AQUATIC RESEARCH
E-ISSN 2618-6365
Aquatic Research 9(4), 323-334 (2026) • https://doi.org/10.3153/AR26026 Research Article

Comparative evaluation of the antimicrobial and antioxidant activities of *Cystoseira barbata*, *Ulva lactuca*, and *Corallina officinalis* collected from the Sinop coast (Black Sea, Türkiye)

Aysel VEYİSOĞLU[1], Demet TATAR[2], Dilara YILMAZ[1], Hünkar Avni DUYAR[3]

Cite this article as:
Veyisoğlu, A., Tatar, D., Yılmaz, D., Duyar, H.A. (2026). Comparative evaluation of the antimicrobial and antioxidant activities of *Cystoseira barbata*, *Ulva lactuca*, and *Corallina officinalis* collected from the Sinop coast (Black Sea, Türkiye). *Aquatic Research*, 9(4), 323–334. https://doi.org/10.3153/AR26026

[1] Sinop University, Vocational School of Health Services, Department of Medical Services and Techniques, 57000, Sinop, Türkiye

[2] Hitit University, Osmancık Ömer Derindere Vocational School, Department of Medical Services and Techniques, 19500, Çorum, Türkiye

[3] Sinop University, Fisheries Faculty, Department of Fishing and Processing Technology, 57000, Sinop, Türkiye

ORCID IDs of the author(s):
A.V. 0000-0002-1406-5513
D.T. 0000-0002-9317-3263
D.Y. 0009-0000-2589-298X
H.A.D. 0000-0002-2560-5407

Submitted: 19.07.2026
Revision requested: 06.08.2026
Last revision received: 12.08.2026
Accepted: 04.09.2026
Published online: 13.09.2026

Correspondence:
Aysel VEYiSOĞLU
E-mail: aveyisoglu@sinop.edu.tr

© 2026 The Author(s)

Available online at
http://aquatres.scientificwebjournals.com

ABSTRACT

This study comparatively evaluated the antimicrobial and antioxidant activities of ethanol extracts obtained from the marine macroalgae *Cystoseira barbata*, *Ulva lactuca*, and *Corallina officinalis* collected from the Sinop coast of the Black Sea (Türkiye). Antimicrobial activity was determined using the disk diffusion method against selected Gram-positive and Gram-negative bacteria as well as yeast and filamentous fungal strains. Antioxidant activity was assessed using the DPPH radical scavenging assay, and IC_{50} values were calculated. The results demonstrated significant species-dependent differences in biological activity. *Corallina officinalis* exhibited the strongest antibacterial activity against *Bacillus subtilis*, *Brevibacillus brevis*, *Listeria monocytogenes*, *Enterobacter aerogenes*, and *Salmonella typhimurium*, whereas *Ulva lactuca* showed the greatest inhibitory activity against *Staphylococcus aureus*, *Candida glabrata*, and *Candida tropicalis*. Although *Cystoseira barbata* displayed moderate antimicrobial activity, it exhibited the highest antioxidant capacity, reaching 60.26% DPPH radical scavenging activity at 1000 µg/mL with the lowest IC_{50} value (577.8 µg/mL). In contrast, *Corallina officinalis* failed to achieve 50% radical scavenging activity within the tested concentration range (IC_{50} >1000 µg/mL). These findings indicate that Black Sea macroalgae represent valuable natural sources of bioactive compounds with promising applications in the pharmaceutical, food, nutraceutical, and biotechnology industries. However, further phytochemical characterization, isolation of active compounds, mechanistic studies, and in vivo investigations are required before their therapeutic and industrial applications can be fully established.

Keywords: *Cystoseira barbata*, *Ulva lactuca*, *Corallina officinalis*, Antimicrobial activities, Antioxidant activities

Introduction

Covering more than two-thirds of the Earth's surface, the oceans represent one of the most important ecosystems for natural product research owing to their remarkable biological diversity. Marine environments harbor a vast array of bioactive molecules that remain largely unexplored due to their exceptional chemical and genetic diversity. Consequently, they are recognized as invaluable resources for drug discovery, biotechnology, and natural product chemistry. A substantial proportion of the metabolites synthesized by marine organisms possess unique chemical structures and remarkable biological properties that are absent in terrestrial organisms. These distinctive characteristics make marine organisms valuable natural resources for pharmaceutical, food, cosmetic, and biotechnological applications (Barbosa et al., 2020; Gnanavel et al., 2019). Among marine organisms, algae constitute a major component of marine biodiversity and have attracted considerable scientific interest in recent years because of their rich content of bioactive metabolites (Lourenço-Lopes et al., 2020).

Macroalgae, commonly referred to as seaweeds, are photosynthetic multicellular eukaryotes that serve as primary producers in coastal ecosystems. In addition to their essential role in maintaining ecological balance in marine environments, their high sensitivity to environmental changes has led to their widespread use as biological indicators of marine ecosystem health. Based on their pigment composition and major biological characteristics, macroalgae are classified into three principal groups: brown algae (*Phaeophyceae*), red algae (*Rhodophyta*), and green algae (*Chlorophyta*). Owing to their distinct metabolic characteristics, these groups exhibit diverse profiles of bioactive compounds (Leandro et al., 2020; Silva et al., 2013).

Macroalgae inhabiting coastal ecosystems are continuously exposed to a wide range of environmental stressors, including intense solar irradiation, ultraviolet (UV) radiation, fluctuations in temperature and salinity, oxidative stress, epiphytic pressure, and microbial colonization. These environmental challenges stimulate the biosynthesis of various secondary metabolites, such as phenolic compounds, phlorotannins, carotenoids, terpenoids, fatty acids, and sulfated polysaccharides, which function as defense mechanisms against adverse conditions (Silva et al., 2020; Tziveleka et al., 2021). Owing to their potent antioxidant, antimicrobial, antiviral, anti-inflammatory, and immunomodulatory properties, these metabolites have attracted considerable scientific interest in recent years (Li et al., 2008; Bedoux et al., 2014; Holdt & Kraan, 2011; Fernando et al., 2016).

