectively inhibit biofilm formation even at lower doses and possesses high antibiofilm potential (Figure 4). In *L. innocua*, biofilm suppression of 88.69% and 94.35% was observed at higher concentrations (28.13 and 14.06 µg/mL, respectively), whereas the effect decreased at lower concentrations, with a 24.39% increase in biofilm formation recorded at 0.8791 µg/mL. These results suggest that the effect is concentration-dependent and that biofilm formation may be stimulated at low doses (Figure 8). Against *B. subtilis* DSMZ 1971, the extract promoted biofilm formation across all concentrations, with increases ranging from 50.40% to 67.39%, indicating a stimulatory effect in this gram-positive strain (Figure 12). In *E. coli* ATCC 25922, inhibition rates ranged from 15.73% to 28.95%, reflecting a more limited effect (Figure 16), while *L. monocytogenes* ATCC 7644 exhibited weaker biofilm suppression, ranging from 10.32% to 23.48% (Figure 20). Overall, the aqueous extract of *R. riparioides* demonstrated significant antibiofilm potential, particularly against *E. coli* and *L. innocua,* while promoting biofilm formation in *B. subtilis*. These findings indicate that the extract's effect depends on the bacterial species and the structure of the biofilm, showing selective activity across strains.

Halamid (3 mg/ml), used as a positive control, showed notable biofilm inhibition particularly against *E. coli* strains but unexpectedly low activity against *B. subtilis*. These results suggest that Halamid may exhibit selective activity depending on differences in bacterial cell wall structures.

Another notable observation is that the results obtained for L. innocua (Figures 5–8) indicated that biofilm structure was almost completely eradicated across all solvents. Although L. monocytogenes is phenotypically and genotypically highly similar to L. innocua, differences such as weaker virulence factors, generally non-pathogenic nature, and higher sensitivity to stress distinguish the two species (Milillo et al., 2012). Considering these differences, the divergence observed for L. monocytogenes (Figures 17–21) becomes meaningful. These findings suggest that the commonly used model strain of L. monocytogenes may not always serve as an appropriate model under all conditions. Indeed, several studies have highlighted that using L. innocua as a model organism can yield misleading results (Mohan et al., 2019; Bruschi et al., 2017; Friedly et al., 2008).

Although L. innocua is considered a non-infectious bacterium, its high genomic similarity with other Listeria species facilitates the potential transfer of resistance and virulence genes (Li et al., 2021). Considering the implications of resistance gene dissemination today and in the future, the findings of this study gain further significance.

4.3.Antimicrobial effects

Disk diffusion tests revealed that the inhibition zones all had a baseline diameter of 7 mm. This suggests that increasing the amount of tested substance could enhance the antimicrobial effect and that strains showing no inhibition at lower doses might respond if tested with higher concentrations.

Among the compared extracts, the n-hexane extract, with the lowest substance amount of 0,37

mg, exhibited antimicrobial activity against four different strains: *C. glabrata*, *S. lugdunensis*, *K. pneumoniae*, and *S. epidermidis*. The ethanol extract, containing 2,71 mg of substance, showed activity against two strains: *L. innocua* and *E. faecalis*. The methanol extract, with the highest substance amount of 4,09 mg, demonstrated antimicrobial effects against *E. coli* and *E. faecalis*.

Tris(2,4-di-tert-butylphenyl) phosphate (TDTBPP), which comprises 79.29% of the n-hexane extract and is the only major compound detected, is considered the primary contributor to the observed antimicrobial activity. Although no studies have directly investigated the antimicrobial effects of TDTBPP, some toxicological research highlights its adverse effects on biological systems. For example, Kang et al. (2025) reported disrupted lipid metabolism in mouse liver cells exposed to TDTBPP. Similarly, Zhang et al. (2024) demonstrated cardiac morphology and function impairments in zebrafish following TDTBPP exposure.

Given these known toxic effects, it is plausible that TDTBPP is responsible for the antimicrobial activity of the extract. The correlation between inhibition zones in disk diffusion tests and MIC values supports this relationship. MIC tests showed that the extract exhibited bactericidal activity at low concentrations such as 0.35 mg/mL. This antimicrobial effect, observed across gram-positive and gram-negative bacteria as well as yeast cells, indicates that TDTBPP's toxicity is not limited to animal cells but extends to microorganisms.
The ethanol extract showed antimicrobial activity exclusively against gram-positive bacteria. MIC and MBC tests revealed bacteriostatic effects at 7,34 mg/mL and bactericidal effects at 14,68 mg/mL concentrations against *E. faecalis* and *L. innocua* strains.

A study by Ceyhan-Güvensen & Keskin (2016) on *Mentha pulegium* (commonly known as pennyroyal) leaves, whose extract consists of 69.95% neophytadiene, reported antimicrobial effects against 11 bacterial strains including *E. faecalis*. This finding is supported by other literature (Stojanović et al., 2000; Alagić et al., 2002; Herrero et al., 2006), indicating that plant extracts containing neophytadiene possess antimicrobial potential.

In the methanol extract, neophytadiene was detected at 21.55%, along with palmitic acid (18.65%) and linolenic acid (10.45%) as major components. When comparing the antimicrobial effects of ethanol and methanol extracts, both showed similar activity against *E. faecalis*, suggesting neophytadiene's possible role in this effect. Other fatty acids present in the methanol extract have also been previously reported to possess antimicrobial properties (Huang et al., 2011). The higher concentrations of these compounds in the methanol extract compared to ethanol extract might have created a synergistic effect, explaining the enhanced efficacy at lower concentrations observed in MIC and MBC tests. For instance, the MIC and MBC values for the methanol extract against *E. faecalis* were 2,14 mg/mL and 4,28 mg/mL, respectively. Additionally, the methanol extract showed direct bactericidal activity against *E. coli* at 4,28 mg/mL concentration.

In the literature, the only study investigating the antimicrobial activity of *Rhynchostegium riparioides* was conducted by Basile et al. (1998), in which only an acetone extract was used and tested against a limited number of bacterial strains. In that study, minimum inhibitory concentrations (MIC) were reported as 4 µg/mL for *Escherichia coli* ATCC 11229 and *Klebsiella pneumoniae* ATCC 27736, 8µg/mL for *Enterobacter cloacae* ATCC 10699 and *Bacillus subtilis* ATCC 10774, 8µg/mL for *Proteus mirabilis* ATCC 7002, 16 µg/mL for *Pseudomonas aeruginosa* ATCC 27853, and 64 µg/mL for *Enterobacter aerogenes* ATCC 13048, while no antimicrobial activity was observed against *Streptococcus faecalis* ATCC 14428, *Staphylococcus aureus* ATCC 13709, *Salmonella typhi* ATCC 19430, and *Proteus vulgaris* ATCC 12454.

In the present study, however, not only standard strains but also food-derived and clinical isolates were included, and a much broader range of microorganisms was evaluated. Moreover, instead of relying solely on acetone, solvents with different polarities such as methanol, ethanol, and n-hexane were used in the extraction process. This approach demonstrates that both the type of solvent and the origin of the microorganism play a significant role in antimicrobial activity and suggests that *R. riparioides* may possess a broader and more diverse antimicrobial profile than previously reported. In both studies, *Enterobacter aerogenes* ATCC 13048 was tested; however, while Basile et al. (1998) reported activity of the acetone extract at 64 µg/mL, no antimicrobial effect was observed with the methanol, ethanol, and n-hexane extracts used in the present study.

Overall, this study demonstrated that extracts obtained from the moss *R. riparioides* exhibit significant antimicrobial and antibiofilm activities, which are highly influenced by solvent polarity

and the resulting phytochemical profiles. The n-hexane extract, characterized predominantly by tris(2,4-di-tert-butylphenyl) phosphate (79.29%), showed notable antimicrobial and antibiofilm effects at very low concentrations, suggesting that this compound is primarily responsible for the observed biological activity. The methanol extract displayed a broader and balanced phytochemical composition, including bioactive compounds such as neophytadiene, palmitic acid, and linolenic acid, which contributed to its effective broad-spectrum antimicrobial and antibiofilm performance. In contrast, the ethanol extract showed moderate activity predominantly against gram-positive bacteria, likely driven by its high neophytadiene content. These findings highlight the importance of selecting appropriate extraction solvents to target desired biological activities. The potent antimicrobial and antibiofilm properties of *R. riparioides* extracts, particularly from n-hexane and methanol solvents, position this moss as a promising natural source for developing novel antimicrobial and antibiofilm agents, paving the way for future pharmacological studies and practical applications.

Declarations

Authors' contributions

Idea/Concept: MEB, KC, CY. Conceptualization and design: CY, DT, AB. Auditing/ Consulting: KC, AB, DT, CY. Resources: ADU, MEB, KOD. Materials: ADU, MEB, ED. Data Collection & Processing: DT, ADU, GG. Analysis & Interpretation: GG, KOD, ED, GG. Literature Review: GG, KOD, ED. Writing: CY, GG, GG. Critical Review: KC.

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Conflict of interest

The authors declare that there is no real, potential, or perceived conflict of interest for this article.

Ethics approval and consent to participate

The authors declare that ethical approval was not required for this study.

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Screening of Bioactive Potential of *Plasteurhynchium striatulum*: Antibiofilm Effects and Phytochemical Profile

Gizem GÜL[1,*], Elif GÖNÜL[2], Cenker YAMAN[1], Melike ERSİN[2], Selime Deniz BOZKURT[1], Gülcan GÖREN[2], Ezginur DUMAN[2], Atakan BENEK[3], Ayşe Dilek UNAN[4], Mustafa Eray BOZYEL[5], Kerem CANLI[2,3]

[1]*Dokuz Eylül University, Graduate School of Natural and Applied Science, Department of Biology, İzmir, TÜRKİYE*
[2]*Dokuz Eylül University, Faculty of Science, Department of Biology, Izmir, TÜRKİYE*
[3]*Dokuz Eylül University, Fauna and Flora Research and Application Center, İzmir, TÜRKİYE*
[4]*Zonguldak Bülent Ecevit University, Faculty of Science and Art, Department of Biology, Zonguldak, TÜRKİYE*
[5]*Department of Biology, Faculty of Arts and Science, Canakkale Onsekiz Mart University, Çanakkale, TÜRKİYE*

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Abstract

In the present study, the bryophyte *Plasteurhynchium striatulum* (Spruce) M. Fleisch was extracted using three different solvents: ethanol, methanol, and n-hexane. Subsequently, the antimicrobial activities of the extracts were evaluated against a range of microorganisms including foodborne isolates, clinical isolates, multidrug-resistant strains, and standard strains using disk diffusion, minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC), and antibiofilm assays. In addition, antioxidant activity was assessed through the DPPH radical scavenging assay. The biochemical constituents of the extracts were identified via gas chromatography–mass spectrometry (GC-MS) analysis. According to the disk diffusion test results, activity was observed against eight bacterial strains, most notably *Escherichia coli* and *Providencia rustigianii*, both of which exhibit multidrug resistance. The highest MIC value was recorded as 0.8816 mg/mL against the *Salmonella infantis* strain. The strongest antioxidant performance was observed at a concentration of 1 mg/mL. GC-MS analysis revealed that the major components of the extract were Tris(2,4-di-tert-butylphenyl) phosphate (52.45%), A'-Neogammacer-22(29)-ene (25.00%), and Neophytadiene (12.72%). In conclusion, *P. striatulum* was found to possess notable antimicrobial and antioxidant activities, along with a rich biochemical composition. These findings suggest that *P. striatulum* holds promise as a potential source for the development of novel antimicrobial and antioxidant agents. Additionally, its biochemical characteristics could offer important information for upcoming studies.

Keywords: Bryophyte, Antimicrobial Activity, Antioxidant Activity, Gas Chromatography-Mass Spectrometry (GC-MS).

Plasteurhynchium striatulum'un Biyoaktif Potansiyelinin Taranması: Antibiyofilm Etkileri ve Fitokimyasal Profili

Öz

Gerçekleştirilen bu çalışmada bir bryofit olan *Plasteurhynchium striatulum* (Spruce) M. Fleisch'un etanol, metanol ve n-hekzan olmak üzere üç farklı solvent ile ekstraksiyonu gerçekleştirilmiştir. Ardından gıda izolatları, klinik izolatlar, çoklu ilaca dirençli ve standart suşlar dahil olmak üzere çeşitli mikroorganizmalara karşı antimikrobiyal aktiviteleri disk difüzyon, minimum inhibitör konsantrasyon (MİK), minimum bakterisidal konsantrasyonu (MBC) ve antibiyofilm testleri ile tespit edilmiştir. Bununla birlikte antioksidan aktivitelerinin tespiti DPPH testi ile gerçekleştirilmiştir. Biyokimyasal içerikleri Gaz kromatografisi-kütle spektrometrisi (GC-MS) yöntemi kullanılarak belirlenmiştir. Disk difüzyon testi bulgularında başta çoklu ilaç direncine sahip *Escherichia coli* ve *Providencia rustigianii* olmak üzere toplamda 8 bakteride etki gözlemlenmiştir. MİK testinde en yüksek sonuç *Salmonella infantis*

* Corresponding author: gizeemmgull@gmail.com

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suşunda 0,8816 mg\mL olarak belirlenmiştir. Antioksidan aktivite testinde en yüksek temizleme performansı ise 1 mg/mL konsantrasyonunda gerçekleşmiştir. GC-MS analizi sonucunda majör madde olarak Tris(2,4-di-tert-butylphenyl) phosphate (%52,45), A'-Neogammacer-22(29)-ene (%25.00) ve Neophytadiene (%12,72) tespit edilmiştir. Sonuç olarak, *P. striatulum*'un antimikrobiyal ve antioksidan aktivitesinin yanı sıra oldukça zengin bir biyokimyasal içeriğe sahip olduğu belirlenmiştir. Bu durum *P. striatulum*'un gelecekte antimikrobiyal ve antioksidan etkinliğe sahip yeni ajanların oluşturulması hususunda umut verici bir nitelik taşırken biyokimyasal yapısının aydınlatılması gelecekteki çalışmalar için önemli bilgiler sunmaktadır.
Anahtar kelimeler: Bryofit, Antimikrobiyal Aktivite, Antioksidan Aktivite, Gaz Kromatografisi-Kütle Spektrometrisi (GC-MS)

1. Introduction

Bryophytes are non-vascular land plants classified into three main groups: hornworts (Anthocerotopsida), liverworts (Hepaticopsida), and mosses (Bryopsida) (Chandra et al., 2017; Das et al., 2022). Globally, bryophytes represent a crucial component of biodiversity and are typically found in moist and high-altitude regions; however, they can also be encountered in deserts, polar areas, and tropical climates (Öztürk et al., 2018; Dziwak et al., 2022). These small plants, which play a critical role in ecosystem stability and plant conservation, have been used by humans for centuries in the treatment of various diseases, skin disorders, and respiratory ailments aimed at preserving human health (Asakawa and Ludwiczuk, 2017; Muhammad et al., 2018; Ursavaş and Keçeli 2019).

The high abundance of bioactive compounds in bryophytes has led to increasing interest in these plants (Klavina, 2015). These plants, lacking evolved structural adaptations to protect against environmental stressors, adapt to stress conditions through their chemical diversity (Cianciullo et al., 2021). Therefore, the metabolites they produce are highly diverse and abundant. These metabolites not only play a significant role in bryophytes' defense against environmental factors, but also function in their interactions with other organisms within the ecosystem (Peters et al., 2019). Bryophytes possess a rich content of bioactive compounds, including glycosides, terpenoids, phenolic compounds, and fatty acids (Akatin et al., 2024). However, bryophytes often go unnoticed due to their small size and inconspicuous nature in the natural environment. Their widespread distribution across diverse substrates such as soil, animals, dead wood, and leaves poses challenges for the collection of pure samples. Additionally, difficulties in identifying and analyzing existing species resulting from their small morphology have led to the neglect of research on these plants (Öztopçu et al., 2017; Ismaeel et al., 2022). However, with the increasing interest in these plants, studies focused on the isolation of their bioactive compounds have been steadily growing (Horn et al., 2021). These studies are crucial for the identification of their chemical constituents. Bryophytes still contain compounds that have not yet been discovered or fully characterized. Therefore, comprehensive analysis of bioactive compounds present in medicinal plants and accurate quantification of therapeutically relevant components are of great importance (Turu et al., 2024).

When the literature is examined, numerous studies are found on the antimicrobial effects of bioactive secondary metabolites derived from plant sources. However, there is a notable lack of sufficient data regarding simple terrestrial plants such as bryophytes. Due to their underdeveloped morphological barriers against environmental stressors, bryophytes rely on their potent chemical compositions as their most effective defense mechanisms (Rodrigues et al., 2020; Valeeva et al., 2022). The well-developed secondary metabolites of bryophytes indicate that they are among the best candidates for the discovery and characterization of novel pharmaceutical compounds (Önbaşlı and Yuvalı, 2021). Some bioactive compounds derived from bryophytes are known to exhibit antimicrobial activity due to the presence of biflavonoids in their composition (Joshi et al., 2023). Bacterial resistance mechanisms against antibiotics are increasing day by day (Alan et al., 2018). Antibiotic resistance, which has become a global issue, leads to an increase in mortality rates associated with infectious diseases. The increasing rate of bacterial resistance reduces the effectiveness of existing antibiotics and necessitates the discovery of compounds with novel mechanisms of action. In this context, the development of antimicrobial agents from plants and the use of plants in alternative therapeutic approaches remain of significant importance. Scientific research in this field contributes valuable knowledge to the literature and holds great importance (Woo et al., 2023; Kırmacı et al., 2024).

In addition to their antimicrobial effects, phytochemicals are also known to be effective against the formation of biofilms, which is one of the antimicrobial resistance mechanisms. The high concentration of various bioactive compounds in plants has been observed not only to enhance

antibiofilm activity but also to prevent the development of resistance. Moreover, pharmacological substances derived from plants offer greater advantages over existing drugs due to their high therapeutic efficacy and cost-effectiveness. However, the incomplete characterization of bioactive compound contents in plants poses a barrier to the efficient utilization of their antibiofilm effects (Rather et al., 2021; Ali and Neelakantan, 2022; Mahamud et al., 2024).

Living organisms produce reactive oxygen species (ROS) as by-products during the metabolic processing of oxygen. These reactive oxygen species cause the degradation of biological molecules and induce oxidative stress. As simple-structured plants, bryophytes possess effective defense mechanisms that confer antioxidant properties; these mechanisms help reduce the harmful effects of reactive oxygen species and minimize cellular damage. As simple-structured plants, bryophytes possess effective defense mechanisms that confer antioxidant properties; these mechanisms help reduce the harmful effects of reactive oxygen species and minimize cellular damage. (Provenzano et al., 2019; Chaves et al., 2020; Bozkurt et al., 2024;). Additionally, the volatile phenolic compounds present in bryophytes contribute to health promotion by exhibiting antioxidant properties that aid in the prevention of age-related diseases and aging (Mitra et al., 2019). Antioxidants obtained through diet or natural sources may be beneficial in combating oxidative stress, which adversely affects human health and contributes to aging. Due to their pharmaceutical effects, these antioxidants have potential applications as health supplements (Amorati and Valgimigli, 2018).

In this study, the biological activities of the phytochemicals present in the moss *Plasteurhynchium striatulum* (Spruce) M. Fleisch were thoroughly investigated. Its antimicrobial potential was assessed using the disk diffusion method, followed by the determination of the Minimum Inhibitory Concentration (MIC) value. The antibiofilm activity of the plant was determined by analyzing bacterial biofilm formation. Additionally, the DPPH (1,1-diphenyl-2-picrylhydrazyl) assay was performed to evaluate its antioxidant capacity. The richness of *P. striatulum*'s phytochemical content was demonstrated by GC-MS analysis, and the obtained active secondary metabolites were assessed to discuss their biological efficacy.

2. Materials and Methods

P. striatulum moss was collected and identified by Dr. Ayşe Dilek Unan from Merkez/Zonguldak (41°27'14.3"N 31°45'49.2"E). The plant material was deposited at the Dokuz Eylül University Fauna and Flora Research and Application Center, Buca, İzmir, Turkey, and is preserved under the herbarium code FFDEU-MEB4.

2.1. Preparation of extracts from Plasteurhynchium striatulum

After drying, the collected samples were ground into small pieces using a grinder (IKA, MF10 basic). Thirty grams of the powdered plant material was placed in an Erlenmeyer flask, to which 200 mL of ethanol was added. The mixture was then shaken at 140 rpm for 2 days. Following the completion of the shaking step, the mixture was passed through Whatman No. 1 filter paper into flasks. Subsequently, the solvent was evaporated using a rotary evaporator, and the remaining residue in the flask was measured and noted. The extract was prepared for further use (Canlı et al., 2019). Extraction was also conducted separately with three distinct solvents ethanol, n-hexane, and methanol by applying the same protocol. The amounts of extract obtained were calculated and recorded as 0.529 g in 25 mL for ethanol, 1.149 g for methanol, and 0.147 g for n-hexane.

2.2. Microorganisms

This research assessed antimicrobial effects on 48 microbial strains in total, comprising 17 standard strains, 7 isolates from food sources, 13 clinical isolates, and 11 multidrug-resistant (MDR) strains. The strains used in this study were sourced from the Biology Department at the Faculty of Science, Dokuz Eylül University (İzmir, Turkey).

2.3. Inoculum preparation

A sterile 0.9% sodium chloride (NaCl) solution was prepared for the microbial strains utilized in the study and microbial suspensions were adjusted to a density of 1.5×10^7 CFU/mL^{-1} for yeasts and 1.5×10^8 CFU/mL^{-1} for bacteria in accordance with the 0.5 McFarland standard (Benek et al., 2024).

2.4. Disc diffusion test

In order to compare the antimicrobial effects of ethanol, methanol, and n-hexane extracts of *P. striatulum* moss on microorganisms, the disk diffusion method was employed. A volume of 25 mL was used for each solvent, and the extract yields were calculated as 0.529 g for ethanol, 1.149 g for methanol, and 0.147 g for n-hexane. Next, to assess antimicrobial activity, sterile petri

dishes were filled with Mueller-Hinton agar that had been prepared beforehand. Antimicrobial test disks were impregnated with 110 µL of ethanol extract and 150 µL each of methanol and n-hexane extracts. Prepared microbial inocula were spread onto agar plates, and the extract-impregnated disks were placed upside down to facilitate more effective diffusion. Following the placement of the disks, petri plates with bacterial strains were incubated at 37°C for 24 hours, whereas those containing yeast strains were incubated at 28°C for 48 hours. Following incubation, the inhibition zones surrounding the disks were measured and documented in tables. Gentamicin served as the positive control. (Şimşek et al., 2023).

2.5. Determination of minimum inhibitor concentrations (MIC)

MIC of *P. striatulum* plant extract against microorganisms that showed antimicrobial sensitivity in the disk diffusion test was determined using the broth microdilution method. For the preparation of the DMSO-water extract required for the MIC test, the ethanol-based extract was first concentrated by rotary evaporation at 40 °C. The concentrated material was then dissolved in dimethyl sulfoxide (DMSO) (Iron Chemistry, Turkey) and processed. Subsequently, dilution was performed with ultrapure water obtained from a distillation system (Thermo Fisher Scientific, USA) to prepare a solution containing 1% DMSO (Gül et al., 2025). Following this procedure, the extract amounts were calculated and recorded as 0.16 g for ethanol-DMSO, 0.377 g for methanol-DMSO, and 0.057 g for n-hexane-DMSO in 15 mL of extract. Mueller-Hinton broth was used as the suitable culture medium for the microorganisms, and the microbial density was adjusted according to the 0.5 McFarland standard. The plant extracts were transferred into sterile 96-well microplates at a volume of 100 µL per well. Subsequently, 50 µL of microbial suspension was added to all wells. Antimicrobial activity was evaluated by visual inspection. For the negative control, wells contained only the culture medium and microbial inoculum, while for the positive control, only the culture medium was added to monitor any contamination. The plates were incubated for 24 hours to determine the necessary concentration to inhibit bacterial growth. The test was conducted in triplicate (Canlı et al., 2023a, 2023b).

2.6. Determination of minimum bactericidal concentration (MBC)

MBC is defined as the minimum concentration of an antimicrobial substance required to eliminate 99.9% of the initial bacterial population. After establishing the MIC value of *P. striatulum* plant extract against the tested microorganisms, 10 µL samples were collected from wells showing inhibition and streaked onto agar plates, which were then incubated at 37°C for 24 hours. The MBC value was determined by examining the agar plates for the presence or absence of microbial growth (Benek et al., 2024).

2.7. Biofilm activity test

The biofilm activity assay was adapted from the study conducted by Tunca-Pınarlı and Canlı (2021). The assessment of biofilm activity was carried out through a two-step process: first, determining the conditions necessary for biofilm formation, and second, evaluating the antibiofilm activity of the moss extracts.

2.7.1. Assessment of conditions for biofilm formation

To determine the antibiofilm activity of *P. striatulum,* a total of five bacterial strains were used: *Escherichia coli* 1209212 (CI), *Listeria innocua* (FI), *E. coli ATCC* 25922, *Listeria monocytogenes* ATCC 7644, and *Bacillus subtilis DSMZ* 1971. The bacterial strains used were standardized to a density of 1.5×10^8 CFU/mL^{-1} in sterile physiological saline solution, in accordance with the 0.5 McFarland standard. Subsequently, Luria–Bertani (LB) broth media containing six different glucose monohydrate concentrations (0.0%, 0.5%, 1.0%, 1.5%, 2.0%, and 2.5%) were loaded into 96-well microplates. The bacterial suspensions were then added, and the plates were incubated at 37°C for 24-8 hours. Following the completion of incubation, the microplates were washed and allowed to dry. After drying, each well was stained with 200 µL of crystal violet solution and allowed to sit for 15 minutes. Following staining, the plates were rinsed with distilled water and dried once more. Finally, 200 µL of a solution composed of 30% acetone and 70% ethanol was added to every well and incubated for 15 minutes before transferring the contents to clean microplates. The absorbance of the wells was measured at 550 nm using a microplate reader (Biotek). As a result, the optimal conditions for high biofilm production were determined for each microorganism.

2.7.2. Antibiofilm activity detection

To evaluate the antibiofilm activity of the moss extracts, concentrations corresponding to ½ of the MIC value were selected. The bacterial strains *Escherichia coli* 1209212 (CI), *E. coli* ATCC 25922, *Bacillus subtilis* DSMZ 1971. *Listeria monocytogenes* ATCC 7644 and *Listeria innocua* (FI) were standardized to a 0.5 McFarland turbidity standard. Subsequently, 100 µL of LB

broth medium, along with 50 µL each of the liquid extract and bacterial suspension, were added to each well of the microplates. After loading, the microplates were incubated under the optimal incubation conditions previously determined for each microorganism. Upon completion of incubation, the plates were washed and allowed to dry. Once dried, 200 µL of a solution composed of 30% acetone and 70% ethanol was added to each well and incubated for 15 minutes. The contents were then transferred to clean microplates. Halamid at a concentration of 3 mg/ml was used as a reference substance for the positive control. The absorbance of each well was measured and recorded at 550 nm using a microplate reader (Yaman et al., 2025).

2.8. Assessment of antioxidant properties

The antioxidant activity of *P. striatulum* extracts was evaluated based on their ability to scavenge DPPH (2,2-diphenyl-1-picrylhydrazyl) radicals. The method used relies on measuring the efficiency of antioxidants present in the plant extract to neutralize the DPPH radical. A quantity of 0.0039 g DPPH was measured and dissolved in 50 mL of ethanol using a glass Erlenmeyer flask to prepare the DPPH solution. The flask was then covered with aluminum foil to shield the solution from light. Extracts and DPPH solution were added to 96-well microplates at concentrations ranging from 7.8125 to 1000 µg/mL. The plates were then kept in the dark at room temperature for 30 minutes. After this incubation period, absorbance was read at 515 nm using a microplate reader and the results were documented. Ascorbic acid served as the positive control, and all tests were performed in triplicate. (Turu et al., 2024; Bozkurt et al., 2024).

2.9. Gas chromatography-mass spectrometry method (GC-MS)

The biochemical content analysis of the moss sample was performed using the methods described by Benek et al. (2024). GC-MS analysis was carried out using the Agilent GC 8890-Agilent GC/MSD 5977B system, with helium gas used as the carrier. Compound identification was performed by matching the acquired spectra against the reference data from the NIST and Wiley databases. Chemical constituents present at concentrations higher than 0.5% were recorded as major components.

2.10. Statistical analysis

The statistical evaluation was carried out using the parametric one-way ANOVA technique. The Pearson correlation coefficient was also determined. All tests were performed in triplicate. P-values of 0.05 or lower ($p \leq 0.05$) were regarded as statistically significant. All statistical analyses were performed using R Studio.

3. Result

3.1. Disk diffusion test

Using the disk diffusion technique, the antimicrobial effects of *P. striatulum* extracts prepared with ethanol, methanol, and n-hexane were assessed against a diverse range of 48 microbial strains.

Based on the outcomes of the disk diffusion assay, *P. striatulum* extracts demonstrated antimicrobial activity against a total of eight different strains. The microbial strains showing inhibition zones with the ethanol extract were identified as *Escherichia coli* (7 mm), *Pseudomonas aeruginosa* (7 mm), *Staphylococcus aureus* (7 mm), *Salmonella infantis* (7 mm), and *Streptococcus mutans* (7 mm). The methanol extract exhibited antimicrobial activity against *Listeria monocytogenes* (7 mm), *Staphylococcus aureus* (7 mm), *Salmonella infantis* (7 mm), and *Streptococcus mutans* (7 mm). In the disk diffusion test performed using the n-hexane extract, activity was recorded only against the *Providencia rustigianii* strain (7 mm). Statistical evaluation indicated that there was no significant variation among the results obtained from the different solvents ($p > 0.05$). Furthermore, when ethanol, methanol, and n-hexane extracts were evaluated separately, no significant difference was observed in the levels of antimicrobial activity against different bacterial species ($p = 0.5 > 0.05$). This finding indicates that a substantial portion of the variance is attributed not to the bacterial species but to other experimental variables. According to the results obtained, the inhibitory effects of the applied biological agents on bacterial species occurred at similar levels, and the differences in sensitivity among species were not statistically significant. This suggests that the tested agents may exhibit a homogeneous effect profile on the target microorganisms or that the bacterial species included in the study possess similar resistance levels. The zones of inhibition surrounding the disks containing *P. striatulum* extracts are shown in Tables 1–4, corresponding to standard isolates (Table 1), food isolates (Table 2), clinical isolates (Table 3), and multidrug-resistant (MDR) strains (Table 4).

Table 1. Disk diffusion test results of *P. striatulum* moss on standard isolated strains

Microorganisms	**Ethanol (110µl)**	**Methanol (150µl)**	**n-hexane (150µl)**	**Gen (10 µg)**
Bacillus subtilis DSMZ l97l	-	-	-	30±0.00
Candida albicans DSMZ l386	-	-	-	12±0.00
Enterobacter aerogenes ATCC l 3048	-	-	-	24±0.00
Enterococcus faecalis ATCC 292l2	-	-	-	12±0.00
Escherichia coli ATCC25922	7±0.00	-	-	22±0.00
Listeria monocytogenes ATCC 7644	-	7±0.00	-	28±0.00
Pseudomonas aeruginosa DSMZ 50071	7±0.00	-	-	15±0.00
Pseudoıuonas fluorescens P 1	-	-	-	13±0.00
Salmonella enteritidis ATCC 13076	-	-	-	21±0.00
Salmonella typhimuriuın SL1344	-	-	-	24±0.00
Staphylococcus aureus ATCC 25923	7±0.00	7±0.00	-	21±0.00
Staphylococcus epiderınidis DSMZ 20044	-	-	-	22±0.00
Staphylococcus hominis ATCC 27844	-	-	-	18±0.00
Staphylococcus warneri ATCC 27836	-	-	-	23±0.00
Bacillus cereus RSKK 863	-	-	-	24±0.00
Shigella flexneri RSKK l84	-	-	-	18±0.00
Acinetobacter baumannii CECT 9111	-	-	-	13±0.00
Gen: Gentamicin, (-): No effect was observed.				

Table 2. Disk diffusion test results of *P. striatulum* moss on food isolate strains

Microorganisms	**Ethanol (110µl)**	**Methanol (150µl)**	**n-hexane (150µl)**	**Gen (10 µg)**
Enterococcus durans	-	-	-	11±0.00
Enterococcus faecium	-	-	-	28±0.00
Klebsiella pneumoniae	-	-	-	19±0.00
Listeria innocua	-	-	-	13±0.00
Salmonella infantis	7±0.00	7±0.00	-	17±0.00
Salmonella kentucky	-	-	-	12±0.00
Escherichia coli	-	-	-	0±0.00
Gen: Gentamicin, (-): No effect was observed.				

Table 3. Disk diffusion test results of *P. striatulum* moss on clinical isolate strains

Microorganisms	Ethanol (110µl)	Methanol (150µl)	n-hexane (150µl)	Gen (10 µg)
Staphylococcus aureus	-	-	-	22±0.00
Streptococcus mutans	7±0.00	7±0.00	-	22±0.00
Staphylococcus hominis	-	-	-	9±0.00
Staphylococcus haemolyticus	-	-	-	10±0.00
Staphylococcus lugdunensis	-	-	-	17±0.00
Shigella boydi	-	-	-	20±0.00
Actinobacter baumannii	-	-	-	18±0.00
Shigella flexneri	-	-	-	16±0.00
Staphylococcus aureus	-	-	-	22±0.00
Enterococcus faecalis	-	-	-	12±0.00
Klebsiella pneumoniae	-	-	-	18±0.00
Candida tropicalis	-	-	-	0±0.00
Candida glabrata	-	-	-	7±0.00
Gen: Gentamicin, (-): No effect was observed.				

Table 4. Disk diffusion test results of *P. striatulum* moss on multidrug-resistant (MDR) strains

Microorganisms	Ethanol (110µl)	Methanol (150µl)	n-hexane (150µl)	Gen (10 µg)
Escherichia coli	7±0.00	-	-	8±0.00
Klebsiella pneumoniae	-	-	-	15±0.00
Acinetobacter baumannii	-	-	-	0±0.00
Enterobacter aerogenes	-	-	-	16±0.00
Serratia odorifera	-	-	-	7±0.00
Proteus vulgaris	-	-	-	11±0.00
Streptococcus pneumonia	-	-	-	10±0.00
Staphylococcus aureus MRSA	-	-	-	0±0.00
Staphylococcus aureus MRSA+ MDR	-	-	-	22±0.00
Providencia rustigianii	-	-	7±0.00	16±0.00
Achromobacter sp.	-	-	-	9±0.00
Gen: Gentamicin, (-): No effect was observed.				

3.2. Minimum inhibitory concentrations (MIC) and minimum bactericidal concentrations (MBC/MFC)

The MIC test results of the ethanol extract of *P. striatulum* are presented in Table 5, the methanol extract results in Table 6, and the n-hexane extract results in Table 7. Among the 11 different strains tested, the MIC value against S. infantis was determined to be 0.8816 mg/mL. Furthermore, the MBC test performed on the strain that showed antimicrobial activity in the MIC test revealed that the extract exhibited a bacteriostatic effect. The MBC test was not performed on microorganisms that showed no effect in the MIC test. Test readings were based on visual inspection. All tests were repeated three times.

Table 5. MIC and MBC/MFC Results of the Ethanol Extract of *P. striatulum*

Microorganisms	MIC (mg/ml)	MBC/MFC (mg/ml)
Escherichia coli ATCC 25922	>7,0533	-
Pseudomonas aeruginosa DSMZ 50071	>7,0533	-
Staphylococcus aureus ATCC 25923	>7,0533	-
Salmonella infantis (FI)	0,8816	>0,8816
Escherichia coli (MDR)	>7,0533	-
Streptococcus mutans (CI)	>7,0533	-
(-): MBC test was not performed for strains where no MIC was determined.		

Table 6. MIC and MBC/MFC Results of the Methanol Extract of *P. striatulum*

Microorganisms	MIC (mg/ml)	MBC/MFC(mg/ml)
Listeria monocytogenes ATCC 7644	>15,32	-
Staphylococcus aureus ATCC 25923	>15,32	-
Salmonella infantis (FI)	>15,32	-
Streptococcus mutans (CI)	>15,32	-
(-): MBC test was not performed for strains where no MIC was determined.		

Table 7. MIC and MBC/MFC Results of the n-Hexane Extract of *P. striatulum*

Microorganisms	MIC (mg/ml)	MBC/MFC(mg/ml)
Providencia rustigianii (MDR)	>1,96	-
(-): MBC test was not performed for strains where no MIC was determined.		

3.3. Findings of the tests determining biofilm formation conditions

As a result of the tests conducted to determine the optimal conditions for biofilm formation, it was found that the *B. subtilis* DSMZ 1971 strain produced the highest level of biofilm after 48 hours of incubation in a medium containing 0% glucose. Similarly, the *E. coli* ATCC 25922 strain formed the highest amount of biofilm after 24 hours of incubation in a 0% glucose medium. The *L. monocytogenes* ATCC 7644 and *L. innocua* strains exhibited maximum biofilm production after 48 hours of incubation in a 0% glucose medium. Lastly, the *E. coli* 1209212 (CI) strain showed the highest level of biofilm formation after 24 hours of incubation in a medium with 0% glucose.

3.4. Antibiofilm activity findings

The antibiofilm effects of *P. striatulum* extracts prepared with ethanol, methanol, n-hexane, and water were examined in this study. The concentrations of the active constituents in the 15 mL extracts were calculated and recorded as follows: 10.67 mg/mL for the ethanol-DMSO extract, 25.13 mg/mL for the methanol-DMSO extract, 3.80 mg/mL for the n-hexane-DMSO extract, and 32.67 mg/mL for the aqueous extract.

The antibiofilm activity results of ethanol, methanol, n-hexane, and aqueous extracts of the bryophyte *P. striatulum* against the standard isolate *B. subtilis* DSMZ 1971 are presented in Figure1.

As a result of the study, all *P. striatulum* (PS) extracts prepared with ethanol, methanol, n-hexane, and water were found to significantly inhibit the biofilm formation of the standard isolate *Bacillus subtilis* DSMZ 1971 at MIC/2 concentrations. The antibiofilm activity of the extracts was found to be much higher than that of the positive control, Halamid (1.347%). The highest antibiofilm effect was observed in the ethanol extract (52.29%), followed by the n-hexane (47.27%) and methanol (44.38%) extracts, respectively. The lowest activity was detected in the aqueous extract (18.79%); however, this extract also exhibited stronger inhibition than the positive control. The standard isolate *E. coli* ATCC 25922 are presented in Figure 2.

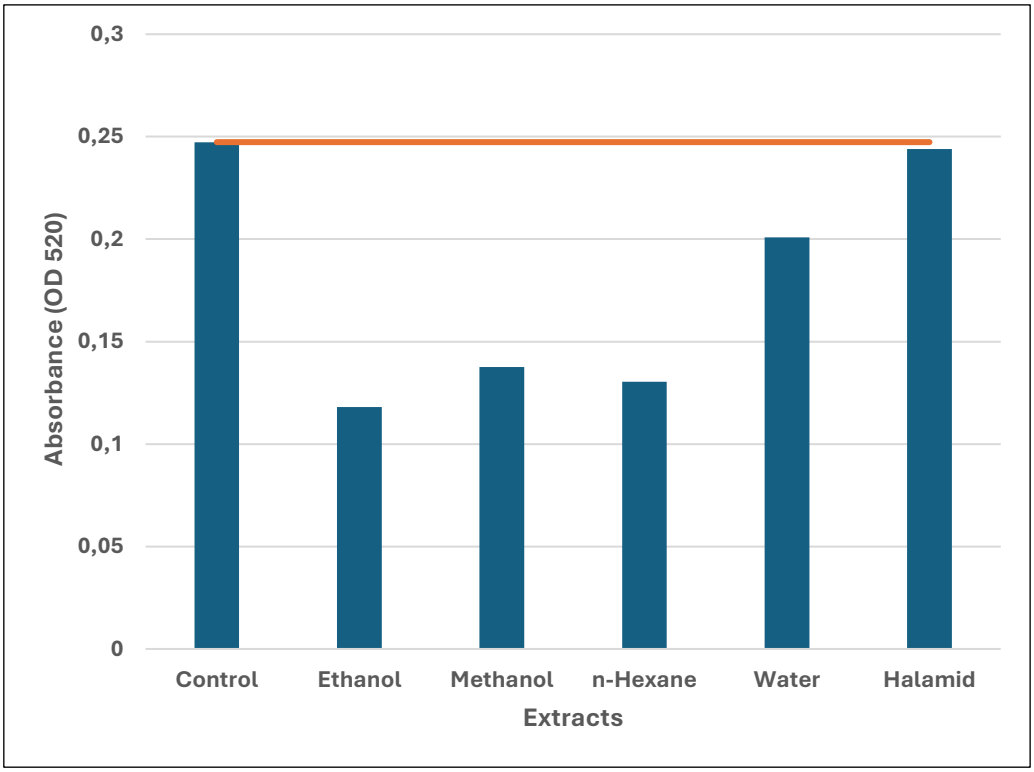

Figure 1. Effect of ethanol, methanol, n-hexane, and aqueous *P. striatulum* extracts on *B. subtilis* DSMZ 1971 biofilm formation (OD values)

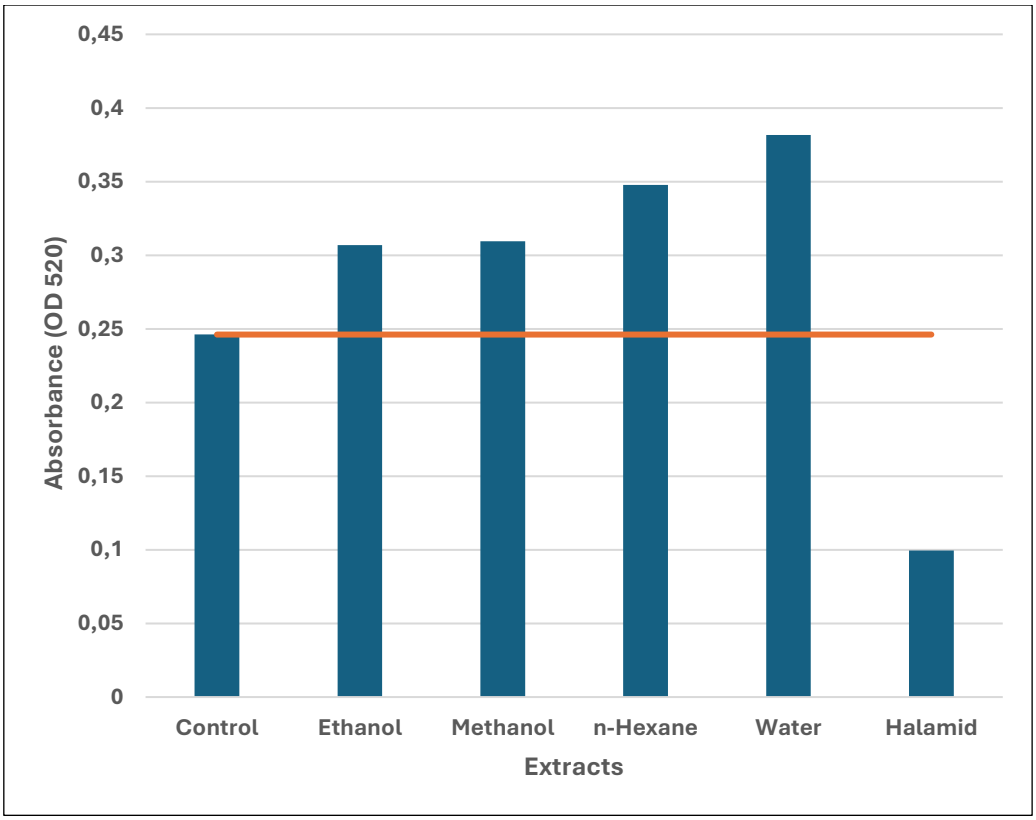

Figure 2. Effect of ethanol, methanol, n-hexane, and aqueous *P. striatulum* extracts on *E. coli* ATCC 25922 biofilm formation (OD values)

The study revealed that all *P. striatulum* (PS) extracts prepared with ethanol, methanol, n-hexane, and water increased rather than inhibited biofilm formation of the standard *E. coli* ATCC 25922 isolate at MIC/2 concentrations. The aqueous extract showed the highest induction of biofilm formation (–55.01%), followed by the n-hexane (–41.25%), methanol (–25.70%), and ethanol (–24.71%) extracts, respectively. This suggests that the extract may contain signaling components capable of stimulating biofilm development or that this concentration may provide a favorable environment for bacterial growth and biofilm formation. *Striatulum* against the standard isolate *L. monocytogenes* ATCC 7644 are presented in Figure 3.

