

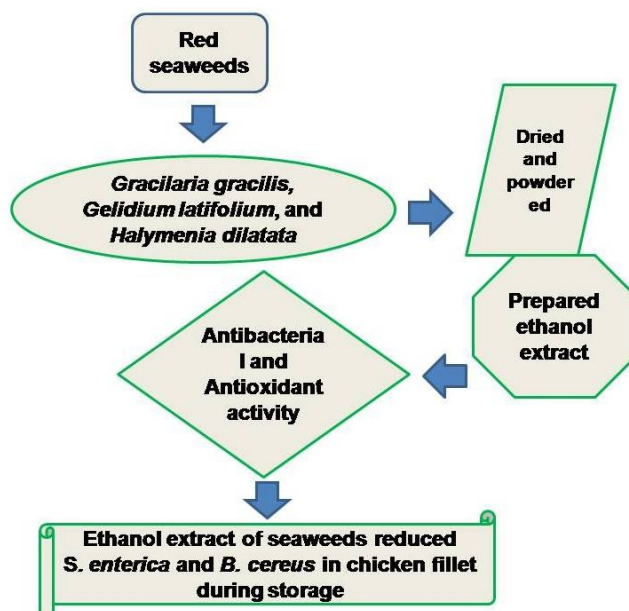
Antioxidant and Antimicrobial Properties of Red Seaweeds for Controlling Foodborne Bacteria in Chicken Fillets

Fatimah S. Al-Khattaf and Ashraf A. Hatamleh  *

*Corresponding author: ahatamleh@ksu.edu.sa

DOI: 10.15376/biores.21.3.6297-6314

GRAPHICAL ABSTRACT



Antioxidant and Antimicrobial Properties of Red Seaweeds for Controlling Foodborne Bacteria in Chicken Fillets

Fatimah S. Al-Khattaf and Ashraf A. Hatamleh  *

Seaweeds are natural resources with antibacterial and antioxidant activities. The major objective of this study was to detect the antibacterial and antioxidant potential and bactericidal activity of chicken fillets during storage. The ethanol extract of *Gracilaria gracilis* had the maximum antibacterial activity, with zones of inhibition of 19 ± 2 mm and 18 ± 2 mm against *Bacillus cereus* ATCC 14579 and *Salmonella enterica* ATCC 13311, respectively. The minimum inhibitory concentration (MIC) of the *G. gracilis* extract ranged from 25 ± 1.25 to 75 ± 5 μ g/mL, and this extract was effective against *B. cereus*. The polyphenol and flavonoid contents were greatest (0.29 ± 0.04 mg GAE/g DW and 37.2 ± 1.8 mg QE/g, respectively) in the *G. gracilis* extract. *G. gracilis* extract exhibited a maximum DPPH scavenging potential of $58.4 \pm 2.4\%$ inhibition. The chicken fillets were experimentally inoculated with *S. enterica* and *B. cereus* and treated with equal proportions of all three seaweeds (*G. gracilis*, *G. latifolium*, and *H. dilatata* extracts) at various concentrations (0 to 8%). The findings revealed that seaweed extracts had antibactericidal effects on chicken fillets stored at 4 °C, reduced the growth of *S. enterica* and *B. cereus*, and improved the sensory properties of chicken fillets.

DOI: 10.15376/biores.21.3.6297-6314

Keywords: Seaweed; Phenolic compounds; Flavonoids; Antioxidants; Chicken fillet

Contact information: Department of Botany and Microbiology, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia; *Corresponding author: ahatamleh@ksu.edu.sa

INTRODUCTION

Macroalgae or seaweeds are diverse organisms in the marine environment. They are widely used in the cosmetic, food, and agricultural industries in the preparation of organic liquid fertilizers, and biomedical products (Fakayode *et al.* 2020). In Asian countries, seaweed has been utilized as a food because of its valuable bioactive substances (Ristivojevic *et al.* 2021). Macroalgal biodiversity has attracted much more attention in recent years to screen for bioactive metabolites that could greatly contribute to the substantial growth of the economy (Čagalj *et al.* 2022). Marine macroalgae are considered novel natural sources of several bioactive substances due to the presence of chemical compounds. Macroalgae synthesize significant amounts of these bioactive secondary metabolites at the end of the growth phase. These secondary metabolites are involved in several functions. Because of their antimicrobial properties, the algal materials are applied to humans and other organisms (Martín-Martín *et al.* 2022). Macroalgae contain compounds, such as phenolic compounds, carotenoids, polysaccharides, phycobiliprotein pigments, and fatty acids, which are largely considered bioactive secondary metabolites that contribute to antimicrobial, anticancer, and antioxidant activities. In recent years,