Antimicrobial resistance has emerged as one of the most critical global public health challenges, severely limiting the effective treatment of infectious diseases. The increasing prevalence of antibiotic-resistant microorganisms, together with the declining efficacy of existing antimicrobial agents, has highlighted the urgent need to discover novel antimicrobial compounds. At the same time, the well-established role of oxidative stress induced by free radicals in aging and the development of numerous chronic diseases has intensified interest in identifying natural sources of antioxidants (Fernando et al., 2016; Tziveleka et al., 2021). In this context, macroalgae have gained considerable attention as promising natural resources for the discovery of bioactive compounds with both antimicrobial and antioxidant properties.

The quantity and biological activity of bioactive compounds obtained from macroalgae are influenced by numerous factors, including species, season, geographical location, habitat characteristics, environmental conditions, and extraction method (Tüney et al., 2006; Demirel et al., 2009; Čagalj et al., 2022). Therefore, comparing different taxonomic groups under identical experimental conditions is essential not only for evaluating their biological activities but also for improving our understanding of the diversity and distribution of macroalgal metabolites.

The macroalgal species evaluated in the present study, *Cystoseira barbata*, *Ulva lactuca*, and *Corallina officinalis*, represent the three major taxonomic groups of macroalgae, namely brown, green, and red algae, respectively. *Cystoseira barbata* is rich in phlorotannins, fucoidans, alginates, and diterpenes and has attracted considerable attention because of its potent antioxidant and antimicrobial properties (De La Fuente et al., 2021; Khan et al., 2022). *Ulva lactuca* possesses significant biotechnological potential owing to its high content of ulvan, sulfated polysaccharides, phenolic compounds, pigments, and proteins (Kidgell et al., 2019; Tanna & Mishra, 2019). *Corallina officinalis*, on the other hand, is characterized by its content of phenolic compounds, flavonoids, terpenoids, minerals, and its calcified cell wall structure, and has been reported to exhibit promising antioxidant, antimicrobial, and other biological activities (El-Din & El-Ahwany, 2016; Rifi et al., 2022).

Recent floristic investigations have highlighted the considerable diversity of macroalgal communities inhabiting Mediterranean coastal ecosystems, with species composition and richness being strongly influenced by habitat characteristics and substrate type. In a comprehensive survey of the Oran coast (Algerian Mediterranean Sea), Mansouri and Kerfouf

(2025) identified 22 macroalgal species representing the three major taxonomic groups—*Phaeophyceae*, *Ulvophyceae*, and *Florideophyceae*—underscoring the ecological significance of rocky intertidal habitats in maintaining macroalgal biodiversity. Despite the increasing number of studies documenting the taxonomic diversity and spatial distribution of marine macroalgae, investigations addressing their biological activities and biotechnological potential remain comparatively limited. In Türkiye, most studies evaluating the bioactive properties of macroalgae have been conducted along the Aegean and Mediterranean coastlines, whereas the Black Sea coast has received considerably less attention (Tüney et al., 2006; Demirel et al., 2009). Although the Sinop coastline is recognized as a region with considerable macroalgal diversity, comparative studies investigating the antimicrobial and antioxidant activities of dominant macroalgal species, including members of the genera *Cystoseira*, *Ulva*, and *Corallina*, remain scarce (Berber et al., 2015).

Recent studies further demonstrate that macroalgae collected from different geographical regions and belonging to different taxonomic groups may exhibit distinct antimicrobial and antioxidant profiles. Karaman et al. (2022) reported antimicrobial activity for solvent extracts of *Cystoseira barbata* collected off Sinop Province, providing geographically relevant evidence for the bioactive potential of this species. Similarly, Mekhaimar et al. (2024) demonstrated that an ethanolic extract of *C. barbata* inhibited several bacterial fish pathogens, although the magnitude of activity varied among microorganisms. For *Ulva lactuca*, Maray et al. (2023) reported antibacterial and weak antioxidant activities of ulvan, whereas Brahimi et al. (2026) demonstrated antioxidant and antimicrobial activities of ethanolic *U. lactuca* extracts and identified several phenolic compounds using UPLC-HRMS Orbitrap. In addition, Chemlal-Kherraz et al. (2024) demonstrated that the antibacterial activity of *Corallina officinalis* methanolic extracts varied among seasons, highlighting the importance of collection season and environmental conditions when comparing algal bioactivities. Collectively, these findings support the need to interpret macroalgal bioactivity in relation to species, extraction solvent, collection conditions, and target microorganisms rather than assuming a uniform biological effect across macroalgae.

The present study aimed to comparatively evaluate the antimicrobial and antioxidant activities of ethanol extracts prepared from *Cystoseira barbata, Ulva lactuca,* and *Corallina officinalis* collected from the Sinop coastline. By investigating three taxonomically distinct macroalgal species collected from the same geographical region under closely comparable experimental conditions, this study sought to examine species-dependent differences in biological activity while recognizing the potential contribution of extraction method, collection period, and target organism. The findings are interpreted in relation to recent studies of *C. barbata, U. lactuca,* and *C. officinalis* to provide a more critical assessment of the bioactive potential of Black Sea macroalgae.

Materials and Methods

Samples Collection

The macroalgal samples were collected from the Sinop coastline in June 2026 (Figure 1). *Cystoseira barbata* and *Ulva lactuca* samples were collected on 6 June 2026, whereas *Corallina officinalis* samples were collected on 16 June 2026 from the coastal area located at 42°01′06.8″ N, 35°09′54.9″ E. Immediately after collection, the macroalgal samples were transported to the laboratory in insulated containers containing ice packs to prevent deterioration and were processed without delay.

The cleaning procedure for the macroalgal samples was carried out using a modified method described by Ye et al. (2009). To remove surface salt, sand, epiphytes, and other adhering foreign materials, the samples were first washed several times under running tap water and subsequently rinsed three times with distilled water. Excess water was removed using a sieve, after which the samples were cut into small pieces to facilitate drying. The samples were then dried in a drying oven at 40 °C until a constant weight was achieved. After drying, the macroalgae were manually broken into smaller pieces and ground into a homogeneous powder using a blender. The powdered samples were stored at −20 °C until extraction and biological activity analyses were performed (Gümüş & Ünlüsayın, 2016).