As a result of the study, the *P. striatulum* (PS) n-hexane extract (17.14%) significantly inhibited biofilm formation of the standard isolate *L. monocytogenes* ATCC 7644 at MIC/2 concentrations. In addition, the water extract (3.49%) also exhibited a noticeable antibiofilm activity. Although the methanol extract (0.22%) showed the lowest antibiofilm effect, the positive control, Halamid (–3.574%), demonstrated a stimulatory effect on biofilm formation. Similarly, the ethanol extract (–15.10%) was also found to promote biofilm development. The antibiofilm activity results of ethanol, methanol, n-hexane, and water extracts of *P. striatulum* moss agains the food isolate *L. innocua* strain are presented in Figure 4.

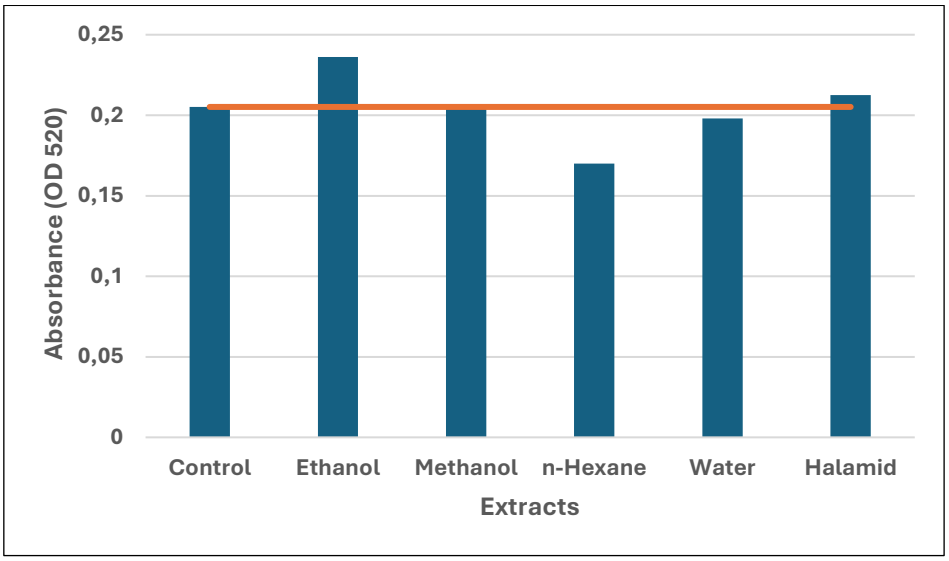

Figure 3. Effect of ethanol, methanol, n-hexane, and aqueous *P. striatulum* extracts on *L. monocytogenes* ATCC 7644 biofilm formation (OD values)

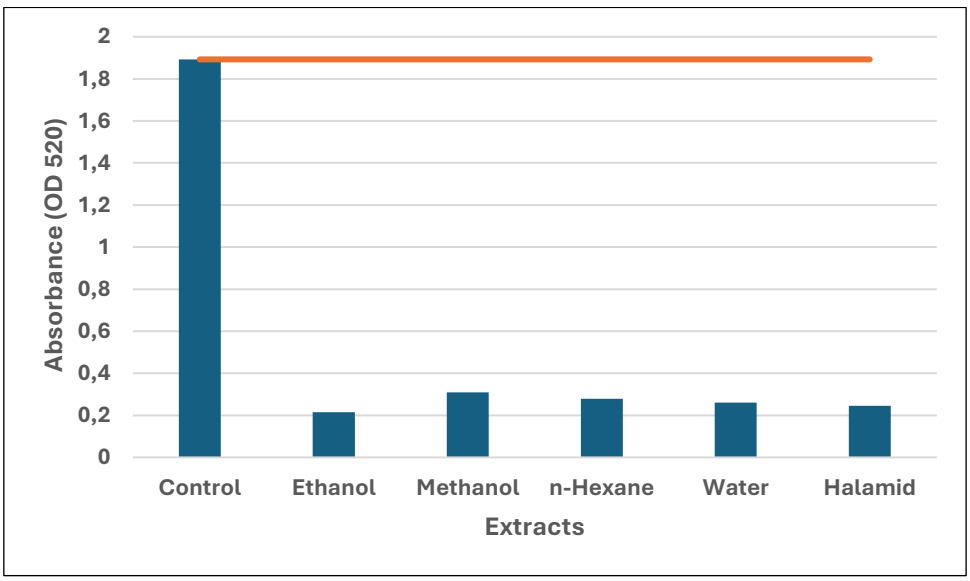

Figure 4. Effect of ethanol, methanol, n-hexane, and aqueous *P. striatulum* moss extracts on biofilm formation of *L. innocua* food isolate (OD values)

As a result of the study, all *P. striatulum* moss extracts prepared with ethanol, methanol, n-hexane, and water at MIC/2 concentrations were found to effectively inhibit biofilm formation of the food isolate *L. innocua*. The highest antibiofilm activity was observed in the ethanol extract (88.65%), followed by the aqueous (86.21%), n-hexane (85.28%), and methanol (83.63%) extracts, respectively. Notably, the ethanol extract exhibited a higher inhibition capacity than the positive control halamid (87.02%), indicating that *P. striatulum* extracts may be effective in preventing biofilm formation and could be considered as potential alternative antibiofilm agents against foodborne bacteria. The antibiofilm activity results of ethanol, methanol, n-hexane, and water extracts of *P. striatulum* moss against the clinically isolated *Escherichia coli* 1209212 strain are presented in Figure 5.

As a result of the study, all *P. striatulum* moss extracts prepared with ethanol, methanol, n-hexane, and water at MIC/2 concentrations were found to inhibit biofilm formation of a clinically isolated *E. coli* strain. The highest activity was observed in the methanol extract (56.24%), followed by the ethanol (54.28%) and aqueous (49.45%) extracts. The lowest activity was recorded in the n-hexane extract (41.46%). The positive control, halamid, achieved 87.20% inhibition.

Biofilm inhibition percentages were calculated using the following formula:

$$\%\text{Inhibition} = \frac{OD_{control} - OD_{sample}}{OD_{control}} \times 100$$

Statistical analysis revealed that the antibiofilm effects of *P. striatulum* extracts varied significantly among different bacterial strains ($p = 0.00000414 < 0.05$). However, no statistically significant differences were observed in the inhibition results among extracts prepared with different solvents ($p = 0.39 > 0.05$).

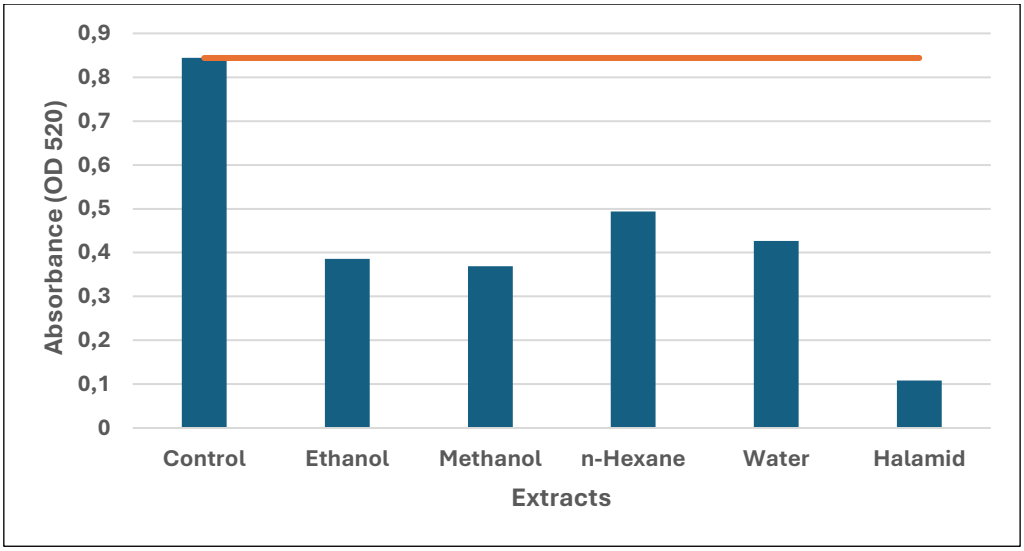

Figure 5. Effect of ethanol, methanol, n-hexane, and aqueous *P. striatulum* moss extracts on biofilm formation of clinically isolated *E. coli* 1209212 (OD values)

3.5. Comprehensive analysis of the biochemical constituents of P. striatulum

The biochemical contents of ethanol, methanol, and n-hexane extracts obtained from *P. striatulum* moss are presented in Table 8.

The biochemical contents of ethanol, methanol, and n-hexane extracts obtained from *P. striatulum* moss were determined by GC-MS analysis. In the ethanol extract, 23 different compounds were identified, with only three remaining unidentified. In the methanol extract, 24 different compounds were detected, four of which could not be identified. Finally, in the n-hexane extract, 24 different compounds were detected, seven of which could not be identified. In the ethanol extract, the compound A'-Neogammacer-22(29)-ene was found to be the most abundant, with a relative percentage of 25.00%. In the methanol extract, Neophytadiene (%12.72) was identified as the major component. In the n-hexane extract, Tris(2,4-di-tert-butylphenyl) phosphate was the most predominant compound, with a relative abundance of 52.45%. The compounds commonly found in the extracts prepared with the three different solvents were identified as n-Hexadecanoic acid, Octadecanoic acid, Vitamin E, and A'-Neogammacer-22(29)-ene.

Table 8. GC-MS analysis results of ethanol, methanol, and n-hexane extracts of *P. striatulum* moss.

RT	Compound name	Formula	MW (g/mol)	PS Ethanol extract	PS Methanol extract	PS n-Hexane extract
35.130	7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione	$C_{17}H_{24}O_3$	276,4	-	-	0.86
36.641	n-Hexadecanoic acid	$C_{16}H_{32}O_2$	256,4	3.73	7.43	1.89
41.814	Linoelaidic acid	$C_{18}H_{32}O_2$	280,4	4.56	-	1.59
41.955	9,12,15-Octadecatrien-1-ol, (Z,Z,Z)-	$C_{18}H_{32}O$	264. 4	-	-	1.15
41.873	Octadecanoic acid	$C_{18}H_{36}O_2$	284,5	0.89	1.09	0.65
45.211	Tricosane	$C_{23}H_{48}$	324,6	-	-	4.04
47.905	Tetracosane	$C_{24}H_{50}$	338,7	-	-	1.25
50.696	Heptacosane	$C_{27}H_{56}$	380,7	-	-	5.08
53.605	Hexacosane	$C_{26}H_{54}$	366,7	-	-	1.87
59.685	Octacosane	$C_{28}H_{58}$	394,8	-	-	3.13
63.907	2,6,10,14,18-Pentamethyl-2,6,10,14 ,18-eicosapentaene	$C_{25}H_{42}$	342,6	-	-	1.59
65.748	Heptacosane, 1-chloro-	$C_{27}H_{55}Cl$	415,2	-	-	1.37
67.108	E,Z-2,15-Octadecadien-1-ol acetate	$C_{20}H_{36}O_2$	308,5	-	-	0.79
68.807	Celidoniol, deoxy-	$C_{29}H_{60}$	408,8	-	-	2.15
68.703	Vitamin E	$C_{29}H_{50}O_2$	430,7	5.47	2.02	4.10
73.218	Tris(2,4-di-tert-butylphenyl) phosphate	$C_{42}H_{63}O_4P$	662,9	-	-	52.45
73.781	A'-Neogammacer-22(29)-ene	$C_{30}H_{50}$	410,7	25.00	8.59	3.96
6.653	2-Furancarboxaldehyde	$C_5H_4O_2$	96.08	-	1.52	-
20.222	2-Furaldehyde, 5-(hydroxymethyl)-	$C_6H_6O_3$	126.11	-	9.04	-
32.270	Neophytadiene	$C_{20}H_{38}$	278,5	22.02	12.72	-
34.931	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	270,5	4.18	1.59	-
39.582	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	$C_{19}H_{34}O_2$	294,5	-	0.82	-
39.787	9,12,15-Octadecatrienoic acid, methyl ester	$C_{19}H_{32}O_2$	292,5	-	0.89	-
40.524	Methyl stearate	$C_{19}H_{38}O_2$	298,5	-	0.51	-
41.439	9,12,15-Octadecatrienoic acid, (Z,Z,Z)-	$C_{18}H_{30}O_2$	278,4	2.15	7.70	-
44.098	5,8,11,14-eicosatetraenoic acid, methyl ester(all-Z)-	$C_{21}H_{34}O_2$	318,5	-	0.97	-
46.424	5,8,11,14,17-eicosapentaenoic acid	$C_{20}H_{30}O_2$	302,5	-	2.01	-
46.554	5,8,11,14-Eicosatetraenoic acid, ethyl ester, (all-Z)-	$C_{22}H_{36}O_2$	332,5	-	1.12	-
52.530	Beta sitosterol	$C_{29}H_{50}O$	414.7	0.75	0.59	-
59.362	Squalene	$C_{30}H_{50}$	410,7	1.66	1.06	-
63.768	trans-Geranylgeraniol	$C_{20}H_{34}O$	290,5	-	4.32	-
66.454	Stigmastan-3,5-diene	$C_{29}H_{48}$	396,7	0.56	0.76	-
73.931	Tricyclo[4.3.0.0(7,9)]Nonane, 2,2,5,5,8,8-Hexamethyl-, (1.Alpha.,6.BEta.,7.Alpha.,9.Alpha.)-	$C_{15}H_{26}$	206,37	-	0.59	-
32.332	(2E)-3,7,11,15-Tetramethyl-2-Hexadecene	$C_{20}H_{40}$	280.5	0.51	-	-
36.345	Hexadecanoic acid, ethyl ester	$C_{18}H_{36}O_2$	284.5	4.18	-	-
39.664	Phytol	$C_{20}H_{40}O$	296.5	0.62	-	-
40.882	Ethyl (9Z,12Z)-9,12-Octadecadienoate	$C_{20}H_{36}O_2$	308.5	1.39	-	-
44.553	Dodecane, 1,1'-oxybis-	$C_{24}H_{50}O$	354.7	0.70	-	-
45.762	Arachidonic acid	$C_{20}H_{32}O_2$	304.5	4.83	-	-

62.905	Bisabolol	$C_{15}H_{26}O$	222.3	5.74	-	-
72.912	Hop-21-ene	$C_{30}H_{50}$	410,7	0.86	-	-
74.440	A-Norcholestan-3-one, 5-ethenyl-,(5.beta.)-	$C_{28}H_{46}O$	398,7	0.80	-	-
14.527	Unknown	-	-	-	1.90	-
16.497	Unknown	-	-	-	2.10	-
33.665	Unknown	-	-	-	5.28	-
51.838	Unknown	-	-	-	1.26	-
18.618	Unknown	-	-	0.56	-	-
33.324	Unknown	-	-	6.06	-	-
50.821	Unknown	-	-	1.05	-	-
51.668	Unknown	-	-	-	-	0.54
55.792	Unknown	-	-	-	-	0.87
60.010	Unknown	-	-	-	-	1.25
64.144	Unknown	-	-	-	-	0.78
67.827	Unknown	-	-	-	-	0.57
72.064	Unknown	-	-	-	-	1.82
75.827	Unknown	-	-	-	-	1.73

3.6. Determination of antioxidant activity

The findings of the DPPH antioxidant assay for the ethanol extract of *P. striatulum* moss are presented in Table 9.

The DPPH radical scavenging test was conducted exclusively on the ethanol extract of *P. striatulum*. The findings are presented in Table 9. At a concentration of 1000 µg/mL, the ethanol extract of *P. striatulum* moss demonstrated the greatest DPPH radical scavenging activity, achieving an inhibition rate of 23.39%. At the same concentration, the positive control, ascorbic acid, showed a scavenging activity of 94.66%, indicating that *P. striatulum* moss exhibited lower antioxidant activity compared to the positive control at an identical concentration. One-way analysis of variance (ANOVA) was employed to perform the statistical analysis a parametric method, and the p-value was determined as 0.0658 ($p > 0.05$). This indicates that the increase in extract concentration did not result in a statistically significant difference in DPPH radical scavenging activity.

Table 9. DPPH antioxidant activity results of the ethanol extract of *P. striatulum* moss.

Concentration (µg/ml)	DPPH (%)	Ascorbic acid (%)
1000	23,39973	94,665
500	5,818852	93,391
250	2,47028	92,077
125	1,117735	90,086
62,5	2,991073	69,943
31,25	1,82574	35,794
15,625	1,640431	17,698
7,8125	1,041601	8,739

4. Discussion and Conclusions

Plants synthesize a wide variety of phytochemicals throughout their lifespan. These compounds are generally classified into two main groups: primary metabolites and secondary metabolites. Primary metabolites are responsible for the growth and developmental processes of the plant and include components such as nucleic acids, proteins, and various carbohydrates. Secondary metabolites, on the other hand, enhance the plant's survival capacity and facilitate its adaptation to environmental conditions. Among the most well-known phytochemical compounds are phenolics, terpenoids, tannins, coumarins, and alkaloids. These compounds are particularly notable for their diverse biological activities, including antimicrobial, antioxidant, and anti-inflammatory effects (Demir and Akpınar, 2020; Bitwell et al., 2023). The World Health Organization has also emphasized that medicinal and aromatic plants may serve as potential sources for the development of novel drugs (Vaou et al., 2021).

Although several studies in the literature have investigated the biological activities of secondary metabolites synthesized by bryophytes (Bozkurt et al., 2025), research on *P. striatulum* remains rather limited. Therefore, in the present study, *P. striatulum* was extracted using three different solvents (ethanol, methanol, and n-hexane). The

aim was to evaluate the antimicrobial, biofilm-inhibitory, and antioxidant activities of the obtained extracts, as well as to perform a biochemical content analysis.

In another study reported in the literature, Benek et al. (2023) evaluated the antimicrobial activities of ethanol extracts from various moss species using the disk diffusion method. These species included *Nogopterium gracile*, *Timmia bavarica*, *Rhynchostegium alopecuroides*, *Pylasia polyantha*, *Plagiomnium medium*, and *Leptodon smithii*. As a result of the disk diffusion test conducted on a total of 20 microorganisms, including nine standard strains, five multidrug-resistant (MDR) strains, three clinical isolates, and three food isolates, *P. medium* exhibited antimicrobial activity against *E. aerogenes* ATCC 13048 and *S. aureus* MRSA strains. *L. smithii* was effective against *S. aureus* MRSA, *E. coli* ATCC 25922, and *P. vulgaris* strains, while *R. alopecuroides* demonstrated activity against *E. aerogenes* ATCC 13048, *L. monocytogenes*, and *K. pneumoniae*. *N. gracile* showed inhibitory effects against *S. aureus* ATCC 25923, *S. kentucky*, and *S. aureus* MRSA strains. Finally, *P. polyantha* exhibited antimicrobial activity against *E. aerogenes* ATCC 13048, *S. aureus* ATCC 25923, and *S. aureus* MRSA, whereas *T. bavarica* was active against *E. faecalis*, *S. aureus* ATCC 25923, and *S. aureus* MRSA strains.

The strains used in the studies and the disk diffusion method applied were the same. The results showed particular similarities against *E. coli*, *S. aureus* ATCC 25923, *E. coli* ATCC 25922, *S. mutans*, and *P. aeruginosa* DSMZ 50071. In addition, the ethanol extract of *P. striatulum* demonstrated activity against the *S. infantis* strain in the disk diffusion test. The compound neophytadiene, identified in both the ethanol and methanol extracts during the biochemical profiling, is known for its antimicrobial, antioxidant, and anti-inflammatory properties (Al-Rajhi et al., 2022), which supports the observed antimicrobial effect. However, no antimicrobial activity was detected against the other strains. The limited antimicrobial activity observed in the study is primarily attributed to the insufficient concentration of the extracts. The administered dose may not have reached the minimum inhibitory concentration of the active compounds, resulting in the detection of small inhibition zones only in a limited number of strains. Furthermore, the inadequate diffusion of the complex extract composition within the agar medium may also have contributed to the apparently low activity. To overcome these limitations and to further support the findings, MIC and MBC values were additionally determined in the study.

Following the disk diffusion assay, minimum inhibitory concentration (MIC) testing was performed on the microorganisms that exhibited antimicrobial activity. The MIC test of the ethanol extract was conducted against *P. aeruginosa* DSMZ 50071, *S. mutans* (CI), *E. coli* ATCC 25922, *S. infantis* (FI), *E. coli* (MDR), and *S. aureus* ATCC 25923 strains. The methanol extract was tested against *S. aureus* ATCC 25923, *S. mutans* (CI), *S. infantis* (FI), and *L. monocytogenes* ATCC 7644, whereas the n-hexane extract was tested against the *P. rustigianii* (MDR) strain. As a result, the ethanol extract exhibited antimicrobial activity against the foodborne *S. infantis* strain at a concentration of 0.881 mg/mL. No MIC value was determined for the methanol and n-hexane extracts. *S. infantis* is one of the five serovar strains responsible for salmonellosis in humans (Zeng et al., 2021), a disease characterized by symptoms such as nausea, diarrhea, and fever, which can be life-threatening particularly in children and the elderly (Montoro-Dasi et al., 2023). During the MBC assay, bacterial growth observed in this strain indicated that the effect was bacteriostatic rather than bactericidal.

Öztürk et al. (2022) lyophilized four bryophyte species (*Palamocladium euchloron*, *Cratoneuron filicinum*, *Plasteurhynchium striatum*, and *Campyliadelphus chrysophylus*) and extracted them with methanol, ethanol, chloroform, acetone, and water, aiming to determine their MIC values. The tested strains included *S. aureus* ATCC 29213, *P. aeruginosa* ATCC 27853, *E. faecalis* ATCC 29212, MRSA ATCC 43300, and *E. coli* ATCC 25922. None of the extracts exhibited antimicrobial activity. Similarly, in the present study, no inhibition was observed against the reference strain *E. coli* ATCC 25922. However, the determination of an MIC value against the foodborne *S. infantis* strain provides a noteworthy contribution to literature.

A review of the literature reveals that no studies to date have investigated the antibiofilm activity of *P. striatulum*. Thus, the present study represents the first systematic attempt to elucidate the antibiofilm potential of this moss. Biofilms are complex structures formed by bacteria adhering to biotic or abiotic surfaces, providing microorganisms with protection against environmental stresses and antimicrobial agents (Liu et al., 2023). Produced by both Gram-positive and Gram-negative bacteria, biofilms play a critical role in the chronicity of infectious diseases and the

development of treatment resistance (Shree et al., 2023). Furthermore, bacterial cells within established biofilms exhibit low metabolic activity, rendering them insensitive to antibiotics, which are effective primarily against metabolically active cells (Razdan et al., 2022). Therefore, biofilm inhibition is a comparatively rare phenomenon, standing out as a biologically significant property beyond ordinary antimicrobial effects.

In the study conducted by Uyar et al. (2023) on the moss *Dichodontium pellucidum*, the antibiofilm activities of ethanol, methanol, ethyl acetate, and acetone extracts were evaluated against various bacterial and fungal strains. Among these, the ethyl acetate extract at the MIC concentration (10.0 µg/mL) exhibited the highest inhibition, achieving 90.03% against *B. subtilis* ATCC 6633. At 1/2 MIC (5.0 µg/mL), the highest results were observed for all extracts ethanol, methanol, ethyl acetate, and acetone against *P. aeruginosa* ATCC 27853, with inhibition rates of 75.33%, 65.05%, 68.07%, and 67.04%, respectively.

In this study, the ethanol, methanol, n-hexane, and aqueous extracts were evaluated for their antibiofilm activities against *L. monocytogenes* ATCC 7644, *E. coli* ATCC 25922, *E. coli* (CI), *L. innocua* (FI), and *B. subtilis* DSMZ 1971 strains. Initially, the optimal conditions for biofilm formation were determined, and subsequently, the effects of the extracts were tested. The results revealed that, at 1/2 MIC concentrations, some extracts stimulated biofilm activity, whereas others significantly inhibited biofilm formation.

Specifically, while the positive control of the test, halamid, exhibited 1.34% inhibition against the Gram-positive *B. subtilis* DSMZ 1971 strain, which shows a high adaptive capacity to environmental conditions, the ethanol extract demonstrated 52.29% inhibition (Arnaouteli et al., 2021; Iqbal et al., 2023). In addition, the n-hexane extract inhibited *L. monocytogenes* ATCC 7644 by 17.14%, whereas halamid was observed to stimulate biofilm formation (-3.57%). The ethanol extract exhibited 88.65% inhibition against *L. innocua*, while the positive control halamid showed 87.02% inhibition. The fact that some of the tested extracts exhibited higher inhibition than positive control indicates their potential for use in the development of new antibiofilm agents.The extracts of *P. striatulum* showed no antibiofilm activity against *E. coli* ATCC 25922; on the contrary, a stimulatory effect on biofilm formation was detected. The methanol extract exhibited 56.24% inhibition against the clinical isolate of *E. coli*. The variability observed in the obtained results can be attributed to differences in materials, methods, solvents, and microbial strain diversity. GC-MS analyses revealed the presence of octadecanoic acid in all solvent-based extracts. Previous studies have reported that this compound exhibits antifungal and antimicrobial properties (AlRaddadi et al., 2024).

The findings suggest that *P. striatulum* can be considered a potential antibiofilm agent. Furthermore, the extract's antibiofilm activity against both Gram-negative and Gram-positive bacteria indicates that it may serve as an effective therapeutic candidate for the treatment of chronic infections. In addition, the presence of yet unidentified compounds in the biochemical profiles of the extracts suggests that these compounds may contribute to the antibiofilm activity of *P. striatulum*. Future studies focusing on the isolation and characterization of these compounds will provide a more comprehensive understanding of the biological potential of this moss. This study not only reveals the existing antibiofilm effects but also provides valuable insights for future research aimed at developing new potential agents against treatment-resistant and biofilm-forming bacteria.

Under conditions such as extreme heat and nutrient deficiency, the generation of reactive oxygen species (ROS) in plants leads to oxidative stress. Certain bioactive compounds present in the biochemical composition of plants exhibit strong antioxidant properties. In particular, phenolic compounds, which belong to the class of secondary metabolites, play a crucial role in mitigating oxidative stress due to their antioxidant activities. Previous studies have shown that the consumption of plants with high phenolic content exerts beneficial effects on human health (Chaves et al., 2020). In recent years, interest in antioxidants has increased due to the adverse effects of free radicals on human metabolism (Gülçin & Alwasel, 2023).

In this study, the antioxidant potential of the ethanol extract of *P. striatulum* was evaluated using the DPPH assay, based on absorbance measurements at 517 nm. The results indicated that the antioxidant capacity of the extract was lower than that of ascorbic acid, which was used as a positive control. While ascorbic acid exhibited strong antioxidant activity at much lower doses, the *P. striatulum* extract required higher concentrations to achieve a comparable effect. The DPPH scavenging rates ranged from 1.04% to 23.39%, with an EC_{50} value of 1.3849. GC-MS analysis revealed the presence of n-hexadecanoic

acid (3.73%) and vitamin E (5.47%) in the biochemical composition of the extract. Although these compounds are reported in the literature to possess strong antioxidant properties, their low absolute concentrations limited the radical scavenging capacity in the DPPH assay (Ganesan et al., 2024; Packer, 2023).

In the literature, a study by Öztürk et al. (2022) evaluated the antioxidant activities of methanol extracts of *C. chrysophyllus*, *P. euchloron*, *C. filicinum*, and *P. striatum* using the DPPH assay. The highest activity was reported for *C. filicinum* (65%), while the *P. striatum* extract exhibited a radical scavenging capacity of 55.22%. The lower antioxidant activity observed in the present study may be attributed to factors such as the different polarity profile of the solvent used, variations in extraction conditions, and the complex matrix structure of the natural extract.

The investigation of the biochemical components of bryophytes is important for understanding their metabolism and identifying the secondary metabolites responsible for their biological activities (Klavina et al., 2015). In the literature, Adebiyi and Tedela (2023) examined the biochemical composition of *Barbula lambaranensis* and *Philonotis hastata* using GC-MS analysis of their n-hexane extracts. A total of 23 different compounds were identified in the n-hexane extract of *P. hastata*, with the major compound being 9-octadecenoic acid, methyl ester (24.10%). In the n-hexane extract of *B. lambaranensis*, 31 compounds were detected, with hexadecanoic acid, methyl ester (11.76%) identified as the predominant compound.

Although there are studies in the literature focusing on the biochemical composition of certain moss species, no research has been conducted on the biochemical profile of *P. striatulum*. This study is the first to characterize the biochemical components of *P. striatulum*. The biochemical composition of its ethanol, methanol, and n-hexane extracts was analyzed using the GC-MS method.

In conclusion, a total of 23 different compounds were identified in the ethanol extract, with A'-Neogammacer-22(29)-ene (25.00%) being the predominant compound. In the literature, Garuba et al. (2023) reported the antiviral activity of this compound. In the methanol and n-hexane extracts, 24 compounds were detected. The major compound in the methanol extract was identified as Neophytadiene (12.72%), which was also observed in the ethanol extract (22.02%). Studies have indicated that neophytadiene possesses analgesic, anti-inflammatory, antimicrobial, and antioxidant properties (Willie et al., 2021). The primary compound in the n-hexane extract was Tris(2,4-di-tert-butylphenyl) phosphate (52.45%), with Heptacosane (5.08%) also detected in the biochemical profile. While Tris(2,4-di-tert-butylphenyl) phosphate has been reported in the literature for its anticancer activity, Heptacosane has been documented as a compound exhibiting antioxidant activity (Zahara et al., 2022; Akpuaka et al., 2013).

In our study, tris(2,4-di-tert-butylphenyl) phosphate was detected at a high concentration (~52%) in the GC-MS analysis of *P. striatulum*. Vinuchakkaravarthy et al. (2010) successfully isolated this compound from the leaves of *Vitex negundo* and reported its antioxidant activity. Based on the information provided in the literature, it can be concluded that this compound is naturally produced by plants. Another study listed this compound as a phytochemical with antioxidant properties (Jain et al., 2024). Similarly, Afrin et al. (2019) identified tris(2,4-di-tert-butylphenyl) phosphate in the biochemical profile of *Cuscuta reflexa* (Roxb.) and reported its antioxidant activity. However, some studies in the literature have also mentioned that this compound may exhibit toxic effects (Wang et al., 2025). According to the results obtained in our study, the high concentration of this compound could contribute to the observed antioxidant activity, while also raising the possibility of contamination. This aspect should be considered in subsequent studies following this preliminary investigation.

Moreover, n-Hexadecanoic acid, commonly found in plant tissues and known for its antimicrobial and antioxidant activities, was detected in all three extracts (Ganesan et al., 2024; Ravi & Krishnan, 2017). Additionally, Octadecanoic acid, Vitamin E, and A'-Neogammacer-22(29)-ene were also common to all three extracts. Octadecanoic acid has been attributed with anticancer, antitumor, antioxidant, and anti-inflammatory effects (Parvathi et al., 2022).

The observed antimicrobial, antibiofilm, and antioxidant activities of *P. striatulum* are consistent with the properties of the compounds identified by GC-MS and their reported biological activities in the literature. However, the potential contribution of synergistic interactions among the compounds present in the biochemical composition of the extracts should not be overlooked. Furthermore, it is suggested that compounds not identified by the GC-MS library

may also contribute to these effects and should be taken into consideration.

Declaration

Author contributions

Idea/Concept: GG, EG, KC; Conceptualization and design: GG, EG, DT; Auditing consulting: AB, KC; References: KC; Materials: ADU; Data collection and/or processing: GG, EG, CY, SDB; Analysis and/or interpretation: GG, GG, ED, EG; Literature search: GG, EG, DT; Writing phase: GG, EG; Critical review: MEB, AB, KC

Conflict of interest

It is declared by the authors that no conflict of interest exists concerning the findings and overall content of the study.

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Ethical approval

This research was conducted under in vitro conditions and therefore does not require ethical approval.

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Current Checklist and Distribution of Liverworts (Marchantiophyta) and Hornworts (Anthocerotophyta) in Türkiye

Kamil Mert Yücel [1,*], Hanife Tarım [2], Tamer Keçeli[3], İsa Gökler[2]

[1]*Ege University, Institute of Science, Department of Biology, Izmir, TÜRKİYE*
[2]*Dokuz Eylül University, Faculty of Science, Department of Biology, Izmir, TÜRKİYE*
[3]*Çankırı Karatekin University, Faculty of Science, Department of Biology, Çankırı, TÜRKİYE*

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Abstract

Through a comprehensive review of the literature, a checklist comprising 80 genera and 219 taxa belonging to 45 families has been compiled. Additionally, their distributions have been presented in a tabular format according to Henderson's (1961) quadrat system. For the first time, a list has been compiled based on up-to-date phylogenetic relationships, replacing the alphabetical arrangement adopted in earlier reference works. Ambiguous station records and species synonymies (covering 200 names) are discussed in 89 separate commentary notes presented under the table. A review of 128 bryophyte publications from 2009 to 2025 was conducted, resulting in the selection of 88 publications for inclusion in the updated reference list of Turkish liverworts and hornworts, presented following the study. After a 16-year hiatus, this investigation documented 45 new species records and 285 new grid records for Türkiye. Thirteen of the new grid records were provided by the present study. The families with the highest number of taxa are Ricciaceae, represented by 28 species, and Scapaniaceae, represented by 24 species. The aim of this study is to present the current status of Türkiye's liverwort & hornwort flora, evaluate the distribution of existing species, document new species and grid records, and contribute to future floristic research.

Keywords: Türkiye, Marchantiophyta, Liverwort, Hornwort, Checklist, Flora, Distribution

Türkiye'deki Ciğerotları (Marchantiophyta) ve Boynuzotlarının (Anthocerotophyta) Mevcut Kontrol Listesi ve Dağılımı

Öz

Literatürdeki tüm kaynakların taranması ile 45 familyaya ait 80 cins buna bağlı 219 taksonun kontrol listesi yapılmıştır. Ek olarak Henderson (1961) kareleme sistemine göre dağılımları tablo şeklinde sunulmuştur. Önceki çalışmalarda başvuru listesinde kullanılan alfabetik sıralama yerine ilk kez güncel filogeniye göre sıralanan yeni bir liste hazırlanmıştır. Belirsiz istasyon kayıtları ve türlerin sinonimlik durumları (200 isim işlem görmüştür) tablo altında verilen 89 ayrı vurgu metninde tartışılmıştır. 2009-2025 yılları arasında sunulan 128 briyofit yayını incenlenmiş ve 88 tanesi güncel Türkiye Ciğerotu ve Boynuzotu referans listesi olarak sonda sunulmuştur. 16 yıl aradan sonra bu araştırmayla Türkiye için 45 yeni tür kaydı ve 280 yeni kare kaydı tespit edilmiştir. Yeni kare kayıtlarının 13'ü bu çalışmada tarafımızdan verilmiştir. En çok takson içeren familyalar Ricciaceae 28 tür, Scapaniaceae 24 tür ile temsil edilmektedir. Bu çalışmanın amacı Türkiye ciğerotu ve boynuzotu florasının güncel durumunu ortaya koymak, mevcut türlerin dağılımını değerlendirmek, yeni tür ve kare kayıtlarını belgelemek ve gelecekte yapılacak floristik çalışmalara katkı sunmaktır.

Anahtar kelimeler: Türkiye, Marchantiophyta, Ciğerotu, Boynuzotu, Checklist, Flora, Dağılım

* Corresponding author: kmlmrtycl@gmail.com

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1. Introduction

The division Marchantiophyta (liverworts), which is classified within terrestrial plants, is represented by approximately 5,000 taxa worldwide (Söderström et al. 2016). The general taxonomic classification of the division is based on the structural forms of the plants, which also play a role in determining the classes. These forms are categorized into three types: thalloid, leafy, and intermediate. Among them, the leafy form contains the highest number of species. Another division within terrestrial plants, Anthocerotophyta (hornworts), is more evolutionarily advanced than other bryophyte divisions. They are represented by approximately 230 taxa worldwide (Söderström et al. 2016). Türkiye is between 26–46°E longitudes and 36–42°N latitudes, covering an area of 783,356 km² (Dönmez and Yerli 2019). As a peninsula country, it has a coastline of 8,333 km and land borders extending 2,875 km (Aytaç et al. 2020). Owing to its location at the convergence of the Euro-Siberian, Mediterranean, and Irano-Turanian phytogeographical regions, Türkiye harbors an exceptionally diverse flora (Efe 2010).

The scientific investigation of liverworts in Türkiye began in the late 1800s. The earliest known record is Wettstein's work titled *"Beiträge zur Flora des Orients"* (*Contributions to the Flora of the Orient*), which includes the first liverwort species reported from Türkiye: *Marchantia polymorpha* L. During the early 1900s, foreign researchers collected bryophyte specimens during botanical expeditions conducted in various regions of Türkiye. Several researchers conducted bryological studies in various regions of Türkiye throughout the 20th century. Handel-Mazzetti explored the Eastern Black Sea Region in 1909; Schiffner worked in different parts of Türkiye in 1913; Reimers collected specimens from the northern regions in 1927; Bornmüller researched several areas in 1931. In 1955, Henderson & Muirhead studied the Central Anatolia, Mediterranean, and Eastern Black Sea regions. Subsequently, Henderson carried out further investigations in Eastern Anatolia (1958), followed by studies in the Black Sea and Mediterranean regions (1961a, 1961b, 1963) Robinson & Godfrey surveyed Türkiye in 1960. Walther & Leblebici focused on western Türkiye in 1969, while Walther also worked in Western Anatolia in 1967, 1970, and 1979. Crundwell & Nyholm conducted research in various regions of Türkiye in 1979. The bryophyte specimens collected were cataloged by Henderson & Prentice (1969), resulting in the documentation of 132 liverwort species for Türkiye. In addition to these records, Henderson (1961) developed a map that divided Türkiye into 15 grid squares to illustrate the distribution of bryophytes (Figure 1).

Since the 1980s, local researchers in Türkiye have conducted studies on the division Hepaticae. Gökler et al. (1984) reported *Pellia neesiana* (Gottsche) Limpr. for the first time in Türkiye. Çetin & Yurdakul (1986) published the liverwort flora of Yedigöller National Park. Gökler et al. (1986) listed 143 liverwort species in the first national checklist compiled by Türkiye researchers. Later, Çetin (1988) expanded the systematic checklist of liverworts in Türkiye to 145 species. Kürschner and Erdağ (2005) presented a bryophyte checklist for Türkiye, reporting 163 liverwort taxa. Özenoğlu & Keçeli (2009) updated the liverwort and hornwort checklist for Türkiye, documenting 172 taxa and indicating their locations based on Henderson's (1961) grid system.

For research data conducted prior to 2009, it is recommended to refer to the publication by Özenoğlu & Keçeli (2009). In addition, the Türkiye Plant List – Mosses, published in 2017; Bryophyte Locality Data from the Near and Middle East – Volume 1, published in 2020; and Flora of Türkiye Mosses, published in 2023, were prepared in book form by Kürschner and Erdağ. These books provide extensive and important data, as well as detailed research, on Türkiye liverworts.

When we examine the important liverwort and hornwort studies conducted in Türkiye after 2009, according to Henderson's (1961) grid system; (The references for the species newly recorded for Türkiye are provided in the table notes. This section includes publications containing grid records.)

- Studies presenting square records for [A1]: Gözcü et al. (2018); Gözcü et al. (2019); Uslu & Keçeli (2019)
- Studies presenting square records for [A2]: Ursavaş & Abay (2009); Cangül & Ezer (2010); Şimşek et al. (2011): Ören et al. (2012); Ören et al. (2015); Gözcü et al. (2018); Sarıoğlu & Keçeli (2018); Gözcü et al. (2019); Ören & Ursavaş (2020)
- Studies presenting square records for [A3]: Söylemez et al. (2017); Çalışkan et al. (2019); Ören & Ursavaş (2020); Uyar & Ören (2025); Yücel et al. (2025)
- Studies presenting square records for [A4]: Erata et al. (2022); Özen et al. (2019)
- Studies presenting square records for [A5]: Batan et al. (2017)

- Studies presenting square records for [B6]: Şimşek (2024)
- Studies presenting square records for [B7]: Yücel and Ezer (2018); Gökler et al. (2022); Yücel et al. (2024)
- Studies presenting square records for [B8]: Gözcü et al. (2013); Kara et al. (2014); Karakaş & Ezer (2017)
- Studies presenting square records for [B10]: Kırmacı et al. (2018)
- Studies presenting square records for [C11]: Kırmacı & Erdağ (2010)
- Studies presenting square records for [C12]: Uygur et al. (2022a), Uygur et al. (2022b),
- Studies presenting square records for [C13]: Kara et al. (2013); Ezer et al. (2015)

Advancements in Molecular Biology and Genetics, combined with greater accessibility to previously unexplored regions and a growing research community, have significantly increased the number of cryptogam specimens recorded in Türkiye. The objective of this study is to compile an updated list of liverworts & hornworts in Türkiye and to map their distribution 16 years later (Table 1).

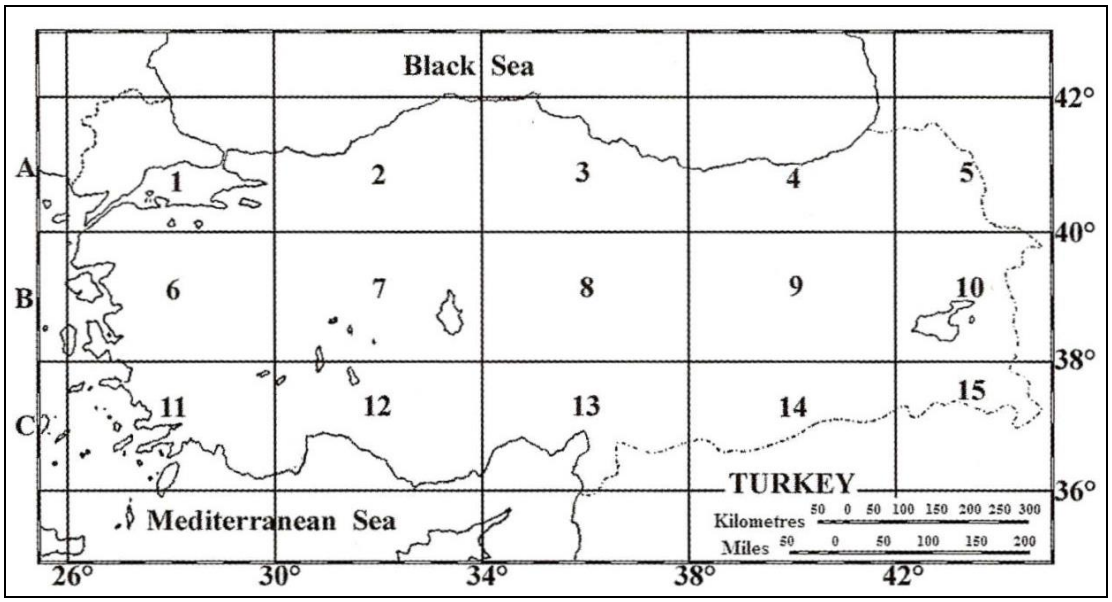

Figure1. Map of Türkiye according to Henderson (1961) quadrature system

2. Materials And Methods

The collection was compiled based on searches conducted in the Web of Science, Scopus, Google Scholar, ScienceDirect (Elsevier), SpringerLink, Wiley Online Library, TR Dizin databases and the analysis of the data forming the basis of this research was carried out with great precision. All national and international journals, symposium proceedings, postgraduate theses, congress proceedings, research notes, books, booklets and poster presentations containing information such as taxonomy, locality, new records, square records of Turkish liverworts and hornworts published after 2009 were meticulously scanned and the content of 128 articles was examined. Following this search, the data was tabulated, and to ensure continuity, the foundations of a database (Scanned database/Indexed publication form/Research subject/Province where the study was conducted/Authors/Year/Publication title/Journal title/Publication number, page/DOI number/Open access status/Square record/New record for Turkey, and reference list) were created. During the literature review, care was taken not to overlook studies where liverworts and hornworts were not presented separately but were included in a common flora list with bryophytes. Publications necessary for the examination of ambiguous type data presented before and in the early 2000s have been accessed; however, it has not been possible to advance beyond the data presented in previous checklists. This is due to the highly limited nature of the data.