increased attention has been given to screening the bioactive potential of seaweed. The materials consist of approximately 50% carbohydrates, 80 to 90% water, 7 to 38% minerals, and only 1 to 3% lipids. The protein content varies widely, ranging from 10 to 47%. Marine macroalgae exhibit a variety of polar molecules, including phenolic compounds and pigments that show antibacterial activity against several bacterial pathogens (Shalaby 2011). Red algae yield sulphated galactans, which exhibit various bioactive properties, including anticoagulant, anticancer, antithrombotic, antiproliferative, gastroprotective, antioxidant, immunomodulatory, and anti-inflammatory properties (Barros *et al.* 2013). Macroalgal-derived sulfated polysaccharides are used in cosmetics, food, pharmaceuticals, and nutraceuticals as gelling, thickening, and stabilizing agents (Lajili *et al.* 2018). The marine macroalgae screened from the Persian Gulf showed pancreatic α -amylase inhibition activity and *in vitro* antioxidant activity. Red algae, such as *Sargassum angustifolium*, *Sirophysalis trinodis*, and *Palisada perforate*, exhibit significant antioxidant activity (Pirian *et al.* 2017). Chicken meat is the major source of protein for humans throughout the world. Chicken meat and meat products are associated with the presence of *Staphylococcus aureus*. It is a pathogenic, facultative anaerobic, and virulent bacterium (Massawe *et al.* 2019). This bacterium is resistant to several antibiotics, including methicillin (Dehkordi *et al.* 2017). In recent years, natural antimicrobial agents have been used to control foodborne *S. aureus* in meat (Phan *et al.* 2025). The main objective of this study was to screen the antimicrobial and antioxidant activities of red seaweed to investigate its potential as a natural preservative in chicken fillets.

EXPERIMENTAL

Pathogenic Bacteria

Three Gram-positive bacteria (*Staphylococcus aureus* ATCC 29213, *Bacillus cereus* ATCC 14579, and *Streptococcus pyogenes* ATCC 12384) and three Gram-negative bacteria (*Enterobacter aerogenes* ATCC 13048, *Escherichia coli* ATCC 8739, and *Salmonella enterica* subsp. *Salmonella enterica* Typhimurium ATCC 13311) were purchased from HiMedia Laboratories, Mumbai, India. The strains were cultured in nutrient broth medium (50 mL) and incubated at 37 °C for 24 h. The growth of each individual strain was monitored *via* a UV–visible spectrophotometer (Thermo Fisher Scientific, Waltham, MA, USA), and the cell density was maintained at approximately 1×10^7 CFU/mL.

Seaweed and Extraction

Three seaweed samples were collected from Red Sea and washed with water, and the epiphytes were removed. The collected seaweeds were identified as described previously by Yang *et al.* (2021) and Salem *et al.* (2019). Three seaweeds (*Gracilaria gracilis*, *Gelidium latifolium*, and *Halymenia dilatata*) were subsequently dried and powdered mechanically. The seaweed powder (5 g) was dissolved individually in 70% ethanol (1:10 solvent ratio) and extracted at 28 ± 1 °C for 24 h as described previously by Das *et al.* (2025).

Antibacterial Activity

The antibacterial activity of the seaweed extract was determined *via* the disc diffusion method. Briefly, the pathogenic bacterial strains were cultivated on Mueller–Hinton broth media for 24 h at 37 °C for inoculum preparation. To determine antibacterial activity, Mueller–Hinton agar plates were prepared, and the seaweed extract was prepared at a 25 mg/mL concentration. The cell density of the inoculums was 1×10^8 CFU/mL. Subsequently, 25 µL of the algal extract was loaded on each disc, dried, and placed on MHA plates, and the zone of inhibition (mm) was observed following incubation at 37 °C for 24 h (Zhang *et al.* 2020).

Determination of the Minimum Inhibitory Concentration

The seaweed extract was diluted on Mueller–Hinton broth medium, and various concentrations (250, 125, 75, 37.5, 25, 12.5, 6.25, 5, 2.5, and 1.25 µg/mL) were prepared. The pathogenic bacteria were subsequently inoculated in Mueller–Hinton broth medium after sterilization, and the growth was adjusted to achieve a cell density of 1×10^8 CFU/mL. Furthermore, 10 µL of the bacterial suspension was loaded into a microtiter plate containing 300 µL of medium, and 100 µL of diluted seaweed extract was added. For the negative control, seaweed extract was added, and the extract was not added to the positive growth control. The absorbance of the sample was read at 600 nm using a UV visible spectrophotometer (Thermo Fisher Scientific, Waltham, MA, USA). The growth of bacteria was compared with that of the negative control, and if the absorbance was equal to that of the negative control, then it was considered the MIC value (Malar *et al.* 2020).