Preparation of Macroalgal Extracts

Macroalgal extracts were prepared by modifying the method described by Rodriguez-Bernaldo de Quirós et al. (2010). Briefly, powdered macroalgal samples were mixed with 95% ethanol at a ratio of 1:20 (w/v) and extracted overnight (approximately 16 h) in a shaking incubator at 40 °C. Following extraction, the mixtures were filtered through Whatman No. 1 filter paper to remove solid residues. The filtrates were then concentrated under reduced pressure using a rotary evaporator (Heidolph, Germany) to remove the ethanol and obtain the crude extracts (Veyisoğlu et al., 2024a; Tatar et al., 2025). The extraction procedure was kept identical for all three macroalgal species.

Figure 1. Macroalgal species used in the study: (A) *Cystoseira barbata*, (B) *Ulva lactuca*, and (C) *Corallina officinalis*

Determination of the Antimicrobial Activity of Macroalgal Extracts

The antimicrobial activities of the macroalgal extracts were determined using a modified disk diffusion method described by Veyisoğlu et al. (2024a,b). The modifications made in the present study were the use of 6-mm sterile filter paper discs, a fixed extract loading of 2 mg/disc, 12.5% DMSO as the solvent, and the microorganism-specific media and incubation conditions described below. The assay included Gram-positive bacteria, Gram-negative bacteria, yeasts, and a filamentous fungus to provide a broader preliminary screening of antimicrobial activity.

The bacterial strains were cultured on Mueller–Hinton Agar (MHA), whereas the fungal strains were cultured on Sabouraud Dextrose Agar (SDA) (Difco, USA). Bacterial cultures were incubated at 37 °C, while fungal cultures were incubated at 28 °C for 18–24 h. Microbial suspensions were adjusted to the 0.5 McFarland standard (approximately 1.5×10^8 CFU/mL), and 100 µL of each suspension was uniformly spread onto the surface of the appropriate agar medium using a sterile cotton swab.

Sterile filter paper discs (6 mm in diameter) were impregnated with 25 µL of macroalgal extract dissolved in 12.5% DMSO to obtain a final loading of 2 mg extract per disc (2 mg/disc). The discs were then dried under a laminar airflow cabinet to allow complete evaporation of the solvent. After drying, the discs were aseptically placed onto the surfaces of the inoculated agar plates. The same extract loading and disc diameter were used for all three macroalgal extracts. Plates inoculated with bacterial strains were incubated at 37 °C, whereas those inoculated with fungal strains were incubated at 28 °C for 18–24 h.

Ampicillin (10 µg/disc) and gentamicin (10 µg/disc) discs were used as positive controls for bacterial strains, while nystatin (100 µg/disc) discs served as the positive control for fungal strains. A 12.5% DMSO solution, used as the solvent for dissolving the extracts, served as the negative control.

Following incubation, the diameters of the inhibition zones were measured in millimeters (mm) using a digital caliper, and the antimicrobial activities of the extracts were evaluated accordingly. All experiments were performed in triplicate using three independent experiments.

For descriptive interpretation of crude-extract disk diffusion results, inhibition zones were classified according to the scheme reported by Ponce et al. (2003): <8 mm, not sensitive; 8–14 mm, sensitive; 15–19 mm, very sensitive; and ≥20 mm, extremely sensitive. Because disk diffusion zone diameters

are influenced by extract loading and diffusion characteristics, and these categories were not developed as clinical susceptibility breakpoints for crude algal extracts, they were used only for comparative descriptive interpretation and not as clinical susceptibility criteria.

Determination of DPPH Free Radical Scavenging Activity of Macroalgal Extracts

The free radical scavenging activities of the macroalgal extracts were determined using a modified DPPH assay based on the method described by Brand-Williams et al. (1995). The assay was performed in 96-well microplates. Macroalgal extracts were prepared in 12.5% DMSO at concentrations of 1000, 750, 500, 250, and 125 µg/mL. For the assay, 100 µL of each extract solution was mixed with 100 µL of 0.2 mM DPPH solution in each well, resulting in a final reaction volume of 200 µL. The reaction mixtures were incubated at room temperature in the dark for 30 min. Following incubation, the absorbance was measured at 517 nm using a microplate reader (Multiskan GO, Thermo Scientific, Finland).

A mixture of DPPH solution and 12.5% DMSO served as the negative control, while gallic acid was used as the positive control. The DPPH radical scavenging activity was calculated using the following equation:

$$\text{DPPH inhibition (\%)} = [(A_0 - A_1) / A_0] \times 100$$

where A_0 represents the absorbance of the control and A_1 represents the absorbance of the sample containing the extract.

The inhibition percentages obtained at different concentrations were used to construct concentration–response curves, and the half-maximal inhibitory concentration (IC_{50}), defined as the concentration required to scavenge 50% of DPPH radicals, was calculated. IC_{50} values were obtained from the concentration–response relationship using the measured inhibition percentages. Because the present concentration range did not produce 50% inhibition for *C. officinalis*, its IC_{50} was reported as >1000 µg/mL. All experiments were performed in triplicate using three independent experiments.

Statistical Analysis

The DPPH data and inhibition-zone measurements were stored and analyzed using SPSS 20 (IBM), and the DPPH concentration–response graph was prepared using Microsoft Excel 2007. For each microorganism, inhibition-zone diameters were compared among treatment groups using one-way analysis of variance (ANOVA), followed by Tukey HSD for multiple comparisons (Genç & Soysal, 2018). Results are presented as arithmetic mean ± standard error (SE) for inhibition zones and mean ± standard deviation (SD) for DPPH measurements, as specified in the corresponding table. Three independent experiments were performed for each assay; therefore, n = 3 represents independent experimental replicates.

Results and Discussion

In the present study, the antimicrobial activities of ethanol extracts obtained from *Cystoseira barbata, Ulva lactuca,* and *Corallina officinalis* collected from the Sinop coast of the Black Sea were comparatively evaluated. The observed inhibition varied substantially among both algal species and target microorganisms. Using the descriptive classification of Ponce et al. (2003), most extract-induced zones in the present study fell within the sensitive range (8–14 mm), whereas values below 8 mm were considered not sensitive. Thus, the results should be interpreted as preliminary in vitro inhibition rather than evidence of strong antimicrobial potency. The absence or low magnitude of inhibition observed for several Gram-negative bacteria is also compatible with the recognized barrier function of the Gram-negative outer membrane, although microorganism-specific physiology and extract diffusion may additionally contribute to the observed pattern.