All taxa presented in the list were prepared according to the current and universal sequence, taking into account Söderström et al. (2016) World checklist of hornworts and liverworts and Hodgetts et al. (2020) An annotated checklist of bryophytes of Europe, Macaronesia and Cyprus. All updates resulting from changes in the synonymy of taxon names and the subspecific/varietal status of species

have been incorporated into this list. Species presented in the previous most recent list that have fallen into synonymy are also addressed in the notes. This will facilitate researchers' access to current names when consulting the table in new studies. References for all species constituting new records for Türkiye are provided in the notes below the table. The exact repositories of each recorded species could not be detailed due to a lack of precise information on the herbaria where they are stored. Another reason for the omission of herbarium data is that researchers often maintain their own personal herbarium records. A detailed study has been conducted on endemic species; however, as noted in Kürschner and Erdağ (2023), the most recent and comprehensive Turkish identification guide, Flora of Türkiye: Keys in Two Languages for the Identification of Hornworts, Liverworts and Leafy Mosses, uncertainties regarding endemic species persist and further research is required to resolve these uncertainties.

In preparing this list, attention was paid to rectifying the shortcomings of previous lists and incorporating innovative aspects from other global checklists. For example, the fluidity and easily traceable nature of the table in Hodgetts (2015) Checklist and country status of European bryophytes – towards a new Red List for Europe were specifically considered. The primary reasons for presenting the table horizontally and incorporating colors are to ensure that every reader can quickly access the desired data without losing continuity or having to return to the beginning.

In 2012, within the scope of the project for writing the Flora of Türkiye under the NGBB-ANG Foundation, an updated mapping system replaced Davis's grid system for Türkiye. However, for the presentation of bryophytes, Henderson's (1961) grid system, specifically developed for cryptogams, maintains its novelty and continues to be used by researchers. For this reason, the table was designed and prepared for presentation following the Henderson (1961) grid system.

3. Findings

As the findings of this research, the current list of liverwort and hornwort taxa in Türkiye and their distribution according to the Türkiye map grid system (Henderson, 1961) are given in Table 1.

Table 1. An up-to-date list of Türkiye's liverwort and hornwort taxa and their distributions

NO	TAXON	A					B					C				
MARCHANTIOPHYTA		The Distribution of The Liverwort and Hornwort Taxa in Türkiye														
JUNGERMANNIOPSIDA STOTLER & CRAND.-STOTL.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Adelanthaceae Grolle																
1.	*Syzygiella autumnalis* (DC.) K. Feldberg, Váňa, Hentschel & Heinrichs [1]				●								■			
Anastrophyllaceae L.Söderstr., De Roo & Hedd.																
2.	*Barbilophozia barbata* (Schmidel ex Schreb.) Loeske		●		●	■	●						■	■		
3.	*Barbilophozia hatcheri* (A.Evans) Loeske	●	●	■	●	■	●		■							
4.	*Barbilophozia lycopodioides* (Wallr.) Loeske [2]		*			■										
5.	*Barbilophozia rubescens* (R.M.Schust. & Damsh.) Kartt. & L.Söderstr. [3]		●													
6.	*Barbilophozia sudetica* (Nees ex Huebener) L.Söderstr., De Roo & Hedd. [4]				●									■		
7.	*Crossocalyx hellerianus* (Nees ex Lindenb.) Meyl. [46]			*												
8.	*Gymnocolea inflata* (Huds.) Dumort. subsp. *inflata*	■	■		●							●		■		
9.	*Gymnocolea inflata* (Huds.)Dumort. subsp. *acutiloba* (Schiffn.) R.M.Schust.&Damsh. ex L. Söderstr.& Váňa		■		●							●				
10.	*Isopaches bicrenatus* (Schmidel ex Hoffm.) H.Buch [5]	●	■		●											
11.	*Neoorthocaulis attenuatus* (Mart.) L.Söderstr., De Roo & Hedd. [6]				●											
12	*Sphenolobus minutus* (Schreb. ex D.Crantz) Berggr. [47]				*											
Cephaloziaceae Mig.																
13.	*Cephalozia ambigua* C.Massal. [48]	■							*					■		
14.	*Cephalozia bicuspidata* (L.) Dumort.	●	●	■	●						■	●		■		
15.	*Fuscocephaloziopsis catenulata* (Huebener) Váňa & L.Söderstr. [7]		■		●											
16.	*Fuscocephaloziopsis lunulifolia* (Dumort.) Váňa & L.Söderstr. [49]		*	■												
17.	*Fuscocephaloziopsis pleniceps* (Austin) Váňa & L.Söderstr. [8]	●			●						■					
18.	*Nowellia curvifolia* (Dicks.) Mitt.		■	■	●											
19.	*Odontoschisma fluitans* (Nees) L.Söderstr. & Váňa [9]	●					●									
Cephaloziellaceae Douin																
20.	*Cephaloziella baumgartneri* Schiffn.	●	■		●		●	■				●	■	■		
21.	*Cephaloziella divaricata* (Sm.) Schiffn.	■	■		●		●	■				●				
22.	*Cephaloziella elegans* (Heeg) Schiffn. [87]				*											
23.	*Cephaloziella hampeana* (Nees) Schiffn. ex Loeske	■	■		●		●	◆	■			●	●			
24.	*Cephaloziella massalongi* (Spruce) Müll.Frib. [50]	*														

NO	TAXON	A					B					C				
JUNGERMANNIOPSIDA STOTLER & CRAND.-STOTL.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
25.	*Cephaloziella rubella* (Nees) Warnst. [51]		*	■	■			■	■		■		■			
26.	*Cephaloziella stellulifera* (Taylor ex Carrington & Pearson) Croz.	●	■				●	■				●	■			
27.	*Cephaloziella integerrima* (Lindb.) Warnst. [52]		*													
28.	*Cephaloziella dentata* (Raddi) Steph.		●		■											
29.	*Cephaloziella turneri* (Hook.) Müll.Frib.	●	■													
30.	*Obtusifolium obtusum* (Lindb.) S.W.Arnell [53]		*	*												
31.	*Oleolophozia perssonii* (H.Buch & S.W.Arnell) L.Söderstr., De Roo & Hedd. [54]				*											
Lophoziaceae Cavers																
32.	*Lophozia longiflora* (Nees) Schiffn.		●		●							■				
33.	*Lophozia ventricosa* (Dicks.) Dumort.	●	●		●	■						●				
34.	*Lophoziopsis excisa* (Dicks.) Konstant. & Vilnet		■		■		●							■		
35.	*Lophoziopsis longidens* (Lindb.) Konstant. & Vilnet				●											
36.	*Trilophozia quinquedentata* (Huds.) Bakalin [10]		●		●	■										
37.	*Tritomaria exsecta* (Schmidel) Schiffn. ex Loeske				●											
38.	*Tritomaria exsectiformis* (Breidl.) Schiffn. ex Loeske	●														
Scapaniaceae Mig.																
39.	*Diplophyllum albicans* (L.) Dumort.	■	●	■	●	●	■									
40.	*Diplophyllum taxifolium* (Wahlenb.) Dumort.			■	●											
41.	*Scapania gracilis* Lindb. [55]		*													
42.	*Scapania aequiloba* (Schwägr.) Dumort.		●	■	●											
43.	*Scapania aspera* M.Bernet & Bernet		●	●	●	■										
44.	*Scapania apiculata* Spruce [56]		*													
45.	*Scapania umbrosa* (Schrad.) Dumort.		■	■	●											
46.	*Scapania compacta* (Roth) Dumort.	●			■		●	◆						■		
47.	*Scapania curta* (Mart.) Dumort.				●											
48.	*Scapania irrigua* (Nees) Nees	●	●	■	●		■									
49.	*Scapania mucronata* H.Buch [57]					*										
50.	*Scapania praetervisa* Meyl. [58]					*										
51.	*Scapania scandica* (Arnell & H.Buch) Macvicar [59]	*	■													

NO	TAXON	A					B					C				
JUNGERMANNIOPSIDA STOTLER & CRAND.-STOTL.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
52.	*Scapania uliginosa* (Lindenb.) Dumort. [60]				*											
53.	*Scapania cuspiduligera* (Nees) Müll.Frib. [61]				*	■										
54.	*Scapania calcicola* (Arnell & J.Perss.) Ingham [62]			*	■											
55.	*Scapania nemorea* (L.) Grolle	■	●	●	●	■										
56.	*Scapania obscura* (Arnell & C.E.O.Jensen) Schiffn. [63]								*							
57.	*Scapania paludosa* (Müll.Frib.) Müll.Frib.	■		■	●											
58.	*Scapania subalpina* (Nees ex Lindenb.) Dumort.	■	■	■	●	■										
59.	*Scapania undulata* (L.) Dumort. [45]	●	●	■	●	■	●	◆				●				
60.	*Scapania glaucocephala* (Taylor) Austin [64]		*													
61.	*Scapania verrucosa* Heeg		●	●	●											
62.	*Schistochilopsis incisa* (Schrad.) Konstant. [11]				●											
Antheliaceae R.M.Schust.																
63.	*Anthelia juratzkana* (Limpr.) Trevis. [12]				●											
Calypogeiaceae Arnell																
64.	*Calypogeia arguta* Nees & Mont.	●	●	■	●		●									
65.	*Calypogeia azurea* Stotler & Crotz	●			●											
66.	*Calypogeia fissa* (L.) Raddi	●	●	●	●		●	◆					●	■		
67.	*Calypogeia muelleriana* (Schiffn.) Müll.Frib.				●	■										
68.	*Calypogeia sphagnicola* (Arnell & J.Perss.) Warnst. & Loeske	●										●				
69.	*Calypogeia suecica* (Arnell & J.Perss.) Müll.Frib. [65]		*													
Gymnomitriaceae H.Klinggr.																
70.	*Gymnomitrion concinnatum* (Lightf.) Corda				●											
71.	*Gymnomitrion obtusum* Lindb. [66]				*											
72.	*Marsupella emarginata* (Ehrh.) Dumort.		■	■	●		●									
73.	*Marsupella funckii* (F.Weber & D.Mohr) Dumort. [42]	●			●											
74.	*Nardia compressa* (Hook.) Gray				●											
75.	*Nardia geoscyphus* (De Not.) Lindb. [67]				*											
76.	*Nardia scalaris* Gray				●											
77.	*Harpanthus scutatus* (F.Weber & D.Mohr) Spruce				●											

NO	TAXON	A					B					C				
JUNGERMANNIOPSIDA STOTLER & CRAND.-STOTL.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Jungermanniaceae Rchb.																
78.	*Liochlaena lanceolata* Nees [13]				●											
79.	*Eremonotus myriocarpus* (Carrington) Lindb. & Kaal. ex Pearson				●											
80.	*Jungermannia atrovirens* Dumort.	●	●	■	●	■	●	◆				●	●	■		
81.	*Jungermannia eucordifolia* Schljakov [68]				*											
82.	*Jungermannia pumila* With. [69]				*											
83.	*Mesoptychia badensis* (Gottsche ex Rabenh.) L.Söderstr. & Váňa [14]		■	■									■			
84.	*Mesoptychia bantriensis* (Hook.) L.Söderstr. & Váňa [15]		■	■	●											
85.	*Mesoptychia collaris* (Nees) L.Söderstr. & Váňa [16]		■	■	●											
86.	*Mesoptychia gillmanii* (Austin) L.Söderstr. & Váňa [88]				*											
87.	*Mesoptychia heterocolpos* (Thed. ex Hartm.) L.Söderstr. & Váňa [70]								*							
88.	*Mesoptychia turbinata* (Raddi) L.Söderstr. & Váňa [17]	●	●	■	■		●	●				●	●	■		
Solenostomataceae Stotler & Crand.-Stotl.																
89.	*Solenostoma obovatum* (Nees) C.Massal. [18]		■		●											
90.	*Solenostoma gracillimum* (Sm.) R.M.Schust. [19]	■	●	■	●	■	●					●				
91.	*Solenostoma handelii* (Schiffn.) Müll.Frib. [20]			■	●											
92.	*Solenostoma hyalinum* (Lyell) Mitt. [21]	●	●		●	■						●				
93.	*Solenostoma caucasicum* (Váňa) Konstant. [22]				●											
94.	*Solenostoma confertissimum* (Nees) Schljakov [71]					*										
95.	*Solenostoma sphaerocarpum* (Hook.) Steph. [23]	●			●				■							
96.	*Solenostoma lignicola* (Schiffn.) Váňa, Hentschel & Heinrichs [24]				●											
97.	*Solenostoma subtilissimum* (Schiffn.) R.M.Schust. [25]			●	●											
Southbyaceae Váňa, Crand.-Stotl., Stotler & D.G.Long																
98.	*Gongylanthus ericetorum* (Raddi) Nees											●	●	■		
99.	*Southbya nigrella* (De Not.) Henriq.	■					●					●	●	■		
100.	*Southbya tophacea* (Spruce) Spruce		●	■	■	■	●				■	●	●	■		
Blepharostomataceae W.Frey & M.Stech																
101.	*Blepharostoma trichophyllum* (L.) Dumort.	■	●		●	●										
Lepidoziaceae Limpr.																
102.	*Bazzania flaccida* (Dumort.) Grolle				●											
103.	*Bazzania tricrenata* (Wahlenb.) Lindb.		●		●											

NO	TAXON	A					B					C				
JUNGERMANNIOPSIDA STOTLER & CRAND.-STOTL.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
104.	*Bazzania trilobata* (L.) Gray		●	■	●											
105.	*Lepidozia reptans* (L.) Dumort.				●											
106.	*Telaranea europaea* J.J.Engel & G.L.Merr.				●											
Lophocoleaceae Vanden Berghen																
107.	*Chiloscyphus pallescens* (Ehrh.) Dumort.	●	●	●	●	■	●						■			
108.	*Chiloscyphus polyanthos* (L.) Corda	●	●	■	●	●	●	◆	■			●		■		
109.	*Leptoscyphus cuneifolius* (Hook.) Mitt. [72]				*											
110.	*Lophocolea bidentata* (L.) Dumort.	●	●	●	●	●	●	●				●	●	■		
111.	*Lophocolea coadunata* (Sw.) Mont. [26]	●	●									●				
112.	*Lophocolea fragrans* (Moris & De Not.) Gottsche, Lindenb. & Nees [73]		*													
113.	*Lophocolea heterophylla* (Schrad.) Dumort.	●	●	●	●	●	●	●						■		
114.	*Lophocolea minor* Nees	●	●	●	●	■			■					■		
Plagiochilaceae Müll.Frib.																
115.	*Pedinophyllum interruptum* (Nees) Kaal.	■	●	■	●											
116.	*Plagiochila asplenioides* (L.) Dumort. [43]	●	●	●	●	●										
117.	*Plagiochila porelloides* (Torr. ex Nees) Lindenb.	●	●	●	●	■	●	●				●	●	■		
Trichocoleaceae Nakai																
118.	*Trichocolea tomentella* (Ehrh.) Dumort. [74]				*											
Myliaceae Schljakov																
119.	*Mylia taylorii* (Hook.) Gray		●		■											
120.	*Frullania dilatata* (L.) Dumort.	●	●	●	●	●	●	◆				●	●	●		
121.	*Frullania fragilifolia* (Taylor) Gottsche, Lindenb. & Nees	■	■			■							■	●		
122.	*Frullania jackii* Gottsche				●											
123.	*Frullania tamarisci* (L.) Dumort.	●	●	●	●	■	●	◆				■	●	●		
124.	*Frullania teneriffae* (F.Weber) Nees [75]			*												
Jubulaceae H.Klinggr.																
125.	*Jubula hutchinsiae* (Hook.) Dumort. subsp. *caucasica* Konstant. & Vilnet	■	●	●	●											
126.	*Jubula hutchinsiae* subsp. *javanica* (Steph.) Verd.	●	■	■	●											
127.	*Jubula hutchinsiae* subsp. *pennsylvanica* (Steph.) Verd. [41]			●	●											
Lejeuneaceae Cavers																
128.	*Cololejeunea calcarea* (Lib.) Steph.		●	■										■		

NO	TAXON	A					B					C				
JUNGERMANNIOPSIDA STOTLER & CRAND.-STOTL.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
129.	*Cololejeunea rossettiana* (C.Massal.) Schiffn.	■	●	■	●								■	■		
130.	*Lejeunea cavifolia* (Ehrh.) Lindb.	●	●	●	●		●	●			■	●	■	■		
131.	*Lejeunea lamacerina* (Steph.) Schiffn.	●	●	●	●		●	◆				●	●			
132.	*Lejeunea patens* Lindb.		●		●									■		
133.	*Microlejeunea ulicina* (Taylor) Steph. [27]				●											
Porellaceae Cavers																
134.	*Porella arboris-vitae* (With.) Grolle	■	●	■	●		●					●		■		
135.	*Porella baueri* (Schiffn.) C.E.O.Jensen						●	●				●				
136.	*Porella cordaeana* (Huebener) Moore	●	●	●	●	■	●	●				●	●	●		
137.	*Porella obtusata* (Taylor) Trevis.	■	■	●	●	■	●					■		■		
138.	*Porella pinnata* L.		■	■	■	■	■					●	●	■		
139.	*Porella platyphylla* (L.) Pfeiff.	●	●	●	●	●	●	●	●			●	●	●		
Radulaceae Müll.Frib.																
140.	*Radula complanata* (L.) Dumort.	●	●	●	●	●	●	●				●	●	●		
141.	*Radula lindenbergiana* Gottsche ex C.Hartm.	●	●	●	●	■	●					●		■		
Ptilidiaceae H.Klinggr.																
142.	*Ptilidium pulcherrimum* (Weber) Vain. [28]		●	●	■											
Aneuraceae H.Klinggr.																
143.	*Aneura pinguis* (L.) Dumort	■	■	■	●	■	■					●	●	■		
144.	*Riccardia chamedryfolia* (With.) Grolle		■	■	●		●									
145.	*Riccardia latifrons* (Lindb.) Lindb.		●													
146.	*Riccardia multifida* (L.) Gray	■	■	■	●					●				■		
147.	*Riccardia palmata* (Hedw.) Carruth.		●	■	●								■	■		
Metzgeriaceae H.Klinggr.																
148.	*Metzgeria conjugata* Lindb.	●	●	●	●	●	●	●				●	■	●		
149.	*Metzgeria furcata* (L.) Corda	●	●	●	●	●	●	●				●	●	●		
150.	*Metzgeria pubescens* (Schrank) Raddi [29]		●	●	●											
Fossombroniaceae Hazsl.																
151.	*Fossombronia angulosa* (Dicks.) Raddi	●	●	■	●		●	◆				●	●	■		
152.	*Fossombronia caespitiformis* (Raddi) De Not. ex Rabenh. subsp. *caespitiformis*	■					●					●	●			
153.	*Fossombronia caespitiformis* (Raddi) De Not. ex Rabenh. subsp. *multispira* (Schiffn.) J.R.Bray & Cargill	●	■									●				
154.	*Fossombronia echinata* Macvicar [76]											*	■			

NO	TAXON	A					B					C				
JUNGERMANNIOPSIDA STOTLER & CRAND.-STOTL.																
155.	*Fossombronia foveolata* Lindb. [30]			■										■		
156.	*Fossombronia maritima* (Paton) Paton [77]	*														
157.	*Fossombronia pusilla* (L.) Nees	●	●	●	●		●	◆	■			●	●	■		
158.	*Fossombronia wondraczekii* (Corda) Dumort. ex Lindb.												●			
Petalophyllaceae Stotler & Crand.-Stotl.																
159.	*Petalophyllum ralfsii* (Wilson) Nees & Gottsche						●					●	●			
Pallaviciniaceae Mig.																
160.	*Pallavicinia lyellii* (Hook.) Gray				●											
Pelliaceae H.Klinggr.																
161.	*Apopellia endiviifolia* (Dicks.) Nebel & D.Quandt [31]	●	●	●	●	●	●	●		●		●	●	■		
162.	*Pellia epiphylla* (L.) Corda	●	●	●	●	●	●	■	■			●		■		
163.	*Pellia neesiana* (Gottsche) Limpr.	●	■		●	■	●				■	●		■		
MARCHANTIOPSIDA CRONQUIST, TAKHT. & W.ZIMM.																
Blasiaceae H.Klinggr.																
164.	*Blasia pusilla* L.	■	■	●	●											
Lunulariaceae H.Klinggr.																
165.	*Lunularia cruciata* (L.) Dumort. ex Lindb.	●	●	●	●	●	●	●		●		●	●	■		
Aytoniaceae Cavers																
166.	*Asterella saccata* (Wahlenb.) A.Evans [78]										*					
167.	*Mannia androgyna* (L.) A.Evans		●		●		●					●	●			
168.	*Mannia fragrans* (Balb.) Frye & L.Clark [32]											■				
169.	*Mannia gracilis* (F.Weber) D.B.Schill & D.G.Long [33]	●					■						●			
170.	*Plagiochasma rupestre* (J.R.Forst. & G.Forst.) Steph.		●	◆	●		●	●				●	●	■		
171.	*Reboulia hemisphaerica* (L.) Raddi [44]	●	●	■	●	■	●	●	●			●	●	●		
Cleveaceae Cavers																
172.	*Clevea hyalina* (Sommerf.) Lindb. [34]	●							●				●	■		
173.	*Clevea spathysii* (Lindenb.) Müll.Frib. [35]												●			
Conocephalaceae Müll.Frib. ex Grolle																
174.	*Conocephalum conicum* (L.) Dumort.	●	●	●	●	●	●	◆	●			●	●	■		
Corsiniaceae Engl.																

NO	TAXON	A					B					C				
MARCHANTIOPSIDA CRONQUIST, TAKHT. & W.ZIMM.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
175.	*Corsinia coriandrina* (Spreng.) Lindb.	■	●	■			●					●	●	■		
Marchantiaceae Lindl.																
176.	*Marchantia paleacea* Bertol.			●	●								●			
177.	*Marchantia polymorpha* L. subsp. *montivagans* Bischl. & Boissel.-Dub.	●	■	■		■	●			●	■			■		
178.	*Marchantia polymorpha* L. subsp. *polymorpha*	●	●	●	●	●	●	●	●	●		●	●	●		●
179.	*Marchantia polymorpha* L. subsp. *ruderalis* Bischl. & Boissel.-Dub. [36]													■		
180.	*Marchantia quadrata* Scop. [79]		*									■	■	■		
Oxymitraceae Müll.Frib. ex Grolle																
181.	*Oxymitra incrassata* (Brot.) Sérgio & Sim-Sim						●					●	●	■		
Ricciaceae Rchb.																
182.	*Riccia atromarginata* Levier [80]											*				
183.	*Riccia beyrichiana* Hampe [81]		■									*				
184.	*Riccia bicarinata* Lindb.	■					●					●	●			
185.	*Riccia bifurca* Hoffm.	■			■		■		●		■	●	■			
186.	*Riccia ciliata* Hoffm.		■				●					●	●			
187.	*Riccia ciliifera* Link	●					●									
188.	*Riccia crinita* Taylor [82]						*					*				
189.	*Riccia crozalsii* Levier	●	■	■			■					●	■	■		
190.	*Riccia glauca* L. var. *ciliaris* Warnst.											●				
191.	*Riccia glauca* L. var. *glauca*	■				■	●		■			●	●	■		
192.	*Riccia gougetiana* Durieu & Mont. var. *armatissima* Levier ex Müll.Frib. [37]						■									
193.	*Riccia gougetiana* Durieu & Mont. var. *gougetiana*	■	■				●					●	■			
194.	*Riccia lamellosa* Raddi [37]						■					■		■		
195.	*Riccia macrocarpa* Levier	■					●					●	■			
196.	*Riccia michelii* Raddi						■					●	●			
197.	*Riccia nigrella* DC.	●	■	■			●					●	●	■		
198.	*Riccia papillosa* Moris [38]	■			■		■		■			●	■			
199.	*Riccia sorocarpa* Bisch.	■	■	■		●	●		■			●	●	■	■	■
200.	*Riccia subbifurca* Warnst. ex Croz. [83]	■	*	■			■					■				
201.	*Riccia trabutiana* Steph. [39]											■				
202.	*Riccia canaliculata* Hoffm. [37]		■										■			

NO	TAXON	A					B					C				
MARCHANTIOPSIDA CRONQUIST, TAKHT. & W.ZIMM.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
203.	*Riccia fluitans* L.		■									●				
204.	*Riccia frostii* Austin			●								●				●
205.	*Riccia perennis* Steph. [84]						■					*				
206.	*Riccia rhenana* Lorb. ex Müll.Frib.						●									
207.	*Riccia cavernosa* Hoffm. [85]		■	■										*		
208.	*Riccia crystallina* L.	■					●					■	■			
209.	*Riccia anatolica* Özenoğlu & Kırmacı [86]												*			
210.	*Ricciocarpos natans* (L.) Corda		●	■												
Targioniaceae Dumort.																
211.	*Targionia hypophylla* L.	●	●	■			●	●				●	●	●		
212.	*Targionia lorbeeriana* Müll.Frib.						●					●				
Riellaceae Engl.																
213.	*Riella helicophylla* (Bory & Mont.) Mont. [40]															
Sphaerocarpaceae Heeg																
214.	*Sphaerocarpos europaeus* Lorb.						●					●	●			
215.	*Sphaerocarpos michelii* Bellardi						●					●	■	■		
ANTHOCEROTOPHYTA		The Distribution of The Hornworts in Türkiye														
NO	**TAXON**	**A**					**B**					**C**				
ANTHOCEROTOPSIDA DE BARY EX JANCZ.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Anthocerotaceae Dumort.																
216.	*Anthoceros caucasicus* Steph. [89]	■	■		*											
217	*Anthoceros punctatus* L.	●	●	●	●		●					●	●			
Phymatocerotaceae R.J.Duff																
218	*Phymatoceros bulbiculosus* (Brot.) Stotler			■			●									
Notothyladaceae Müll.Frib. ex Prosk.																
219.	*Phaeoceros laevis* (L.) Prosk.	●	■	■	●	■	●					●	●			
Total number of taxa reported for each square:		**95**	**121**	**90**	**136**	**50**	**84**	**34**	**20**	**5**	**9**	**84**	**69**	**63**	**1**	**3**

[*]: Symbol signifies new record for Türkiye. | **[■]: Symbol signify new records for individual square.**

[●]: Symbol signify former reports. | **[◆]: Symbol signifies new records done by us.**

Table Brief Notes:

[1] Syn: *Jamesoniella autumnalis* (DC.) Steph.
[2] Syn: *Lophozia lycopodioides* (Wallr.) Cogn.
→ This species has been reported by Keçeli et al. (2011) from Türkiye.
[3] Syn: *Lophozia rubescens* R.M. Schust. & Damsh.
[4] Syn: *Jungermannia sudetica* Nees ex Huebener, *Lophozia sudetica* (Nees ex Huebener) Grolle
[5] Syn: *Jungermannia bicrenata* Schmidel ex Hoffm., Lophozia bicrenata (Schmidel ex Hoffm.) Dumort.
[6] Syn: *Barbilophozia attenuata* (Mart.) Loeske
[7] Syn: *Cephalozia catenulata* (Huebener) Lindb.
[8] Syn: *Cephalozia pleniceps* (Austin) Lindb.
[9] Syn: *Cladopodiella fluitans* (Nees) H.Buch
[10] Syn: *Tritomaria quinquedentata* (Huds.) H. Buch
[11] Syn: *Jungermannia incisa* Schrad., *Lophozia incisa* (Schrad.) Dumort.
[12] Syn: *Anthelia julacea* subsp. *juratzkana* (Limpr.) Meyl.
[13] Syn: *Jungermannia leiantha* Grolle
[14] Syn: *Jungermannia badensis* Gottsche ex Rabenh., *Leiocolea badensis* (Gottsche ex Rabenh.) Jørg.
→ "This species has been reported by Çetin (1988) from Türkiye without collection data and locality."
[15] Syn: *Jungermannia bantriensis* Hook., *Leiocolea bantriensis* (Hook.) Jørg.
[16] Syn: *Leiocolea collaris* (Nees) Schljakov, *Leiocolea alpestris* (Schleich. ex F.Weber) Isov.
[17] Syn: *Jungermannia turbinata* Raddi, *Leiocolea turbinata* (Raddi) H. Buch
[18] Syn: *Jungermannia obovata* Nees
[19] Syn: *Jungermannia gracillima* Sm.
[20] Syn: *Jungermannia handelii* (Schiffn.) Amakawa
[21] Syn: *Jungermannia hyalina* Lyell
[22] Syn: *Jungermannia caucasica* Váňa
[23] Syn: *Jungermannia sphaerocarpa* Hook.
[24] Syn: *Jungermannia lignicola* (Schiffn.) Grolle → Endemic species to Türkiye
[25] Syn: *Jungermannia subtilissima* (Schiffn.) Grolle → Endemic species to Türkiye
[26] Syn: *Lophocolea bidentata* var. *rivularis* (Raddi) Schiffn.
[27] Syn: *Lejeunea ulicina* (Taylor) Gottsche, Lindenb. & Nees
[28] Syn: *Jungermannia pulcherrima* Weber
[29] Syn: *Apometzgeria pubescens* (Schrank) Kuwah.
[30] → "The species *Fossombronia foveolata* Lindb. has been reported by Smith (1990) from Türkiye without locality data."
[31] Syn: *Pellia endiviifolia* (Dicks.) Dumort.
[32] → "This species has been reported by Çetin (1988) from Türkiye without collection data and locality."
[33] Syn: *Asterella gracilis* (F.Weber) Underw.
[34] Syn: *Athalamia hyalina* (Sommerf.) S.Hatt.
[35] Syn: *Athalamia spathysii* (Lindenb.) S.Hatt.
[36] → "This taxon was reported by Ros et al. (2007) from Türkiye without collection data and locality."
[37] → "This taxon was reported by Jovet-Ast (1986) from Türkiye without collection data and locality."
[38] → "This species has been reported by Çetin (1988) from Türkiye without collection data and locality."
[39] → "This taxon was reported by El-Oqlah et al. (1988) from Türkiye without collection data and locality."
[40] → "This species has been reported by Çetin (1988) from Türkiye without collection data and locality."
[41] → "According to Kürschner (2013) all doubtful records for Türkiye as the taxon has an American distribution pattern. Almost certainly, the Türkiye records all belong to. *Jubula hutchinsiae* subsp. *caucasica*"
[42] Syn: *Marsupella funckii* var. *major* (Nees) Boulay
[43] Syn: *Plagiochila asplenioides* var. *riparia* Breidl.
[44] *Reboulia hemisphaerica* var. *macrocephala* Massal. in Sommier / *Reboulia hemisphaerica* var. *microspora* Schiffn.
→ "The taxonomic status of this infrageneric, endemic variety given for Türkiye is doubtful (Kürschner & Frey 2011)
[45] Syn: *Scapania undulata* var. *dentata* (Dumort.) McArdle
[46] → "This species has been reported by Unan and Ören (2021) from Türkiye."
[47] → "This species has been reported by from Erata and Batan (2020) Türkiye."
[48] → "This species has been reported by Ezer et al. (2013) from Türkiye."
[49] → "This species has been reported by Unan and Ören (2021) from Türkiye."
[50] → "This species has been reported by Gözcü et al. (2019) from Türkiye."
[51] → "This species was collected recently (2012-2013) by local researchers. It is not known for sure who recorded the species"
[52] → "This species has been reported by Ören et al. (2015) from Türkiye."
[53] → "This species has been reported by Ören et al. (2017) from Türkiye."
[54] → "This species has been reported by Erata et al. (2021) from Türkiye."
[55] → "This species has been reported by Ezer et al. (2013) from Türkiye."
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[88] → "This species has been reported by Erata et al. (2025)"
[89] → "This species has been reported by Kırmacı et al. (2012)"

4. Result and Discussion

As a result of the review of published records, a reference list comprising 219 taxa belonging to 80 genera and 45 families was presented. Among the taxa, 142 are leafy, 9 are transitional forms, and 68 are thalloid forms. The families with the highest number of taxa are Ricciaceae with 28 species, Scapaniaceae with 24 species, and Anastrophyllaceae, Cephaloziellaceae, and Jungermanniaceae, each represented by 10 species. This study, conducted after a 16-year hiatus, has identified 45 new species records and 280 new grid records for Türkiye. The families with the highest number of species recorded are Scapaniaceae (10 species), Ricciaceae (7 species), and Cephaloziellaceae (6 species). The Ricciaceae family, which contains the highest number of species in Türkiye's liverwort flora, was revised for Türkiye by Kırmacı & Özenoğlu (2019). In the same study, the species *Riccia anatolica* Özenoğlu & Kırmacı was introduced to the literature.

The highest number of new species, 11 taxa, was recorded for grid square A2 (Western Black Sea Region). The grid square with the most new grid data is C13 (Adana Region) with 50 taxa, followed by A3 (Central Black Sea Region) with 45 taxa. Grid square A2, which has the highest number of species records, is the region where the most intensive bryophyte studies have been conducted. According to grid data, the A2/A3 squares within the Black Sea Region are among the areas most frequented by cryptogam researchers due to their suitable habitat characteristics. Grid square C13 has been an area with little to no prior research on Türkish bryophytes. However, recent studies by Kara et al. (2013) have highlighted that the region contains ideal habitats for liverworts.

The squares with the highest number of taxa reported were A4 (136 taxa), A2 (121 taxa), and A1 (95 taxa), while the squares with the fewest records were C14 (1 taxa), C15 (3 taxa), and B9 (5 taxa). This situation is due to factors such as the climatic, geological, ecological, geographical, and phytosociological characteristics of the geographic region, as well as the accessibility of the area, distance to the universities where the thesis was conducted, and security conditions (state of extraordinary zones, etc.). Since security and transportation/access problems to research areas have largely been eliminated, conducting taxonomic research in these localities with low square records will be an important step toward revealing the true potential of both these squares and Türkiye's liverwort and hornwort flora.

Bryophyte species represent the terrestrial plant group with the second-highest biodiversity after seed plants. Regions with little or no data on Hepaticae and Hornwort species, as well as areas with ecologically suitable habitats, have the potential to yield new findings through floristic research. In addition to floristic investigations, the application of molecular analysis techniques should be incorporated to further support the morphological and anatomical characteristics of bryophytes. Moreover, there is an urgent need for an action plan aimed at the conservation of Türkiye's bryophyte species, with the immediate classification of these species under the appropriate IUCN Red List categories, in accordance with global standards.

Declaration

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Conflict of interest

It is declared by the authors that no conflict of interest exists concerning the findings and overall content of the study.

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Ethical approval

This research was conducted under in vitro conditions and therefore does not require ethical approval.

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Notes on a Rare Hornwort Species from Türkiye: *Phymatoceros bulbiculosus* (Brot.) Stotler, W.T. Doyle & Crand.-Stotl. (Anthocerotophyta)

Hatice ÖZENOĞLU[1,*], Gözde ASLAN[2], Mesut KIRMACI[3]

[1]Aydın Adnan Menderes University, Faculty of Education, Department of Science and Mathematics Education 09010 Aydın, TÜRKİYE
2 Aydın Adnan Menderes University, Koçarlı Vocational School, Department of Plant and Animal Processing, Medicinal and Aromatic Plants 09010, Aydın, TÜRKİYE
3 Aydın Adnan Menderes University, Faculty of Science, Department of Biology, 09010 Kepez- Aydın, TÜRKİYE

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Abstract

Phmatoceros bulbiculosus is one of the rare hornwort species known from Türkiye. The species was first recorded from İzmir by Bornmüller in 1906; however, the accuracy of this identification was later questioned. The presence of distinctly stalked ventral tubers, a well-developed midrib, and smooth spores clearly distinguishes *P. bulbiculosus* from *Phaeoceros laevis.* In the present study, the stalked tubers considered the most diagnostic morphological feature for separating this species are clearly illustrated and described. In addition, a revised identification key for the members of Anthocerotophyta in Türkiye are provided.

Key words: Anthocerotophyta, hornwort, Muğla, ventral tuber

Türkiye'den Nadir Bir Boynuzluot Türü Üzerine Notlar: Phymatoceros bulbiculosus (Brot.) Stotler, W.T. Doyle & Crand.-Stotl. (Anthocerotophyta)

Öz

Phmatoceros bulbiculosus, Türkiye'den bilinen, nadir boynuzlu ot türlerinden biridir. Tür, ilk olarak 1906 yılında Bornmüller tarafından İzmir'den kaydedilmiş, ancak bu tanımlamanın doğruluğu sonradan tartışmalı bulunmuştur. Ventral yüzeyden çıkan belirgin saplı tüberler, iyi gelişmiş orta damar (midrib) ve düzgün yüzeyli sporlar, *P. bulbiculosus*'u, *Phaeoceros laevis*'ten açık biçimde ayıran karakterlerdir. Bu çalışmada, türün ayırt edilmesinde en önemli morfolojik özellik olan saplı tüberler açık biçimde ortaya konulmuştur. Ayrıca, Türkiye'deki Anthocerotophyta üyeleri için yenilenmiş bir teşhis anahtarı sunulmuştur.

Anahtar kelimeler: Anthocerotophyta, boynuzluot, Muğla, ventral tuber

* Corresponding author: hozenoglu@adu.edu.tr
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1. Introduction

The hornworts are a small group of plants comprising about 250 taxa, whose affinities with bryophytes and vascular plants remain uncertain (Plášek et al., 2024). They probably represent a long and separate evolutionary lineage (Frey et al., 2006). Approximately 1,892 bryophyte taxa are naturally distributed in Europe, including 1,390 species of mosses, 494 species of liverworts, and 8 species of hornworts (Hodgetts et al., 2020). The total number of bryophytes recorded in Türkiye has increased to 1,280 taxa, including 1,051 mosses, 224 liverworts, and 5 hornworts (Erdağ and Kürschner, 2024; Aslan et al., 2024). Members of Anthocerotophyta appear to be more distantly related to other bryophytes, and genetic evidence suggests that they may be more closely allied with ferns. However, certain chemical evidence places them nearer to the liverworts; for instance, both hornworts and liverworts lack isoprene emission, whereas mosses and ferns produce it (Glime, 2017).

The hornworts are divided into two classes (Anthocerotopsida and Leiosporocerotopsida) (Stotler and Crandall-Stotler, 2005), a concept supported by molecular data (Frey and Stech, 2005). Anthocerotopsida is the largest and best known of these, the *Nostoc* colonies are scattered in discrete globose colonies. The class is Leiosporocerotopsida differs from members of the other class, having the *Nostoc* in longitudinal canals (Villarreal and Renzaglia, 2006). All taxa distributed in our country are included in Anthocerotopsida.

Members of Anthocerotophyta are considered among the most ancient lineages of land plants and play an important role in understanding early plant evolution. They typically inhabit moist or periodically flooded areas such as stream banks, wet soils, and shaded valleys. The genus *Phaeoceros* (Prosk.) Hassel is one of the most characteristic representatives of this group, recognized by its thin, green thalli and distinct horn-like sporophytes. In Türkiye, *Phmatoceros bulbiculosus* is a particularly rare species, previously reported from only a few localities (Erdağ and Kürschner, 2024). The discovery of new populations of this taxon provides valuable insights into the diversity, ecology and biogeographical distribution of hornworts in the Mediterranean region.

2. Findings

Phymatoceros bulbiculosus (Brotero) Stotler, W.T.Doyle & Crand.-Stotl., Phytologia 87: 114 (2005).

Turkish name: Dikboynuz

Syn: *Anthoceros dichotomus* Raddi, *Phaeoceros bu*lbiculosus (Brot.) Prosk.

Thallus narrow lingulate, 6-15 mm in diameter, usually divided into irregular segments with entire, undulate margins. Unlike other hornwort species, *P. bulbiculosus* does not form rosettes. Stalked tubers frequent on ventral side of thallus. Spores yellow, brownish when mature, proximal nearly smooth or with 1-3 protuberances. Proximal face of spores finely spinose to finely papillose, or weakly papillose at centre in *Phaeoceros laevis*.

Tubers are more frequently on the ventral side of the thallus in *P. bulbiculosus* than *Phaeroceros laevis*. The capsules of *P. bulbiculosus* are usually thicker. However these two characters do not permit to keep the two taxa apart with certainty. Only spore coat ornamentation clearly separates them.

Türkiye: Province Muğla, Köyceğiz, N 36°59'55" E 28°42'29", on soil, 180 m, 23 March 2024, *leg.* H. Özenoğlu, G. Aslan & M. Kırmacı, AYDN 5075 and AYDN 5076 (SND 20 and 30).

The general vegetation consists of a *Pinus brutia* Ten. forest, degraded maquis elements dominated by *Quercus coccifera* L., and *Olea europaea* L. plantation.

Associated bryophytes are *Corsinia coriandrina* (Spreng.) Lindb., *Riccia crozalsii* Levier, *Lunularia cruciata* (L.) Dumort. ex Lindb., *Ptychostomum imbricatulum* (Müll.Hal.) Holyoak & N.Pedersen, *Timmiella barbuloides* (Brid.) Mönk., *Fissidens viridulus* (Sw. ex anon.) Wahlenb., *Weissia condensa* (Voit) Lindb., *Tortula acaulon* var. *marginata* (Herrnst. & Heyn) R.H. Zander.

General distribution: recorded from Southwest Asia (Israel & Cis-Jordan, Lebanon, Türkiye), Azores, Albania, Canary Islands, Corsica, Crete, Croatia, Cyprus, France, Greece, Italy, Ireland, Madeira, Malta, Montenegro, Portugal, Sardinia, Scotland, Sicily, Spain, the Baltic State, N. W. Russia, North and Central America. (Frey et al., 2006; Heyn and Herrnstadt, 2004; Söderström et al. 2016; Erdağ and Kürshner, 2021; Hodgetts and Lockhart, 2020).