The present findings can be further contextualized by recent studies. Karaman et al. (2022), working with *C. barbata* collected from Sinop Province, evaluated several solvent extracts and reported antimicrobial effects against a broad panel of microorganisms, illustrating that solvent polarity can influence the activity obtained from the same algal species. Mekhaimar et al. (2024) likewise reported that 95% ethanol extracts of *C. barbata* produced measurable inhibition against bacterial fish pathogens, but the inhibition zones varied by strain. These observations support the interpretation that the activity detected in the present study is species- and microorganism-dependent and may also be extraction-dependent. In addition, the seasonal variation reported for *C. officinalis* by Chemlal-Kherraz et al. (2024) indicates that collection time should be considered when comparing inhibition zones across studies. Because the present work used a single extraction solvent and samples collected during June, differences among species cannot be attributed exclusively to metabolite abundance.

Among the tested macroalgae, *Corallina officinalis* produced the largest inhibition zones against *Bacillus subtilis, Brevibacillus brevis, Listeria monocytogenes, Enterobacter aerogenes,* and *Salmonella typhimurium.* However, the observed zones (generally 7–10 mm for these microorganisms) correspond to preliminary/sensitive-level inhibition under the Ponce et al. (2003) descriptive scheme rather than strong activity. Recent work on *C. officinalis* has also demonstrated

that inhibitory activity varies with collection season, reinforcing the importance of environmental and temporal factors when comparing results among studies (Chemlal-Kherraz et al., 2024). The association of this activity with phenolic compounds, flavonoids, bromophenols, or terpenoids should therefore be considered a plausible explanation based on the literature, not a demonstrated mechanism in the present study, because the active metabolites were not chemically identified.

Ulva lactuca demonstrated the greatest inhibition against *Staphylococcus aureus, Candida glabrata,* and *Candida tropicalis*. This finding is broadly compatible with previous evidence that *U. lactuca* and its ulvan-rich fractions can exhibit antibacterial activity (Maray et al., 2023). Importantly, the present study used a crude ethanol extract rather than an isolated ulvan fraction, and therefore the contribution of ulvan or any individual metabolite cannot be established from the current data. Brahimi et al. (2026) further showed that ethanolic *U. lactuca* extracts contain diverse phenolic and flavonoid constituents and display antimicrobial and antioxidant activities, illustrating the complex chemical basis of crude seaweed extracts. The relatively modest inhibition zones obtained here should consequently be interpreted as screening-level activity rather than evidence of high antimicrobial potency.

The ethanol extract of *Cystoseira barbata* produced measurable but generally limited inhibition against several tested microorganisms. Brown macroalgae are recognized as sources of phlorotannins, fucoidans, diterpenes, and other metabolites with reported biological activities; however, the present study did not determine the chemical composition of the extracts. Therefore, the observed inhibition cannot be assigned to a particular metabolite. Differences among *C. barbata* results reported in the literature may reflect solvent polarity, extraction conditions, season, geographic origin, and environmental conditions. This interpretation is supported by Karaman et al. (2022), who obtained different antimicrobial responses from *C. barbata* solvent extracts, and by Mekhaimar et al. (2024), who reported strain-dependent inhibition by an ethanolic *C. barbata* extract.

None of the macroalgal extracts produced a measurable inhibition zone against *Escherichia coli,* whereas the standard antibiotics produced inhibition. This strain-specific lack of activity should not be interpreted as evidence that all Gram-negative bacteria are resistant to macroalgal extracts. Rather, it indicates that the ethanol extracts tested under the present disk-diffusion conditions were ineffective against the *E. coli* strain used. Similarly, no inhibition was observed against *Aspergillus niger.* These negative results emphasize the importance of target-organism selection and demonstrate that the biological activity of crude macroalgal extracts cannot be generalized across microorganisms.

The standard antimicrobial agents produced larger inhibition zones than the macroalgal extracts, as expected for standardized antimicrobial agents used at defined concentrations. The extract zones observed in this study were mostly within the 7–14 mm range and should therefore be described cautiously as weak-to-moderate or sensitive-level preliminary inhibition rather than as strong antimicrobial activity. In addition, statistical significance indicates differences among experimental groups but does not by itself establish antimicrobial potency or therapeutic relevance. Because MIC/MBC values were not determined, the present disk-diffusion data should be regarded as an initial screening assessment.

The antioxidant activities of the ethanol extracts obtained from the three macroalgal species were evaluated using the DPPH radical scavenging assay. All extracts showed concentration-dependent increases in radical-scavenging activity, but the magnitude of the response differed among species. This species-dependent pattern is consistent with recent work showing that antioxidant activity of macroalgae varies with taxonomic identity, extraction conditions, phenolic composition, and environmental factors (Čagalj et al., 2022; Brahimi et al., 2026).

Cystoseira barbata showed the highest measured DPPH radical-scavenging activity at 1000 µg/mL (60.26 ± 2.19%) and the lowest IC_{50} value among the three extracts (577.8 µg/mL). *Ulva lactuca* reached 50.44 ± 3.63% at 1000 µg/mL, whereas *Corallina officinalis* reached 49.76 ± 1.54% and therefore did not reach 50% within the tested range. These values indicate that *C. barbata* had the greatest DPPH-scavenging capacity under the specific assay conditions used here; they do not establish that it is intrinsically the most potent antioxidant macroalga in general.

The higher DPPH response of the *C. barbata* extract is broadly consistent with reports that brown macroalgae can contain substantial levels of phenolic compounds and phlorotannins. De La Fuente et al. (2021) reported pronounced antioxidant activity in *Cystoseira amentacea* extracts, while Čagalj et al. (2022) demonstrated seasonal changes in the composition and antioxidant activity of *Cystoseira compressa*. More recently, Brahimi et al. (2026) reported strong antioxidant activity for ethanolic *U. lactuca* and *Sargassum muticum* extracts and linked their activities to identified phenolic compounds. In contrast, Maray et al. (2023) reported limited antioxidant activity for isolated *U. lactuca* ulvan, illustrating that the measured antioxidant response depends

strongly on which fraction of the alga is extracted and analyzed. These comparisons support the importance of considering extraction strategy and chemical fraction when interpreting inter-study differences.

The antioxidant activities of the ethanol extracts obtained from the three macroalgal species differed considerably depending on algal taxonomy. Among the tested extracts, *Cystoseira barbata* exhibited the highest DPPH radical scavenging activity at all tested concentrations and presented the lowest IC_{50} value (577.8 µg/mL), indicating the strongest antioxidant capacity. In contrast, *Ulva lactuca* showed moderate antioxidant activity (IC_{50} = 976.8 µg/mL), whereas *Corallina officinalis* failed to achieve 50% radical scavenging activity within the tested concentration range (IC_{50} >1000 µg/mL). The increase in radical scavenging activity with increasing extract concentration observed for all three species confirms the concentration-dependent antioxidant behavior that has been widely reported for marine macroalgae.

The relatively high DPPH-scavenging activity of *C. barbata* may be associated with phenolic and phlorotannin-rich fractions reported for brown macroalgae. However, because no phytochemical analysis was performed in the present study, this interpretation remains literature-based and cannot be used to identify the compounds responsible for the observed activity. The result should therefore be described as an association with the known chemical profile of brown macroalgae rather than a demonstrated metabolite–activity relationship.

The present findings are consistent with previous investigations reporting that brown macroalgae generally exhibit stronger antioxidant activity than green and red algae. Demirel et al. (2009) demonstrated that ethanol extracts of several brown algal species collected from the Aegean Sea possessed higher DPPH radical scavenging activity than other macroalgal groups, largely owing to their elevated phenolic content. Similarly, Ye et al. (2009) reported that ethanol extracts of the brown alga *Sargassum pallidum* showed strong dose-dependent antioxidant activity, emphasizing the importance of phenolic compounds in free radical scavenging. Seasonal and environmental factors have also been shown to influence antioxidant capacity through alterations in secondary metabolite production, particularly in brown algae (Čagalj et al., 2022).

Although *U. lactuca* exhibited lower antioxidant activity than *C. barbata*, its radical scavenging activity increased steadily with concentration and reached approximately 50% inhibition at the highest tested concentration. This antioxidant capacity has been associated with the presence of sulfated polysaccharides (ulvan), flavonoids, chlorophyll derivatives, carotenoids, and phenolic compounds, all of which contribute to oxidative stress reduction through different mechanisms (Kidgell et al., 2019; Tanna & Mishra, 2019; Leandro et al., 2020). However, the comparatively higher IC_{50} value suggests that the concentration of antioxidant metabolites in *U. lactuca* was lower than that of the brown macroalga examined in this study.

The relatively weak antioxidant activity observed for *C. officinalis* agrees with previous reports indicating that many calcified red algae generally contain lower concentrations of phenolic antioxidants than brown algae. Although red algae synthesize bromophenols, flavonoids, terpenoids, and other bioactive compounds with antioxidant potential, the abundance and bioavailability of these metabolites vary considerably among species and environmental conditions (El-Din & El-Ahwany, 2016; Rifi et al., 2022). Furthermore, the calcified cell wall characteristic of *Corallina* species may reduce extraction efficiency, thereby limiting the recovery of antioxidant constituents during ethanol extraction.

The positive control (gallic acid) showed an IC_{50} value of 590 µg/mL, which was numerically close to the value obtained for *C. barbata* (577.8 µg/mL). However, IC_{50} values should be interpreted together with the complete concentration–response profiles, and the present data do not permit conclusions about synergistic interactions among individual compounds. Because the extracts were not chemically characterized, any attribution of the observed antioxidant effect to specific metabolites or synergistic combinations remains speculative.

Overall, the present results indicate that *C. barbata* had the highest DPPH radical-scavenging capacity among the three extracts under the conditions tested. This finding provides a useful basis for further investigation, but it should not be interpreted as proof of superior antioxidant efficacy beyond the present in vitro assay. Phytochemical characterization using HPLC-MS/MS or LC-MS/MS, together with complementary assays such as ABTS, FRAP, ORAC, or CUPRAC, would be required to determine the chemical basis and broader antioxidant profile of these extracts.

Study limitations should also be considered when interpreting these findings. The present work evaluated crude 95 % ethanol extracts obtained with a single extraction protocol and used disk diffusion as a preliminary antimicrobial screening method; MIC/MBC testing was not performed. Likewise, antioxidant activity was assessed using DPPH alone, and the extracts were not subjected to targeted or untargeted phytochemical characterization. The samples were collected during a single month, and *C. barbata/U. lactuca* and *C. officinalis* were collected on different dates in June 2026. Consequently,

the observed interspecific differences may reflect both taxonomic and collection-related variation. These limitations should be addressed in future studies using multiple solvents, standardized chemical profiling, MIC/MBC assays, complementary antioxidant methods, and sampling across seasons.

Table 1. Comparison of the antimicrobial activities of macroalgal extracts against the tested microorganisms with standard antimicrobial agents

	Inhibition zone (mm)							
Microorganisms	***Cystoseira barbata***	***Ulva lactuca***	***Corallina officinalis***	**AMP10**	**CN10**	**NY100**	**DMSO (12.5%)**	**P value**
Bacillus subtilis ATCC 6633	-	8.00 ±0.58^{b}	10.00 ±0.58^{b}	35.00 ±0.58^{a}	22.00 ±0.58^{ab}	ND	-	<0.001
Brevibacillus brevis ATCC 35690	7.00 ±0.58^{c}	7.00 ±0.58^{c}	10.00 ±0.58^{b}	-	22.00 ±0.58^{a}	ND	-	<0.001
Listeria monocytogenes NCTC 5348	7.00 ±0.58^{c}	7.00 ±0.58^{c}	10.00 ±0.58^{b}	-	22.00 ±0.58^{a}	ND	-	<0.001
Staphylococcus aureus ATCC 25923	12.00 ±0.58^{c}	14.00 ±0.58^{b}	10.00 ±0.58^{d}	25.00 ±0.58^{a}	20.00 ±0.58^{ab}	ND	-	<0.001
Escherichia coli ATCC 25922	-	-	-	22.00 ±0.58^{a}	20.00 ±0.58^{a}	ND	-	0.070
Enterobacter aerogenes CCU 2531	-	8.00 ±0.58^{c}	10.00 ±0.58^{c}	7.00 ±0.58^{c}	22.00 ±0.58^{a}	ND	-	<0.001
Proteus vulgaris FMC1	10.00 ±0.58^{b}	10.00 ±0.58^{b}	10.00 ±0.58^{b}	10.00 ±0.58^{b}	20.00 ±0.58^{a}	ND	-	<0.001
Salmonella typhimurium NRRL E4413	7.00 ±0.58^{c}	-	10.00 ±0.58^{b}	-	22.00 ±0.58^{a}	ND	-	<0.001
Candida albicans ATCC 10231	-	-	-	ND	ND	25.00 ±0.58^{a}	-	-
Candida glabrata ATCC 15126	10.00 ±0.58^{b}	13.00± 0.58^{a}	10.00 ±0.58^{b}	ND	ND	-	-	0.016
Candida tropicalis ATCC 13803	10.00 ±0.58^{b}	13.00± 0.58^{a}	10.00 ±0.58^{b}	ND	ND	-	-	0.016
Aspergillus niger ATCC 16404	-	-	-	ND	ND	-	-	-