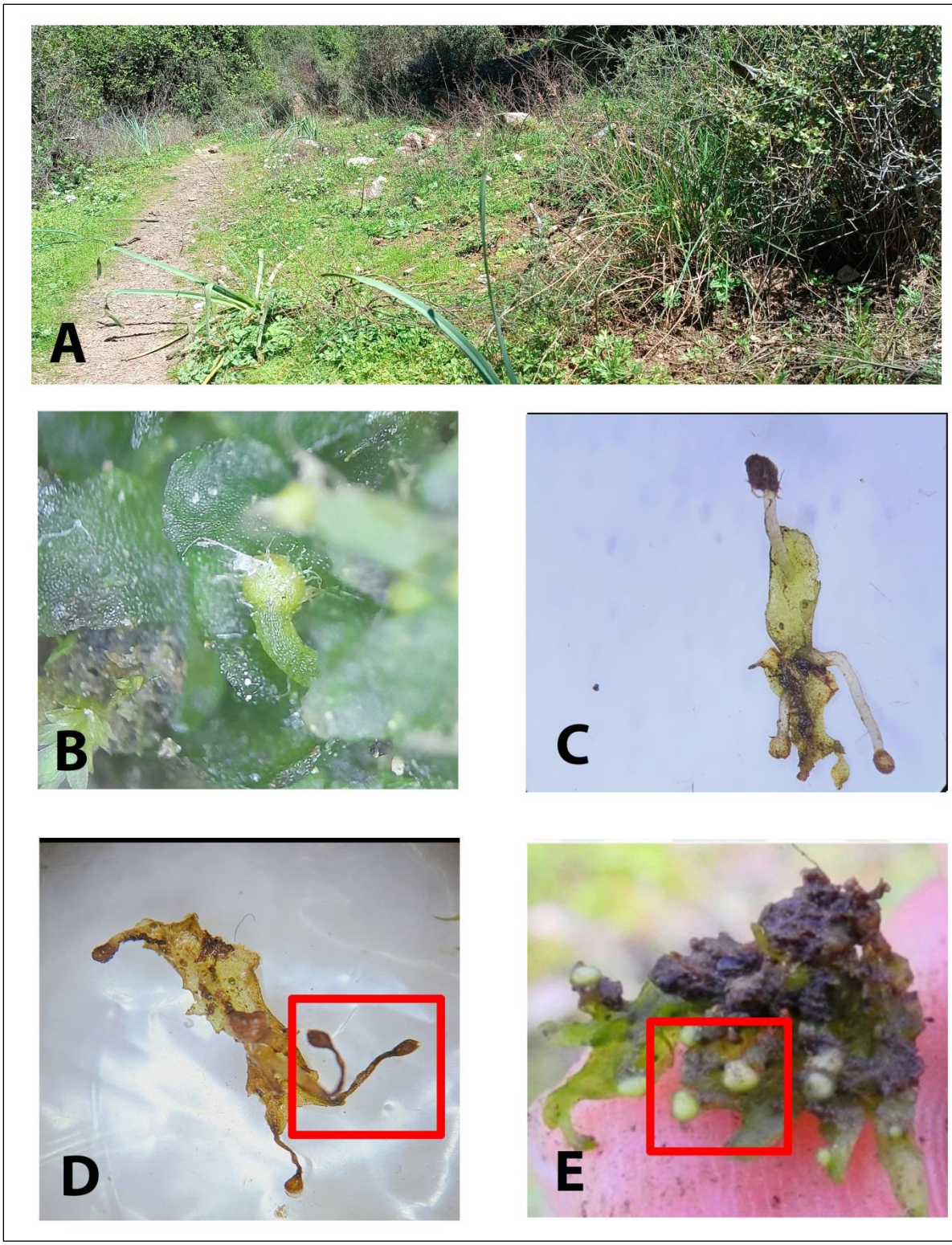

Figure 1. A: General view of collected area, B: Plant with tuber in natural habitat, C and D The appearance of plant with tubers under the microscope, E. The photograph provided by Söylemez (2017) showing the tubers of *P. bulbiculosus*.

Key to families, genera and species of Anthocerotophyta in Türkiye (This key was created by revising the assignment keys in studies Frey et al., 2006; Kürschner and Frey, 2011; Kürschner and Erdağ, 2023).

1. Thallus cavernous, usually pale green with crisped margins forming concave rosettes, 1.5-3.0 cm in diameter; thallus in cross section 10-20 (30) cells thick, with numerous cavities; spores blackish to brownish Anthocerotaceae Dumort.-*Anthoceros* L. ……...2
1* Thallus solid, usually dark green, margins rarely crisped, cavities absent; spores yellowish ……..…..4

2 Spores proximal bluntly spinose; sides of tetraeder letches smooth and conspicouos; on moist soil and rocks ……*A. caucasicus* Steph.
2* Spores proximal reticulate-faveolate; sides of tetraeder edges not smooth and insconsipicouos …. 3

3 Mature antheridia 100-130 (150) µm long; ……..……*A. punctatus* L.
3* Mature antheridia 50-90 µm long; …… *A. agrestis* Paton

4. Thallus narrow lingulate, costa-like thickened in middle part; spores yellow, brownish when mature, proximal (distal face) nearly smotth or with 1-3 protuberances; on moist soil and cultivated ground ……..…Phymatocerotaceae R.J. Duff-Phymatoceros Stotler, W.T Doyle & Crand. ……. *P. bulbiculosus* (Brotero) Proskauer
4* Thallus lobed, thin; spores yellow when mature, proximal (distal face) spinose to tuberculate; on moist soil and cultivated ground, paths, on banks of ponds and lakes…….……Notothladaceae Müll. Frib. ex Prosk. – Phaeoceros Prosk. ……..….. *P. laevis* (L.) Prosk.

3. Results and Discussion

The species *Phymatoceros bulbiculosus* was first included in the flora of Türkiye by Bornmüller in 1906, when it was collected at an altitude of about 900 m in the Tire district of İzmir (Bornmüller, 1908). Henderson (1961) confirmed the distribution of this species in İzmir Province in their publications by citing Bornmüller's record. However, Walter (1967) added a note regarding this species and stated that the information previously given was incorrect. According to Reimers (1927), the specimen collected by Bornmüller near Tire in 1906 actually belonged to *Phaeoceros laevis* (Bornmüller, 1931).

The specimen housed at Herbarium-Hamburgense (Hamburg/Germany) and collected by Bornmüller does not possess tuber-like structures arising from the ventral surface, which are the main diagnostic features distinguishing *P. bulbiculosus* from related taxa. In addition, the costa-like structure in the central part of the thallus is not very prominent, and the spores are densely papillate. In contrast, in Walter's (1967) study, the material collected from İzmir–Narlıdere was described as having ventral tubers, a distinct midrib-like structure on the thallus, and smooth spores. More recently, the species was collected from Sinop by Söylemez et al. (2017) (Sinop Peninsula, Abalı, 42°03'16.3"N, 34°56'14.3"E, 35 m, deciduous forest, 12 October 2015).

The most recent record of the species was collected from Muğla. The stalked tubers protruding ventrally are very prominent in the Muğla specimens. In the photographs provided by Söylemez in her thesis (Söylemez, 2017), the stalked tubers are not clearly visible; they appear more similar to the small tubercles located at the thallus tips of *Phaeoceros laevis*. The absence of a distinct stalk in the tubers shown in the photograph provided by Söylemez (Figure 1E) suggests that the researcher may have made the same misidentification as Bornmüller. Nevertheless, it would not be appropriate to draw a definitive conclusion without a thorough examination of the specimen. Since these structures cannot be clearly observed on herbarium materials, additional samples were not requested from the researchers. The issue can only be clarified with fresh specimens collected from the field during the appropriate collection period.

Declarations

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Authors' contributions
Idea/Concept: HÖ, GA, MK. Conceptualization and design: HÖ, GA, MK. Auditing/ Consulting: HÖ, GA, MK. Resources: HÖ, GA, MK. Materials: HÖ, GA, MK. Data Collection & Processing: HÖ, GA, MK. Analysis & Interpretation: HÖ, GA, MK. Literature Review: HÖ, GA, MK. Writing: HÖ, GA, MK. Critical Review: HÖ, GA, MK.

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Conflict of interest
The authors declare that there is no real, potential, or perceived conflict of interest for this article.

Ethics approval and consent to participate
The authors declare that ethical approval was not required for this study.

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Spores and Capsules Morphology of Some *Orthotrichum* and *Lewinskya* Species (Orthotrichaceae) in Türkiye

Merve Can GÖZCÜ[1], Oktay BIYIKLIOĞLU[2,*], Serhat KARABICAK[2], Güray UYAR[1], Talip CETER[2]

[1] *Department of Biology, Polatlı Faculty of Science and Arts, Ankara Hacı Bayram Veli University, Ankara, TÜRKIYE.*
[2] *Department of Biology, Faculty of Science, Kastamonu University, Kastamonu, TÜRKIYE.*

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Abstract

Orthotrichum Hedw. and *Lewinskya* F. Lara, Garilleti & Goffinet are widespread genera within the family Orthotrichaceae Arn. Although spore size is commonly used in the identification of these genera, detailed information on spore ornamentation remains insufficient. Therefore, in this study, the detailed spore morphological characteristics and capsule structures of several *Orthotrichum* species collected from Türkiye (*O. bistratosum* (Schiffn.) J. Guerra, *O. diaphanum* Schrad. ex Brid., *O. pallens* Bruch ex Brid., *O. pumilum* Sw. ex anon., *O. scanicum* Gronvall, *O. stramineum* Hornsch. ex Brid.) and *Lewinskya* striata (Hedw.) F. Lara, Garilleti & Goffinet were examined using light microscopy (LM) and scanning electron microscopy (SEM). The aperture regions of most of the examined spores were found to possess a leptoma. In addition, depending on the type of sclerine ornamentation, the spores of the studied species correspond to three morphological categories: verrucate, gemmate, and granulate. The spores are also katalept, monolete, or trilete. In equatorial view, spore shapes range from spheroidal to plan-convex. Generally, the surface ornamentation elements are prominent, accompanied by smaller projections such as micro-verrucae, nano-gemmae, and granulae. Furthermore, the polar outline of the spores is typically circular to ellipsoidal, and occasionally subtriangular. The average polar axis (P) length ranges from 10.41 µm to 21.77 µm, while the equatorial diameter (E) ranges between 11.66 µm and 24.67 µm. It was determined that characteristics such as spore shape, size, and surface ornamentation vary among the examined taxa, indicating their taxonomic significance.

Keywords: Bryophyta, Orthotrichaceae, spore morphology, capsule structure, light microscope (LM), scanning electron microscope (SEM), Türkiye

Türkiye'de Bazı Orthotrichum ve Lewinskya Türlerinin Spor ve Kapsül Morfolojisi (Orthotrichaceae)

Öz

Orthotrichum Hedw. ve Lewinskya F. Lara, Garilleti & Goffinet, Orthotrichaceae Arn. familyasında yaygın olarak bulunan cinslerdir. Spor boyutu bu cinslerin teşhisinde kullanılmasına rağmen, spor ornamentasyonu (yüzey süslemeleri) hakkında ayrıntılı bilgiler hâlen yetersizdir. Bu nedenle, bu çalışmada Türkiye'den toplanan bazı *Orthotrichum* türlerinin (*O. bistratosum* (Schiffn.) J. Guerra, *O. diaphanum* Schrad. ex Brid., *O. pallens* Bruch ex Brid., *O. pumilum* Sw. ex anon., *O. scanicum* Gronvall, *O. stramineum* Hornsch. ex Brid.) ve *Lewinskya striata* (Hedw.) F. Lara, Garilleti & Goffinet'in ayrıntılı spor morfolojik özellikleri ve kapsül yapıları ışık mikroskobu (LM) ve taramalı elektron mikroskobu (SEM) kullanılarak incelenmiştir. İncelenen sporların çoğunun apertur bölgelerinin leptoma yapısına sahip olduğu belirlenmiştir. Ayrıca türlere ait sporlar, sklerin tabakasındaki süsleme tipine bağlı olarak üç morfolojik tipe karşılık gelmektedir: verrukat (siğilimsi), gemmat (taneli), ve granulat (granüllü). Sporlar ayrıca katalept, monolete veya trilete olabilir. Ekvatorel görünümde spor şekilleri küresel yapıdan plan-konveks forma kadar değişmektedir. Genel olarak yüzey ornamentasyon elemanları büyük olup, mikro-verrukae, nano-gemmae ve granula şeklinde daha küçük çıkıntılar taşımaktadır. Bunun yanında sporların polar görünümünde konturlar genellikle dairesel veya elipsoidal, bazen de yarı üçgensi (subtriangular) yapıdadır. Polar eksen uzunluğu (P) ortalama 10.41 µm ile 21.77 µm arasında değişirken, ekvator çapı (E) 11.66 µm ile 24.67 µm arasında belirlenmiştir. Spor şekli, boyutu ve yüzey ornamentasyonu gibi karakteristik özelliklerin incelenen taksonlar arasında farklılık gösterdiği ve bu nedenle taksonomik açıdan önemli olduğu saptanmıştır.

Anahtar kelimeler: Bryophyta, Orthotrichaceae, spor morfolojisi, kapsül yapısı, ışık mikroskobu (LM), taramalı elektron mikroskobu (SEM), Türkiye

* Corresponding author: oktayman@gmail.com
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1. Introduction

Bryophytes, which are the descendants of the first plants that successfully colonized terrestrial habitats, contain the three lineages of plants: mosses, liverworts and hornworts. In contrast to other land plants, the gametophyte is the dominant photosynthetic active generation, and the sporophyte is unbranched and cannot live independently (Schofield, 1985; Qiu, 2008). In addition, bryophytes are generally dispersed both by spores that are produced in capsules and by propagules that descend from the gametophyte or by unspecialized gametophyte fragments (Correns, 1899; Heinrichs et al., 2009).

Spores play a crucial role in dispersal and the establishment of new bryophyte populations. At the same time, the spores may have to endure harsh conditions, such as drought, ultraviolet light, and extreme temperatures, during dispersal, which is why spore resistance appears to be a primary factor affecting the dispersal range of many bryophyte species. Moreover, size and the number of spores are as effective as spore resistance in dispersal strategies of bryophytes. However, it remains unclear if different spore characteristics, such as ornamentation morphology, wall stratification, and cytological features, reflect different dispersal strategies (During, 1979; Kürschner and Frey, 2012; Medina and Estebanez, 2014). It is also known that these spore characteristics are important in both taxonomy and dispersal. Nevertheless, the spore ornamentation morphology has been of limited value in taxonomy; it has been usefull in solving taxonomic problems and is a potential source of information regarding evolutionary processes, which may lead to the definition of biological or taxonomic boundaries (Carrion et al., 1995). For this reason, many studies conducted on Bryophytes spore morphology emphasize the distinctive characteristics of spores (Potoglu Erkara and Savaroglu 2007; Savaroglu et al. 2007; Savaroglu and Potoglu Erkara 2008; Ascı et al. 2010; Potoglu Erkara, 2017; Can Gözcü et al., 2018a, 2018b; Çeter et al., 2018; Potoglu Erkara et al., 2018; Aslan et.al., 2022).

The Orthotrichaceae family, which includes the genera studied in this work, is a large and diverse moss family characterized by broad morphological heterogeneity. The family members are small to medium-sized, saxicolous or epiphytic plants primarily associated with xerophytic habitats. They consist of cushions, tufts, or prostrate gametophytes with erect-ascending lateral branches and terminal sporophytes. At the same time, *Orthotrichum* Hedw. is one of the most common genera of this family. It is generally epiphytes that grow on tree trunks and branches in open, sunny habitats, and they are less often found in saxicolous substrates (Lewinsky, 1993; Sawicki et al., 2017). It is readily recognizable from other moss genera by its immersed to short-exerted and often ribbed capsules, with large, campanulate to mitrate calyptrae covering the entire capsules (Ochyra et al., 2008). The genera *Orthotrichum* Hedw. and *Ulota* F.Weber were re-evaluated by Plášek et al. (2015) and divided into six genera: *Orthotrichum*, *Dorcadion* Lindb., *Nyholmiella* Holmen & E.Warncke, *Pulvigera* Plášek, Sawicki & Ochyra, *Plenogemma* Plášek, Sawicki & Ochyra, and *Ulota.* Lara et al (2016) reported that the genus *Orthotrichum* Hedw. should be divided based on the location of the stomata. Accordingly, species with superficial stomata were included in the genus *Lewinskya* F.Lara, Garilleti & Goffinet. In recent studies based on molecular data, a new taxonomical arrangement was proposed for *Orthotrichum,* dividing it into four genera: *Lewinskya* F.Lara, Garilleti & Goffinet, *Nyholmiella* Holmen & E.Warncke, *Pulvigera* Plášek, Sawicki & Ochyra, and *Orthotrichum* Hedw. (Plášek et al., 2015; Lara et al., 2016; Sawicki, 2017). In these genera, spore sizes have also been used for diagnostic purposes (Lewinsky, 1993; Nyholm, 1998; Smith, 2004; Lara et al., 2009, 2016).

The most comprehensive study on the spore morphology of the Orthotrichaceae family was performed by Hirohama (1977). In this study, the spore morphology of 56 taxa belonging to the genera *Amphidium*, *Zygodon, Sclotheimia*, *Ulota*, *Drummondia*, and *Macromitrum*, as well as 26 *Orthotrichum* species, was studied using SEM. Additionally, the spore morphology of the Orthotricaceae family has been extensively studied by numerous researchers. (Erdtman, 1957; Boros and Járai-Komlódi, 1975; Boros et al., 1993; Punt et al., 1994; Kapp et al., 2000; Medina and Estebanez, 2014; Savaroğlu, 2015).

This study aims to contribute to taxonomy by revealing the morphological characteristics of spores and capsules of five species of the genus *Orthotrichum* and one species of the genus *Lewinskya* collected from Türkiye.

2. Material and Methods

Spore and capsule materials were obtained from the Bryophyte herbarium in the Department of Biology of Polatlı Science and Arts Faculty, Ankara Hacı Bayram Veli University. The list of the taxa examined is given in Table 1.

Table 1. Locality details of the examined specimens

Species	Collection Sites
O. bistratosum	Sakarya, Pamukova, Meşruriye locality, on rock, 40°34'57"N, 30°06'09"E, 651 m alt., 08.09.2018.
O. diaphanum	Yalova, İstihkam Hill, on tree trunk, 40°35'58"N, 29°18'44"E, 399 m alt., 25.05.2018.
O. pallens	Yalova, Samanlı locality, on tree trunk, 40°38'05"N, 29°13'29"E, 78 m. alt., 25.05.2018.
O. pumilum	Yalova, Çınarcık, Teşvikiye locality, on tree trunk, 40°36'41"N, 29°04'18"E, 130 m alt., 25.05.2018.
O. scanicum	Yalova, Dereiçi locality, on tree trunk, 40°34'02"N, 29°13'11"E, 206 m alt., 25.05.2018.
O. stramineum	Kocaeli, Başiskele, Erciova Plateau, 40°33'34"N, 29°59'29"E, 1110 m alt., 25.05.2018
L. striata	Kocaeli, Kartepe, 40°39'31"N, 30°05'56"E, 1222 m alt., 25.05.2018.

The spore slides were prepared according to Wodehouse's method (1935) for light microscopy (LM) studies. The measurements of the polar axis (P) and the equatorial diameter (E) were taken from 25 randomly selected spores. The capsules were observed by stereo microscopy and scanning electron microscopy. The mouth diameter, length, and width in 20 randomly selected capsules were measured. The Olympus SZX7 light microscope, BX47 stereo microscope, and SC 100 image analysis system were used to photograph and measure the spores and capsules of the moss specimens.

For scanning electron microscopy, the spores and the capsules were directly placed onto stubs with a double-sided carbon band. The stubs were coated with a gold palladium alloy at a voltage of 40 mV for 60 seconds in a vacuum evaporator and examined using a Quanta FEG 250 scanning electron microscope at the Kastamonu University Central Research Laboratory. SEM images were taken at 5.0 and 10.0 kV to obtain the clearest images. Spore morphology terms were determined according to the suggestions made by Punt et al. (2007). Also, references from Erdtman (1957), Boros and Járai-Komlódi (1975), Hirohama (1977), Blackmore and Barnes (1991), Boros et al. (1993), Kapp et al. (2000), Punt et al. (2007), Medina et al. (2009), and Halbriter et al. (2018) were used.

Principal Coordinates Analysis (PCoA) analyses were performed using the PAST v.4.14 software (Hammer et al., 2001). The analysis was based on the following morphological characters: polar axis length, equatorial diameter, aperture type, capsule length (L), capsule width (W), the L/W ratio, and peristome teeth length

3. Results

The aperture regions of the investigated spores are composed of leptoma. According to the aperture, spores are determined as katalept, monolete, or trilete. The shapes of spores in an equatorial view vary from spheroidal to plan-convex. Additionally, outlines of spores in polar view are usually circular to ellipsoidal, sometimes subtriangular. The average length of the polar axis (P) ranges from 10.41 µm to 21.77 µm, and the equatorial diameter (E) is between 11.66 µm and 24.67 µm. In addition, the spores of the examined species correspond to three morphological types depending on the sclerine ornamentation: verrucate, gemmate, and granulate. Generally, the surface ornamentation elements are prominent and have smaller projections in the form of micro-verrucae, nano-gemmae, and granulae (Table 2).

***Orthotrichum bistratosum* (Schiffn.) J.Guerra:** Spores are small, circular, bilaterally symmetric, heteropolar, and katalept. The average length of the polar axis is 13.83 µm, and the average equatorial diameter is 15.84 µm (Table 2, Figure 1). The exine surface is ornamented with verrucate-gemmate elements. The gemmae-shaped elements are more densely distributed and larger in the distal pole and are smaller and sparsely distributed in the leptoma area. The surfaces of the gemmae and the areas between them are covered with micro-verrucae to granulae. The diameters of the gemmae range from 0.7 to 1.4 µm. The apertural region consists of a concave, rounded to subtriangular area. This area was interpreted to be leptoma. (Figure 2, 3). Capsules are erect, pyriform to ovoid-pyriform with conspicuous 16 furrows and constricted below the mouth when dry (Figure 4). Capsule sizes average 0.58 mm wide, 2.19 mm long, ~3.9 times as long as wide. The furrows have an average thickness of 59 µm. Peristome teeth are 16, lanceolate, striate, and average 334.5 µm long (Figure 5a, b).

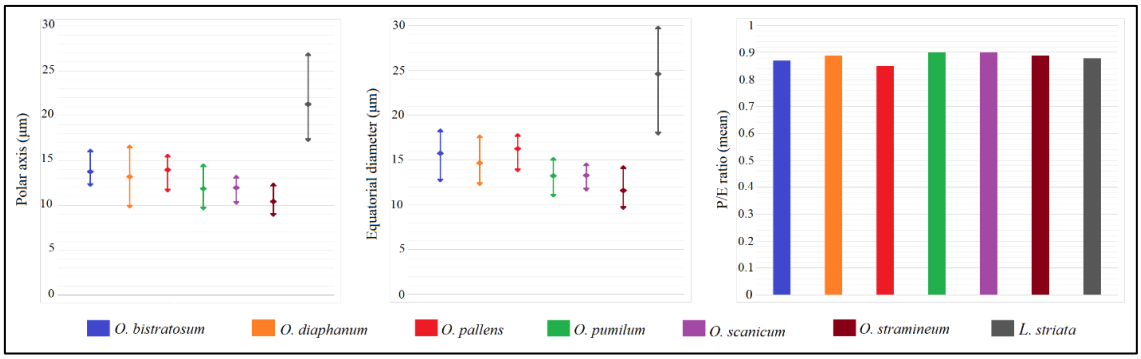

Figure 1. Graphical comparison of the length of polar axis (P), equatorial diameter (E) and P/E ratios (minimum, maximum and mean values)

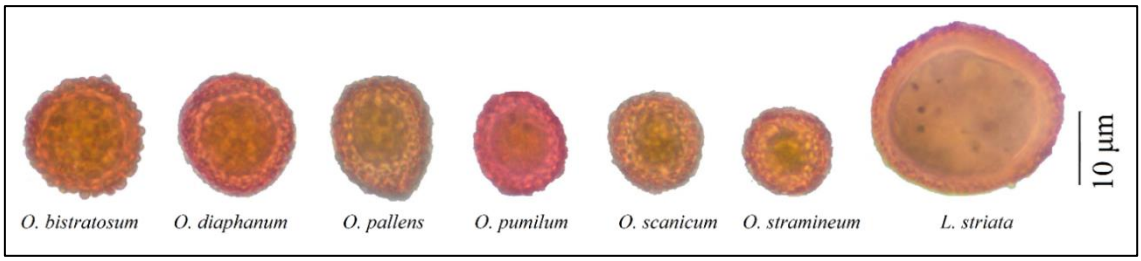

Figure 2. L.M spore microphotograph

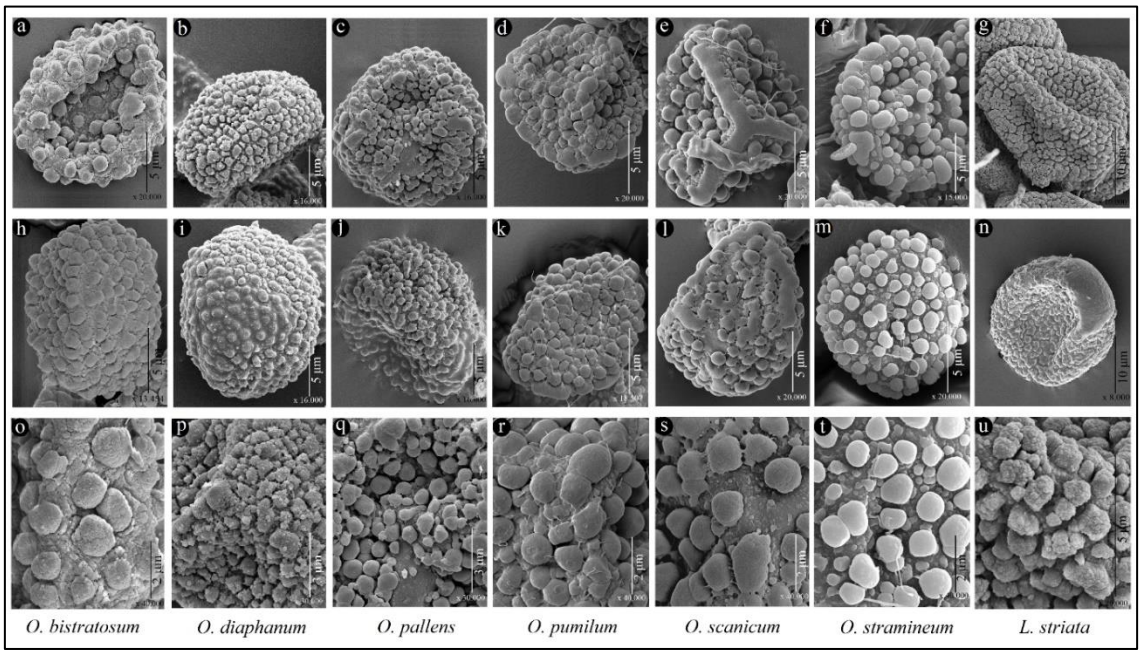

Figure 3. SEM spore microphotograph.

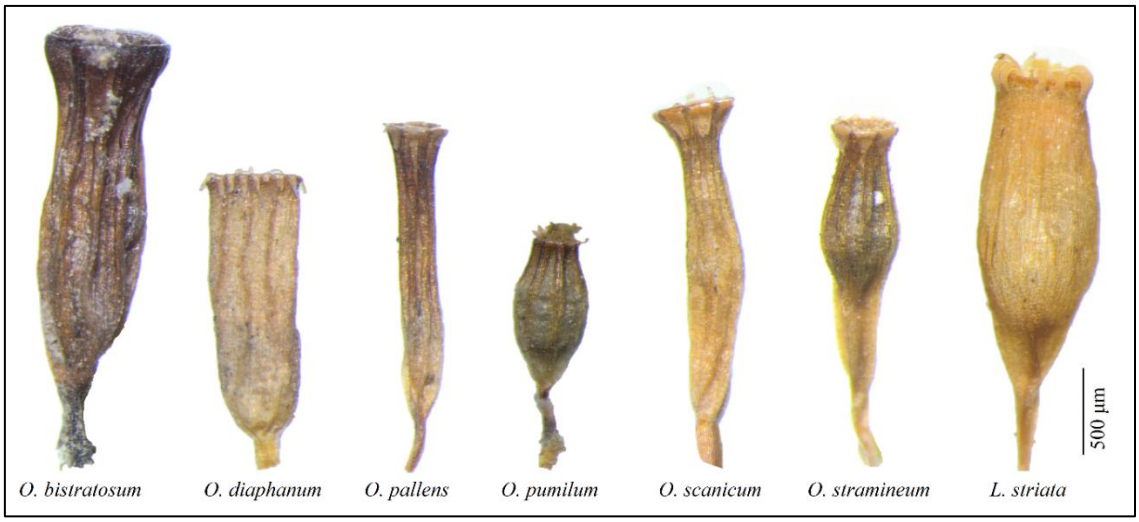

Figure 4. Stereo microscopy capsule photograph.

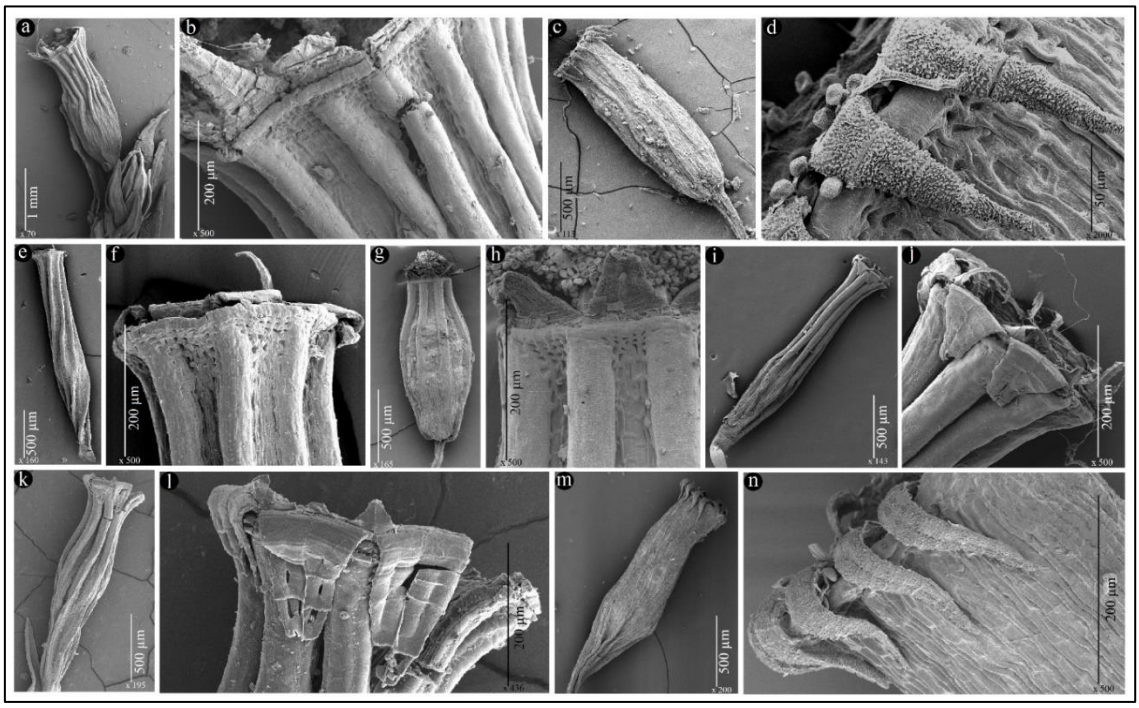

Figure 5. SEM capsule microphotograph. a-b: *O. bistratosum,* c-d: *O. diaphanum*, e-f: *O. pallens*, g-h: *O. pumilum*, i-j:*O. scanicum*, k-l: *O. stramineum*, m-n: *L. striata*.

Table 2. The spore morphological parameters (all values measured in the equatorial view)

Species	P (µm)				E (µm)				Shape in equatorial view	Outline in polar view (amb)	Aperture	Ornamentations	
	Min	Max	Mean	SD	Min	Max	Mean	SD				Distal area	Proximal (Leptoma) area
O. bistratosum	12.05	16.37	13.83	1.09	12.60	18.42	15.84	1.30	Concave-convex	Circular	Katalept	Densely and broadly gemmate, micro-verrucate, granulate	Rare and small gemmate, micro-verrucate, granulate
O. diaphanum	9.69	16.72	13.23	1.44	12.10	17.84	14.78	1.39	spheroidal	Circular-ellipsoidal	Monolete	Irregular verrucate, densely nanogemmate, granulate	Large and densely verrucate, granulate
O. pallens	11.51	15.72	13.93	1.41	13.82	17.98	16.25	1.44	Concave-convex	Circular-ellipsoidal	Katalept	Gemmate, verrucate	Gemmate, verrucate
O. pumilum	9.62	14.57	11.83	1.21	10.90	15.30	13.13	1.08	Concave-convex	Circular-ellipsoidal	Trilete	Gemmate, verrucate	Gemmate, verrucate
O. scanicum	10.13	13.33	11.94	0.99	11.62	14.58	13.21	0.82	Plane-convex	Circular-subtriangular	Trilete	Gemmate, verrucate	Psilate
O. stramineum	8.83	12.46	10.41	0.78	9.50	14.43	11.66	0.93	Plane-convex	Circular-subtriangular	Trilete	Densely gemmate, verrucate	Sparsely gemmate verrucate
L. striata	17.11	27.03	21.77	3.03	17.86	29.58	24.67	3.33	Spheroidal	Circular-ellipsoidal	Monolete	Verrucate, micro-verrucate	Verrucate, micro-verrucate

P: Polar axis , E: equatorial diameter, SD: Standart deviation

Table 3. The capsule and peristome teeth measurements (values in µm)

Species	Capsule length			Capsule width			L/W (Mean)	Peristome teeth length (Mean)
	Min	Max	Mean	Min	Max	Mean		
O. bistratosum	1.93	2.48	2.19	0.38	0.73	0.58	3.9	0.33
O. diaphanum	1.34	1.61	1.47	0.36	0.50	0.45	3.2	0.18
O. pallens	1.74	1.90	1.86	0.20	0.40	0.29	6.5	0.16
O. pumilum	0.85	1.10	1.01	0.43	0.56	0.49	2.0	0.11
O. scanicum	1.72	1.93	1.83	0.20	0.33	0.28	6.6	0.18
O. stramineum	0.97	1.76	1.33	0.40	0.78	0.50	2.6	0.18
L. striata	1.13	1.70	1.37	0.36	0.67	0.47	2.9	0.25

***Orthotrichum diaphanum* Brid.:** Spores are small, circular to ellipsoidal, bilaterally symmetric, heteropolar, and monolete. The average length of the polar axis is 13.23 µm, and the average equatorial diameter is 14.78 µm (Table 2, Figure 1). Irregular verrucate elements ornament the exine surface. The verrucae are covered with densely nanogemmate elements. The diameters of the verrucae are approximately between 0.5 and 0.9 µm. The apertural region consists of a rounded to elliptic leptoma. A long and wide laesura is noticeable. The laesurae have similar ornamentation to exine surfaces, with larger and denser verrucae and granulae (Figures 2 and 3). The capsules are erect, oblong to cylindrical, averaging 0.45 mm in width and 1.47 mm in length, with a length-to-width ratio of ~3.2. (Figure 4). The capsules have indistinct eight furrows. Peristomes consist of 16 exostome teeth and 16 endostome segments. Exostome teeth are lanceolate, striate, obviously papillose, average 185.5 µm, and reflexed when dry. Endostome segments are shorter than teeth, linear, densely papillose, and average 65 µm (Figure 5c, d).

***Orthotrichum pallens* Bruch ex Brid.:** Spores are small, circular to ellipsoidal, bilaterally symmetric, sometimes asymmetric, and heteropolar, with a katalept pattern. The average length of the polar axis is 13.93 µm, and the average equatorial diameter is 17.98 µm (Table 2, Figure 1). The exine surface is ornamented with irregular gemmate and verrucate elements. The elements range in diameter from 0.2 to 1.3 µm. The apertural region consists of a concave leptoma in a rounded to subtriangular shape (Figures 2 and 3). The leptoma has similar ornamentation to exine surfaces. Capsules are erect, cylindrical, and have conspicuous eight furrows, which have an average thickness of 45 µm (Figure 4). Capsules are ~0.29 mm wide, 1.86 mm long, and about 6.5 times as long as they are wide. Peristomes have eight lanceolate exostome teeth and eight linear endostome segments. Exostome teeth are an average of 161.6 µm and reflexed when dry, and endostome segments are an average of 85 µm (Figure 5e, f).

***Orthotrichum pumilum* Sw. ex anon.:** Spores are small, circular to ellipsoidal, bilaterally sometimes radially symmetric or asymmetric, heteropolar, and trilete. The length of the polar axis averages 11.83 µm, and the equatorial diameter averages 13.13 µm (Table 2, Figure 1). Gemmate and verrucate elements ornament the exine surface. These are approximately between 0.5 and 1.5 µm in diameter. The apertural region consists of a trilete leptoma. The laesurae have similar ornamentation to the exine surfaces (Figures 2 and 3). Capsules are erect, pyriform, and have conspicuous eight furrows, which have an average thickness of 58 µm (Figure 4). Capsule sizes are ~0.49 mm wide, 1.01 mm long, and about 2.0 times as long as they are wide. Peristomes consist of 8 exostome teeth and eight endostome segments. Exostome teeth are papillose, measuring an average of 113.3 µm, and reflexed when dry. (Figure 5g, h).

***Orthotrichum scanicum* Grönvall:** Spores are small, circular to subtriangular, bilaterally sometimes radially symmetric, heteropolar, and trilete. The length of the polar axis averages 11.94 µm, and the equatorial diameter averages 13.21 µm (Table 2, Figure 1). Gemmate and verrucate elements ornament the exine surface. The elements are approximately between 0.6 and 1.3 µm in diameter. The apertural region consists of a trilete leptoma. The prominent and straight laesurae extend to the equator. The laesurae have psilate ornamentations (Figures 2 and 3). Capsules are erect, cylindrical, constricted below the mouth, and have conspicuous eight furrows, which have an average thickness of 60 µm (Figure 4). Capsule

sizes average 0.28 mm wide, 1.83 mm long, and ~6.6 times as long as wide. Peristomes have eight exostome teeth and 16 endostome segments. Exostome teeth are papillose, average 186.2 µm, and are reflexed when dry. Endostome segments are smooth, linear, and average 137.7 µm (Figure 5i, j).

***Orthotrichum stramineum* Hornsch. exBrid.:** Spores are small, circular to subtriangular, bilaterally sometimes radially symmetric, heteropolar, and trilete. The length of the polar axis averages 10.41 µm, and the equatorial diameter averages 11.66 µm (Table 2, Figure 1). Gemmate-verrucate elements ornament the exine surface. These are denser in the distal pole, and sparse in the leptoma area. They are approximately between 0.5 and 1.8 µm in diameter. The apertural region consists of a trilete leptoma. The laesurae have similar ornamentation to the exine surfaces (Figures 2 and 3). Capsules are erect, ellipsoid to pyriform, and have eight furrows, which have an average thickness of 68 µm (Figure 4). Capsule sizes average 0.50 mm in width, 1.33 mm in length, and ~2.6 times as long as wide. Peristomes consist of 8 papillose exostome teeth, which average 192.4 µm and are reflexed when dry, and eight smooth endostome segments (Figure 5k, l).

***Lewinskya striata* (Hedw.) F.Lara, Garilleti & Goffinet:** Spores are medium-sized, circular to ellipsoidal, bilaterally sometimes radially symmetric, heteropolar, and monolete. The length of the polar axis averages 21.77 µm, and the equatorial diameter averages 24.67 µm (Table 2, Figure 1). The exine surface is ornamented with verrucate elements bearing micro-verrucae. The diameters of the verrucae are approximately between 0.4 and 1.1µm. The apertural region consists of monolete leptoma. The laesurae have similar ornamentation to the exine surfaces (Figures 2 and 3). Capsules are erect, oblong to ovoid, smooth, average 0.47 mm wide, 1.37 mm long, ~2.9 times as long as wide (Figure 4). Peristomes consist of 16 exostome teeth and 16 endostome segments. Exostome teeth are lanceolate, striate, papillose, average 253 µm, and are reflexed when dry. Endostome segments are linear and average 132.4 µm (Figure 5m, n).

PCoA clearly grouped the studied species. *Lewinskya striata* was positioned quite distantly from other taxa. *Orthotrichum pumilum* and *O. stramineum* were grouped separately from other Orthotrichum species. PCoA explained 74% of the variation based on spore and capsule morphology among the species (Axis 1: 53.18%, Axis 2: 20.52%).

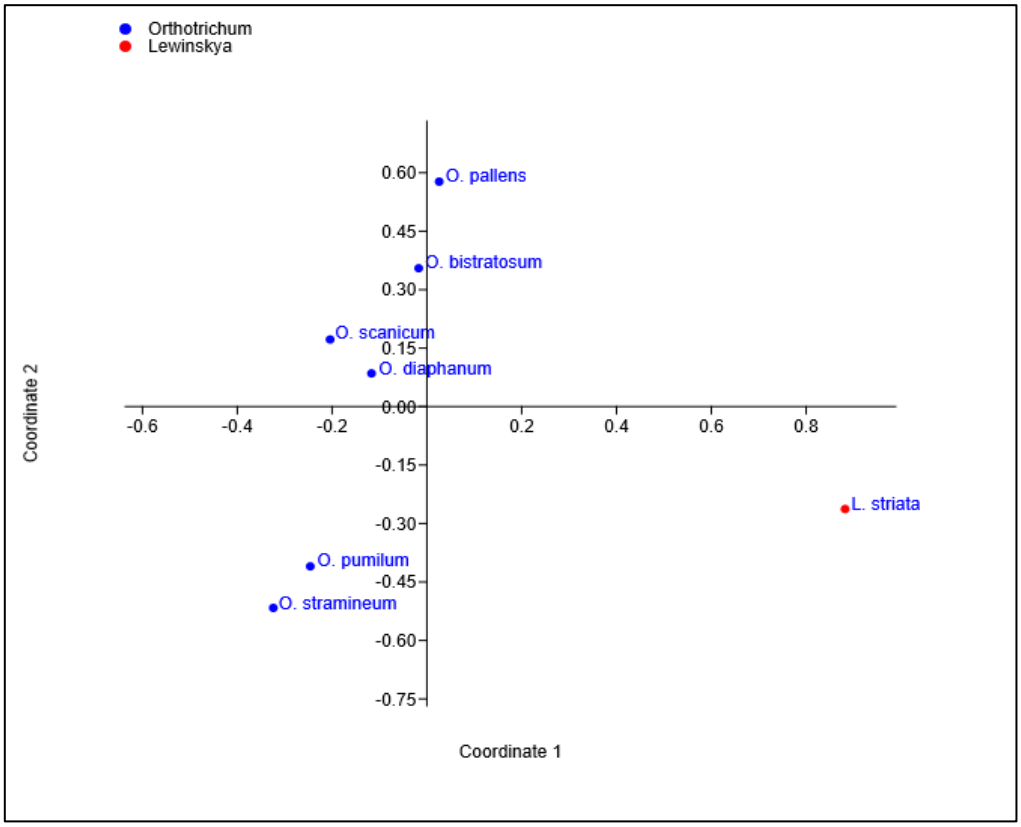

Figure 6. Principal Coordinates Analysis

4. Discussion

Spore morphology of some species belonging to Orthotrichaceae had been studied previously by Erdtman (1957), Boros and Járai-Komlódi (1975), Boros et al. (1993), Punt et al. (1994), Kapp et al. (2000), Khoshravesh and Kazempour Osaloo (2007), Medina et al. (2009), Medina and Estebanez (2014), Savaroğlu (2015), and Erkara et al. (2018). Hirohama (1977) investigated the spor morphology of 56 taxa belonging to Orthotricaceae, including 25 *Orthotricum* species. In this study, capsule micromorphology and spore morphology of *Orthotrichum bistratosum, O. diaphanum, O. pallens, O. pumilum, O. scanicum, O. stramineum*, and *Lewinskya striata* were studied using LM and SEM in detail.

The spore size is recognized as an important character in the systematics of Orthotrichaceae (Lara et al., 2009; Lara et al., 2016). Spores of studied taxa were determined as monads, and the spore sizes ranged between 8.83 and 29.58 µm. The average lengths of the polar axis (P) range between 10.41 and 21.77 µm, and the equatorial diameters (E) range between 11.66 and 24.67 µm. The smallest spores of these taxa were found in *O. stramineum* with 8.83-12.46 µm polar axis and 9.50-14.43 µm equatorial axis, while the largest spores were observed in *L. striata* with 17.11-27.03 µm polar axis and 17.86-29.50 µm equatorial axis. Also, the size of *O. diaphanum* measured as 9.69-16.72 µm for the polar axis and 12.10-17.84 µm for the equatorial axis in this study.