DMSO: Dimethyl sulfoxide (12.5%); AMP10: Ampicillin (10 µg/disc); CN10: Gentamicin (10 µg/disc); NY100: Nystatin (100 µg/disc); -: No effect; ND: not determined/not tested. Inhibition-zone values for extracts represent 2 mg/disc. The activity categories are used only for descriptive interpretation of crude extracts and should not be equated with clinical antimicrobial susceptibility breakpoints

Table 2. DPPH radical scavenging activity (RSA %) and IC_{50} values of ethanol extracts obtained from macroalgae. Values are expressed as mean ± standard deviation (SD) (n = 3)

Macroalgal extract	125 µg/mL	250 µg/mL	500 µg/mL	1000 µg/mL	IC_{50} (µg/mL)
Cystoseira barbata	16.70 ±1.50	32.37 ±4.37	48.11 ±2.88	60.26 ±2.19	577.8
Ulva lactuca	20.54 ±3.70	25.95 ±3.23	40.98 ±1.44	50.44 ±3.63	976.8
Corallina officinalis	14.00 ±1.01	25.46 ±1.96	37.80 ±2.94	49.76 ±1.54	>1000
Gallic acid (positive control)	38.76 ±4.30	43.01 ±2.88	50.51 ±2.58	57.15 ±1.83	590

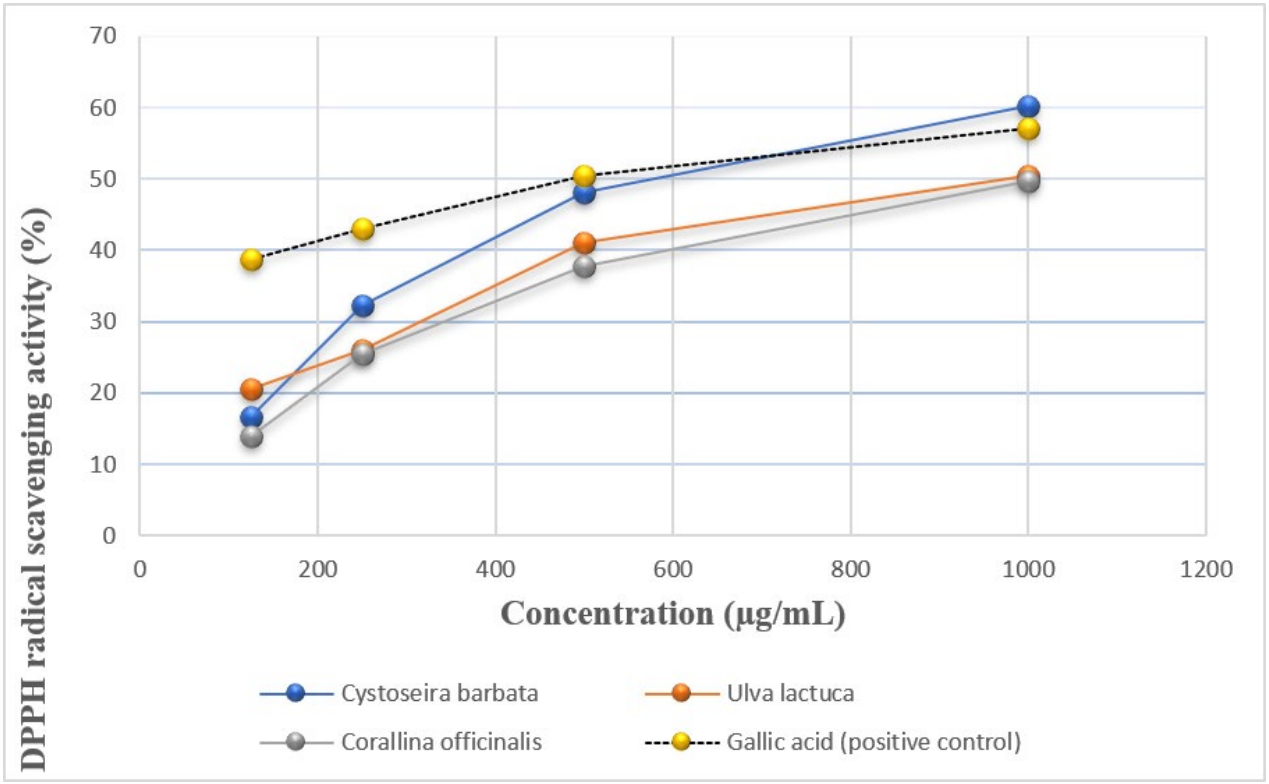

Figure 2. DPPH radical scavenging activity of ethanol extracts obtained from three macroalgal species at different concentrations. Values are expressed as mean ± SD (n = 3)

Conclusion

The present study demonstrated species- and microorganism-dependent differences in the antimicrobial and antioxidant activities of ethanol extracts from *Cystoseira barbata, Ulva lactuca,* and *Corallina officinalis* collected from the Sinop coast. *Corallina officinalis* produced the largest inhibition zones against several bacterial strains, whereas *Ulva lactuca* showed the greatest inhibition against *Staphylococcus aureus* and the tested *Candida* species. *Cystoseira barbata* exhibited the highest DPPH radical-scavenging capacity and the lowest IC_{50} value among the three extracts. However, the antimicrobial inhibition zones were generally limited, and the results should therefore be interpreted as preliminary in vitro activity rather than strong antimicrobial potency.

Overall, the findings support the continued investigation of Black Sea macroalgae as sources of bioactive compounds, while emphasizing that their activity is influenced by species, extraction conditions, collection period, and target organism. The present data do not permit identification of specific active metabolites or prediction of therapeutic efficacy. Future studies should therefore include comparative solvent extraction, MIC/MBC determination, phytochemical characterization, complementary antioxidant assays, toxicity evaluation, and in vivo validation before claims regarding pharmaceutical, nutraceutical, or industrial applications can be substantiated.

Compliance with Ethical Standards

Conflict of interest: The author(s) declare no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: The authors declare that this study does not involve experiments with human or animal subjects, and therefore, ethics committee approval is not required.

Data availability: The data will be made available upon request from the author.

Funding disclosure: This study was supported by the TÜBİTAK 2209-A University Students Research Projects Support Program under the 2025 call and was conducted under project number 1919B012502761.

Acknowledgments: -

Disclosure: -

References

Barbosa, F., Pinto, E., Kijjoa, A., Pinto, M., Sousa, E. (2020). Targeting Antimicrobial Drug Resistance with Marine Natural Products. *International Journal of Antimicrobial Agents*, 5, 106005. https://doi.org/10.1016/j.ijantimicag.2020.106005

Bedoux, G., Hardouin, K., Burlot, A.S., Bourgougnon, N. (2014). Bioactive components from seaweeds: Cosmetic applications and future development. Elsevier: Amsterdam, The Netherlands, Volume 71, ISBN 9780124080621 https://doi.org/10.1016/B978-0-12-408062-1.00012-3

Berber, İ., Avşar, C., Koyuncu, H. (2015). Antimicrobial and antioxidant activities of *Cystoseira crinita* Duby and *Ulva intestinalis* Linnaeus from the coastal region of Sinop, Turkey. *Journal of Coastal Life Medicine*, 3(6), 441–445. https://doi.org/10.12980/JCLM.3.2015JCLM-2015-0013

Brahimi, I., Ayam, I.M., Benyamane, M., Belasla, N., El Kamli, T., Rocha, J.M., Errachidi, F., Rihani, M., & Zinedine, A. (2026). Unlocking the phytochemical and biological attributes of *Ulva lactuca* and *Sargassum muticum* extracts: Antioxidant and antimicrobial activity, and phenolic compounds identification by UPLC-HRMS Orbitrap. *Algal Research,* 96, 104687. https://doi.org/10.1016/j.algal.2026.104687

Brand-Williams, W., Cuvelier, M.E., & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT – Food Science and Technology, 28*(1), 25–30. https://doi.org/10.1016/S0023-6438(95)80008-5

Čagalj, M., Skroza, D., Razola-Díaz, M.D.C., Verardo, V., Bassi, D., Frleta, R., Generalić Mekinić, I., Tabanelli, G., Šimat, V. (2022). Variations in the composition, antioxidant and antimicrobial activities of *Cystoseira compressa* during seasonal growth. *Marine Drugs*, 20(1), 64. https://doi.org/10.3390/md20010064

Chemlal-Kherraz, D., Khelil, F., Mazouzi, M., Matallah-Boutiba, A., & Bouderbala, M. (2024). The seasonal variation of the inhibitory effect of bioactive extracts of a marine algae (*Corallina officinalis*) collected from the Algerian west coast. *Notulae Scientia Biologicae,* 16(3), 11974. https://doi.org/10.55779/nsb16311974

De La Fuente, G., Fontana, M., Asnaghi, V., Chiantore, M., Mirata, S., Salis, A., Damonte, G., Scarfi, S. (2021). The remarkable antioxidant and anti-inflammatory potential of the extracts of the brown alga *Cystoseira amentacea* var. *stricta*. *Marine Drugs,* 19(1), 2. https://doi.org/10.3390/md19010002

Demirel, Z., Yilmaz-Koz, F.F., Karabay-Yavasoglu, U.N., Ozdemir, G., Sukatar, A. (2009). Antimicrobial and antioxidant activity of brown algae from the Aegean Sea. *Journal of the Serbian Chemical Society*, 74(6), 619–628. https://doi.org/10.2298/JSC0906619D

El-Din, S.M.M., El-Ahwany, A.M.D. (2016). Bioactivity and phytochemical constituents of marine red seaweeds (*Jania rubens*, *Corallina mediterranea* and *Pterocladia capillacea*). *Journal of Taibah University for Science*, 10(4), 471–484. https://doi.org/10.1016/j.jtusci.2015.06.004

Fernando, I.P.S., Kim, M., Son, K.-T., Jeong, Y., Jeon, Y.-J. (2016). Antioxidant activity of marine algal polyphenolic compounds: A mechanistic approach. *Journal of Medicinal Food*, 19(7), 615–628. https://doi.org/10.1089/jmf.2016.3706

Genç, S., & Soysal, M.İ. (2018). Parametrik ve parametrik olmayan çoklu karşılaştırma testleri. *Black Sea Journal of Engineering and Science*, 1(1), 18–27.

Gnanavel, V., Roopan, S.M., Rajeshkumar, S. (2019). Aquaculture: An overview of the chemical ecology of seaweeds (Food Species) in natural products. *Aquaculture*, 507, 1–6. https://doi.org/10.1016/j.aquaculture.2019.04.004

Gümüş, B., Ünlüsayın, M. (2016). Determination of antimicrobial activity of two macroalgae extracts. *Ege Journal of Fisheries and Aquatic Sciences*, 33(4), 389–395. https://doi.org/10.12714/egejfas.2016.33.4.13

Holdt, S.L., Kraan, S. (2011). Bioactive compounds in seaweed: Functional food applications and legislation. *Journal of Applied Phycology*, 23, 543–597. https://doi.org/10.1007/s10811-010-9632-5

Karaman, U., Yucel, T.B., Cebeci, T., Arici, Y.K., Yucel, M., & Korkmaz, B. (2022). Investigation of biological, scolicidal and antimicrobial activities of the solvent extracts components of *Cystoseira barbata* seen off Sinop Province. *Indian Journal of Pharmaceutical Education and Research,* 56(2 Suppl), S312–S325. https://doi.org/10.5530/ijper.56.2s.102