Boros et al. (1993) determined a tetrahedral tetrad in *O. anomalum* and *O. urnigerum*, while monad spores in *O. affine*. Hirohama (1977) investigated the spore morphology of 25 taxa of Orthotrichum, including *O. stramineum* and *O. diaphanum.* The spore size of all studied taxa ranges between 10 and 35 µm. Spore size of *O. stramineum* measured as 10-15 µm and *O. diaphanum* 16-25 µm in his study. In both studies, similar size values were found for *O. stramineum*; however, significant size differences were observed for *O. diaphanum*. Medina and Estebanez (2014) and Medina et al. (2009) observe spore sizes of *O. acuminatum, O. affine, O. ibericum, O. lyellii, O. speciosum, O. striatum,* and *O. tortidontium* that range between 12 and 38 mm. It is thought that the reason for this difference is determined in the *O. diaphanum* taxon may be due to geographical differences or intraspecific genetic diversity. Additionally, Savaroğlu (2015) observed that the spore sizes of *O. lyelli, O. speciosum, O. rupestre, O. anomalum*, and *O. cupulatum* ranged between 7 and 23 µm. Similarly, important size differences were observed between the measurements of Hirohama (1977) and Savaroğlu (2015) on many taxa.

Boros et al. (1993) described spheroid, plane-convex, and concave-convex pore shapes in equatorial view and circular, triangular, and subtriangular outlines in the polar view. They determined a spheroidal shape for *O. affine* and a subtriangular spore shape for *O. urnigerum*. In the present study, spheroidal (*O. diaphanum, L. striata*), concave-convex (*O. bistratosum, O. pallens, O. pumilum*), and plane-convex (*O. scanicum, O. stramineum*) spore shapes were determined in equatorial view. In contrast, circular (*O. bistratosum*), circular-elipsoidal (*O. diaphanum, O. pallens, O. pumilum, L. striata*), circular-subtriangular (*O. scanicum, O. stramineum*) spore shapes were determined in polar view. Savaroğlu (2015) determined concave-convex spore shape in equatorial view and subcircular shape in polar view for *O. lyellii*, *O. rupestre*, *O. anomalum*, and *O. cupulatum*, while plane-convex to concave-convex shape in polar view and rounded to sub-rounded in equatorial view for *O. speciosum* and *O. affine*.

Boros et al. (1993) described four (Atreme/alete, katalept, monolete, trilete) aperture types in their comprehensive study on moss spores, and they determined the katalept aperture (leptoma) for *O. affine*, *O. anomalum*, and *O. urnigerum*. Also, Savaroğlu (2015) determined katalept aperture (leptoma) for six *Orthotrichum* species. In the present study, katalept (*O. bistratosum, O. pallens*), monolete (*O. diaphanum, L. striata*), and trilete (*O. scanicum, O. stramineum, O. pumilum*) aperture types were determined in the studied taxa of *Orthotricum*. While the aperture type appears to be a systematically informative character among the studied species, upon considering the literature studies, it becomes evident that a more comprehensive analysis is necessary to reveal the contribution of this character more clearly.

Savaroglu et al. (2007) reported that the pililoid and granuloid ornamentation types are distinguishing characters in Bryaceae Schwägr species. Savaroglu and Potoglu Erkara (2008) examined the spore morphology of five different species of the *Pottiaceae* Schimp. family. As a result of this study, they reported that the use of spore ornamentation as a distinguishing character would be limited. Boros et al. (1993) described seven ornamentation elements and four bacula types based on their size and appearance in moss spore morphology. They determined that verrucate gemmate ornamentation is present in *O. affine, O. anomalum*, and *O. urnigerum*. Additionally, Savaroğlu (2015)

identifies the ornamentation elements of Gemmate (*O. lyellii*, *O. rupestre*, *O. anomalum*, and *O. cupulatum*) and verrucate (*O. speciosum* and *O. affine*) species within Orthotrichum. Medina and Estebanez (2014) identify verrucate-baculate and verrucate primary ornamentation elements with varying sizes, fusion, and distinct secondary ornamentation patterns in seven *Orthotrichum* species. In the present study, verrucae and gemmae, the primary ornamentation elements, as well as microverrucae and granulae, the secondary ornamentation elements, were observed in the studied taxa (Table 2). Nevertheless, density, size, and the combination of these primary and secondary ornamentation elements between species support a valuable contribution to systematic discrimination of the studied taxa.

PCoA analysis placed the genera *Lewinskya* and *Orthotrichum* at a considerable distance from each other. The spore size of L. striata markedly contributes to its distinct grouping from the other taxa. Lara et al. (2016) reported that the genus *Lewinskya* is separated from *Orthotrichum* based on molecular and morphological characters. This finding indicates that spore size supports the results of both molecular and macro-morphological studies.

Furthermore, *O. pallens* and *O. scanicum* differ significantly from the other *Orthotrichum* species due to their relatively high L/W ratios. This supports the view that spore and capsule morphology possess distinguishing characteristics at both genus and species levels.

As a result, it has been found that SEM analyses provide valuable information for the identification and characterization of spore morphology. It was found that spore size, polar axis, equatorial axis, spore shape in polar and equatorial views, aperture type, and surface ornamentation of seven species of *Orthotrichum* and *Lewinskya* showed significant differences, contributing to the systematics of the studied species. The fact that *Lewinskya striat* has spores that are considerably larger than other taxa supports the idea that spore morphology has strong characters in distinguishing between genera. These characteristicscan can be used as a supporting feature in conjunction with other gametophytic and sporophytic characters for diagnosis. However, considering previous studies, it is necessary to conduct comprehensive research with a broader range of species to determine the contribution of these spore features to the family level.

Declaration

Author contributions

Idea/Concept: MCG, OB, SK, GU, TC; Conceptualization and design: MCG, OB, SK, GU, TC; Auditing consulting: MCG, OB, SK, GU, TC; References: MCG, OB, SK, GU, TC; Materials: MCG, OB, SK, GU, TC; Data collection and/or processing: MCG, OB, SK, GU, TC; Analysis and/or interpretation: MCG, OB, SK, GU, TC; Literature search: MCG, OB, SK, GU, TC; Writing phase: MCG, OB, SK, GU, TC; Critical review: MCG, OB, SK, GU, TC.

Conflict of interest

It is declared by the authors that no conflict of interest exists concerning the findings and overall content of the study.

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Ethical approval

This research was conducted under in vitro conditions and therefore does not require ethical approval.

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Çankırı Karatekin Üniversitesi Uluyazı Kampüsü Karayosunu Florası (Çankırı-Türkiye)

Simge ÇİZGEN TAN[1,*], Serhat URSAVAŞ[2]

[1]Çankırı Karatekin Üniversitesi, Fen Bilimleri Enstitüsü, Orman Mühendisliği Anabilim Dalı, Çankırı, TÜRKİYE
[2]Çankırı Karatekin Üniversitesi, Orman Fakültesi, Orman Mühendisliği Bölümü, Çankırı, TÜRKİYE

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Öz

Bu çalışma, Orta Anadolu'nun yarı kurak iklim kuşağında yer alan Çankırı Karatekin Üniversitesi Uluyazı Kampüsü'nün karayosunu (Bryophyta) florasını ortaya koymak amacıyla gerçekleştirilmiştir. Araştırma sonucunda, 10 familya ve 26 cinse ait toplam 62 takson tespit edilmiştir. Teşhis edilen tüm briyofit örnekleri Bryophyta bölümüne aittir. En fazla taksona sahip familya Pottiaceae olup, toplam taksonların yaklaşık %50'ini oluşturmaktadır. Bunu Bryaceae ve Brachytheciaceae familyaları izlemiştir. Örneklemeler, kampüs alanında belirlenen 11 farklı lokalitede, toprak, kaya, beton, duvar ve ağaç gövdeleri gibi farklı mikrohabitatlardan, 2024 yılı sonbahar ve 2025 yılı ilkbahar dönemlerinde gerçekleştirilmiştir. Çalışma sonucunda, Çankırı ili için 13 yeni kayıt ve Türkiye için 1 yeni kayıt (*Tortula bolanderi* (Lesq.) M.Howe) belirlenmiştir. Özellikle *Tortula muralis*, *Syntrichia caninervis* ve *Bryum argenteum* gibi türlerin baskınlığı, briyofitlerin yarı kurak ve kentleşmiş ortamlara yüksek uyum yeteneğini göstermektedir. Antropojenik baskının yüksek olmasına karşın kampüs alanında saptanan zengin tür çeşitliliği, kentsel ekosistemlerin mikrorefugium (mikro sığınak) niteliğinde olduğunu ve briyofitlerin sürdürülebilirliği açısından önemli mikroklimatik yaşam alanları sunduğunu göstermektedir. Bu çalışma, hem Çankırı ili briyoflorasına önemli katkılar sağlamakta hem de yarı kurak kentsel ekosistemlerde gelecekte yapılacak briyolojik, ekolojik ve biyocoğrafik araştırmalar için temel bir veri seti sunmaktadır.
Anahtar kelimeler: Bryophyta, flora, yeni kayıt, mikrorefugium, Orta Anadolu

Moss Flora of Çankırı Karatekin University Uluyazı Campus (Çankırı, Türkiye)

Abstract

This study was conducted to reveal the bryophyte flora of the Uluyazı Campus of Çankırı Karatekin University, which is located in the semi-arid climatic zone of Central Anatolia (Çankırı, Türkiye). As a result of the research, a total of 62 bryophyte taxa belonging to 10 families and 26 genera were identified, all of which belong to the division Bryophyta. The richest family was Pottiaceae, representing approximately 50% of the total taxa, followed by Bryaceae and Brachytheciaceae. Specimens were collected from 11 different localities within the campus area during the autumn of 2024 and the spring of 2025, covering a variety of microhabitats such as soil, rock, concrete, wall, and tree bark. As a result, 13 taxa were recorded for the first time from the province of Çankırı, and one species (*Tortula bolanderi* (Lesq.) M.Howe) was determined as a new record for Türkiye. The dominance of species such as *Tortula muralis*, *Syntrichia caninervis*, and *Bryum argenteum* indicates the high adaptability of bryophytes to semi-arid and urbanized environments. Despite strong anthropogenic pressure, the rich bryophyte diversity observed in the campus area demonstrates that urban ecosystems can function as microrefugia (micro-shelters), providing important microclimatic habitats for the persistence of bryophyte communities. This study not only contributes significantly to the bryofloristic knowledge of the Çankırı province but also provides a baseline dataset for future bryological, ecological, and biogeographical research in semi-arid urban ecosystems of Türkiye.
Keywords: Bryophyta, flora, new record, microrefugium, Central Anatolia

* Corresponding author: scizgen@gmail.com
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1. Giriş

Kentleşmenin hızlandığı günümüzde doğal yaşam alanlarının küçülmesi, habitatların parçalanması ve ekolojik işlevlerin zayıflaması önemli bir çevresel sorun oluşturmakta; bu durum yalnızca büyük damarlı bitkileri değil, ekosistem dinamizmi için temel role sahip briyofitleri de etkilemektedir (Bairoch, 1988; Öner ve ark., 2007; Nicol-Harper, ve ark., 2023). Küçük boyutları, suya bağımlı yaşam biçimleri ve hızlı çevresel tepki verebilme özellikleriyle briyofitler, kentsel ekosistemlerde habitat değişimlerini yansıtan önemli biyolojik göstergelerdir (Glime, 2017).

Türkiye, üç farklı fitocoğrafik bölgenin kesişiminde yer alması nedeniyle Avrupa ve Asya ülkeleri arasında en yüksek briyofit çeşitliliğine sahip ülkelerden biri olarak kabul edilir (Erdağ ve Kürschner, 2017). Güncel çalışmalar ışığında Türkiye'de yaklaşık ± 1057 (Ursavaş ve Işın, 2019; Kürschner H. Erdağ A. 2023; Batan ve ark., 2024a, b; Ellis ve ark., 2024a, b; Erdağ ve Kürschner 2024; Aslan ve ark., 2024; Erata ve ark., 2025a). Türkiye için toplam briyofit taksonu 1293 (1057 karayosunu, 231 ciğerotu, ve 5 boynuzsu ot). (Batan ve ark., 2024a, b; Ellis ve ark., 2024a, b; Erdağ ve Kürschner 2024; Erata ve ark., 2025a, 2025b; Ursavaş, Çizgen Tan, 2025) Bu çeşitliliğin önemli bir bölümü, insan etkisinin yoğun olduğu kentsel peyzaj içerisinde hayatta kalmayı başaran ve geniş adaptasyon yeteneği gösteren karayosunlarından oluşmaktadır (Sabovljević ve Grdović, 2009).

Üniversite kampüsleri, barındırdığı yeşil alanlar ve mikrohabitat çeşitliliği nedeniyle briyofitler için birer "kentsel sığınak" niteliğindedir. Nitekim Türkiye'de kampüs alanlarında yapılan önceki çalışmalar dikkat çekici floristik zenginlik ortaya koymuştur. Örneğin; Zonguldak Karaelmas Üniversitesi Merkez Kampüsü'nde 53 takson (Alataş et al., 2011), Karadeniz Teknik Üniversitesi Kanuni Kampüsü'nde 102 takson, bunlardan 23'ü Trabzon için yeni kayıt (Erata ve ark., 2017), Recep Tayyip Erdoğan Üniversitesi Zihni Derin Kampüsü'nde 57 takson, 9'u Rize için yeni kayıt (Abay, 2018), Ankara Üniversitesi Beşevler 10. Yıl Kampüsü'nde 28 takson (Ezer ve ark., 2021), Fırat Üniversitesi Merkez Kampüsü'nde 37 takson, 11'i Elazığ için yeni kayıt (Alataş ve ark., 2024), Maltepe Üniversitesi Merkez Kampüsü'nde 42 takson, 19'u İstanbul için yeni kayıt rapor edilmiştir (Gürsu ve ark., 2024).

Bu çalışmaların ortak bulgularına göre, Pottiaceae ve Orthotrichaceae familyaları kent içi kampüs floralarının baskın gruplarını oluşturmaktadır. Bunun başlıca nedenleri, bu familyalara ait taksonların kurak, ışıklı ve besince fakir yüzeylere yüksek tolerans göstermesi ve antropojenik habitatlara uyum yetenekleridir (Plášek ve ark., 2015; Hodgetts ve ark., 2020).

Benzer şekilde Türkiye'nin İç Anadolu Bölgesi'nde yer alan Çankırı Karatekin Üniversitesi Uluyazı Kampüsü, yarı kurak (karasal) iklim koşullarına rağmen farklı mikrohabitat tiplerini (toprak, kaya, beton yüzeyler, binalar, dolgu alanları vb.) bir arada bulunduran geniş peyzaj alanlarıyla çalışılması gereken önemli bir kampüs ekosistemidir. Ancak, Uluyazı Kampüsü üzerine şu ana kadar briyofloristik bir araştırma yapılmamıştır. Bu nedenle, kampüste bulunan karayosunu taksonlarının belirlenmesi yalnızca yerel biyolojik çeşitliliğe katkı sağlamayacak; aynı zamanda kentsel ekosistemlerde briyofitlerin rolünün daha iyi anlaşılmasına ve gelecekte yapılacak ekolojik izleme çalışmalarına temel oluşturacaktır.

Bu çalışma, Çankırı Karatekin Üniversitesi Uluyazı Kampüsünün karayosunu florasını belirlemek, familya, cins ve takson zenginliğini ortaya koymak ve mevcut habitat kullanım özelliklerini değerlendirmek amacıyla gerçekleştirilmiştir.

1.1. Çalışma alanı

Bu çalışma, Çankırı Karatekin Üniversitesi Uluyazı Kampüsü sınırları içerisinde yürütülmüştür. Kampüs, İç Anadolu Bölgesi'nin Orta Kızılırmak Bölümünde yer almakta olup, Çankırı kent merkezinin kuzeybatısında konumlanmaktadır. Çalışma alanı yaklaşık olarak 881– 932 m yükselti aralığında değişmektedir. Kampüs alanı, toprak, kaya, beton, duvar yüzeyleri ve ağaç gövdeleri gibi farklı substrat ve mikrohabitat tiplerini bir arada bulundurması nedeniyle briyofitler için uygun çevresel koşullar sunmaktadır.

Arazi çalışma ve gözlemleri, kampüs içerisinde 11 farklı lokalitede gerçekleştirilmiş olup GPS koordinatları aşağıdaki gibidir (Tablo 1).

Tablo 1. Çalışma ananına ait lokalite bilgileri

Lokalite No:	Lokalite	Koordinat	Yükseklik (m)	Tarih
1	Mühendislik Fakültesi	K 40º 37' 14. 10" D 33º 37' 04. 57"	895	29.09.2024
2	Fen Fakültesi	K 40º 37' 12. 87" D 33º 37' 11. 04"	889	29.09.2024
3	Kütüphane	K 40º 37' 14. 87" D 33º 37' 16. 09"	904	17.10.2024
4	Halı Saha	K 40º 37' 16. 49" D 33º 37' 22. 31"	910	22.11.2024
5	Çedene Kafe, Bilgi İşlem Arası	K 40º 37' 19. 79" D 33º 37' 17. 12"	904	11.03.2025
6	Diş Hekimliği Yemekhane Arası	K 40º 37' 20. 41" D 33º 37' 08. 61"	898	07.04.2025
7	Şehitler Tepesi	K 40º 37' 06. 41" D 33º 37' 24. 09"	932	15.04.2025
8	Camii, Yurtlar Civarı	K 40º 37' 27. 25" D 33º 37' 04. 65"	910	28.04.2025
9	Sera Civarı	K 40º 37' 30. 27" D 33º 36' 54. 65"	895	29.04.2025
10	Rektörlük	K 40º 37' 20. 60" D 33º 36' 51. 68"	881	05.05.2025
11	Barbaros Kafe	K 40º 37' 10. 67" D 33º 37' 08. 69"	898	10.05.2025

Şekil 1. Uluyazı kampüsünde arazi çalışmalarının gerçekleştiği lokaliteler (Google Earth 2025)

Arazi, İç Anadolu'nun genel karakteristiğine uygun olarak yarı kurak karasal iklim etkisindedir. Yaz ayları sıcak ve kurak; kış ayları ise aşırı soğuk ve don olaylarının sık görüldüğü bir yapıya sahiptir. Bitki örtüsü, insan etkisi nedeniyle büyük ölçüde kültüre alınmış peyzaj bitkileri, çalı formasyonları ve çim alanlar ile temsil edilmektedir. Kampüs yerleşkesi, zemin formasyonu bakımından kısmen dolgu toprak, kısmen jipsli ve killi-tınlı ana kaya yüzeyi içermekte olup; beton yüzeyler, yaya yolları, kaya blokları, taş istinat ve duvarlar gibi antropojenik habitatlar baskın durumdadır. Bu durum, Pottiaceae ve Bryaceae gibi stres toleransı yüksek briyofitlerin yayılışı için uygun bir ortam oluşturmaktadır.

2. Materyal ve Metot

Uluyazı Kampüsü'nde briyofit örnekleri, kampüsün farklı mikrohabitat özelliklerini temsil edecek şekilde 11 lokaliteden toplanmıştır. Örneklemeler, iki farklı vejetasyon dönemini kapsayacak biçimde 2024 yılı sonbaharından, 2025 yılı ilkbahar dönemlerine kadar yapılmıştır. Örnekleme sırasında; her taksonun substrat tercihi, gölge-ışık koşulları ve habitat özellikleri kaydedilmiştir.

Substratlar aşağıdaki şekilde sınıflandırılmıştır: Toprak (T), Taş (Ta), Kaya (K), Duvar (D), Beton (B) ve Ağaç (A). GPS koordinatları ve yükseltiler Garmin el GPS cihazı ile belirlenmiş ve lokalite listesinde verilmiştir (Tablo 1). Bitki materyalleri, habitat yüzeyinden bir bıçak ve el yardımıyla alınmış, etiketlenerek kağıt zarflar içinde laboratuvara taşınmıştır. Karayosunu örneklerinin teşhislerinde; Leica EZ4 HD Stereo mikroskop ve Olympus BX50 Işık mikroskobunda incelenmiştir (Ursavaş ve Keçeli, 2021). Karayosunu örneklerinin teşhisinde çeşitli flora ve revizyon eserlerinden yararlanılmıştır (Hedenäs, 1992; Lewinsky, 1993; Zander, 1993; Smith, 2004; Plášek, ve ark., 2015; Lara ve ark., 2016). Bitki listelerinin hazırlanması sırasında, geçerli isim ve sinonimlik durumları ile sistematik düzenleme Hodgetts ve ark., (2020) ve WFO (2025 https://wfoplantlist.org) web sitesinden yararlanılmıştır. Floristik listedeki taksonlar alfabetik sıraya göre verilmiştir.

Karayosunu taksonlarının Türkiye'den ve Çankırı ilinden ilk kayıt durumları, mevcut güncel veri tabanı ve literatür ile çapraz kontrol edilmiştir: Türkiye genel kayıt güncellemeleri (Kürschner ve Erdağ, 2005; Özdemir ve Batan, 2017), Çankırı ili kontrol listesi (Abay ve Ursavaş, 2019) ve Çankırı Karatekin Üniversitesi, Orman Fakültesi Araştırma ve Uygulama Ormanının Karayosunu Florasına Katkılar (Ursavaş ve Tuttu, 2020) araştırılmaları taranarak elde edilmiştir. Tüm materyaller, Çankırı Karatekin Üniversitesi Orman Fakültesi, Orman Botaniği Laboratuvarı geçici koleksiyonunda muhafaza edilmektedir.

3. Bulgular

Bu çalışma sonucunda, Çankırı Karatekin Üniversitesi Uluyazı Kampüsü'nde 10 familya ve 26 cins ait 62 karayosunu taksonu tespit edilmiştir. Taksonların tamamı Bryophyta (karayosunları) bölümüne aittir. Ayrıca alandan ciğerotu (Marchantiophyta) taksonlarına ise rastlanmamıştır. Kampüs florasında en fazla türe sahip familya Pottiaceae olup çalışmada belirlenen taksonların %50'sini temsil etmektedir. Onu Bryaceae (%20) ve Brachytheciaceae (%11) familyaları izlemektedir.

Yapılan arazi çalışmaları (29.09.2024 - 10.05.2025 tarihleri arasında) sonucunda, toplamda 11 istasyon noktasından 244 adet karayosunu örneği toplanmıştır. 210 adet örneğin tamamının teşhisi yapılmıştır. 34 örneğin ise sporofit gibi bazı teşhis karakteristiklerinin olmaması sebebi ile teşhisleri yapılamamıştır.

3.1. Floristik liste

Çankırı Karatekin Üniversitesi, Uluyazı Kampüsünden tespit edilen karayosunları Tablo 2'de verilmiştir. L.N.: Lokalite Numarası, A: Ağaç, B: Beton, D: Duvar, T: Toprak, Ta: Taş, K: Kaya, Ç: Çankırı İli için yeni, T: Türkiye için yeni kayıt

Tablo 2. Karayosunu listesi, lokalite ve substrat bilgileri

No	Cins	Takson	L.N.	Substrat						Yeni Kayıt	
		Pottiaceae		A	B	D	T	Ta	K	Ç	T
1	*Barbula*	*Barbula unguiculata* Hedw.	2, 4, 5, 6, 8, 9, 10		+	+	+				
2	*Didymodon*	*Didymodon acutus* (Brid.) K.Saito	9,					+			
3		**D. rigidulus* Hedw.	9,				+			*	
4		*D. tophaceus (*Brid.*) Lisa*	4,					+			
5		*Didymodon vinealis* (Brid.) R.H.Zander	10,			+					
6		*D. nicholsonii* Culm.	4, 10,			+		+			

7	*Geheebia*	**Geheebia lurida* (Hornsch. ex Spreng.) J.A.Jiménez & M.J.Cano	9,			+				*	
8	*Ptychostomum*	**Ptychostomum cernuum* (Hedw.) Hornsch.	5,			+				*	
9	*Pterygoneurum*	*Pterygoneurum ovatum* (Hedw.) Dixon	2, 3, 5, 6, 7, 9,				+	+	+		
10		**Pterygoneurum lamellatum* (Lindb.) Jur.	3, 5, 7,				+	+		*	
11		*Pterygoneurum subsessile* (Brid.) Jur.	2, 3,				+		+		
12	*Syntrichia*	*Syntrichia caninervis* var. *caninervis* Mitt.	1, 3, 6, 8,			+	+	+			
13		*Syntrichia caninervis* var. *gypsophila* (J.J.Amann ex G.Roth) Ochyra	3, 6, 8,				+	+			
14		*Syntrichia ruralis* var. *ruralis* (Hedw.) F.Weber & D.Mohr,	1, 5,			+	+				
15		*Syntrichia ruralis* var. *ruraliformis* (Besch.) Delogne	4, 6, 8, 9,				+				
16		*Syntrichia latifolia* (Bruch ex Hartm.) Huebener	8,				+				
17		**Syntrichia sinensis* (Müll.Hal.) Ochyra	9,				+			*	
18	*Streblotrichum*	*Streblotrichum convolutum* (Hedw.) P.Beauv.	2, 8, 9,			+	+				
19	*Tortella*	*Tortella inclinata* (R.Hedw.) Limpr. (Syn: *Tortula inclinata* R.Hedw.)	3,					+			
20	*Tortula*	**Tortula acaulon* (With.) R.H.Zander	4,					+		*	
21		***Tortula bolanderi* (Lesq.) M.Howe	1,		+					*	**
22		*Tortula brevissima* Schiffn.	3, 4,					+	+		
23		*Tortula muralis* subsp. *muralis* Hedw.	1, 2, 3, 4, 5, 7, 8, 9,			+	+	+	+		
24		*Tortula muralis* subsp. *muralis* var. *aestiva* Brid. ex Hedw.	4,					+			
25		*Tortula subulata* Hedw.	1, 4, 5, 6, 8, 11,			+	+	+			
26		*Tortula inermis* (Brid.) Mont.	1, 2, 3, 4, 5, 6, 8, 9,			+	+	+	+		
27		*Tortula caucasica* Lindb.	6,				+				
28		**Tortula lingulata* Lindb.	6,				+			*	
29		*Tortula revolvens* (Schimp.) G.Roth	9,				+				
30	*Trichostomum*	*Trichostomum brachydontium* Bruch	3, 4,				+				
31	*Weissia*	**Weissia rutilans* (Hedw.) Lindb.	4,					+		*	
		Ditrichaceae									
32	*Ceratodon*	*Ceratodon conicus* (Hampe ex Müll.Hal.) Lindb.	6				+				
		Funariaceae									
33	*Funaria*	*Funaria hygrometrica* Hedw.	1, 3, 6, 9,		+	+	+	+			
		Bryaceae									
34	*Bryum*	*Bryum argenteum* Hedw.	1, 2, 3, 6, 8,		+	+	+				
35		* *B. radiculosum* Brid.	3, 6,		+		+			*	
36		*B. dichotomum* Hedw.	1, 2, 3, 8,			+	+	+			
37	*Imbribryum*	*Imbribryum mildeanum* (Jur.) J.R.Spence	8,				+				
38	*Ptychostomum*	*Ptychostomum pallens* (Sw.) J.R.Spence	5, 6, 9, 10,		+		+				
39		*Ptychostomum pallescens* (Schleich. ex Schwägr.) J.R.Spence	10,				+	+			

40		*Ptychostomum imbricatulum* (Müll.Hal.) Holyoak & N.Pedersen	2, 3, 10,		+		+	+	+		
41		**Ptychostomum inclinatum* (Sw. ex Brid.) J.R.Spence	1, 3,			+		+		*	
42		*Ptychostomum creberrimum* (Taylor) J.R.Spence & H.P.Ramsay	2, 3, 11,				+	+			
43		*Ptychostomum pseudotriquetrum* (Hedw.) J.R.Spence & H.P.Ramsay	6,				+				
44		* *Ptychostomum inclinatum* (Sw. ex Brid.) J.R.Spence	8, 10, 11,			+	+			*	
45		*Ptychostomum capillare (*Hedw.) Holyoak & N.Pedersen,	1, 3, 4, 5, 6, 8, 9, 10,		+	+	+	+	+		
		Grimmiaceae									
46	*Grimmia*	*Grimmia trichophylla* Grev.	1, 2, 3, 4, 6,		+	+	+	+	+		
47		*Grimmia pulvinata* (Hedw.) Sm.	4, 8,					+			
48		*Grimmia orbicularis* Bruch ex Wilson	4,					+			
49	*Schistidium*	*Schistidium apocarpum* (Hedw.) Bruch & Schimp.	1, 4, 8,					+	+		
50		*Schistidium trichodon* (Brid.) Poelt	1			+					
		Amblystegiaceae									
51	*Amblystegium*	*Amblystegium serpens* (Hedw.) Schimp.	1, 2, 4, 10, 11,	+			+	+			
52	*Leptodictyum*	*Leptodictyum riparium* (Hedw.) Warnst.	2, 4, 10,				+	+	+		
		Brachytheciaceae									
53	*Brachythecium*	*Brachythecium erythrorrhizon* Schimp.	4, 10, 11,			+	+	+			
54		*Brachythecium rutabulum* (Hedw.) Schimp.	1, 2, 10,				+				
55		*Brachythecium mildeanum* (Schimp.) Schimp. ex Milde	2, 3,				+				
56		*Brachythecium glareosum* (Bruch & Schimp. ex Fiedl.) Schimp.	1,				+				
57		*Brachythecium salebrosum* (Hoffm. ex F.Weber & D.Mohr) Schimp.	2,				+				
58	*Brachytheciastrum*	*Brachytheciastrum velutinum* (Hedw.) Ignatov & Huttunen	1, 4,				+	+			
59	*Homalothecium*	*Homalothecium lutescens* (Hedw.) H.Rob.	1,				+				
		Entodontaceae									
60	*Entodon*	**Entodon concinnus* (De Not.) Paris	10,				+			*	
		Mniaceae									
61	*Plagiomnium*	*Plagiomnium affine* (Blandow) T.J.Kop.	2,				+				
		Orthotrichaceae									
62	*Orthotrichum*	*Orthotrichum urnigerum* Myrin	3,					+			

3.2. Sinonim listesi

Aşağıda Uluyazı Kampüsü'nde belirlenen bazı türlerin sinonimleri verilmiştir:

- *Didymodon luridus* Hornsch. ex Spreng.) J.A.Jiménez & M.J.Cano
  Syn.: *Vinealobryum luridum* (Hornsch.) R.H.Zander
- *Didymodon tophaceus* (Brid.)
  Syn.: Lisa *Geheebia tophacea* (Brid.) R.H.Zander
- *Streblotrichum convolutum* (Hedw.) P.Beauv.
  Syn.: *Barbula convoluta* Hedw.
- *Didymodon vinealis* (Brid.) R.H.Zander
  Syn.: *Vinealobryum vineale* (Brid.) R.H.Zander
- *Didymodon nicholsonii* Culm.
  Syn.: *Vinealobryum nicholsonii* (Culm.) R.H.Zander
- *Bryum dichotomum* Hedw.

Syn.: *Gemmabryum dichotomum* (Hedw.) J.R.Spence & H.P.Ramsay

- *Ptychostomum imbricatulum* (Müll.Hal.) Holyoak & N.Pedersen

Syn.: *Bryum caespiticium* Hedw.; *Bryum badium* (Brid.) Bruch ex Milde

4. Tartışma ve Sonuç

Bu çalışma, Çankırı Karatekin Üniversitesi Uluyazı Kampüsü'nde 10 familya, 26 cins ve 62 karayosunu taksonunu tespit edilmiş olup, İç Anadolu'nun yarı kurak bir bölgesinde kentsel habitatların briyofit çeşitliliği açısından barındırdığı potansiyeli gözler önüne sermektedir. Elde edilen tür sayısı, benzer kentsel alanlarda yapılan diğer kampüs floraları ile karşılaştırıldığında dikkate değer düzeydedir (Tablo 3).

Familyaların takson yoğunluğu: *Amblystegium serpens, Barbula unguiculata*, *Bryum argenteum*, *Grimmia trichophylla, Pterygoneurum ovatum*, *Ptychostomum pallens*, *Syntrichia caninervis*, *Syntrichia ruralis, Tortula muralis*, *Tortula inermis,* kampüsün yaygın türleri olup, 5 ten fazla lokalitede bulunmuşlardır. Ayrıca bu türler, kentleşme göstergesi taksonlar olarak değerlendirilebilir.

Benzer kampüs florası çalışmalarının karşılaştırılması, bazı familyaların yalnızca belirli bölgelerde sınırlı kaldığını göstermektedir. Örneğin, Phymatocerotaceae familyasından bir takson yalnızca Fırat Üniversitesi Merkez Kampüsü'nde, Bartramiaceae familyasından üç takson ise sadece Recep Tayyip Erdoğan Üniversitesi Zihni Derin Kampüsü'nde rapor edilmiştir. Ayrıca, Hylocomiaceae familyasından bir takson yalnızca Zonguldak Karaelmas Üniversitesi Merkez Kampüsü'nden, Leucodontaceae ve Cinclidiaceae familyalarına ait birer takson ise yalnızca Karadeniz Teknik Üniversitesi Kanuni Kampüsü'nden bildirilmiştir. Bu durum, kampüslerin coğrafi konumları, iklimsel farklılıkları ve habitat çeşitliliklerinin, özellikle nadir veya ekolojik toleransı dar briyofit taksonlarının dağılımında belirleyici rol oynadığını göstermektedir. Uluyazı Kampüsü florasında bu familyalara ait herhangi bir türe rastlanmamış olması, bölgenin yarı kurak iklim koşulları, sınırlı nem rejimi ve yüksek antropojenik baskı ile ilişkilendirilebilir. Buna karşın, kampüsün sahip olduğu yüksek Pottiaceae ve Bryaceae çeşitliliği, kuraklık toleransı yüksek türlerin baskınlığını ve kentsel ortamlarda bile briyofitlerin yaşam stratejilerini sürdürebilme yeteneklerini ortaya koymaktadır.

Table 2. Uluyazı kampüsü ile Türkiye'deki diğer kampüslerde yapılan bazı karayosunu florası çalışmalarının karşılaştırılması

Article	**Çankırı Karatekin Üniveristesi Uluyazı Kampüsü (Çizgen Tan and Ursavaş, 2025)**		**Fırat Üniversitesi Merkez Kampüsü Karayosunu Florası (Alataş et al., 2024)**		**Maltepe Universitesi Merkez Kampüsü (Gürsu et al., 2024)**		**Ankara Universitesi Beşevler 10. Yıl Kampüsü (Ezer et al., 2021)**		**Recep Tayyip Erdoğan Universitesi, Zihni Derin Kampüsü (Abay, 2018)**		**Karadeniz Technik Universitesi Kanuni Kampüsü (Erata et al., 2017)**		**Zonguldak Karaelmas Universitesi Merkez Kampüsü (Alataş et al., 2011)**	
Toplam Takson Sayısı	**62**		**37**		**42**		**28**		**53**		**94**		**51**	
Families	T.S.	%	T.S.	%	T.S.	%	T.S.	%	T.S.	%	T.S.	%	T.S.	%
Pottiaceae	31	50	16	43	7	17	9	32	12	23	16	17	12	23,6
Bryaceae	12	20	6	16	5	12	3	11	5	9,4	10	11	5	10
Brachytheciaceae	7	11	1	3	13	31	5	18	13	25	21	23	15	29,5
Grimmiaceae	5	8,5	3	8	4	9,5	2	7,1	-	-	12	13	2	4
Amblystegiaceae	2	3	4	11	1	2,3	2	7,1	1	1,8	4	4,2	1	1,9
Orthotrichaceae	1	1,5	5	13	3	7,1	6	21,3	2	3,7	3	3,2	4	7,8
Funariaceae	1	1,5	-	-	1	2,3	1	3,5	1	1,8	1	1	1	1,9
Ditrichaceae	1	1,5	-	-	1	2,3	-	-	2	3,7	2	2,2	-	-
Mniaceae	1	1,5	1	3	-	-	-	-	-		6	6,3	3	5,8
Entodontaceae	1	1,5	-	-	-	-	-	-	-		2	2,2	-	-
Fissidentaceae	-	-	-	-	1	2,3	-	-	1	1,8	2	2,2	3	5,8
Hypnaceae	-	-	-	-	6	14,2	-	-	4	7,4	6	6,3	2	4
Thuidiaceae	-	-	-	-	-	-	-	-	-		2	2,2	-	-
Dicranaceae	-	-	-	-	-	-	-	-	3	5,6	2	2,2	1	1,9
Cinclidiaceae	-	-	-	-	-	-	-	-	-		1	1	-	-
Rhabdoweisiaceae	-	-	-	-	-	-	-	-	1	1,8	1	1	-	-
Polytrichaceae	-	-	-	-	-	-	-	-	5	9,4	1	1	1	1,9
Leucodontaceae	-	-	-	-	-	-	-	-	-		1	1	-	-
Bartramiaceae	-	-	-	-	-	-	-	-	3	5,6	-	-	-	-
Hylocomiaceae	-	-	-	-	-	-	-	-	-	-	-	-	1	1,9
Phymatocerotaceae	-	-	1	3		-	-	-	-	-	-	-	-	-
		100				100		100		100		100		100

T.S: Takson Sayısı

Türkiye'deki kampüs florası çalışmaları incelendiğinde; Zonguldak Karaelmas Üniversitesi Merkez Kampüsü'nde 53 tür (Alataş ve ark., 2011), Karadeniz Teknik Üniversitesi Kanuni Kampüsü'nde 94 tür (Erata ve ark., 2017), Recep Tayyip Erdoğan Üniversitesi Zihni Derin Kampüsü'nde 57 tür (Abay, 2018), Ankara Üniversitesi Beşevler Kampüsü'nde 28 tür (Ezer ve ark., 2021), Maltepe Üniversitesi Merkez Kampüsü'nde 42 tür (Gürsu ve ark., 2024) ve Fırat Üniversitesi Merkez Kampüsü'nde 37 tür (Alataş ve ark., 2024) rapor edilmiştir. Uluyazı Kampüsü'nde tespit edilen 62 takson, bu değerlerin ortalamasının üzerinde olup, karasal iklime sahip bir kent kampüsü için yüksek bir çeşitlilik düzeyi temsil etmektedir.

Çalışmada en fazla türe sahip familya olan Pottiaceae (%50), kentleşmiş ve yarı kurak ortamlarda baskınlık gösteren bir gruptur. Bu familyaya ait *Tortula*, *Syntrichia* ve *Didymodon* cinslerinin geniş ekolojik toleransları, antropojenik alanlardaki başarısını açıklamaktadır (Plášek ve ark., 2015; Hodgetts ve ark., 2020). Benzer şekilde, Bryaceae ve Brachytheciaceae familyalarının varlığı, habitat neminin nispeten korunduğu mikro alanlarda briyofitlerin yaşamını sürdürebildiğini göstermektedir.

Substrat analizleri, Uluyazı Kampüsü'ndeki türlerin çoğunun toprak (%85) ve kaya/taş (%66) üzerinde geliştiğini, bunu beton ve duvar yüzeylerinin izlediğini ortaya koymuştur. Bu durum, karayosunlarının kentsel yüzeylere uyum sağlama yeteneğini ve özellikle epilitik (kaya) ve epigeik (toprak) taksonların baskınlığını göstermektedir (Sabovljević ve Grdović, 2009; Glime, 2017).

Bu çalışma ile Çankırı ili için 13 yeni karayosunu kaydı ve Türkiye için 1 yeni kayıt (*Tortula bolanderi* (Lesq.) M.Howe) belirlenmiştir. *T. bolanderi,* uluslararası Plant Biosystems isimli dergiden kabul almış fakat henüz yayınlanmamıştır. Bu taksonun Türkiye'den ilk kez rapor edilmesi, çalışmanın ulusal düzeydeki floristik önemini artırmaktadır. Bu tür daha önce Kuzey Amerika ve Batı Akdeniz'de yayılış göstermekte olup (Zander, 1993; Ros ve ark., 2008), yarı kurak İç Anadolu koşullarında tespit edilmesi, türün geniş ekolojik plastisitesini işaret etmektedir.

Çankırı ili için yeni kaydedilen taksonların büyük çoğunluğu Pottiaceae ve Bryaceae familyalarına aittir. Bu durum, bölgenin kurak iklim karakteristiği ile uyumlu bir sonuçtur. *Syntrichia sinensis*, *Pterygoneurum lamellatum*, *Gemmabryum dichotomum* ve *Weissia rutilans* gibi türler, tolerans sınırları geniş, genellikle yüksek ışıklı alanları tercih eden taksonlardır. Dolayısıyla bu çalışma, Çankırı ilinin bryofit çeşitliliğini %5 oranında artırarak bölgesel floraya önemli bir katkı sağlamıştır.

Kampüs Floralarının Karşılaştırmalı Değerlendirmesi:

Karşılaştırmalı analizler göstermektedir ki, Uluyazı Kampüsü'nün tür zenginliği (62 tür), Fırat (37 tür), Maltepe (42 tür) ve Ankara Üniversitesi Beşevler (28 tür) kampüslerine göre daha yüksektir, ancak Karadeniz Teknik Üniversitesi (94 tür) florasından düşüktür. Bu fark, iklimsel nem farklılığı ve Karadeniz ikliminin sürekli nem sağlayan koşullarına bağlanabilir. Yarı kurak Çankırı iklim koşullarında ulaşılan bu çeşitlilik, habitat mikroheterojenitesinin önemini vurgulamaktadır. Ayrıca, Uluyazı Kampüsü'nde belirlenen türlerin çoğu kentleşme göstergesi (urban-tolerant) taksonlardır. *Tortula muralis*, *Bryum argenteum* ve *Syntrichia caninervis* gibi yaygın türlerin varlığı, kentsel yüzeylerde briyofitlerin çevresel streslere adaptasyon başarısını desteklemektedir (Abay, 2018; Ezer ve ark., 2021).

Ekolojik ve Koruma Açısından Değerlendirme:

Uluyazı Kampüsü, beton yüzeyler, kaya duvarlar ve dolgu alanları gibi antropojenik baskı altındaki mikrohabitatları ile tipik bir kentsel ekosistem örneğidir. Buna karşın, çalışmada saptanan yüksek tür çeşitliliği, kampüs alanlarının mikrorefugium özelliğini desteklemektedir. Bu alanlar, kentsel biyolojik çeşitliliğin sürdürülmesi için potansiyel koruma çekirdekleri işlevi görebilir (Alataş ve ark., 2024; Gürsu ve ark., 2024).

Bu araştırma ile:

1. Uluyazı Kampüsü'nün karayosunu florası ilk kez ortaya konulmuştur.
2. Çankırı için 13, Türkiye için 1 yeni kayıt belirlenmiştir.
3. Kampüs florasında Pottiaceae familyasının baskınlığı, yarı kurak iklim koşullarına adaptasyonun güçlü bir göstergesidir.
4. Bulgular, kentsel alanların briyofitler için önemli mikrohabitat çeşitliliği barındırdığını ve bu alanların korunmasının gerekliliğini ortaya koymaktadır.

Bu çalışma, gelecekte yapılacak biyocoğrafik, ekolojik ve izleme temelli araştırmalara temel oluşturmakla birlikte, Çankırı ilinin briyofloristik veritabanına önemli bir katkı sunmaktadır.

Deklarasyon

Yazar katkıları

Fikir/Kavram, SÇT, SU; Tasarım ve dizayn, SÇT, SU; Denetleme danışmanlık, SÇT, SU; Kaynaklar, SÇT, SU; Malzemeler, SÇT, SU; Ver toplama ve/veya İşleme, SÇT, SU; Analiz ve/veya yorum, SÇT, SU; Literatür taraması, SÇT, SU; Yazım aşaması, SÇT, SU; Eleştirel inceleme, SÇT, SU.

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The Bryophyte Flora of Demirkapı Plateau Glacial Lakes (Çaykara, Trabzon) and Its Surroundings

Zeynep Gizem KÖROĞLU[1], Hüseyin ERATA[2], Nevzat BATAN[3,*]

[1]Karadeniz Technical University, Graduate School of Natural and Applied Sciences, 61080, Trabzon, TÜRKIYE
[2] Gümüşhane University, Kürtün Vocational School, Gümüşhane, 29830 TÜRKIYE
[3] Karadeniz Technical University, Faculty of Science, Department of Molecular Biology and Genetics, 61080, Trabzon, TÜRKIYE

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Abstract

In this study, the moss flora of Demirkapı Plateau Glacial Lakes and its surroundings in the Çaykara region of Trabzon were investigated. Bryofloristic study was conducted at 24 different localities during various vegetation periods between 2024 and 2025, and a total of 1060 bryophyte specimens were collected. As a result of the identification of bryophyte specimens 291 bryophyte taxa (244 taxa mosses, 46 taxa liverworts, and 1 taxon hornworts) were identified from the study area. Among the results, *Lophozia silvicola*, *Andreaea alpestris*, *Andreaea mutabilis*, *Niphotrichum canescens* subsp. *latifolium* and *Sphagnum russowii* were recorded for the second time in the bryophyte flora of Türkiye. Furthermore, 43 bryophyte taxa are new for Trabzon Province and 119 bryophyte taxa are new for Çaykara District. Distribution and habitat information is provided for each identified bryophyte taxon.