Khan, F., Jeong, G.-J., Khan, M.S., Tabassum, N., Kim, Y.-M. (2022). Seaweed-derived phlorotannins: A review of multiple biological roles and action mechanisms. *Marine Drugs,* 20(6), 384. https://doi.org/10.3390/md20060384

Kidgell, J.T., Magnusson, M., de Nys, R., Glasson, C.R. K. (2019). Ulvan: A systematic review of extraction, composition, and function. *Algal Research*, 39, 101422. https://doi.org/10.1016/j.algal.2019.101422

Leandro, A., Pereira, L., Gonçalves, A.M.M. (2020). Diverse applications of marine macroalgae. *Marine Drugs*, 18(1), 17. https://doi.org/10.3390/md18010017

Li, K., Li, X.M., Ji, N.Y., Wang, B.G. (2008). Bromophenols from the marine red alga *Polysiphonia urceolata* with DPPH radical scavenging activity. *Journal of Natural Products*, 71, 28–30. https://doi.org/10.1021/np070281p

Lourenço-Lopes, C., Fraga-Corral, M., Jiménez-López, C., Pereira, A.G., Garcia-Oliveira, P., Carpena, M., Prieto, M.A., Simal-Gandara, J. (2020). Metabolites from macroalgae and its applications in the cosmetic ındustry: A circular economy approach. *Resources*, 9(9), 101. https://doi.org/10.3390/resources9090101

Mansouri, A., & Kerfouf, A. (2025). Biodiversity of marine macroalgae in the Oran coast (Algerian west coast – Mediterranean Sea). *Aquatic Research*, 8(2), 108–119. https://doi.org/10.3153/AR25011

Maray, S.O., Abdel-Kareem, M.S.M., Mabrouk, M.E. M., El-Halmouch, Y., & Makhlof, M.E.M. (2023). In vitro assessment of antiviral, antimicrobial, antioxidant and anticancer activities of ulvan extracted from the green seaweed *Ulva lactuca*. *Thalassas: An International Journal of Marine Sciences,* 39, 779–790. https://doi.org/10.1007/s41208-023-00584-z

Mekhaimar, A.S., El Asely, A.M., Negm, S., & Shaheen, A.A. (2024). Evaluation of antibacterial properties of *Laurencia obtusa* and *Cystoseira barbata* against some bacterial fish pathogens. *Benha Veterinary Medical Journal,* 46, 97–101. https://doi.org/10.21608/bvmj.2024.266909.1781

Ponce, A.G., Fritz, R., del Valle, C.E., & Roura, S.I. (2003). Antimicrobial activity of essential oils on the native microflora of organic Swiss chard. LWT – *Food Science and Technology,* 36(7), 679–684. https://doi.org/10.1016/S0023-6438(03)00088-4

Rifi, M., Alwan, S., Hodroj, M.H., Daher, C.F., Rizk, S. (2022). The Lebanese red algae *Jania rubens*: Promising biomolecules against colon cancer cells. *Marine Drugs*, 20(10), 629. https://doi.org/10.3390/md20100629

Rodríguez-Bernaldo de Quirós, A., Lage-Yusty, M.A., & López-Hernández, J. (2010). Determination of phenolic compounds in macroalgae for human consumption. *Food Chemistry, 121*(2), 634–638. https://doi.org/10.1016/j.foodchem.2009.12.078

Silva, A., Silva, S.A., Carpena, M., García-Oliveira, P., Gullón, P., Barroso, M.F., Prieto, M.A., Simal-gandara, J. (2020). Macroalgae as a source of valuable antimicrobial compounds: Extraction and applications. *Antibiotics*, 9(10), 642. https://doi.org/10.3390/antibiotics9100642

Silva, M., Vieira, L., Almeida, A.P., Kijjoa, A. (2013). The marine macroalgae of the genus Ulva: Chemistry, biological activities, and potential applications. *Journal of Oceanography and Marine Research,* 1, 1–6.

Tanna, B., Mishra, A. (2019). Nutraceutical potential of seaweed polysaccharides: Structure, bioactivity, safety, and toxicity. *Comprehensive Reviews in Food Science and Food Safety*, 18(3), 817–831. https://doi.org/10.1111/1541-4337.12441

Tatar, D., Veyisoğlu, A., Duyar, H. A., Yılmaz, R. (2025). Determination of antimicrobial activities of methanolic extracts of some medicinally ımportant plants found around Çorum province. *Akademik Ziraat Dergisi*, 14(2), 375–381. https://doi.org/10.29278/azd.1788621

Tüney, İ., Çadırcı, B.H., Ünal, D., Sukatar, A. (2006). Antimicrobial activities of the extracts of marine algae from the coast of Urla, İzmir, Turkey. *Turkish Journal of Biology*, 30, 171–175.

Tziveleka, L.-A., Ioannou, E., Roussis, V. (2021). Metabolites with antioxidant activity from marine macroalgae. *Antioxidants*, 10(9), 1431. https://doi.org/10.3390/antiox10091431

Veyisoğlu, A., Balta, Y.E., & Tatar, D. (2024b). Investigation of the antimicrobial activity of water and methanol extracts of *Salvadora persica* L. (Miswak) plant against some pathogenic microorganisms. *International Journal of Agriculture Environment and Food Sciences*, 8(4), 964–969. https://doi.org/10.31015/jaefs.2024.4.25

Veyisoğlu, A., Yeşilyer, A., Tatar, D. (2024a). Ticari olarak satılan *Spirulina platensis*'in üç farklı çözücü ile elde edilen ekstraktlarının seçilmiş patojenik bakteri ve mantarlara karşı antimikrobiyal aktivitelerinin belirlenmesi. *Black Sea Journal of Engineering and Science*, 7(5), 1031–1035. https://doi.org/10.34248/bsengineering.1533314

Ye, H., Zhou, C., Sun, Y., Zhang, X., Liu, J., Hu, Q., Zeng, X. (2009). Antioxidant activities ın vitro of ethanol extract from brown Seaweed *Sargassum pallidum*. *European Food Research Technology*, 230, 101–109. https://doi.org/10.1007/s00217-009-1147-4