Keywords: Bryophyte, Çaykara, Glacial lakes, Trabzon, Türkiye

Demirkapı Yaylası (Çaykara, Trabzon) Buzul Gölleri ve Çevresi Briyofit Florası

Öz

Bu çalışmada, Trabzon'un Çaykara bölgesindeki Demirkapı Yaylası Buzul Gölleri ve çevresi araştırılmıştır. Çalışma, 2024-2025 yılları arasında 24 farklı istasyondan vejetasyon farklı periyotlarında arazi çalışması yapılmış ve toplam 1060 briyofit örneği toplanmıştır. Yapılan teşhisler sonucunda çalışma sahasından 291 (244 takson yapraklı karayosunu, 46 takson ciğerotları ve 1 takson boynuzsu ot) briyofit taksonu tespit edilmiştir. Elde edilen sonuçlar arasında *Lophozia silvicola*, *Andreaea alpestris*, *Andreaea mutabilis*, *Niphotrichum canescens* subsp. *latifolium* ve *Sphagnum russowii* Türkiye briyofit florası için ikinci kez kaydedilmiştir. Ayrıca, 43 briyofit taksonu Trabzon ili için ve 119 briyofit takson Çaykara ilçesi için yenidir. Teşhis edilen her bir briyofit taksonu için dağılım ve habitat bilgisi verilmiştir.

Anahtar kelimeler: Briyofit, Çaykara, Buzul Göller, Trabzon, Türkiye

* Corresponding author: nevzatbatan@gmail.com

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1. Introduction

Demirkapı Plateau, determined as the research area, is located on the southwestern slopes of the Haldizen Mountains within the borders of the Çaykara district of Trabzon (Figure 1). The Demirkapı Plateau is located approximately 15 km south of the Uzungöl Nature Park. These mountains constitute the second highest topographic structure after the Kaçkar Mountains, which represent the characteristic high-altitude mountain range of the Eastern Black Sea Region. Haldizen mountains are surrounded by the Uzungöl Basin to the north, the high plateaus of Bayburt to the south, the Çaykara Plain and İkizdere Valley to the west, and the mountainous areas of Gümüşhane to the east (URL-1).

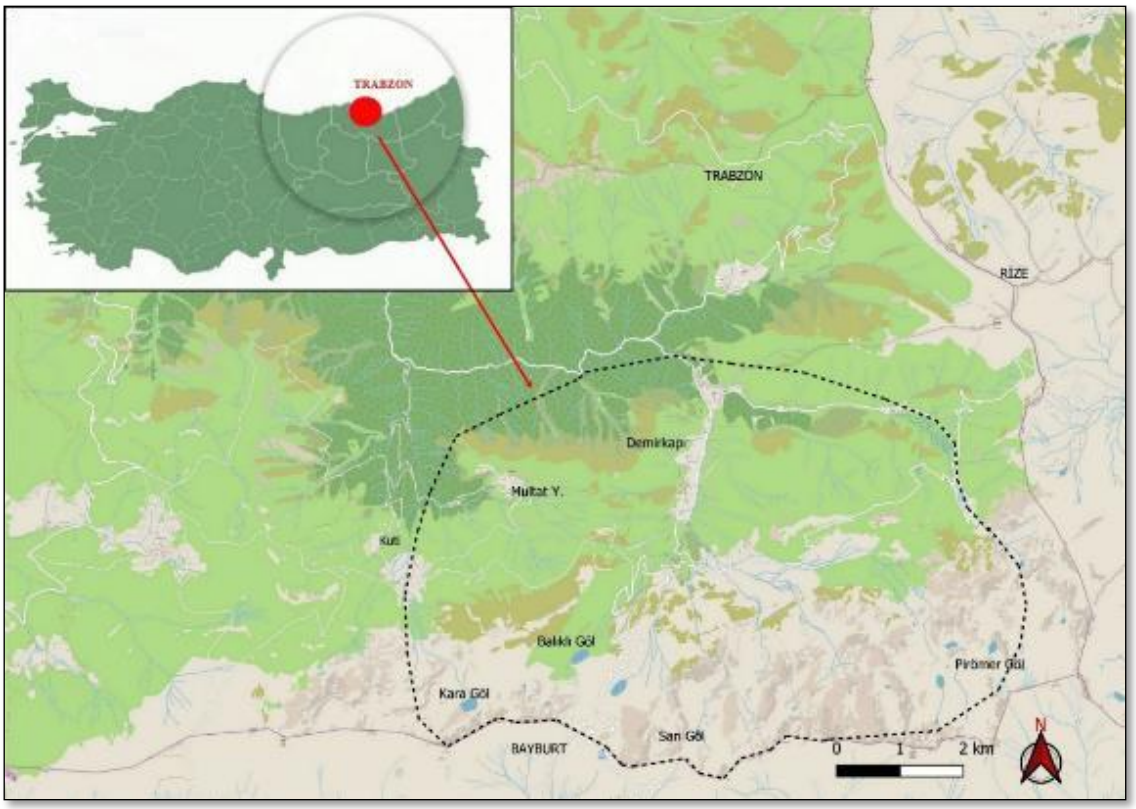

Figure 1. The study area.

In the Demirkapı Plateau, broadleaf and mixed forests dominate, in harmony with the humid climate of the Black Sea. *Fagus orientalis* L. is found around the Haldızen Stream on the Demirkapı Plateau, whereas beech trees form mixed forests further up. Due to the effect of altitude, *Picea orientalis* (L.) Link. began to appear densely. After the upper limit of the *P. orientalis* forests, *Betula pubescens* Ehrh. trees begin in the forest upper zone, which represents the transition from the spruce forests to the alpine (treeless) zone. Around 1800-2000 meters, the tree line forms and the subalpine zone begins; dwarf shrubs and herbaceous plants predominate in this zone. The alpine zone dominates at 2000 m and above. Above the forest line, dense shrubs of *Rhododendron caucasicum* Pall. are common, along with meadows. Steep cliffs and high-altitude lakes are found at the summits. This zone is dominated by short-growing herbaceous plants that are adapted to harsh climatic conditions. Alpine meadows and forest-top vegetation generally predominate around the plateau (İnkaya, 2019).

The Haldizen Mountains contain numerous glacial lakes formed by the melting of glaciers at higher elevations. In addition to, lakes such as Aygır Lake, Balıklı Lake, Karagöl Lake, and Sarı Lake, this area contains numerous glacial lakes of various sizes, ranging from 100 to 1900 m. These lakes are generally located at altitudes of 2500 m and above, and high-mountain ecosystems encompassing subalpine and alpine zones have developed around them. Vegetation in these ecosystems is sparse and dominated by species resistant to cold climate conditions; herbaceous and dwarf plants, such as *Vaccinium* spp., dwarf shrubs, and alpine pastures, form the main components. (İnkaya, 2019).

The average annual rainfall in the research area is 1104 mm, and the average annual temperature is 7.07 °C. (Mbm, 2025).

2. Materials and Methods

The bryophytes samples were collected in 24 different localities between 05 July 2024 and 28 June 2025 from Demirkapı Plateau and its surroundings in Çaykara from Türkiye (Table 1). The collected bryophyte specimens were identified by consulting various floras and keys (Nyholm, 1986, 1989, 1993, 1998; Paton, 1999; Smith, 1996, 2004; Cortini-Pedrotti 2001, 2006; Guerra et al., 2006; Frey et al., 2006; Brugués et al., 2007; Casas et al., 2009; Brugués and Guerra, 2015; Lüth, 2019; Kürschner and Frey, 2020). Hodgetts et al. (2020) was followed in the creation of the plant list and for the nomenclatural changes and synonyms of bryophytes. The status of bryophyte taxa for Trabzon Province was evaluated by reviewing the relevant literature (Batan and Özdemir, 2013; Özdemir and Batan, 2017; Erata et al., 2018, 2020a, 2020b, 2022; Kırmacı et al., 2019; Yıldırım et al., 2025). The localities and substrates from which each taxon was collected are provided in the floristic list. Taxa recorded for the second time for Turkey are indicated with (+), taxa new to Trabzon province are indicated with (*), and taxa new to Çaykara district are indicated with (#). In the floristic list, the families to which the taxa belong, along with their valid Latin names and authors, are listed in alphabetical order. Additionally, the collection location, habitat, altitude, coordinates, and collection date for each taxon are also given.

Bryophyte samples are deposited in the private herbarium at the Karadeniz Technical University, Trabzon, Türkiye.

Table 1. Localities of bryophyte samples collected

No	Locality	Coordinates	Altitude (m)	Date
1	Çaykara, Demirkapı village Aygır lake, Uzungöl	(37T) 4487448 N/ 0617789 E	2728	5.07.2024
2	Çaykara, Demirözü Köyü, Balıklı lake	(37T) 4487930 N/ 0617556 E	2570	5.07.2024
3	Çaykara, on the Multat Plateau road, stream	(37T) 4490404 N/ 0614214 E	1835	20.07.2024
4	Çaykara, On the Multat Plateau Road, 4 (Alpine Meadow, Streamside)	(37T) 4489395 N / 0613957 E	2170	20.07.2024
5	Çaykara, Balıklı göl and ıts surroundings	(37T) 4487563 N / 0616981 E	2590	20.07.2024
6	Çaykara, Balıklı göl Snow Cover, Snow Peak	(37T)4469726 N / 0629403 E	2886	20.07.2024
7	Çaykara, Between Multat and Haldızen 1	(37T) 4489706 N / 0617508 E	2651	21.07.2024
8	Çaykara, Between Multat and Haldızen 2	(37T) 4489347 N / 0617350 E	2700	21.07.2024
9	Çaykara, Multat Yaylası on the Karagöl road 1	(37T) 4487894 N / 0614829 E	2458	21.07.2024
10	Çaykara, Karagöl	(37T)4487450 N / 0615273 E	2800	22.07.2024
11	Çaykara, Multat Plateau Village	(37T) 4489000 N / 0615200 E	2306	22.07.2024
12	Çaykara, Multat Plateau 1 (Alpine Meadow)	(37T) 4489250 N / 0615400 E	2230	22.07.2024
13	Çaykara, Multat Plateau 1-2	(37T) 4488482 N / 0614556 E	2281	22.07.2024
14	Çaykara, Demirkapı Neighborhood Entrance Küksen Area	(37T) 4490156 N / 0618487 E	2208	25.08.2024
15	Çaykara, Demirkapı Neighborhood, Lake Surroundings, Above Aygır Lake 1	(37T) 4487162 N / 0617550 E	2752	25.08.2024
16	Çaykara, Multat Plateau 3-4	(37T)4490199 N / 0616343 E	2253	11.06.2025
17	Çaykara, Karagöl 1	(37T) 4487150 N / 0615701 E	2857	11.06.2025
18	Çaykara, Between Karagöl and Balıklı Lake, Kaz Lake,	(37T) 4487328 N / 0616281 E	2700	11.06.2025
19	Çaykara, Demirkapı Exit Rocky Area	(37T) 4489056 N / 0619004 E	2300	11.06.2025
20	Çaykara, on the Sarıçiçek Lake Road, Small Lake	(37T) 4487002 N / 0618500 E	2725	26.05.2025
21	Çaykara, Above Aygır Lake, Bayburt Border	(37T) 4486173 N / 0617796 E	3018	26.05.2025
22	Çaykara, On the road to Sarıçiçek Lake, Below Küçük Lake	(37T) 4474420 N / 0629498 E	2784	26.05.2025
23	Çaykara, Büyük Plateau 1	(37T) 4489025 N /0620481 E	2393	27.06.2025
24	Çaykara, Multat Plateau Kırklar road	(37T) 4489672 N / 0612120 E	2546	28.06.2025

3. Results and Discussion

As a result of the evaluation of bryophyte samples collected from the study area, a total of 291 bryophyte taxa were identified, including 244 moss taxa (97 genera and 46 families), 46 liverwort taxa (29 genera and 21 families) and 1 hornwort taxon (1 genus and 1 family).

3.1. Bryoflorostic list

Anthocerotophyta
Anthocerotaceae Dumort.
Anthoceros L.
#Anthoceros punctatus L.
Loc.: 1; on wet soil.
Marchantiophyta
Adelanthaceae Grolle
Syzygiella Spruce
**Syzygiella autumnalis* (DC.) K.Feldberg, Váňa, Hentschel&Heinrichs,
Loc.: 1; on soil.
Anastrophyllaceae L.Söderstr., De Roo & Hedd.
Barbilophozia Loeske.
Barbilophozia barbata (Schmidel ex Schreb.) Loeske
Loc.: 4, 10, 12, 15, 19; on soil, on wet soil
Barbilophozia hatcheri (A.Evans) Loeske
Loc.: 8, 9, 12,13, 16, 19; on wet soil, on soil
**Barbilophozia lycopodioides* Wallr.) Loeske
Loc.: 12, 13; on wet soil.
#Barbilophozia sudetica (Nees ex Huebener) L.Söderstr., De Roo&Hedd.
Loc.: 12, 13; on soil, on rock.
Sphenolobus (Lindb.) Berggr.
Sphenolobus minutus (Schreb. ex D. Crantz) Berggr
Loc.: 1, 10; on wet soil, on soil, on rock
Cephaloziaceae Mig.
Cephalozia (Dumort.) Dumort.
Cephalozia bicuspidata (L.) Dumort.
Loc.: 1, 2; on wet soil
Fuscocephaloziopsis Fulford [PleurocladulaGrolle]
**Fuscocephaloziopsis lunulifolia* (Dumort.) Váňa&L.Söderstr.,
Loc.: 1; on soil
**Fuscocephaloziopsis pleniceps* (Austin) Váňa&L.Söderstr
Loc.: 9; on wet soil
Cephaloziellaceae Douin
Cephaloziella (Spruce) Schiffn. [Dichiton Mont.
**Cephaloziella baumgartneri* Schiffn
Loc.: 22; on soil.
C. divaricata (Sm.) Schiffn.
Loc.: 1, 2; on wet soil, on soil, on rock.
Lophoziaceae Cavers
Lophozia (Dumort.) Dumort.
Lophozia longiflora (Nees) Schiffn
Loc.: 1, 12, 13; On a dead tree trunk, on soil
+*Lophozia silvicola* H.Buch,
Loc.: 1; On wet soil
L. ventricosa (Dicks.) Dumort
Loc.: 6, 12, 13on soil
Trilophozia (R.M.Schust.) Bakalin
Trilophozia quinquedentata (Huds.) Bakalin,
Loc.: 10, 16; on wet soil
Scapaniaceae Mig
Diplophyllum (Dumort.) Dumort.
#Diplophyllum taxifolium(Wahlenb.) Dumort.
Loc.: 2, 6, 8, 10, 12, 13, 15, 16; on soil,
Scapania (Dumort.) Dumort.
#Scapania compacta (Roth) Dumort.
Loc.:1, On wet soil
S.irrigua (Nees) Nees
Loc.: 1, 2, 10, 12, 13; On wet soil
**S.uliginosa* (Lindenb.) Dumort.
Loc.: 1; on soil
#S. subalpina (Nees ex Lindenb.) Dumort
Loc.: 1, 2, 10; On wet soil
S.undulata (L.) Dumort
Loc.: 1, 10; On wet soil,
Gymnomitriaceae H.Klinggr
Gymnomitrion Corda [Apomarsupella R.M.Schust.]
Gymnomitrion obtusum Lindb
Loc.: 6; on soil
Marsupella Dumort.
Marsupella funckii (F.Weber&D.Mohr) Dumort
Loc.: 12, 13; On rock, on wet rock, on soil, on wet soil.
Nardia Gray.
Nardia scalaris Gray
Loc.: 6; on soil,
Liochlaena Nees
Liochlaena lanceolata Nees [*Jungermannia lanceolata* auct. non L., *Jungermannia leiantha* Grolle, *Jungermannia subulata* var. *leiantha* (Grolle) Damsh.]
Loc.: 1; on soil
Jungermanniaceae Rchb.
Jungermannia L.
**Jungermannia eucordifolia* Schljakov
Loc.: 1; on soil
Solenostomataceae Stotler&Crand.-Stotl.
Solenostoma Mitt. [Plectocolea (Mitt.) Mitt.
#Solenostoma gracillimum (Sm.) R.M.Schust
Loc.: 1, 2; on soil,
S. hyalinum (Lyell)Mitt
Loc.: 1, 2, 10; on wet soil
S. sphaerocarpum (Hook.) Steph.
Loc.: 1, 2, 22; on wet soil,
Blepharostomataceae W.Frey&M.Stech
Blepharostoma (Dumort.) Dumort.
Blepharostoma trichophyllum (L.) Dumort
Loc.: 1; on wet soil
Lophocoleaceae Vanden Berghen
Chiloscyphus Corda.
Chiloscyphus pallescens (Ehrh.) Dumort

Loc.: 4, 11, 19; on soil
C. polyanthos (L.) Corda
Loc.:1, 7, 8, 10, 16; on wet soil, on soil
Plagiochilaceae Müll. Frib.
Pedinophyllum Lindb. exNordst.
Pedinophyllum interruptum (Nees) Kaal.
Loc.:1, 6, 12, 13; on soil,
Plagiochila (Dumort.) Dumort.
Plagiochila asplenioides(L.) Dumort.
Loc.: 3, 10, 22; on soil,
P. porelloides (Torr. ex Nees) Lindenb.
Loc.: 1, 3, 4, 5, 7, 8, 9, 10, 12, 13, 16, 19, 22; on soil, on wet soil
Frullaniaceae Lorch
Frullania Raddi.
Frullania tamarisci (L.) Dumort
Loc.: 3, 5; on rock.
Lejeuneaceae Cavers
Lejeunea Lib.
Lejeunea cavifolia (Ehrh.) Lindb
Loc.: 3; on tree bark..
Porellaceae Cavers
Porella L.
Porella platyphylla (L.) Pfeiff.
Loc.: 2, 21; on rock
Radulaceae Müll.Frib
Radula Dumort.
Radula complanata (L.) Dumort.
Loc.: 4, 5, 7, 8, 10, 11, 16, 19; on rock, on soil, on wet soil
R. lindenbergiana Gottsche ex C.Hartm
Loc.: 4, 9, 15; on soil
Metzgeriaceae H.Klinggr
Metzgeria Raddi [Apometzgeria Kuwah]
Metzgeria furcata (L.) Corda
Loc.: 1, 2, 7, 10; on rock
Pelliaceae H.Klinggr.
Apopellia (Grolle) Nebel&D.Quandt
Apopellia endiviifolia (Dicks.) Nebel&D.Quandt
Loc.: 1; on soil
Pellia Raddi.
Pellia epiphylla (L.) Corda
Loc.: 4; on soil
P. neesiana (Gottsche) Limpr.
Loc.: 1, 2, 10; on wet soil.
Conocephalaceae Müll. Frib. exGrolle
Conocephalum Hill.
Conocephalum conicum (L.) Dumort.
Loc.: 4, 9, 19, 21; on soil, on wet soil
Marchantiaceae Lindl.
Marchantia L.
Marchantia polymorpha L.
Loc.: 19; on soil
Bryophyta
Sphagnaceae Dumort.
Sphagnum L.
#Sphagnum medium Limpr.,
Loc.: 5; submerged
#S. squarrosum Crome
Loc.: 5; submerged
#S. teres (Schimp.) Ångstr
Loc.: 5, 6; submerged
S. capillifolium (Ehrh.) Hedw.,
Loc.: 23; submerged
#S. fuscum (Schimp.) H.Klinggr.
Loc.: 5; submerged
#S. quinquefarium (Lindb. inBraithw.) Warnst.,
Loc.: 23; submerged
#S. rubellum Wilson,
Loc.: 23; submerged
+S. russowii Warnst.,
Loc.: 2, 5; On wet soil
Andreaeaceae Dumort.
Andreaea Hedw.
+Andreaea alpestris (Thed.) Schimp.,
Loc.: 6, 8, 9, 12, 13, 15, 16, 23; on rock
+A. mutabilis Hook.f. & Wilson
Loc.: 8, 9, 12, 13, 16, 17, 19; on rock
 # A. rupestris Hedw.
Loc.: 17, 19, 22; on rock
Polytrichaceae Schwägr.
Atrichum P.Beauv
Atrichum undulatum (Hedw.) P.Beauv
Loc.: 3;on soil.
Pogonatum P.Beauv.
**Pogonatum aloides* (Hedw.) P.Beauv.
Loc.:3; on soil
**P. dentatum* (Menzies ex Brid.) Brid.
Loc.: 3, 22; on rock.
P. urnigerum (Hedw.) P.Beauv.
Loc.: 6, 9, 12, 13, 15, 19, 24; on soil
Polytrichastrum G.L. Sm.
Polytrichastrum alpinum (Hedw.) G.L. Sm.
Loc.: 1,3, 5, 6, 7, 9, 10, 11, 12, 13, 15, 17, 18, 19, 20, 22, 24; on soil, on wet soil, on rock.
**P. sexangulare* (Brid.) G.L.Sm.
Loc.: 20; on soil
Polytrichum Hedw.
Polytrichum formosum Hedw
Loc.: 5, 9, 17; on soil
#P. juniperinum Hedw.
Loc.: 1, 4, 8, 12, 13, 15, 16, 19, 21, 22; on wet soil, on soil
#P. piliferum Hedw.
Loc.:1, 4, 6, 8, 12, 13, 15, 16, 17, 22, 23, 24; on soil, on rock
#P. strictum Menzies ex Brid.
Loc.: 5, 15, 23; on wet soil.
Encalyptaceae Schimp
Encalypta Hedw.
#Encalypta ciliata Hedw
Loc.: 7; on soil
**E. microstoma* Bals.-Criv. & De Not
Loc.: 7, 14; on wet rock, on rock.
Distichiaceae Schimp
Distichium Bruch & Schimp.

Distichium capillaceum (Hedw.) Bruch & Schimp
Loc.: 1, 5, 6, 9, 10, 17, 18, 20, 22; on wet soil, on soil, on rock
Hymenolomataceae Ignatov&Fedosov
Hymenoloma Dusén.
#Hymenoloma compactum (Schleich ex Schwägr) Ochyra
Loc.: 1; on soil
#H. crispulum (Hedw.) Ochyra
Loc.:1,2, 4, 5, 6, 8, 9, 10, 12, 13, 14, 15, 16, 18, 19, 19, 20, 24; on rock, on soil
Flexitrichaceae Ignatov&Fedosov
Flexitrichum Ignatov & Fedosov
**Flexitrichum flexicaule* (Schwägr.) Ignatov & Fedosov
Loc.: 9; on soil
#F. gracile (Mitt.) Ignatov&Fedosov
Loc.: 9; on rock
Leucobryaceae Schimp
Leucobryum Hampe.
#Leucobryum glaucum (Hedw.) Ångstr
Loc.: 3, 14, 19; on soil
Amphidiaceae M.Stech
Amphidium Schimp.
#Amphidium mougeotii (Schimp.) Schimp
Loc.:1; on rock
Aongstroemiaceae De Not.
Dichodontium Schimp.
Dichodontium pellucidum (Hedw.) Schimp
Loc.: 3, 11, 19; on wet soil, on rock
Diobelonella Ochyra.
#Diobelonella palustris (Dicks.) Ochyra [*Synonymous: Dichodontium palustre* (Dicks.) M.Stech]
Loc.: 1; on wet soil
Dicranellaceae M.Stech
Dicranella (Müll. Hal.) Schimp.
Dicranella heteromalla (Hedw.) Schimp
Loc.: 10, 12, 13, 18; on soil,
#D. howei Renauld & Cardot
Loc.:1; on soil
Fissidentaceae Schimp.
Fissidens Hedw.
Fissidens adianthoides Hedw.
Loc.: 3; on rock
F. dubius P.Beauv.
Loc.: 3; on rock
Dicranaceae Schimp.
Dicranum Hedw.
#Dicranum bonjeanii De Not
Loc.: 1, 6, 11, 12, 13, 15, 21, 22, 23; on soil,
#D. flexicaule Brid
Loc.: 5, 19, 23; on soil,
**D. leioneuron* Kindb.
Loc.: 5; on soil
#D. majus Sm.
Loc.: 18, 20; on soil
#D. polysetum Sw. ex anon
Loc.:1, 5, 10, 20; on soil
D. scoparium Hedw
Loc.:1, 5, 6, 9, 11, 12, 13, 15, 18, 19, 20, 23; on soil
 # D. spadiceum J.E. Zetterst
Loc.: 1, 5, 6, 9, 12, 13, 18, 19, 22; on soil
Paraleucobryum (Limpr.) Loeske.
#Paraleucobryum enerve (Thed.)Loeske
Loc.: 22; on soil
**P. sauteri* (Bruch & Schimp.) Loeske
Loc.: 4; on soil
Rhabdoweisiaceae Limpr
Dicranoweisia Milde
Dicranoweisia cirrata (Hedw.) Lindb.
Loc.:1, 6; on wet soil,
Oncophorus (Brid.) Brid.
#Oncophorus virens (Hedw.) Brid.
Loc.: 6, 9, 21; on soil
Ditrichaceae Limpr
Ceratodon Brid.
Ceratodon purpureus (Hedw.) Brid
Loc.: 22; on soil, on rock
Pottiaceae Schimp
Syntrichia Brid.
**Syntrichia minor* (Bizot) M. T. Gallego, J.Guerra, M J. Cano, Ros&Sánchez-Moya
Loc.: 19; on rock
**S. norvegica* F.Weber
Loc.: 12, 13, 14,19, 20, 22; on rock,
**S. papillosissima* (Copp.) Loeske,
Loc.: 7; on rock
#S. ruraliformis (Besch.) Mans.
Loc.: 7, 10, 12, 13, 14, 15, 19; on rock
S. ruralis (Hedw.) F.Weber & D.Mohr
Loc.: 12, 13, 14, 19; on rock
**S. virescens* (De Not.) Ochyra
Loc.: 14; on rock
Tortula Hedw.
**Tortula hoppeana* (Schultz) Ochyra
Loc.: 6, 9, 17; on soil
#T. marginata (Bruch & Schimp.) Spruce
Loc.: 19; on soil
**T. mucronifolia* Schwägr.
Loc.: 14; on soil
**T. Schimperi* M. J.Cano, O.Werner & J.Guerra
Loc.: 17; on rock
Anoectangium Schwägr.
Anoectangium aestivum (Hedw.) Mitt.
Loc.: 12, 13; on soil
Chionoloma Dixon.
Chionoloma tenuirostre (Hook&Taylor) M.Alonso, M. J. Cano & J.A.Jiménez [Synonymous: *Oxystegus tenuirostris* (Hook. & Taylor) A.J.E.Sm.]
Loc.: 4, 11, 12, 13; on soil
Tortella (Müll. Hal.) Limpr.
#Tortella fasciculata (Culm.) Culm
Loc.: 1, 3, 5, 17, 18; on soil
T. tortuosa (Hedw.) Limpr

Loc.: 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 19, 23, 24; on soil, on rock
Trichostomum Bruch.
#Trichostomum crispulum Bruch
Loc.: 5; on rock
Saelaniaceae Ignatov & Fedosov
Saelania Lindb.
#Saelania glaucescens (Hedw.) Broth
Loc.: 5, 10, 15, 18, 19, 22, 23, 24; on rock, on soil
Grimmiaceae Arn.
Racomitrium Brid.
#Racomitrium aciculare (Hedw.) Brid
Loc.: 11; on rock, on soil
R. affine (F.Weber&D.Mohr) Lindb
Loc.:1, 4, 10, 11, 14, 15, 19, 20; on soil, on rock
R. aquaticum (Brid. ex Schrad.) Brid
Loc.: 15; on rock
R. canescens subsp. *canescens* (Hedw.) Brid
Loc.:1, 2, 4, 6, 7, 8, 10, 11, 12, 13, 16, 17, 18, 23, 24; on rock
+R. canescens subsp. latifolium (C.E.O.Jensen) Frisvoll [*Niphotrichum canescens subsp. latifolium* (Frisvoll) Bedn.-Ochyra & Ochyra]
Loc.:1; on rock
R. ericoides (Brid.) Brid.
Loc.:1, 4, 11; on rock
#R. macounii subsp. *alpinum* (E.Lawton) Frisvoll
Loc.:1, 10, 12, 13, 15, 23; on rock
 # R. macounii subsp. *macounii* Kindb.
Loc.: 5, 6, 12, 13, 15; on soil, on rock
#Racomitrium obtusum (Brid.) Brid.,
Loc.: 19; on rock
 # R. sudeticum (Funck) Bruch & Schimp
Loc.: 1, 4, 6, 12, 13, 15, 19; on rock
Grimmia Hedw.
Grimmia alpestris (F.Weber&D.Mohr) Schleich
Loc.: 1, 6, 7, 9, 15, 20; on rock
Grimmia anodon Bruch & Schimp.,
Loc.: 14; On rock
**G. anomala* Hampe ex Schimp
Loc.: 1, 15; on rock
**G. caespiticia* (Brid.) Jur.
Loc.: 6, 12, 13, 15; on rock
#G. donniana Sm.
Loc.: 9; on rock
#G. elatior Bruch ex Bals.-Criv. & De Not
Loc.: 12, 13, 18; on rock
#G. funalis (Schwägr.) Bruch & Schimp
Loc.: 5, 7, 9, 12, 13, 15, 19, 20, 24; on rock
#G. hartmanii Schimp
Loc.: 4, 9, 12, 13, 15; on rock
#G. longirostris Hook
Loc.: 5, 12, 13, 14, 23; on rock
G. ovalis (Hedw.) Lindb.,
Loc.: 14, 19; on rock
**G. unicolor* Hook
Loc.: 6; on rock
Schistidium Bruch & Schimp.
#Schistidium agassizii Sull. &Lesq.
Loc.: 9; on rock
S. apocarpum (Hedw.) Bruch & Schimp
Loc.: 9; on rock, on wet soil
#S. boreale Poelt
Loc.: 3, 7, 10; on rock
S. confertum (Funck) Bruch & Schimp.
Loc.: 9, 10; on rock
S. papillosum Culm.
Loc.: 9, 11, 19; on rock
S. rivulare (Brid.) Podp
Loc.: 4; on rock
Hedwigiaceae Schimp
Hedwigia P.Beauv.
#Hedwigia emodica Hampeex Müll. Hal.
Loc.: 7, 9, 12, 13, 14; on rock
**H. stellata* Hedenäs
Loc.: 12, 13; on rock
#Hedwigia ciliata (Hedw.) P.Beauv.,
Loc.: 5, 19; on rock
Bartramiaceae Schwägr
Bartramia Hedw.
#Bartramia halleriana Hedw.
Loc.: 3, 11, 15, 18; on rock, on soil
#B. ithyphylla Brid
Loc.: 7, 9, 10, 11, 12, 13, 15, 18, 20, 22, 23, 24; on soil
Philonotis Brid.
Philonotis caespitosa Jur
Loc.: 14, 19, 21, 22; on wet soil
#P. calcarea (Bruch & Schimp.) Schimp
Loc.: 2, 4; on wet soil
P. fontana (Hedw.) Brid
Loc.:1, 5, 9, 15, 23; on wet soil, on soil
#P. marchica (Hedw.) Brid.
Loc.:2, 15; on wet soil
#P. seriata Mitt.
Loc.:1, 4, 5, 6, 7, 11, 19, 23; on rock, on soil, on wet soil
Bryaceae Schwägr
Bryum Hedw.
Bryum argenteum Hedw
Loc.: 19; on soil
**Bryum canariense* Brid.,
Loc.: 4; on soil
B. dichotomum Hedw
Loc.: 1, 7; on soil,
Imbribryum Pedersen.
#Imbribryum alpinum (Huds. ex With.) N.Pedersen
Loc.: 9; on soil
I. mildeanum (Jur.) J.R.Spence
Loc.: 6, 15; on soil
**I. muehlenbeckii* (Bruch & Schimp.) N.Pedersen
Loc.: 5; on rock
Ptychostomum Hornsch.
**Ptychostomum arcticum* (R.Br.) J.R.Spence ex Holyoak & N.Pedersen,
Loc.: 1; on wet soil

* *Ptychostomum compactum* Hornsch.,
Loc.: 5, 14, 17, 18; on wet rock, on soil
P. creberrimum (Taylor) J.R.Spence & H.P.Ramsay
Loc.:1, 4; on rock
Ptychostomum donianum (Grev.) Holyoak & N.Pedersen,
Loc.: 1, 3, 5, 7, 10, 11, 15, 19, 23; on wet soil, on rock, on soil
P. elegans (Nees) D.Bell & Holyoak
Loc.: 4, 12, 13, 20; on soil, on rock
P. imbricatulum (Müll. Hal.) Holyoak & N.Pedersen
Loc.: 14, 22; on soil
P. inclinatum (Sw. ex Brid.) J.R.Spence
Loc.: 4, 6, 7, 9, 15, 17, 19; on soil
**P. intermedium* (Brid.) J.R.Spence
Loc.: 17; on rock
P. moravicum (Podp.) Ros & Mazimpaka
Loc.: 3, 4, 9, 12, 13, 14, 15, 23; on tree bark, on soil
P. pallens (Sw. ex anon.) J.R.Spence
Loc.: 1, 5, 22; on wet soil
P. pallescens (Schleich. ex Schwägr.) J.R.Spence
Loc.: 1, 2, 7, 10, 14, 15, 23; on soil, on rock
P. pseudotriquetrum (Hedw.) J.R.Spence & H.P.Ramsay ex Holyoak & N.Pedersen var. *bimum* (Schreb.) Holyoak & N.Pdersen
Loc.:1, 15; on soil
P. pseudotriquetrum (Hedw.) J. R. Spence & H. P. Ramsayex Holyoak & N.Pedersen var. *pseudotriquetrum*
Loc.: 1, 4, 5, 9, 10, 12, 13, 15; on wet soil, on soil
P. rubens (Mitt.) Holyoak & N. Pedersen
Loc.: 9; on soil
P. schleicheri (DC.) J.R.Spence ex D. Bell & Holyoak
Loc.:1, 2, 4, 5, 6, 8, 11, 12, 13, 16, 19, 23; on wet soil, on soil, on rock
P. torquescens (Bruch & Schimp.) Ros & Mazimpaka
Loc.: 3; on soil,
#*P. turbinatum* (Hedw.) J.R.Spence
Loc.: 6, 9; on soil
**P. weigelii* (Biehler) J.R.Spence
Loc.:1, 5, 19, 22, 23; on wet soil
Rhodobryum (Schimp.) Limpr.
Rhodobryum ontariense (Kindb.) Kindb
Loc.: 8, 11, 12, 13, 16, 19, 24; on soil, on rock
R. roseum (Hedw.) Limpr
Loc.: 8, 16; on soil
Mniaceae Schwägr
Pohlia Hedw.
P. cruda (Hedw.) Lindb
Loc.: 3, 6, 7, 9, 10, 11, 12, 13, 17, 19, 20, 21, 22; on rock, on soil
P. lescuriana (Sull.) Ochi
Loc.: 12,13; on soil
#*P. nutans* (Hedw.) Lindb
Loc.: 22, 23; on soil
Mnium Hedw.
#*Mnium hornum* Hedw.
Loc.: 6, 11; on rock, on soil
#*M. lycopodioides* Schwägr
Loc.: 3, 5, 9, 11, 18, 20, 22; on rock, on soil
#*M. marginatum* (Dicks.) P.Beauv
Loc.: 10, 18, 21; on soil
M. spinosum (Voit) Schwägr
Loc.: 10, 19; on soil, on rock
M. spinulosum Bruch & Schimp
Loc.: 3, 7, 9, 10, 11, 12, 13, 19, 22; on wet soil, on soil
M. thomsonii Schimp.
Loc.: 3, 5, 9, 22; on rock, on soil
Plagiomnium T.J.Kop.
Plagiomnium affine (Blandow ex Funck) T.J.Kop.
Loc.: 3; on soil,
P. cuspidatum (Hedw.) T.J.Kop.
Loc.: 17, 22; on soil
P. elatum (Bruch & Schimp.) T.J.Kop.
Loc.: 4; on soil
#*P. ellipticum* (Brid.) T.J.Kop.
Loc.:1, 3, 19, 22; on wet soil
P. medium (Bruch & Schimp.) T.J.Kop.
Loc.: 3, 11, 19; on soil,
P. rostratum (Schrad.) T.J.Kop.
Loc.: 1, 3, 14, 17, 24; on wet soil, on soil
P. undulatum (Hedw.) T.J.Kop.
Loc.:1, 3, 22; on soil
Rhizomnium (Broth.) T.J.Kop.
Rhizomnium magnifolium Horik.) T.J.Kop.
Loc.: 9, 10, 12, 13, 19; on wet soil
#*R. pseudopunctatum* (Bruch & Schimp.) T.J.Kop.
Loc.: 21, 23; on soil
R. punctatum (Hedw.) T.J.Kop
Loc.: 1, 2, 3, 4, 5, 9, 10, 11, 12, 13, 19, 24; on soil, on wet soil
Orthotrichaceae Arn
Lewinskya F. Lara, Garilleti & Goffinet.
**Lewinskya laevigata* (J.E.Zetterst.) F.Lara, Garilleti & Goffinet
Loc.: 14; on rock
L. rupestris (Schleich. ex Schwägr.) F.Lara, Garilleti & Goffinet
Loc.: 9, 14, 19, 20; on rock,
Orthotrichum Hedw.
**Orthotrichum alpestre* Bruch & Schimp
Loc.: 3; On rock
**O. bistratosum* (Schiffn.) Guerra
Loc.: 19; on tree bark
O. pallens Bruch ex Brid
Loc.: 19; on tree bark
**O. patens* Bruch ex Brid
Loc.: 3; on tree bark
Zygodon Hook. & Taylor.
#*Zygodon rupestris* Schimp. exLorentz
Loc.: 3; on tree bark

Aulacomniaceae Schimp
Aulacomnium Schwägr.
Aulacomnium palustre (Hedw.) Schwägr
Loc.: 1, 2, 5, 9, 18, 21, 22; on rock, on soil
Fontinalaceae Schimp.
Fontinalis Hedw.
#*Fontinalis antipyretica* Hedw.
Loc.: 23; submerged
* *Fontinalis squamosa* Hedw.,
Loc.: 14; submerged
Plagiotheciaceae M.Fleisch
Plagiothecium Bruch & Schimp.
Plagiothecium cavifolium (Brid.) Z.Iwats
Loc.: 10; on soil
P. laetum Schimp.
Loc.: 22; on soil
P. nemorale (Mitt.) A.Jaeger;
Loc.: 3; on tree bark
P. platyphyllum Mönk.,
Loc.: 8, 16; on soil
P. succulentum (Wilson) Lindb
Loc.:1, 10, 12, 13; on soil
Pterigynandraceae Schimp
Pterigynandrum Hedw.
Pterigynandrum filiforme Hedw
Loc.: 3, 4, 5, 7, 9, 11, 12, 13, 14, 20, 23; on tree bark, on rock, on soil
Climaciaceae Kindb
Climacium F. Weber & D.Mohr.
Climacium dendroides (Hedw.) F.Weber & D.Mohr
Loc.: 1, 2, 5, 11, 12, 13, 15, 22, 23; on wet soil, submerged
Amblystegiaceae G.Roth
Cratoneuron (Sull.) Spruce.
Cratoneuron filicinum (Hedw.) Spruce
Loc.: 4, 9, 12, 13, 19; on rock
Palustriella Ochyra.
Palustriella commutata (Hedw.) Ochyra
Loc.: 4, 14; near stream, on wet soil
P. decipiens (De Not.) Ochyra
Loc.: 1, 2, 5, 9, 10, 11, 19, 21; on wet soil, on soil, on wet rock
P. falcata (Brid.) Hedenäs
Loc.: 1, 5, 9, 12, 13, 18, 23; on rock, ıslak on rock, on wet soil
Campyliadelphus (Kindb.) R.S.Chopra.
#*Campyliadelphus elodes* (Lindb.) Kanda
Loc.: 19, 24; on wet soil
Campylium (Kindb.) R.S.Chopra
Campylium protensum (Brid.) Kindb
Loc.:1, 2, 5, 10, 11, 12, 13, 19, 23, 24; on wet soil, on rock
C. stellatum (Hedw.) Lange & C.E.O. Jensen
Loc.: 1, 2, 9, 12, 13, 23; on wet soil, on rock
Campylophyllopsis W.R. Buck.
Campylophyllopsis calcarea (Crundw. & Nyholm) Ochyra [Synonymous: *Campylophyllum calcareum* (Crundw. & Nyholm) Hedenäs]
Loc.: 3; on tree bark.
Drepanocladus (Müll.Hal.) G.Roth
Drepanocladus aduncus (Hedw.) Warnst
Loc.: 5; on wet soil
D. polygamus (Schimp.) Hedenäs
Loc.: 1; submerged
Hygroamblystegium Loeske.
Hygroamblystegium tenax (Hedw.) Jenn
Loc.: 14; submerged
Hygrohypnum Lindb.
#*Hygrohypnum luridum* (Hedw.) Jenn
Loc.: 3; submerged, on wet rock
89. Platyhypnum Loeske.
#*Platyhypnum duriusculum* (De Not.) Ochyra
Loc.: 5, 7, 9, 10, 15, 22, submerged, on wet rock, on wet soil
#*P. molle* (Dicks. ex Hedw.) Loeske
Loc.: 1, 4; submerged
Scorpidiaceae Ignatov & Ignatova
Hygrohypnella Ignatov & Ignatova
#*Hygrohypnella ochracea* (Turner ex Wilson) Ignatov & Ignatova
Loc.:1; on wet soil
Sanionia Loeske.
Sanionia uncinata (Hedw.) Loeske
Loc.: 1, 3, 6, 8, 9, 10, 12, 13, 15, 16, 19, 20, 21, 22; on wet soil, on rock, on soil
Pseudoleskeaceae Schimp
Lescuraea Bruch & Schimp.
Lescuraea incurvata (Hedw.) E.Lawton
Loc.: 1, 4, 5, 8, 10, 12, 13, 15, 16, 19, 22; on rock
L. mutabilis (Brid.) Lindb. exI. Hagen
Loc.: 4, 6, 10, 15, 17; on rock
L.patens Lindb
Loc.:1, 3, 9, 15, 20, 24; On rock, on wet soil
* *L. plicata* (Schleich. Ex F.Weber & D.Mohr) Broth.
Loc.: 12, 13; on rock, on soil
L. radicosa (Mitt.) Mönk
Loc.:1,4, 6, 15, 20, 22, 23; on rock
**L. saviana* (De Not.) E.Lawton
Loc.: 10, 11, 12, 13, 15, 24; on rock
L. saxicola (Schimp.) Molendo
Loc.: 10, 11, 15, 18, 20, 22, 23, 24; on rock
Pseudoleskeellaceae Ignatov & Ignatova
Pseudoleskeella Kindb.
Pseudoleskeella nervosa (Brid.) Nyholm
Loc.: 19; on tree bark
Thuidiaceae Schimp
Abietinella Müll. Hal.
Abietinella abietina (Hedw.) M.Fleisch.
Loc.: 7; on rock.
A. abietina (Hedw.) M.Fleisch var. *hystricosa* (Mitt.) Sakurai
Loc.: 4, 9; on soil, on rock
Thuidium Bruch & Schimp.
Thuidium asimile (Mitt.) A.Jaeger
Loc.: 3, 7, 11; on soil, On rock

T. delicatulum (Hedw.) Schimp.
Loc.: 19; on rock
Brachytheciaceae Schimp
Eurhynchium Bruch & Schimp.
Eurhynchium angustirete (Broth.) T.J.Kop
Loc.: 3, 22; on rock
E. striatum (Hedw.) Schimp
Loc.: 10, 22; on soil
Pseudoscleropodium (Limpr.) M.Fleisch.
Pseudoscleropodium purum (Hedw.) M.Fleisch.
Loc.: 12, 13; on soil
Rhynchostegium Bruch & Schimp.
#*Rhynchostegium alopecuroides* (Brid.) A.J.E.Sm.,
Loc.:1, 3, 7, 9; on wet soil, on rock, on soil
Rhynchostegiella (Schimp.) Limpr.
#*Rhynchostegiella litorea* (De Not.) Limpr.,
Loc.: 20; on soil
Brachytheciastrum Ignatov & Huttunen.
#*Brachytheciastrum collinum* (Schleich. ex Müll.Hal.) Ignatov & Huttunen
Loc.: 14, 15; on rock, on soil
B. velutinum (Hedw.) Ignatov & Huttunen
Loc.: 3; 15, 17; on rock
Brachythecium Schimp.
Brachythecium albicans (Hedw.) Schimp
Loc.: 12, 13; on soil
**B. erythrorrhizon* Schimp
Loc.: 22; on soil
#*B. geheebii* Milde
Loc.: 3, 12, 13; on soil
B. glareosum (Bruch ex Spruce) Schimp
Loc.: 1, 3, 4, 7, 12, 13, 19, 22, 23; on wet soil, on soil
B. rivulare Schimp
Loc.: 1, 3, 5, 8, 9, 11, 12, 13, 14, 15, 16, 19, 23; on wet soil, on soil
B. rutabulum (Hedw.) Schimp
Loc.: 2, 3, 10, 14, 15, 19, 23, 24; On wet soil, on rock, on soil, on wet rock
**Brachythecium turgidum* (Hartm.) Kindb.,
Loc.:1, 8, 16, 21; on wet soil, on soil
Eurhynchiastrum Ignatov & Huttunen.
Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen
Loc.: 8, 15, 16, 17, 24; on soil
Homalothecium Schimp.
Homalothecium lutescens (Hedw.) H. Rob
Loc.: 3, 7, 8, 11, 16; on rock
H. sericeum (Hedw.) Schimp
Loc.: 14; on rock
Sciuro-hypnum (Hampe) Hampe.
**Sciuro-hypnum latifolium* (Kindb.) Ignatov & Huttunen
Loc.: 22; on rock
S. populeum (Hedw.) Ignatov & Huttunen
Loc.: 10; on rock
#*S. reflexum* (Starke) Ignatov & Huttunen
Loc.: 19, 20; on rock
#*S. starkei* (Brid.) Ignatov & Huttunen
Loc.: 19; on rock
Hypnaceae Schimp
Hypnum Hedw.
Hypnum andoi A. J. E. Sm
Loc.: 3; on tree bark
H. cupressiforme Hedw var. *cupressiforme*
Loc.: 3, 9; on rock
H. cupressiforme Hedw. var. *lacunosum* Brid.
Loc.: 11, 14, 23; on rock
#*H. cupressiforme* Hedw. var. *subjulaceum* Molendo
Loc.: 19; on rock
#*H. jutlandicum* Holmen & E.Warncke
Loc.: 8, 10, 11, 14, 16, 19, 20, 22; on soil, on rock
H. resupinatum Taylor
Loc.: 7, 9, 12, 13; on rock
Jocheniaceae Jan Kučera & Ignatov
Jochenia Hedenäs, Schlesak & D.Quandt.
**Jochenia pallescens* (Hedw.) Hedenäs, Schlesak & D.Quandt [Synonymous: *Hypnum pallescens* (Hedw.) P. Beauv.]
Loc.: 19; on soil
Pylaisiaceae Schimp.
Buckia D.Rios, M.T. Gallego & J.Guerra.
Buckia vaucheri (Lesq.) D.Rios, M.T. Gallego & J.Guerra [Synonymous: *Hypnum vaucheri* Lesq.]
Loc.: 19; on rock
Calliergonella Loeske.
Calliergonella cuspidata (Hedw.) Loeske
Loc.: 14; on wet soil, submerged, near stream
C. lindbergii (Mitt.) Hedenäs
Loc.: 1; on wet soil
Pseudohygrohypnum Kanda
#*Pseudohygrohypnum eugyrium* (Schimp.) Kanda [Synonymous: *Hygrohypnum eugyrium* (Schimp.) Broth.]
Loc.: 3; on rock, submerged
Pylaisia Schimp.
Pylaisia polyantha (Hedw.) Schimp.
Loc.: 4; on rock,
Roaldia P.E.A.S.Câmara & Carv.-Silva.
Roaldia revoluta (Mitt.) P. E. A S.Câmara & M. Carvalho-Silva [Synonymous: *Hypnum revolutum* (Mitt.) Lindb.]
Loc.: 17, 18, 22; on soil
Hylocomiaceae M.Fleisch
Hylocomiadelphus Ochyra & Stebel.
Hylocomiadelphus triquetrus (Hedw.) Ochyra & Stebel
Loc.: 3, 5, 8, 9, 10, 11, 12, 13, 15, 16, 19, 24; on soil, on rock
Hylocomiastrum Broth
Hylocomiastrum pyrenaicum (Spruce) M.Fleisch. ex Broth.,
Loc.: 3, 5, 8, 9, 10, 11, 16; on rock
Hylocomium Bruch & Schimp.
Hylocomium splendens (Hedw.) Schimp

Loc.: 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 19, 24; on rock, on soil
Pleurozium Mitt.
Pleurozium schreberi (Willd. ex Brid.) Mitt
Loc.: 12, 13; on soil,
Rhytidiadelphus (Limpr.) Warnst.
Rhytidiadelphus squarrosus (Hedw.) Warnst.
Loc.: 19; on rock
Rhytidiaceae Broth.
Rhytidium (Sull.) Kindb.
Rhytidium rugosum (Hedw.) Kindb.
Loc.: 3, 5, 6, 7, 9, 10, 11, 12, 13, 19; on rock
Entodontaceae Kindb.
Entodon Müll. Hal.
Entodon concinnus (De Not.) Paris
Loc.: 4, 9; on soil
Leucodontaceae Schimp
Leucodon Schwägr.
 # Leucodon immersus Lindb
Loc.: 3, 7, 14; on rock
L. sciuroides (Hedw.) Schwägr.
Loc.: 3, 14; on tree bark, on soil
Neckeraceae Schimp
Alleniella S.Olsson, Enroth & D.Quandt.
Alleniella complanata (Hedw.) S.Olsson, Enroth & D.Quandt
Loc.: 3; on tree bark
Exsertotheca S. Olsson, Enroth & D.Quandt.
Exsertotheca crispa (Hedw.) S.Olsson, Enroth & D.Quandt
Loc.: 3, 4; on soil, on rock
Neckera Hedw.
**Neckera pumila* Hedw.
Loc.: 3; on tree bark
Thamnobryum Nieuwl.
 # Thamnobryum alopecurum (Hedw.) Gangulee.
Loc.: 3; on tree bark
#Thamnobryum neckeroides (Hook.) E.Lawton,
Loc.: 19; on tree bark
Heterocladiellaceae Ignatov & Fedosov
Heterocladiella Ignatov & Fedosov.
#Heterocladiella dimorpha (Brid.) Ignatov & Fedosov [Synonymous: *Heterocladium dimorphum* (Brid.) Schimp.]
Loc.: 15, 17, 18, 20, 23, 24; on rock, on soil
Lembophyllaceae Broth.
Isothecium Brid.
Isothecium alopecuroides (Lam. ex Dubois) Isov
Loc.: 3, 9, 10, 11, 12, 13, 23; on rock, on tree bark, on soil
#Isothecium interludens Stirt.,
Loc.: 3; on rock
Myuriaceae M.Fleisch
Ctenidium (Schimp.) Mitt.
Ctenidium molluscum (Hedw.) Mitt
Loc.: 3, 11; on rock, on soil
Anomodontaceae Kindb
Anomodon Hook. & Taylor.
Anomodon rugelii (Müll.Hal.) Keissl
Loc.: 19; on tree bark

The liverwort families with the highest taxon numbers are Scapaniaceae with 6 taxa (13.04 %), Anastrophyllaceae with 5 taxa (10.87 %), and Gymnomitriaceae with 4 taxa (8.7 %). The liverwort families with the lowest taxon numbers are Jungermanniaceae, Blepharostomataceae, Conocephalaceae, Frullaniaceae, Lejeuneaceae, Marchantiaceae, Metzgeriaceae, Adelanthaceae, and Porellaceae, respectively, with a percentage of 2.17%.

The moss families with the highest taxon numbers are Grimmiaceae with 27 taxa (11.07%), Bryaceae with 26 taxa (10.66%), and Brachytheciaceae with 21 taxa (8.61%). The moss families with the lowest taxon numbers are Leucobryaceae, Myuriaceae, Amphidiaceae, Anomodontaceae, Aulacomniacea, Climaciaceae, Distichiaceae, Ditrichaceae, Entodontaceae, Heterocladiellaceae, Jocheniaceae, Pseudoleskeellaceae, Pterigynandraceae, Rhytidiaceae, Saelaniaceae with a percentage of 0.41%.

Hornwort is represented by 1 family and 1 taxon.
The most common liverwort genera are *Scapania* (5), *Barbilophozia* (4), *Lophozia* (3), and *Solenostoma* (3). Other liverwort genera have two or fewer taxa.

The most common moss genera are *Ptychostomum* (17), *Grimmia* (11), *Racomitrium* (10), *Sphagnum* (8), *Dicranum* (7), *Plagiomnium* (7), *Brachythecium* (7), *Lescuraea* (7), *Hypnum* (6), *Mnium* (6), *Syntrichia* (6), *Plagiothecium* (5), and *Philonotis* (5). Other moss genera have four or fewer taxa.

The most common liverworts taxa are *Barbilophozia barbata*, *B. hatcheri*, *Lophozia longiflora*, *L. ventricosa*, *Diplophyllum taxifolium*, *Scapania irrigua*, *Solenostoma hyalinum*, *S. sphaerocarpum*, *Chiloscyphus pallescens*, *C. polyanthos*, *Pedinophyllum interruptum*, *Plagiochila asplenioides*, *P. porelloides*, *Radula complanata*, *R. lindenbergiana*, *Metzgeria furcata*, *Conocephalum conicum*.

The most common moss taxa are *Andreaea alpestris*, *A. mutabilis*, *Pogonatum urnigerum*, *Polytrichastrum alpinum*, *Polytrichum juniperinum*, *P. piliferum*, *Distichium capillaceum*, *Hymenoloma crispulum*, *Dicranum bonjeanii*, *D. scoparium*, *D. spadiceum*, *Syntrichia norvegica*, *S. ruraliformis*, *S. ruralis*, *Tortella tortuosa*, *Saelania glaucescens*, *Racomitrium affine, R. canescens*

subsp. *canescens*, *R. macounii* subsp. *alpinum*, *R. macounii subsp. macounii*, *R. sudeticum*, *Grimmia alpestris*, *G. funalis*, *G. hartmanii*, *Bartramia ithyphylla*, *Philonotis seriata*, *Ptychostomum donianum*, *P. inclinatum*, *P. moravicum*, *P. pallescens*, P. *pseudotriquetrum* var. *pseudotriquetrum*, *P. schleicheri*, *Rhodobryum ontariense*, *Pohlia cruda*, *Mnium lycopodioides*, *M. spinulosum*, *Rhizomnium punctatum*, *Aulacomnium palustre*, *Pterigynandrum filiforme*, *Climacium dendroides*, *Campylium protensum*, *Sanionia* uncinata, *Lescuraea incurvata*, *L. radicosa*, *L. saxicola*, *Brachythecium rivulare*, *B. rutabulum*, *Hypnum jutlandicum*, *Hylocomiadelphus triquetrus*, *Hylocomiastrum pyrenaicum*, *Hylocomium splendens*, *Rhytidium rugosum*, *Heterocladiella dimorpha*, *Isothecium alopecuroides*.

When station data are examined, liverworts such as *Plagiochila porelloides*, *Plagiochila asplenoides*, *Diplophyllum taxifolium*, *Conocephalum conicum*, *Radula complanata*, *Chiloscyphus polyanthos*, *Metzgeria furcata*, *Barbilophozia barbata*, *Solenostoma hyalinum*, *Solenostoma sphaerocarpum*, *Pedinophyllum interruptum*, and *Scapania undulata* are commonly found on soil and on wet soil, whereas mosses such as *Brachythecium rutabulum*, *Rhizomnium punctatum*, *Brachythecium rivulare*, *Philonotis seriata*, *Philonotis. fontana*, *Climacium dendroides*, *Campylium protensum, Ptychostomum pseudotriquetrum* var. *pseudotriquetrum*, *Palustriella falcata*, *Palustriella decipiens*, and *Palustriella commutata* are generally concentrated on wet or moist soil and are commonly found in aquatic and streamside vegetation types. Submerged; *Sphagnum capillifolium*, *Fontinalis antipyretica*, *Fontinalis squamosa*, *Hygrohypnum luridum*, *Platyhypnum duriusculum*, *P. molle*; while on rock substrates, species such as *Grimmia funalis*, *Racomitrium canescens*, *Schistidium papillosum*, *Syntrichia ruraliformis*, *Lescuraea incurvata*, *L. saxicola*, *Mnium lycopodioides*, *Rhytidium rugosum*, *Pohlia cruda*, *Bartramia ithyphylla*, *Tortella tortuosa*, *Saelania glaucescens*, *Andreaea alpestris*, and *Andreaea mutabilis* were predominantly identified. *Distichium capillaceum*, *Dicranum scoparium*, *Polytrichastrum alpinum*, *Polytrichastrum juniperinum*, *Hymenoloma crispulum*, *Sanionia uncinata*, *Hylocomium splendens*, *Hylocomiadelphus triquetrus*, *Ptychostomum donianum*, *Brachythecium glareosum*, and *Hypnum jutlandicum*, were observed on soil.

When the habitat distributions of 291 bryophyte specimens identified in the study area were examined, it was observed that the majority of the species were found on rocks (121 taxa, 41.58%), followed by habitats on soil (85 taxa, 29.21%) and wet soil (44 taxa, 15.12%). submerged and tree trunk areas were identified as relatively less preferred microhabitats, with (17 taxa 5.84%) each, whereas the lowest proportion was found in habitats on wet rocks (7 taxa, 2.41%).

Declarations

Authors' contributions

Idea/Concept: ZGK, HE, NB. Conceptualization and design: ZGK, HE, NB. Auditing/ Consulting: ZGK, HE, NB. Resources: ZGK, HE, NB. Materials: ZGK, HE, NB. Data Collection & Processing: ZGK, HE, NB. Analysis & Interpretation: ZGK, HE, NB. Literature Review: ZGK, HE, NB. Writing: ZGK, HE, NB. Critical Review: ZGK, HE, NB.

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Conflict of interest

The authors declare that there is no real, potential, or perceived conflict of interest for this article.

Ethics approval and consent to participate

The authors declare that ethical approval was not required for this study.

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Briyofitlerde Su Stresi ve Adaptasyon Mekanizmaları

Kahraman SELVİ[1], Özcan ŞİMŞEK[1,*]

[1]Çanakkale Onsekiz Mart Üniversitesi, Yenice Meslek Yüksekokulu, Ormancılık Bölümü, Çanakale, TÜRKİYE

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Öz

Karasal yaşamın öncüleri olan briyofitler (karayosunları, ciğerotları ve boynuzotları), su dengelerini aktif olarak koruyacak damar sistemlerinden yoksundur. Bu derleme, bu canlıların bu temel zorluğa karşı geliştirdikleri adaptasyon stratejilerini morfolojik, ekolojik ve moleküler düzeyleri entegre ederek bütüncül bir bakış açısıyla sentezlemektedir. Briyofitlerin hayatta kalma stratejisi, su mevcudiyetine göre metabolizmayı pasif olarak askıya alıp (desikasyon) yeniden başlatabildikleri "poikilohidrik" yaşam tarzına dayanır. Morfolojik düzeyde, akrokarpöz (yastık) ve plörokarpöz (mat) büyüme formları, su tutma kapasitesini (WHC) ve kapilariteyi optimize eder. Bu yapısal özellikler, ekolojik düzeyde briyofitlerin mikro-iklimi tamponlamasına, turbalıklar (peatlands) aracılığıyla küresel karbon döngüsünde kilit rol oynamasına ve ektohidrik yapıları sayesinde ağır metaller gibi kirleticiler için hassas biyoindikatörler olarak kullanılmalarına olanak tanır. Moleküler düzeyde ise, desikasyon toleransı (kriptobiyoz), Absisik Asit (ABA) tarafından yönetilen karmaşık bir sinyal ağı ile sağlanır. Bu ağ, hücresel yapıları koruyan LEA proteinlerini, ozmotik dengeyi sağlayan prolin ve çözünür şekerleri ozmolitleri ve oksidatif hasarı önleyen antioksidan enzimleri (SOD, CAT, APX) koordine eder. Bu sentez, briyofitlerin yapısal basitliğinin, su stresine karşı ne kadar karmaşık fizyolojik ve moleküler yanıtlar barındırdığını ortaya koymakta ve gelecekteki omik (transkriptomik, proteomik) çalışmalar için bir temel oluşturmayı hedeflemektedir.

Anahtar kelimeler: Briyofitler, poikilohidri, su stresi, adaptasyon mekanizmaları, biyoindikatör.

Water Stress and Adaptation Mechanisms in Bryophytes

Abstract

The bryophytes (mosses, liverworts, and hornworts), pioneers of terrestrial life, lack vascular systems that would actively maintain their water balance. This review synthesizes, from an integrated morphological, ecological, and molecular perspective, the adaptive strategies these organisms have evolved to cope with this fundamental challenge. The survival strategy of bryophytes is based on a poikilohydric lifestyle, which enables them to passively suspend (desiccate) and subsequently resume metabolic activity in response to water availability. At the morphological level, acrocarpous (cushion-forming) and pleurocarpous (mat-forming) growth forms optimize water-holding capacity (WHC) and capillarity. These structural adaptations allow bryophytes, at the ecological level, to buffer microclimatic conditions, play a key role in the global carbon cycle through peatlands, and serve as sensitive bioindicators for pollutants such as heavy metals due to their ectohydric water conduction. At the molecular level, desiccation tolerance (cryptobiosis) is regulated by a complex signaling network governed by Abscisic Acid (ABA). This network coordinates Late Embryogenesis Abundant (LEA) proteins that protect cellular structures, osmolytes such as proline and soluble sugars that maintain osmotic balance, and antioxidant enzymes (SOD, CAT, APX) that prevent oxidative damage. This synthesis highlights how the structural simplicity of bryophytes conceals highly intricate physiological and molecular responses to water stress, aiming to provide a conceptual foundation for future omics (transcriptomic, proteomic) studies.

Keywords: Bryophytes, poikilohydry, water stress, adaptation mechanisms, bioindicator.

* Corresponding author: ozcansimsek@comu.edu.tr

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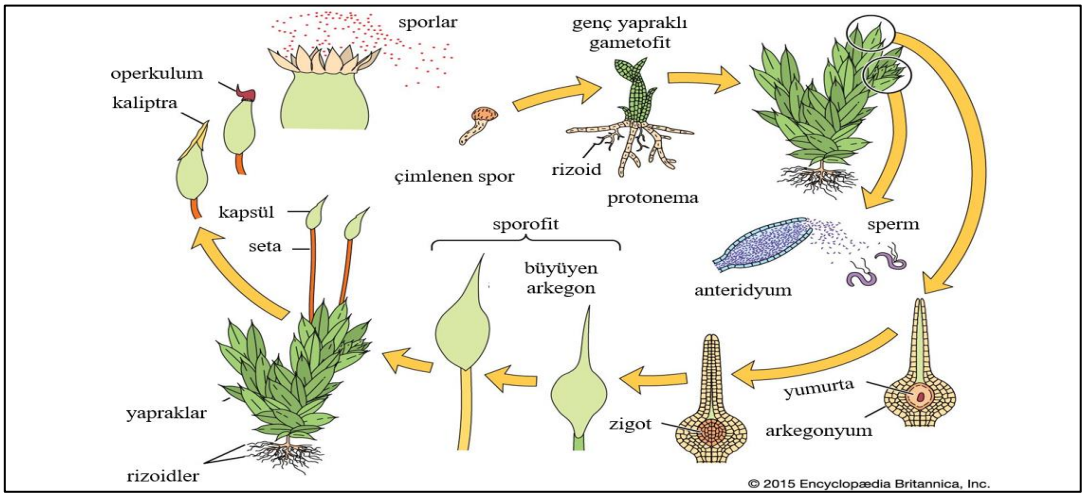
1. Giriş

Karasal ortamlarda suyun mevcudiyeti, tüm canlılar için sınırlayıcı bir faktördür. Bazı bitkiler su kaybını önlemek veya tolere edebilmek amacıyla evrimsel süreçte fizyolojik ve morfolojik olarak çeşitli mekanizmalar geliştirmiştir (Pizarro ve ark., 2019). Bitkilerin karasal yaşama geçişindeki en önemli basamaklardan biri de yaşamın sudan bağımsız olarak sürdürülebilmesini mümkün kılan adaptasyonların kazanılmasıdır. Bu kapsamda briyofitler (karayosunları, ciğerotları ve boynuzotları), sucul alg atalarından karasal ortama geçiş yapan ilk bitki grubu olarak, bu evrimsel sürecin "öncüleri" kabul edilmektedir (Şimşek ve ark., 2016). Bu süreçte farklı bitki grupları, su stresine karşı kendilerine özgü stratejiler geliştirmiştir. Özellikle briyofitler, çevresel koşullara karşı geliştirdikleri olağanüstü tolerans mekanizmaları ile dikkat çekmektedir (Zhou ve ark., 2023).

Morfolojik olarak basit, iletim demetlerinden (floem ve ksilem) yoksun, gerçek kök yerine rizoidlere sahip olan briyofitler, haploit (gametofit) evresi baskın olan damarsız kara bitkileridir (Goffinet ve Buck, 2013). Tohumlu bitkilerin aksine, briyofitlerin üreme süreçleri suya bağımlıdır (Şekil 1). Vasküler dokuları olmamasına rağmen, birçok briyofit türü, doku su içeriğini çevresel nemle dengeleyerek hem mezik (nemli) hem de kserik (kurak) habitatlarda yaşamını sürdürebilmektedir. Dolayısıyla bu bitkiler, sadece nemli orman ekosistemlerinde değil, aynı zamanda kutup tundralarından kurak çöl habitatlarına kadar geniş bir coğrafik alanda dağılım göstermektedir (Takezawa, 2018). Briyofitler, karasal bitkiler olarak kabul edilmelerine rağmen, özellikle nemli iklime sahip bölgelerde, gölgeli alanlarda ve tatlı su kenarlarında yaygındırlar. Bununla birlikte, toprak ve nemin kıt olduğu kurak ortamlar veya ağaç kabukları ve açık kaya yüzeyleri gibi birçok bitkinin hayatta kalamayacağı ekstrem koşullarda da hayatta kalabilirler (Şimşek, 2024).

Briyofitlerin çevresel stres koşullarına karşı hayatta kalmalarını sağlayan temel özelliklerden biri de bitki-su ilişkisinin damarlı bitkilere (Tracheophyta) kıyasla belirgin biçimde farklılık göstermesidir. Trakeofitlerde, köklerden alınan su, ksilem boyunca transpirasyon yoluyla oluşan bir basınç gradyanı ile sürgünlere taşınır. Bu süreç, stomalar ve kalın kutikula tabakası tarafından sıkı bir şekilde kontrol edilir. Oysa birçok briyofit türünde suyun taşınımı, dokuların dış yüzeyinde gerçekleşen kapiler hareketlerle pasif biçimde sağlanır. Bazı türlerde ise ksileme benzeyen içsel su iletim sistemleri gelişmiştir (Charron ve Quatrano, 2009).

Yapısal basitliklerine rağmen briyofitler, su durumlarını çevresel nem koşullarına dinamik bir biçimde uyarlayabilen ve böylelikle kuraklık ya da desikasyona karşı (aşırı kuruma) tolerans gösterebilen bitkilerdir. Düşük ışık yoğunluğu, aşırı sıcaklık değişimleri, besin kısıtlılığı ve uzun süreli kuraklık gibi çevresel faktörlere karşı fizyolojik ve morfolojik adaptasyonlar sayesinde yaşamlarını sürdürebilen briyofitler aynı zamanda diğer bitki ve mikroorganizmalar için de mikrohabitatlar oluşturarak uygun yaşam koşulları sağlar (Ochyra ve ark., 2008). Bu özellikleriyle birçok ekosistemin öncüsü olarak değerlendirilen briyofitler, çevresel stres yanıtlarının, tolerans mekanizmalarının ve direnç stratejilerinin araştırılmasında ideal model organizmalar olarak öne çıkmaktadır. Ayrıca briyofitlerin suya bağımlı yaşam stratejilerinin ekolojik, yapısal ve moleküler temellerinin anlaşılması, kara bitkilerinin adaptasyon süreçlerinin ve evrimsel geçişlerinin belirlenmesi açısından da kritik öneme sahiptir (Marks ve ark., 2019).



Şekil 1. Briyofitlerin yaşam döngüsü (URL1)

Günümüze kadar, briyofitlerle ilgili çok sayıda çalışma; yapısal ve morfolojik adaptasyonları ile ekolojik rollerini (Charron ve Quatrano, 2009; Ursavaş ve Ediş 2024; Ursavaş ve Edis, 2025), biyoizleme potansiyellerini (Printarakul ve Meeinkuirt, 2021; Boquete ve ark., 2021; Postiglione ve ark., 2025), hücresel ve moleküler düzeyde stres yanıtları (Ghosh ve ark., 2021; Maresca ve ark., 2022; Zhou ve ark., 2023) kapsamaktadır. Ancak, bu çalışmalar konunun genellikle spesifik bir yönüne (morfoloji, ekoloji veya moleküler biyoloji) odaklanmakta ve bu farklı düzeyler arasındaki entegrasyonu sağlayan güncel bir sentez, özellikle de Türkçe literatürde, eksik kalmaktadır. Bu derleme, briyofitlerin su stresine karşı geliştirdiği adaptasyon stratejilerini yapısal, ekolojik ve moleküler düzeylerde bütüncül bir çerçevede birleştirerek, bu alandaki dağınık bilgileri birleştirmeyi ve Türkiye'deki araştırmacılar için kapsamlı bir kaynak oluşturmayı hedeflemektedir.

2. Yapısal ve Morfolojik Adaptasyonlar

Briyofitler, su stresine karşı geliştirdikleri yüksek uyum yeteneklerine rağmen, minimal morfolojik bir yapıya ve basit bir yaşam döngüsüne sahiptir. Bu yapısal özellikler, bu canlıların ekolojik ortamda suyu etkin kullanmasını ve nem koşullarındaki değişimlere hızlı tepki verebilmelerini sağlar. Böylece onları ekosistemlerdeki su döngüsünü stabilize eden önemli organizmalar hâline getirir (Takezawa, 2018).

Briyofitlerin yaşam döngüsünde baskın olan haploit evre gametofit aşamasıdır. Doğada yaygın olarak gözlemlenebilen karakteristik yapraklı gametoforlar, nemli alt yüzeyle temas halinde büyüyen, doğrusal ve dallanmış ipliksi protonemlerden gelişir. Olgun gametoforlar gametangium adı verilen eşey organları oluşturur. Bu organlarda gelişen kamçılı spermler, suda döllenme için suya ihtiyaç duyar. Döllenme sonucunda gametoforun tepesinde oluşan diploit sporofit, mayoz bölünme ile haploit spor tetratlarını üretir. Daha sonra bu sporlar çimlenerek protonem ipliklerine dönüşür böylece yaşam döngüsü tamamlanır (Goffinet ve Buck, 2013).

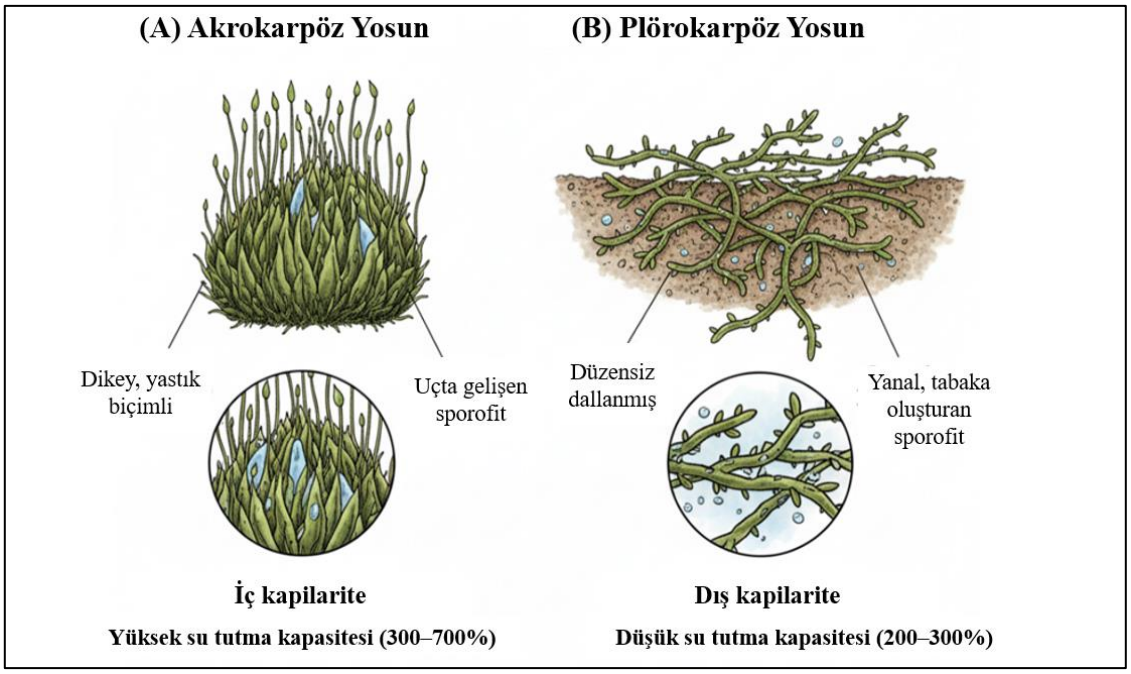
2.1. Su alımı ve taşıma mekanizması

Briyofitler, yaşam döngülerinin tüm aşamalarında, su alınımını, taşınımını ve korunmasını optimize eden özgün morfolojik ve yapısal stratejiler geliştirmiştir. Gerçek kök, gövde ve damarlı iletim dokuları ile porlu epidermal stomalardan yoksun olmalarına rağmen gametofit dokuları nemli yüzeylerle doğrudan temas halindedir. Yoğun kümeler halinde büyüyen bu sürgünler, suyun buharlaşmasını geciktirir ve nem kaybını azaltır (Charron ve Quatrano, 2009).

Briyofitlerin çevresel nemle pasif biçimde denge kurmalarını sağlayan poikilohidrik yaşam biçimi, dokularındaki su içeriğinin ortam nem koşullarıyla sürekli olarak uyum içinde kalmasına olanak tanıyan bir hidrolik adaptasyon stratejisidir. Bu bitkiler, suyu ve çözünmüş iyonları tüm yüzeylerinden emer (ektohidrik yaşam formu). Suyun olmadığı koşullarda metabolik faaliyetleri büyük ölçüde dururken, suyla yeniden temas ettiklerinde hızla aktive olabilir (Takezawa, 2018; Boquete ve ark., 2021). Kenar kapiler yapraklar, papilla ve hiyalin gibi hücreler mikromorfolojik unsurlar, suyun dış ortamdan hızla emilimini ve dokular arasında dengeli dağılımını kolaylaştırır. Buna karşılık desikasyon toleransı ve hızlı rehidrasyon gibi fizyolojik stratejiler, uzun süreli kurak dönemlerde bitkinin varlığını devam ettirmesini mümkün kılar (Ursavaş ve Edis, 2025).

2.2. Su tutma kapasitesi

Briyofitlerin büyüme formu, suyun tutulması ve buharlaşma süreçlerini doğrudan etkileyerek su tutma kapasitesini (WHC) belirler. Plörokarpöz yosunlar, sürünücü sürgünleri ve dallanmış yapılarıyla dışa doğru kapiler iletimi artırırken, yatay yönde geniş yüzey alanlarını kaplayarak yüksek su tutma kapasitesi sergiler (Proctor, 2000; Glime, 2024). Örneğin; *Homalothecium lutescens* (Hedw.) ve *Hypnum lacunosum* (Brid.) gibi plörokarpöz türlerin, *Tortella tortuosa* (Hedw.) gibi akrokarpöz türlere kıyasla %20-35 daha fazla su tutabildiği ve su tutma kapasitesinin kuru ağırlıklarının %300-700'ü olduğu bildirilmiştir (Ursavaş ve Edis, 2025). Akrokarpöz türler ise dikey büyüme formları sayesinde suyun yukarı yönlü taşınmasını kolaylaştırır. Özellikle açık ve kurak habitatlara uyum sağlamış akrokarpöz karayosunları, kompakt ve yoğun yapılar oluşturarak, suyun yaprak aralıklarında ve hücre boşluklarında tutulmasını sağlar (Liu ve She, 2020). *Dicranum scoparium* (Hedw.) gibi bazı akrokarpöz türler ise yoğun yastık formasyonu ve kıvrık yaprakları sayesinde yüksek su tutma kapasitesi sergileyebilmektedir (Ursavaş ve Edis, 2025). Karayosunlarının büyüme formları (Akrokarpöz vs. Plörokarpöz) ve su tutma stratejileri Şekil 2'de gösterilmiştir.



Şekil 2. Büyüme Formları (Akrokarpöz vs. Plörokarpöz) ve su tutma stratejileri

2.3. Kuraklık ve desikasyon toleransı

Desikasyon (kuruma) toleransı konusunda son derece gelişmiş ve etkili mekanizmalara sahip olan birçok briyofit türü, hiperozmoz, kuruma ve uzun süreli donma gibi stres koşullarında kriptobiyotik bir durumda hayatta kalabilir (Takezawa, 2018). *Ptychostomum pseudotriquetrum* (Hedw.) ve *Sanionia uncinata* (Hedw.) türlerinin buzullar altında yaklaşık altı yüzyıl boyunca kriptobiyoz yoluyla hayatta kaldığı rapor edilmiştir (Cannone ve ark., 2017). Kuru durumda briyofitler, ekstrem hava koşullarına dayanıklılık gösterebilir; fizyolojik aktiviteleri suyun mevcudiyetine bağlı olduğundan dehidrasyon süresi boyunca metabolizmaları neredeyse durur. Yeniden hidrasyonla birlikte ise fotosentetik aktivitelerini kısa sürede geri kazanabilirler (Clegg, 2001; Proctor ve ark., 2007). Bu yüksek rejenerasyon kapasitesi, herbaryum ve permafrost örneklerinin uzun yıllar sonra dahi canlılığını koruyabilmesini sağlamıştır (Breuil-Sée, 1993; Takezawa, 2018). Bu kapsamda; kuruma toleransı yüksek olan *Polytrichum formosum* (Hedw.) türünün, yeniden ıslatılmanın ardından kısa bir sürede solunum yeteneğini geri kazandığı (Proctor ve ark., 2007), *Syntrichia ruralis* (Hedw.) türünün ise rehidrasyonunun birkaç dakika sürdüğü ve normal fonksiyonuna geri dönüşün sadece birkaç saat içinde gerçekleştiği bildirilmiştir (Oliver ve ark., 2005).

2.4. Donma stresine karşı fizyolojik aklimatizasyon

Donma, bitki dokularındaki suyun buz kristallerine dönüşmesiyle birlikte şiddetli dehidrasyona yol açan en önemli abiyotik stres faktörlerinden biridir. Ancak briyofitler, damarlı bitkilerden farklı olarak su dengesini düzenleme ve hücresel bütünlüğü koruma yetenekleri sayesinde donma ile kuruma koşullarına karşı fizyolojik aklimatizasyon sergiler. Antartika'da yapılan bir çalışmada (Roads ve ark., 2014), karayosunu *Chorisodontium aciphyllum* (Hook. f. & Wilson) ile ciğerotu *Cephaloziella* türlerinin permafrost içinde 1500 yıldan fazla bir süre hayatta kaldıkları belirlenmiştir. Benzer şekilde La Farge ve ark. (2013), Küçük Buzul Çağında buzullar altında kalan briyofitlerin, kutup ekosistemlerinde yaklaşık 400 yıl boyunca canlılıklarını koruyabildiklerini bildirmişlerdir. Bulgular, bu organizmaların kutup ekosistemlerinde uzun süreli donma koşullarına dayanabilen bitkiler arasında yer aldığını ortaya koymaktadır.

Briyofitlerin donma toleransı, türe ve bulundukları çevreye büyük ölçüde bağlıdır. Balagurova ve ark. (1996) tarafından gerçekleştirilen bir çalışmada ılıman bölgelerden gelen *Sphagnum* türlerinin soğuk iklim kökenli türlere kıyasla daha düşük donma toleransına sahip oldukları rapor edilmiştir. Hidrasyon durumu da donma toleransını önemli ölçüde etkilemektedir. Dilks ve Proctor (1975), kuru durumdaki briyofit örneklerinin -30°C'ye kadar direnç gösterebildiğini ancak birçok türün nemli durumda -10°C'de donarak öldüğünü bildirmişlerdir. Araştırmalar, briyofitlerde donma

toleransının, yalnızca bir dormansi durumu olmadığını; bu canlılarda dehidrasyon toleransı, zar stabilizasyonu ve koruyucu osmolitlerin birikimi gibi fizyolojik düzenlemelerin aktif olarak devam ettiğini göstermektedir.

3. Briyofitlerin Ekolojik Özellikleri

Bitki ile su arasındaki etkileşim, yalnızca fizyolojik süreçleri değil, aynı zamanda bitkinin ekolojik performansını belirleyen temel bir faktördür. Bu etkileşim briyofitlerde suyun alınması ve kaybedilmesi ile mikro habitat koşullarının oluşumunu doğrudan etkiler.

Su, doğrudan yağış ya da gövde akışı yoluyla sağlanabilirken, yoğunlaşma süreçleri de (sis ve çiğ) bazı türler için önemli bir su kaynağı sayılabilir (Reiter ve ark., 2008). Briyofitler gelişmiş dermal dokulardan yoksun oldukları için bitkinin su potansiyeli, ortamın buhar basıncıyla hızla dengelenir. Bu nedenle çevresel nem koşullarındaki küçük değişimler bile dokuların su içeriğini etkiler. Briyofit dokuları yüksek nem koşullarında (%100 bağıl nem ve yaklaşık 0 MPa su potansiyeli) hidrat durumdadır. Ancak ortamın nemi %50'nin (-100 MPa) altına düştüğünde dehidrate duruma geçerler (Takezawa, 2018). Su içeriklerini aktif olarak düzenleyemedikleri bu süreçte, dokuların hidrasyon durumu pasif biçimde ortam nem koşullarını takip eder (Walter ve Stadelmann, 1968). Bu poikilohidrik yaşam biçimi, briyofitlerin suya bağlı genel fizyolojik aktivite süresini belirlerken, ışık ve sıcaklık bu aktivitenin hızını ve metabolik dengesini düzenler (Lange ve Green, 1996). Epifitik briyofit topluluklarının mikroklimatik koşulları ve su içeriği dalgalanmalarını inceleyen bir çalışmada (Löbs ve ark., 2020), bu organizmaların fizyolojik aktivitelerinin yalnızca nemli koşullar altında sürdürülebildiği, dolayısıyla su içeriği, sıcaklık ve ışık düzeylerinin farklı briyofit türlerinin ekolojik işlevleri üzerinde belirleyici olduğu bildirilmiştir.

3.1. Mikro-iklim tamponlama rolü

Briyofit toplulukları, özellikle orman zeminleri, turbalıklar ve yarı kurak sistemlerde suyun zamansal ve mekânsal dağılımını düzenleyerek, su stresine karşı mikro ölçekli tamponlar olarak işlev görürler. Bu organizmalar, yüzey nemini koruyarak buharlaşmayı azaltır ve toprak sıcaklığını dengeleyerek mikroklimayı stabilize eder (Van Tooren ve ark., 1985). Yarı kurak bir ekosistemde yapılan bir çalışmada (Ursavaş ve Edis, 2025), dört farklı karayosunu türünün hem su miktarını hem de su kalitesini düzenleyen mikro ölçekli tamponlar olarak işlev gördüğü; böylece toprak stabilitesine, infiltrasyona ve kuraklığa karşı dirence katkıda bulunduğu rapor edilmiştir. Farklı briyofit türlerinde su ekonomisinin, tür fizyolojik ve morfolojik özellikleri ile bu özelliklerin etkileşimlerine bağlı olarak kontrol edildiği bildirilmiştir (Michel ve ark., 2012). Briyofitler, yağmur suyunun etkisini yumuşatarak infiltrasyonu kolaylaştırır ve erozyonu engeller. Öncü briyofit topluluklarının, ılıman ormanlarda bozulmalar sonrası toprak erozyonunu önlediği bildirilmiştir (Gall ve ark., 2022). Ayrıca hızlı kolonizasyon yetenekleri sayesinde toprağı stabilize ederek, rüzgâr ve su erozyonuna karşı önemli ekosistem hizmetleri sağladıkları rapor edilmiştir (Hardman ve McCune, 2010).

Hidrolojik işlevlerinin yanı sıra, briyofitler besin döngüsünde de kilit roller üstlenir. Oluşturdukları briyofit matları, toprak nemindeki kısa dalgalanmaları tamponlayarak, mikroorganizmalar, mantarlar ve omurgasız canlılar için kararlı habitatlar sağlar (Glime, 2024). Ayrıca, siyanobakterilerle kurdukları simbiyotik ilişkiler aracılığıyla azot fiksasyonuna katkı sağlayarak topraktaki azot dengesini düzenlerler (Zackrisson ve ark., 2004). Bununla birlikte su kısıtlı sistemlerde fide oluşumunu ve bitki örtüsünün yenilenmesini kolaylaştırdıkları da bildirilmiştir (Delgado-Baquerizo ve ark., 2018).

3.2. Karbon dinamikleri ve biyomonitor potansiyeli

Kalın bir kütikül tabakasından yoksun briyofitler, suyu kök benzeri bir yapı ile değil; tüm yüzeyleri aracılığıyla alan ektohidrik organizmalardır. Bu özellik, onların çevresel nem koşullarına doğrudan bağımlı bir su dengesi stratejisi geliştirmesine neden olur. Nemli dönemlerde dokularındaki su içeriğinin artışı, fotosentetik aktivitenin yeniden başlamasına olanak tanır. Bununla birlikte aşırı su birikimi, gaz difüzyonunu kısıtlayarak CO_2 gaz değişim oranlarını azaltabilir (Cowan ve ark., 1992).

Briyofit bakımından zengin turba bataklıkları ve orman ekosistemleri, küresel karbon döngüsünde önemli bir yere sahiptir. Bu sistemlerde briyofitler, atmosferik karbondioksitin tutulması ve dokularda depolanması süreci olan karbon sekestrasyonunda önemli bir katkı sağlar (Zha ve Zhuang, 2021). Briyofitlerin karbon dinamiklerindeki bu rolü sahip oldukları benzersiz morfolojik ve fizyolojik özellikleriyle yakından ilişkilidir. Özellikle turba karayosunlarından *Sphagnum* türleri, karbon depolama ve hidrolojik rejimlerin düzenlemesindeki işlevleri sayesinde ekosistem mühendisleri olarak tanımlanmaktadır (Glime, 2024).

İklim değişikliğine bağlı etkilerin simüle edildiği bir modelleme çalışmasında (Erata ve ark., 2024),

briyofitlerin küresel ısınma koşullarında bile yaşam döngülerini sürdürebilme potansiyeli açısından avantajlı gruplar arasında olduğu vurgulanmıştır. Ancak deneysel olarak ısıtılan bir bataklıkta *Sphagnum* sp. türünün hızla azaldığı gözlemlenmiştir (Norby ve ark., 2019). İklim değişikliğinin tetiklediği sıcak hava dalgaları, kuraklık ve su seviyelerindeki düşüşler, özellikle bu *Sphagnum* karayosunlarının baskın olduğu donmuş topraklar ve turbalıklara zarar vermektedir. Bu durum, dünyanın en büyük karbon yutaklarından olan bu alanlardaki karbon depolama dengesini bozarak, karbon yutaklarının karbon kaynaklarına dönüşmesine neden olabilir (Şimşek ve Selvi, 2023b). Bu sonuç, briyofitlerin, sadece statik karbon rezervuarlar olmadığını, aynı zamanda hidrolojik streslere karşı biyokimyasal ve fizyolojik tepkileri sayesinde, iklim değişikliğine karşı dinamik ve hassas göstergeler olduğunu göstermektedir. Sürekli ısınma ve kuraklaşma sürecinin briyofit topluluklarındaki gerilemeye yol açması, ekosistem yapısı ve işlevi üzerinde olumsuz etkiler yaratırken, küresel karbon döngüsü ve iklim değişikliği hakkında önemli geri bildirimler sağlayabilir (Kulshrestha ve ark., 2022).

Kentsel alanlarda toplanan briyofitlerdeki ağır metal konsantrasyonları, doğal veya uzak alanlarda toplanan briyofitlerdekinden önemli ölçüde daha yüksektir (Gómez-Ensastegui ve ark., 2025). Briyofitlerin çevresel stres faktörlerine karşı yüksek hassasiyeti, biyomonitör olarak önemlerini vurgulamaktadır. Özellikle ağır metalleri ve metaloidleri absorbe etme yetenekleri, briyofitleri hava ve toprak kirliliğinin izlenmesinde etkili birer biyomonitör haline getirmiştir (Postiglione ve ark., 2025). Örneğin; sucul bir ciğerotu türü olan *Ricciocarpus natans* (L.) Corda ve karasal karayosunlarından *Entodon serrulatus* (Mitt.) üzerinde yapılan bir çalışmada, son derece kirli kentsel alanlardaki havadaki partikül maddelerle ilişkili ağır metalleri (özellikle Cd ve Pb) biriktirme konusunda eşdeğer yetenekleri olduğu gösterilmiştir (Gómez-Ensastegui ve ark., 2025). Benzer bir çalışmada (Vásquez ve ark., 2019), sucul ve reofilik briyofitlerin ağır metal biriktirme kapasitesi ve kentsel kirliliğe karşı verilen yanıtlar incelenmiştir. Sekiz briyofit taksonunun metal biriktirme potansiyellerinin incelendiği başka bir çalışmada (Printarakul ve Meeinkuirt, 2021), *Scopelophila cataractae* (Mitt.) türünün Cu, Cd, Zn ve Fe biriktirme potansiyeli en yüksek briyofit taksonu olduğu tespit edilmiştir. Sonuçlar, briyofitlerin pasif birikim mekanizmaları aracılığıyla çevre kirleticilerinin mekânsal dağılımını yansıttığını ve bu sayede çevre kalitesi değerlendirmeleri için düşük maliyetli, güvenilir ve ekolojik temelli göstergeler olduklarını göstermektedir (Şimşek ve Selvi, 2023a). Briyofitlerin biyoizleme potansiyeli, kentsel veya endüstriyel alanlardaki yerel kirliliği tespit etmenin ötesine uzanmaktadır. Bu organizmalar, Antarktika gibi uzak ve bozulmamış bölgelerde dahi atmosferik ağır metal taşınımının tespit edilmesine imkân tanımaktadır (Canlı ve Çetin, 2017). Karasal ortamlardaki bu rollerine ek olarak, briyofitler özellikle sucul ekosistemlerde de kritik bir görev üstlenirler. Bu bitkiler su kalitesindeki değişimlerin, ötrofikasyon (besin zenginleşmesi) düzeylerinin ve pH değişimlerinin (asidifikasyon) izlenmesinde de etkin bir şekilde kullanılmaktadırlar (Şimşek ve Selvi, 2023b).

4. Hücresel ve Moleküler Adaptasyonlar

Briyofitler, karasal ortamlarda yaşamlarını sürdürebilmek için su içeriğini çevre koşullarıyla sürekli dengeleyen hücresel adaptasyon mekanizmalarına sahiptir. Bu adaptasyon hem sürekli koruma mekanizmaları hem de çevresel sinyallerle düzenlenen indüklenebilir yanıtlar aracılığıyla gerçekleşir. Böylece bitki, su stresine karşı önleyici ve uyarlanabilir bir tolerans stratejisi sergiler. Gao ve ark. (2015), çöl habitatlarında yaşayan *Bryum argenteum* (Hedw.) türünün, uzun süreli kuraklık koşullarında hayatta kalmasını sağlayan kalıcı ve uyarılabilir tolerans mekanizmaları geliştirdiğini bildirmişlerdir. Bu çalışma, briyofitlerin su stresine karşı verdiği yanıtların, fizyolojik, hücresel, moleküler ve metabolik düzeylerde işleyen esnek ve çok katmanlı düzenleme ağları tarafından yönetildiğini ortaya koymaktadır. Bu ağların hücresel düzeydeki işleyişi, ozmotik dengeleme süreçleri, hücre duvarının yeniden yapılanması, absisik asit (ABA) aracılı sinyal molekülleri ve koruyucu moleküllerin sentezinde kendini göstermektedir. Bu bağlamda, bazı briyofit türleri, hücrelerin dehidrasyona karşı korunmasında rol oynayan temel hücresel bileşenleri sürekli olarak yüksek düzeyde bulundururken bazı türlerde ise bu bileşenlerin sentezini, dehidrasyon koşullarında indüklenebilir mekanizmalar aracılığıyla gerçekleştirir (Oliver ve ark., 2005).

LEA proteinleri (Geç embriyogenezde bol miktarda bulunan proteinler), kuraklık, soğuk ve tuzluluk gibi abiyotik streslere yanıt olarak ifade edilen hidrofilik koruyucu proteinlerdir. Hücresel dehidrasyon toleransının indüklenmesi durumunda sükroz gibi düşük molekül ağırlıklı çözünür şekerlerin ve LEA proteinlerinin, hücre zarını ve diğer makro molekülleri koruduğu kabul edilmektedir (Takezawa, 2018).

Kuraklık toleransının bir diğer temel mekanizması, prolin gibi organik ozmolitlerin birikimiyle ozmotik

dengelemenin sürdürülmesidir. Prolin, membran stabilitesinin korunması, reaktif oksijen türlerinin (ROS) temizlenmesi ve hücresel homeostazisin korunmasında önemli rol oynar. Briyofitler, ozmotik strese karşı iç su potansiyelini korumaya yönelik çeşitli uyum mekanizmaları geliştirmiştir. Bu süreçlerin anlaşılmasında, karasal bitkilerin evrimi ve adaptasyonuna ilişkin anahtar fizyolojik ve moleküler özellikleri temsil eden *Marchantia polymorpha* (L.) önemli bir model organizma olarak öne çıkmaktadır. Ghosh ve ark. (2021), kuraklığın yol açtığı osmotik stresin, *M. polymorpha* türünde prolin içeriğinde önemli bir artışa neden olduğunu bildirmişlerdir. Ayrıca çalışmada kuraklık maruziyetinin, H_2O_2 birikimini ve lipit peroksidasyon ürünü olan malondialdehit (MDA) seviyelerini artırdığını ve elektrolit sızıntısı oranını yükselttiğini, kuraklığın hücre zarı bütünlüğünü bozarak oksidatif hasara yol açtığını bildirmişlerdir. Briyofitler, bu hasarı nötralize etmek için Süperoksit Dismutaz (SOD), Katalaz (CAT), Askorbat Peroksidaz (APX), Glutatyon S-Transferaz (GST) ve Dehidroaskorbat Redüktaz (DHAR) gibi enzimleri içeren bir antioksidan savunma sistemini kullanır (Salbitani ve ark., 2023). Kuraklığa karşı *M. polymorpha*'nın adaptasyon mekanizmalarının araştırıldığı bir çalışmada (Postiglione ve ark., 2025), bu enzimlerin aktivitesindeki artışın, kuraklık veya ağır metal stresine karşı güçlü bir savunma tepkisi olarak ortaya çıktığı bildirilmiştir.

Absisik Asit (ABA), bitki gelişimini ve abiyotik stres tepkilerini düzenleyen evrensel bir fitohormondur. Briyofitlerde ABA'nın su stresine yanıt sürecindeki işlevi, indüklenebilir kurumaya ve donmaya karşı toleransın sağlanmasında merkezi bir düzenleyici olarak öne çıkar (Pizarro ve ark., 2019). *Physcomitrella patens* (Hedw.) üzerinde yapılan bir çalışmada (Nagao ve ark., 2005), dışsal uygulanan ABA uygulamasının, çözünür şekerlerin birikimini artırdığı ve hücresel ozmotik potansiyelin düzenlemesine katkı sağladığı bildirilmiştir. Hatanaka ve Sugawara (2010), *M. polymorpha*'nın kallus hücrelerindeki sükroz birikiminin, daha yüksek sıcaklıkta camsı geçişi hızlandırarak kuruma toleransını indüklediğini göstermiştir. Benzer şekilde, Godinez-Vidal ve ark. (2020), su stresi koşullarında *M. polymorpha* bireylerinde büyüme hızının azaldığını, tallus morfolojisinde belirgin değişimlerin ortaya çıktığını ve ABA seviyelerinin anlamlı şekilde yükseldiğini rapor etmişlerdir. Ayrıca çalışmada, su eksikliğinin, çoğunlukla merkezi vakuol hacmindeki değişiklikler yoluyla hücre organellerinin konumunda kaymalara neden olduğu ve bu durumun ozmotik potansiyelin yeniden ayarlanmasıyla ilişkili olduğu bildirilmiştir. Shinde ve ark. (2012) tarafından yapılan çalışmada, ABA'nın *Physcomitrella patens* (Hedw.) türünde LEA proteinlerinin birikimini içeren dehidrasyon stresi kaynaklı salınımları düzenlediği bildirmişlerdir. Bulgular ABA aracılı sinyallemenin hem hücresel osmoregülasyonun sürdürülmesinde hem de dehidrasyon sırasında metabolik dengenin korunmasında temel bir düzenleyici rol üstlendiğini göstermektedir. Briyofitlerde su stresine yanıt olarak görev alan temel hücresel ve moleküler bileşenler ve işlevleri Tablo 1'de özet olarak sunulmuştur.

Tablo 1. Briyofitlerde su stresine yanıt olarak görev alan temel hücresel ve moleküler bileşenler ve işlevleri

Molekül / Sistem	Kategori	Temel İşlevi (Su Stresine Yanıt)	Metin İçi Kaynaklar (APA)
LEA Proteinleri	Koruyucu Protein	Hidrofilik yapıdadırlar; dehidrasyon sırasında hücre zarını ve diğer makro molekülleri korurlar.	Takezawa, 2018; Shinde ve ark., 2012
Prolin	Organik Ozmolit	Ozmotik dengelemeyi sağlar; membran stabilitesini korur, Reaktif Oksijen Türlerini (ROS) temizler ve hücresel homeostazisi sürdürür.	Ghosh ve ark., 2021
Antioksidan Enzimler (SOD, CAT, APX, GST, DHAR)	Savunma Enzimleri	Oksidatif stresi tetikleyen Reaktif Oksijen Türlerini (ROS) nötralize ederek hücresel hasarı önlerler.	Salbitani ve ark., 2023 Postiglione ve ark., 2025
Absisik Asit (ABA)	Fitohormon (Sinyal)	İndüklenebilir kuruma ve donma toleransını düzenleyen merkezi sinyal molekülüdür. LEA proteinlerinin ve çözünür şekerlerin birikimini tetikler.	Pizarro ve ark., 2019; Nagao ve ark., 2005; Shinde ve ark., 2012
Çözünür Şekerler (örn. Sükroz)	Ozmolit / Koruyucu	Hücresel ozmotik potansiyeli düzenlerler; camsı geçişi (vitrifikasyon) hızlandırarak kuruma toleransını indüklerler.	Takezawa, 2018; Nagao ve ark., 2005; Hatanaka ve Sugawara, 2010

5. Sonuç ve Öneriler

Briyofitler, kara bitkileri arasında en dayanıklı ve ekolojik açıdan en etkili gruplarından birini temsil eder. Basit morfolojik yapılarının aksine, aşırı çevre koşullarında hayatta kalmalarını sağlayan olağanüstü fizyolojik ve moleküler esneklik sergilerler. Kuruma-rehidrasyon döngüleri sırasında metabolik süspansiyon ve yeniden aktivasyona olanak tanıyan poikilohidrik yaşam tarzları, bu bitkilerin karasal habitatlardaki evrimsel başarısının temelini oluşturur.

Fizyolojik dirençlerinin ötesinde briyofitler, ekosistem mühendisleri olarak üstlendikleri rollerle de dikkat çekerler: nem rejimini düzenler, karbon sekestrasyonuna katkı sağlar ve besin döngüsünü destekler. Ayrıca kirleticilere karşı yüksek duyarlılıkları briyofitleri, iklim kaynaklı baskıların erken tespiti için güvenilir biyoindikatörler haline getirir. Bu adaptasyonlar, sadece briyofitlerin hayatta kalmasını sağlamakla kalmaz; aynı zamanda erozyon kontrolü, su döngüsünün düzenlenmesi ve karbon sekestrasyonu gibi kritik ekosistem hizmetleri sunarak, iklim değişikliğinin olumsuz etkilerine karşı ekosistemlerin dayanıklılığını artırmada vazgeçilmez bir rol oynamaktadır. Özellikle turbalıklardaki *Sphagnum* türlerinin küresel karbon yutakları olarak fonksiyonu, briyofitlerin korunmasının ve araştırılmasının gezegenimiz için taşıdığı önemi bir kez daha ortaya koymaktadır.

Briyofitler üzerinde yapılan ekolojik ve fizyolojik çalışmalar, bu organizmaların hayatta kalma stratejilerinin damarlı bitkilerden köklü biçimde farklılaştığını göstermektedir. Fotosentetik ve hücresel özellikler bakımından diriliş bitkileri (resurrection plants) ile olan benzerlikleri, yüksek kuruma toleransına sahip türlerde ortak stres adaptasyon ağlarının varlığına işaret etmektedir. Bununla birlikte briyofitlerin kuruma toleransını düzenleyen moleküler epigenetik mekanizmalar henüz tam olarak çözümlenememiştir. Bu da gelecekteki fonksiyonel genomik çalışmalar için önemli bir araştırma boşluğu oluşturmaktadır.

Hücresel düzeyde ozmotik dengeleme, antioksidan savunma sistemleri ve LEA proteinleri, briyofitlerin kuraklık ve donma streslerine karşı dayanıklılığın temelini oluşturur. ABA aracılı sinyal yolları, transkripsiyonel ve metabolik tepkileri bütünleştirerek briyofitlerin aktif stres adaptasyonu kapasitelerini güçlendirir. Ek olarak aklimatizasyon süreci boyunca düşük molekül ağırlıklı şekerlerin birikimi hücre içi su dengesinin korunmasına katkı sağlar. Ancak sıcaklık düşüşünü algılayan ve soğuğa yanıt veren gen aktivasyonunu düzenleyen mekanizmalar hakkındaki çalışmalar sınırlıdır.

Son yıllarda gelişen genomik, transkriptomik ve biyokimyasal yaklaşımlar, briyofitlerde stres toleransının hücresel ve moleküler temellerini çok yönlü olarak inceleme olanağı sunmaktadır. Basit morfolojik yapıları ve kısa yaşam döngüleri sayesinde briyofitler, özellikle moleküler etiketleme ve genetik manipülasyon teknikleri için model organizmalar olarak öne çıkmaktadır. Özellikle *Physcomitrella patens* (Hedw.) ve *Marchantia polymorpha* (L.) gibi türlerde yürütülen omik tabanlı araştırmalar, stresle ilişkili gen ağları, biyosentetik yollar ve sekonder metabolit çeşitliliği hakkında önemli bilgiler sağlamıştır. Bununla birlikte, boynuzotları (*Anthoceros agrestis,* Paton vd.), kuraklığa dayanıklı karayosunları (*Tortula* spp., *Ceratodon* spp. vd.) ve *Sphagnum* türleri üzerinde genomik kaynakların genişletilmesi, poikilohidri ve özelleşmiş metabolizmanın evrimsel temellerini anlamak için önemlidir.

Türkiye gibi zengin briyofit biyoçeşitliliğine sahip bölgelerde, yerel türlerin su stresi toleransı üzerine yapılacak detaylı fizyolojik ve moleküler araştırmalar, hem küresel bilgi birikimine önemli katkılar sunacak hem de bu eşsiz floranın korunması için bilimsel temeller oluşturacaktır. Gelecek çalışmalarda, briyofitlerin çevresel adaptasyonlarının fizyolojik, moleküler ve biyokimyasal temellerinin aydınlatılması amacıyla transkriptomik, proteomik ve metabolomik analizlerin entegrasyonuna odaklanılması önerilmektedir.

Deklarasyon

Yazar katkıları: Fikir/Kavram KS, ÖŞ; Tasarım ve dizayn, KS, ÖŞ; Denetleme danışmanlık, KS, ÖŞ; Kaynaklar, KS, ÖŞ; Malzemeler, KS, ÖŞ; Veri toplama ve/veya İşleme, KS, ÖŞ; Analiz ve/veya yorum, KS, ÖŞ; Literatür taraması, KS, ÖŞ; Yazım aşaması, KS, ÖŞ; Eleştirel inceleme, KS, ÖŞ.

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Anatolian Bryology, related to mosses, liverworts and hornworts, publishes original research articles on morphology, ultrastructure, diversity, distribution, conservation, threatened species and their habitats, genetics, biotechnology, systematic, evolution phytogeography, ecology, environmental management, and interrelationship among of the bryophytes.

Descriptive or experimental studies presenting clear research questions are accepted. The submitted paper must be original and unpublished and not under consideration for publication elsewhere. Manuscripts in English or in Turkish languages are welcome. Printed in Turkey. This journal is published two times a year, open access, and free.

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1. **Research articles:** Original research in various fields of bryophyte will be evaluated as research articles.

2. **Research notes:** These include articles such as preliminary notes on a study or manuscripts on the morphological, anatomical, cytological, chemical, and other properties of bryophyte species.

3. **Reviews:** Reviews of recent developments, improvements, discoveries, and ideas in various fields of bryophyte will be requested by the editor or advisory board.

4. **Letters to the editor:** These include opinions, comments relating to the publishing policy of the Turkish Journal of Botany, news, and suggestions. Letters are not to exceed one journal page.

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Preparation of Manuscript

Style and format: Manuscripts should be double-spaced with 3-cm margins on all sides of the page, in Times New Roman font. Every page of the manuscript, including the title page, references, tables, etc., should be numbered. All copies of the manuscript should also have line numbers starting with 1 on each consecutive page. Manuscripts must be written in English and in Turkish. Contributors who are not native English speakers are strongly advised to ensure that a colleague fluent in the English language or a professional language editor has reviewed their manuscript. Concise English without jargon should be used. Repetitive use of long sentences and passive voice should be avoided. It is strongly recommended that the text be run through computer spelling and grammar programs. Either British or American spelling is acceptable but must be consistent throughout.

Symbols, units, and abbreviations: In general, the journal follows the conventions of Scientific Style and Format, The CSE Manual for Authors, Editors, and Publishers, Council of Science Editors, Reston, VA, USA (7^{th} ed.). If symbols such as ×, μ, η, or ν are used, they should be added using the Symbols menu of Word. Degree symbols (°) must be used from the Symbol menu, not superscripted letter o or number 0. Multiplication symbols must be used (×), not the letter x. Spaces must be inserted between numbers and units (e.g., 3 kg) and between numbers and mathematical symbols (+, –, ×, =, <, >), but not between numbers and percent symbols (e.g., 45%). Please use SI units. Generally, all numbers should be given as numerals (e.g., “In 2 previous studies…”); please consult the above-mentioned style manual for full details. All abbreviations and acronyms should be defined at first mention. Latin terms such as et al., in vitro, or in situ should not be italicized.

Manuscript content: Research articles should be divided into the following sections. Principal sections should be numbered consecutively (1. Introduction, 2. Materials and Methods, 3. Findings, 4. Results and Dicussion etc.) and subsections should be numbered 1.1., 1.2., etc.

Since January 1st, 2017, "Anatolian Bryology" uses the iThenticate screening service to verify the authenticity of content submitted before publication. The iThenticate software checks submissions against millions of published research papers, documents on the web and other relevant sources. Authors can also use iThenticate to screen their work before submission by visiting http://www.ithenticate.com
The overall similarity index for submitted manuscript should be less than 20% (Except for taxa list and bibliography). This journal has used iThenticate (Plagiarism Detection Software).

Ethical Rules and Responsibilities
The editorial and publication processes of the journal are shaped in accordance with the guidelines of) the Council of Science Editors (CSE), the Committee on Publication Ethics (COPE), the European Association of Science Editors (EASE), and National Information Standards Organization (NISO). Anatolian Bryology conforms to the Principles of Transparency and Best Practice in Scholarly Publishing (https://doaj.org/bestpractice).

Title and contact information
The first page should contain the full title in sentence case (e.g., The response of the xerophytic plant *Syntrichia caninervis* var. *gypsophila* (J.J. Amann ex G. Roth) Ochyra to salt and drought stresses: the role of the antioxidant defence system), the full names (last names fully capitalized) and affiliations of all authors (Department, Faculty, University, City, Country), and the contact e-mail address for the clearly identified corresponding author.

Abstract
The abstract should provide clear information about the research and the results obtained, and should not exceed 200 words.

Keywords
Please provide 3–10 key words or phrases to enable retrieval and indexing. Acronyms should be avoided.
In order to establish a standard terminology in the keywords and to enable the researchers to access the articles in an easy way, scientific articles should have the appropriate number of keywords in the appropriate quality and standard terminology. Scientific keywords in the article should be selected from Turkey Science Terms. In this regard: http://www.bilimterimleri.com can be used.

1. Introduction
This should argue the case for your study, outlining only essential background, and should not include the findings or the conclusions. It should not be a review of the subject area, but should finish with a clear statement of the question being addressed.

2. Materials and Methods
Please provide concise but complete information about the materials and the analytical and statistical procedures used. This part should be as clear as possible to enable other scientists to repeat the research presented. Brand names and company locations should be supplied for all mentioned equipment, instruments, chemicals, etc.

3. Findings
Station information and plant list etc.

4. Results and Discussion
The same data or information given in a Table must not be repeated in a Figure and vice versa. It is not acceptable to repeat extensively the numbers from Tables in the text or to give lengthy explanations of Tables or Figures. Statements from the Introduction and Finding sections should not be repeated here. The final paragraph should highlight the main conclusions of the study.

Acknowledgements and/or disclaimers, if any
Names of funding organizations should be written in full.

References
References should be cited in the text by the last name(s) of the author(s) and year of publication with a comma between them: for example, (Ursavaş, 2014) or (Ursavaş and Keçeli, 2012). If the citation is the

subject of the sentence, only the date should be given in parentheses: "According to Ursavaş (2012)…" For citation of references with 3 or more authors, only the first author's name followed by et al. (not italicized) should be used: (Abay et al., 2002). If there is more than one reference in the same year for the same author, please add the letters a, b, etc. to the year: (Keçeli et al., 2004a, 2004b). References should be listed in the text chronologically, separated by semicolons: (Abay, 2000; Keçeli et al., 2003; Ursavaş and Ören, 2012). Website references should be (URL1, URL2, …). Do not include personal communications, unpublished data, or other unpublished materials as references, although such material may be inserted (in parentheses) in the text. In the case of publications in languages other than English, the published English title should be provided if one exists, with an annotation such as "(article in Turkish with an abstract in English)". If the publication was not published with an English title, provide the original title only; do not provide a self-translation. References should be listed alphabetically at the end of the text without numbering. All authors should be included in reference lists unless there are 10 or more, in which case only the first 10 should be given, followed by 'et al.'. The manuscript should be checked carefully to ensure that the spellings of the authors' names and the years are exactly the same in the text as given in the reference list. References should be formatted as follows (please note the punctuation and capitalization):

Journal articles: Short Journal titles should be written clearly, without abbreviation. Abbreviation can be used in long journal titles.
Ursavaş S. Çetin B. 2012. *Seligeria donniana* (Sm.) Müll. Hal. (Seligeriaceae) a new record to the bryophyte flora of Turkey. Biological Diversity and Conservation. 5:2, 70-72.

Books
Smith A.J.E. 1990. The liverworts of Britain and Ireland. Cambridge University Press. London.

Chapters in books
Ursavaş S. Çetin B. 2013. Contribution to the Moss Flora of Kizildağ (Isparta) National Park in Turkey. Current Progress in Biological Research. Silva-Opps M. Editor(s). Rijeka, Croatia. pp. 41-70.

Web sites (no print version):
URL1. Missouri Botanical Garden. 2016. Website: http://www.tropicos.org/Project/IPCN [Accessed: 00 Month 2008].
URL2. Missouri Botanical Garden. 2018. Website: http://www.tropicos.org/Name/35147246 [Accessed: 00 Month 2008].

Tables and Figures:
All illustrations (photographs, drawings, graphs, etc.), not including tables, must be labelled "Figure." Figures must be submitted both in the manuscript and as separate files.

All tables and figures must have a caption and/or legend and be numbered (e.g., Table 1, Figure 2), unless there is only one table or figure, in which case it should be labelled "Table" or "Figure" with no numbering. Captions must be written in sentence case (e.g., macroscopic appearance of the samples.). The font used in the figures should be Times New Roman. If symbols such as ×, μ, η, or ν are used, they should be added using the Symbols menu of Word

All tables and figures must be numbered consecutively as they are referred to in the text. Please refer to tables and figures with capitalization and unabbreviated (e.g., "As shown in Figure 2…", and not "Fig. 2" or "figure 2"). The tables and figures themselves should be given at the end of the text only, after the references, not in the running text.

The resolution of images should not be less than 118 pixels/cm when width is set to 16 cm. Images must be scanned at 1200 dpi resolution and submitted in jpeg. or tiff. format.

Graphs and diagrams must be drawn with a line weight between 0.5 and 1 point. Graphs and diagrams with a line weight of less than 0.5 point or more than 1 point are not accepted. Scanned or photocopied graphs and diagrams are not accepted.

Charts must be prepared in 2 dimensions unless required by the data used. Charts unnecessarily prepared in 3 dimensions are not accepted.

Figures that are charts, diagrams, or drawings must be submitted in a modifiable format, i.e. our graphics personnel should be able to modify them. Therefore, if the program with which the figure is drawn has a "save as" option, it must be saved as *.ai or *.pdf. If the "save as" option does not include these extensions, the figure must be copied and pasted into a blank Microsoft Word document as an editable object. It must not be pasted as an image file (tiff, jpeg, or eps) unless it is a photograph.

Tables and figures, including caption, title, column heads, and footnotes, must not exceed 16 × 20 cm and should be no smaller than 8 cm in width. For all tables, please use Word's "Create Table" feature, with no tabbed text or tables created with spaces and drawn lines. Please do not duplicate information that is already presented in the figures.

Tables must be clearly typed, each on a separate sheet, and double-spaced. Tables may be continued on another sheet if necessary, but the dimensions stated above still apply.

Correspondence Address

Manuscripts can only be submitted through our online system. Other correspondence may be directed to:
E-mail: anatolianbryology@gmail.com, serhatursavas@gmail.com
or Dr. Serhat URSAVAŞ Çankırı Karatekin University, Faculty of Forestry, Department of Forest engineering, Department of Forest Botany, Anatolian Bryology. 18200 Çankırı/TURKEY

Anatolian Briyoloji Dergisinin Kapsamı

Anadolu Briyoloji Dergisi, karayosunu, ciğerotları ve boynuzsu ciğerotları ile ilgili değişik alanlarda yapılan, morfolojik, mikroskobik yapıları, biyolojik çeşitlilik, koruma, biyoteknoloji, çevre düzenleme, tehlike altındaki türler, tehlike altındaki habitatları, sistematik, vejetasyon, ekoloji, biyocoğrafya, genetik ve tüm briyofitler arasındaki ilişkileri konu alan orijinal makaleleri yayınlar. Tanımlayıcı ya da deneysel ve sonuçları net olarak belirlenmiş deneysel çalışmalar kabul edilir. Makale yazım dili Türkçe veya İngilizcedir. Yayınlanmak üzere gönderilen yazı orijinal, daha önce hiçbir yerde yayınlanmamış olmalı veya işlem görüyor olmamalıdır. Yayınlanma yeri Türkiye'dir. Bu dergi yılda iki sayı yayınlanır, erişime açık ve ücretsizdir.

Dergi yazım kurallarına uymayan veya derginin kapsamı dışındaki konulardan oluşan makaleler hakem değerlendirme sürecine girmeden reddedilir. Her makale için, gerekli kurallara göre doldurulmuş ve yazar veya yazarların hepsi tarafından imzalanmış olan Telif Hakkı Devir Formu, makale yayınlanmadan önce dergi editörüne gönderilmelidir. Dergiye gönderilecek makaleler ve süreç ile ilgili her türlü yazışmalar, doğrudan internet ortamında elektronik posta ile yapılmalıdır. Dergi tüm milletlerdeki araştırmacılara açıktır. Makalelerin aşağıdaki şekilleri dikkate alınacaktır.

1. **Araştırma makaleleri:** Briyofitlerin çeşitli alanlarındaki özgün araştırma makaleleri değerlendirilecektir.

2. **Araştırma notları:** Bunlar morfolojik, anatomik, sitolojik, kimyasal bir çalışma ya da araştırma notları üzerinde ön bilgiler ve briyofit türlerinin diğer özellikleri gibi makaleler yer alır.

3. **Yorumlar:** Editör veya danışman kurulu tarafından talep edilecek; briyofitler ile alakalı çeşitli alanlardaki son ilerlemeler, gelişmeler, keşifler yorumlar ve fikirlerdir.

4. **Editöre Mektuplar:** Bunlar; Anadolu Briyoloji Dergisinin yayın politikalarına ilişkin, görüşleri, yorumları içerir. Yazılar bir dergi sayfasını geçmez.

Yazar Rehberi
Makalenin hazırlanması

Stil ve biçim: Makale çift satır aralığı ve sayfanın her tarafından 3 cm kenar boşluğu bırakılarak Times New Roman formatında yazılmalıdır. Makalelerin her sayfası başlık, kaynaklar, tablolar, vb. numaralandırılmalıdır. Makalelerin her sayfası, satır numarası 1 ile başlamak kaydıyla numaralandırılır. Makaleler İngilizce veya Türkçe yazılabilir. Anadili İngilizce olmayan yazarlar için; Bir dil editörüne veya akıcı bir şekilde İngilizceyi konuşabilen bir meslektaşından yardım almaları tavsiye edilir. Kullanılan kelimelerde argo olmaksızın öz İngilizce kullanılmalıdır. Uzun cümle ve edilgen yapılardan kaçınılmalıdır. Eserin bilgisayar programı kullanılarak imla ve dilbilgisi kurallarına uygun olup olmadığı kontrol edilmelidir. Makalenin tamamı İngilizce (Amerikan) yazım kuralı ile tutarlı olmalıdır.

Semboller, birimler ve kısaltmalar: Genel olarak dergi kuralları, Yazarlar için CSE Kılavuzu, Editör ve Yönetim Kurulu, VA, ABD. ve Yayıncılar için vb. bilimsel stil ve format kullanılmalıdır. Eğer ×, μ, η, or ν gibi semboller kullanılacaksa Word semboller menüsü kullanılarak eklenmelidir. Derece sembolleri (°), klavye üzerindeki o veya 0 kullanılarak değil semboller menüsü kullanılarak oluşturulmalıdır. Çarpma sembolleri (×), harfi değil x sembolü kullanılmalıdır. Alansal ifadeler sayı ve birimler arasına (Ör. 3 kg), yine aynı şekilde numara ve matematik sembolleri (+, -, ×, =, <,>) arasına konulmalıdır fakat sayı ve yüzde sembolleri kullanılacaksa İngilizce makalelerde rakamdan sonra yüzde işareti (Ör. 45%) konulmalıdır. Genellikle tüm sayılar (ör. "2 önceki çalışmada"…) rakam olarak verilmelidir. Lütfen tüm ayrıntılar için yukarıdaki yazım kılavuzunu inceleyiniz. Tüm açıklamalar ve kısaltmalar ilk geçtiği yerde belirtilmelidir. Latince olan bazı terimler örneğin: et al., in vitro ya da in situ Latince yazılmamalıdır.

Makale içeriği: Araştırma makalelerini şu bölümlere ayrılması tavsiye edilir: Ana bölümler (1. Giriş, 2. Materyal ve Metot, 3. Bulgular, 4. Tartışma ve Sonuç vb.) ve alt bölümler 1.1., 1.2., vb. numaralı olması gerekir.

01 Ocak 2017 tarihinden itibaren, dergimize gönderilen tüm makalelerin özgünlüğünün tespit edilmesi amacıyla iThenticate (İntihali Engelleme) Yazılım'ında tarama hizmeti kullanılmaktadır. **iThenticate** yazılımı aracılığı ile web üzerinde ve diğer kaynaklar üzerinde yayınlanmış makale ve dökümanlar arasında makale özgünlük kontrolü yapılmaktadır. Yazarlar**,** **http://www.ithenticate.com** web adresini ziyaret ederek makalelerini dergimize göndermeden önce özgünlük kontrolü yapabilirler.

Anatolian Bryology dergisine sunulan çalışmaların benzerlik oranı **%20'nin** (Tür listesi ve kaynakça hariç) altında olmalıdır.

Etik Kurallar ve Sorumluluklar
Derginin editörlüğü ve yayınlanma süreçleri, Bilim Editörleri Konseyi (CSE), Yayın Etiği Komitesi (COPE), Avrupa Bilim Editörleri Birliği (EASE) ve Ulusal Bilgi Standartları Örgütü'nün kurallarına uygun olarak şekillendirilmiştir (NISO). Anatolian Bryology Dergisi Bilimsel Yayıncılıkta Şeffaflık ve Etik Kurallar İlkelerine uygun bir şekilde yayın yapmaktadır **(https://doaj.org/bestpractice**).

Başlık ve iletişim bilgileri: Makalenin başlığı tüm metni özetler nitelikte olmalıdır (Ör: Kurakçıl bir bitki olan *Syntrichia caninervis* var. *gypsophila* (J.J. Amann ex G. Roth) Ochyra'nın tuz ve kuraklık stresine tepkisi: antioksidan savunma sisteminin rolü). Tüm yazarların tam isimleri (Adı Soyadı tam harflerle), tüm yazarların bağlı oldukları birim (Üniversite, Fakülte, Bölüm, Şehir, Ülke) ve sorumlu yazar için açıkça belirtilmiş e-mail adresi.

Öz:
Özet elde edilen araştırma ve sonuçları hakkında net bilgiler vermelidir ve 200 kelimeyi geçmemelidir.

Anahtar kelimeler:
Erişim ve indekslemeleri etkinleştirmek için 3-10 anahtar kelime veriniz ve başlık ile aynı olmamasına dikkat ediniz. Kısaltma kullanmayınız.
Anahtar kelimelerde standart bir terminoloji oluşturulması ve araştırmacıların makalelere kolay bir şekilde ulaşabilmeleri için, bilimsel makalelerde uygun sayıda, uygun nitelikte ve standart terminolojide anahtar kelimeler bulunması gereklidir. Bilimsel makalelerdeki anahtar kelimelerin, Türkiye Bilim Terimleri arasından seçilmelidir. Bu konuda: **http://www.bilimterimleri.com** adresinden yararlanılabilir.

1. Giriş
Çalışmanın olgusunu savunmanız, sadece arka planda yapılan çalışmaları özetlemeniz gerekir. Sonuç ve bulgular gibi kısımları içermemelidir. Çalışılan konunuz yorumu olmamalı fakat sorun net bir şekilde ele alınarak belirtilmedir.

2. Materyal ve Metot
Materyal ve kullanılan analitik ve istatistiksel işlemler hakkında kısa ama net bilgi veriniz. Bu bölüm mümkün olduğunca açık olmalı yapılan çalışmalar tekrarlanmamalı. Yapılan çalışma ile alakalı marka isimleri, şirketin yerleri, belirtilen tüm ekipman, alet, kimyasallar, vb. verilmelidir.

3. Bulgular
İstasyon bilgileri, bitki listesi, vb.

4. Tartışma ve Sonuç
Sonuç kısmında şekil veya tabloda verilen bilgiler olduğu gibi tekrar edilmemelidir. Tablo veya şekilleri içerisinde yer alan verileri uzun uzadıya tekrarlamak kabul edilemez. Giriş ve bulgular bölümündeki tablolar burada yeniden verilmemelidir. Son paragrafta çalışmanın ana sonuçlarına vurgu yapmak gerekir.

Eğer varsa: Teşekkür ve/veya Feragatname vb.
Finansman kuruluşlarının isimleri tam olarak yazılmalıdır.

Kaynaklar
Metin içerisinde kaynak belirtme, yazar veya yazarların soyadları (virgül) makalenin yayınlandığı tarih verilmelidir. Örnek: (Ursavaş, 2014) veya (Ursavaş ve Keçeli, 2014). Eğer atıf cümle başında verilecekse sadece tarih parantez içerisinde verilmelidir. Örnek: "Ursavaş (2012)'ye göre…". Üç ve daha fazla yazarların atıfları için; ilk yazarın soyadı ve devamında ve ark., (italik değil) kullanılır. Örnek: (Abay ve

ark., 2002). Aynı yazarın aynı yıl içerisinde birden fazla kaynağı varsa, lütfen yılsonuna a, b, c, gibi harf ekleyin: (Keçeli ve ark., 2002a, 2002b). Kaynaklar kronolojik olarak sıralanıp kaynaklar noktalı virgül ile ayrılmalıdır: (Abay, 2000; Keçeli ve ark., 2003; Ursavaş ve Ören, 2012). Web sitesi atıfları (URL1, URL2, …) olmalıdır. Kişisel iletişim ile yayınlanmamış herhangi bir veriyi kaynak olarak kullanmayın ancak metin içerisinde (parantez içerisinde) verilebilir. İngilizce dili dışında yayınlanan bir makaleniz varsa makalenin İngilizce başlığı verilmeli, parantez içerisinde (Türkçe makale, özet İngilizce) gibi bir açıklama ile belirtilmelidir. Eğer yayınlanan makalenin İngilizce bir başlığı yoksa sadece orijinal başlık verilmeli çeviri yapılmamalıdır. Kaynaklar numaralandırılmadan metnin sonunda alfabetik olarak listelenmiş olmalıdır. Makalenin yazarlarının 10 ve aşağısı tümü verilmelidir, 10 yazardan fazla makalelerde ilk 10 yazar verilip geri kalan yazarlar için ve ark., yazılmalıdır. Makalede kaynaklar listesinde verilen yazarların adları yazılışlarının ve yayın yıllarının makale içerisindeki metin ile aynı olup olmadığının dikkatlice kontrolünü yapınız. Kaynaklara aşağıdaki formatta yazılmalıdır: (Lütfen harf ve noktalamaya dikkat edelim):

Dergi isimleri: Kısa dergi isimleri kısaltma yapılmadan açıkça yazılmalıdır. Uzun dergi isimlerinde kısaltma kullanılabilir.
Ursavaş S. Çetin B. 2012. *Seligeria donniana* (Sm.) Müll. Hal. (Seligeriaceae) a new record to the bryophyte flora of Turkey. Biological Diversity and Conservation. 5:2, 70-72.

Kitaplar:
Smith A.J.E. 1990. The liverworts of Britain and Ireland. Cambridge University Press. London.

Kitap bölümü
Ursavaş S. Çetin B. 2013. Contribution to the Moss Flora of Kizildağ (Isparta) National Park in Turkey. Current Progress in Biological Research. Silva-Opps M. Editor(s). Rijeka, Croatia. pp. 41-70.

Web sitesi (Basılı değilse):
URL1. Missouri Botanical Garden. 2016. Website: http://www.tropicos.org/Project/IPCN [Erişim: 00 Ay 2008].
URL2. Missouri Botanical Garden. 2018. Website: http://www.tropicos.org/Name/35147246 [Erişim: 00 Ay 2008].

Tablolar ve Şekiller:
Tüm resimler (Fotoğraf, çizim, grafik vb.) tablolar hariç Şekil etiketi olmalı. Şekiller hem makale içersinde hem de ayrı dosyalar olarak sunulmalıdır.

Tüm tablo ve Şekiller bir başlık veya lejantı olmalı (Ör: Tablo 1, Şekil 1) tüm makaledeki tablo ve şekiller birden fazla ise hepsi sırasıyla numaralandırılmalıdır. Başlıklar cümle halinde yazılmalı (Ör: Örneğin mikroskobik görüntüsü.). Şekil ve tablolarda Times New Roman yazı tipi kullanılmalıdır. Eğer ×, μ, η, ya da ν gibi semboller kullanılacaksa Word Semboller menüsü kullanılarak eklenmelidir.

Metin içerisindeki tüm şekil ve tablolarda atıflar ardışık olarak numaralandırılmalıdır. Tüm tablo ve şekiller büyük harfle ve kısaltma kullanmadan kullanılmalıdır (Ör: Şekil 2, Tablo 3 gibi, şekil 2 veya Tab. 3 gibi değil). Tablo ve şekiller metin içerisindeki atıftan hemen sonra verilmelidir.

Resimlerin çözünürlüğü 118 piksel/cm den az ve 16 cm genişliğinden fazla olmamalıdır. Resimler 1200 dpi çözünürlükte taranmış ve jpeg veya tiff formatında olmalıdır.

Grafikler ve şemalar 0.5 ve 1 nokta arasında ki bir çizgi ağırlığı ile çizilmelidir. Grafikler ve şemalar 0.5 ten az veya 1 den fazla ise kabul edilmez. Taranmış haldeki grafikler ve şemalar kabul edilmezler.

Kullanılan verilerin gerekli olmadığı sürece 2 boyutlu grafikler kabul edilir. Gereksiz yere 3 boyutlu hazırlanmış grafikler kabul edilmez.

Grafikler, temalar, çizimler veya rakamlar değiştirilebilir bir formatta sunulmalı biz basım aşamasında eğer onları değiştirmemiz gerekirse üzerinde değişiklik yapılabilmelidir.

Şekil çizilebilen hangi programı kullanılıyorsanız kullanın farklı kaydet seçeneği kullanarak *.ai veya *.pdf şeklinde kaydedilmesi gerekir. Eğer kullandığınız program farklı kaydet seçeneği yoksa şekil kopyalanıp

düzeltilebilir boş bir Microsoft Word belgesine yapıştırılması gerekir. Bir fotoğraf veya resim dosyası (jpeg, tiff veya eps) olmadığı sürece grafikler veya temalar kopyala yapıştır yapılmamalıdır.

Tablo ve şekiller, ana başlık dahil, sütun başlıkları ve dipnotlar 16 × 20 cm geçmemeli ve genişliği 8 cm den küçük olmamalıdır. Oluşturulan sekmesiz veya sekmeli, çizilen çizgiler veya boşluklardaki bütün tablolar için lütfen Word'ün "Tablo Oluştur" özelliğini kullanın. Lütfen bilgileri çoğaltmayınız zaten şekiller içerisinde sunulmuştur.

Tablolar açıkça yazılmalı ve her bir sayfada çift aralık kullanılmalıdır. Tablolar gerekirse bir sonraki sayfada devam edebilir ancak yukarıda belirtilen boyutlar geçerli olmak kaydıyla.

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Makaleler sadece çevrimiçi sistem üzerinden sunulabilir. Diğer yazışmalara yönelik
E-mail: anatolianbryology@gmail.com, serhatursavas@gmail.com

veya

Dr. Serhat URSAVAŞ Çankırı Karatekin Üniversitesi, Orman Fakültesi, Orman Mühendisliği Bölümü, Orman Botaniği Anabilim Dalı, Anadolo Briyoloji Dergisi 18200 Çankırı/TÜRKİYE

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