Total Phenolic Content of Seaweed Extracts

The total phenolic content (TPC) of the seaweed extract was determined as described earlier. Briefly, 50 µL of ethanol extract (1 mg/mL) was mixed with 450 µL of 1 N Folin–Ciocalteu reagent diluted in double distilled water. Furthermore, the mixture was incubated for 10 min at 30 °C. The absorbance of each sample was measured at 725 nm *via* a microplate reader (BMG LABTECH, 77799 Ortenberg, Germany). The TPC was expressed as gallic acid equivalents/g dry weight seaweed (mg GAE/g DW). A gallic acid suspension was prepared at various concentrations for the preparation of a calibration curve (Antolovich *et al.* 2002).

Total Flavonoid Contents of the Seaweed Extracts

To determine the total flavonoid content (TFC), 250 µL of algal extract was combined with 1 mL of double distilled water and 5% 100 µL of NaNO₂. The mixture was subsequently incubated for 10 min at 30 °C, after which 100 µL of AlCl₃ (10%) was added. The mixture was incubated in the dark for 5 min, and 0.5 mL of 1 M NaOH solution was added. The absorbance of the sample and the standard were read at 510 nm against a reagent blank. Quercetin was used as a standard and was prepared at various concentrations (0.01 to 0.1 mg/mL). The results are expressed as quercetin equivalents/g dry weight seaweed (mg QE/g DW) (Chang *et al.* 2002).

Analysis of Diphenyl-1-Picrylhydrazyl (DPPH) Radical Scavenging Potential

The antioxidant activity of the algal extract was measured *via* the DPPH method. Briefly, the seaweed extract was prepared in methanol at a concentration of 1 mg/mL. The diluted algal extract (1 mL) was subsequently mixed with 1 mL of a 1 mg/mL DPPH solution prepared in methanol. The mixture was incubated for 30 min in darkness, and the absorbance of the sample was read at 517 nm. Ascorbic acid was used as a positive control (Bobo-García *et al.* 2015). The percentage of the seaweed extract inhibited by DPPH was calculated *via* the following formula,

$$\text{DPPH inhibition(\%)} = [(A \text{ of control} - A \text{ of the sample}) / A \text{ of control}] \times 100(1)$$

where *A* refers to the absorbance.

Antibacterial Properties of Seaweed Extracts against *S. enterica* and *B. cereus* in Chicken Fillets

Chicken fillets were cut into small pieces using a sterile knife (50 ± 5 g). The samples were previously sterilized *via* ultraviolet light treatment for 20 min. The chicken fillets were divided into 2 sets (6 chicken fillets for *S. enteric* and 6 chicken fillets for *B. cereus*). For each set of experiments, the experimental setup was as follows: control group (chicken fillet without any seaweed extract treatment, 0% seaweed extract), experimental group 1 (chicken fillet with 2% seaweed extract), experimental group 2 (chicken fillet with 4% seaweed extract), experimental group 3 (chicken fillet with 6% seaweed extract), and experimental group 4 (chicken fillet with 8% seaweed extract). Preliminary analysis revealed that *G. gracilis*, *G. latifolium*, and *H. dilatata* exhibited significant antibacterial activity against selected bacterial pathogens. Hence, all these three extracts were combined and used to analyze their effects on *S. enterica* and *B. cereus* in stored chicken fillets. For the experimental group, chicken fillets were inoculated with either *S. enterica* or *B. cereus* at a concentration of $1 \times 10^8 \text{Log}_{10}\text{CFU/mL}$. The chicken fillet was subsequently incubated for 10 min to improve cell attachment and then stored at 4 °C. The bacterial load was assessed every 2 days of storage, and cells (*S. enterica* and *B. cereus*) were counted *via* the standard method for up to two weeks (FDA 2001).

Sensory Properties

A sensory evaluation was performed to analyze the acceptability of the seaweed extract as a food additive. This was carried out in grilled uninoculated chickens treated with seaweed extract. The chicken fillets were treated with 2, 4, 6, or 8% seaweed extract and stored at 4 °C for two weeks. The sensory properties were analyzed every 2 days. The physical properties, such as odor, color, texture, and taste, of the grilled chicken were analyzed, and the overall acceptance was tabulated. The numerical value 10 is more accepted, and 1 represents less acceptability (Hamad *et al.* 2022).

Statistical Analysis

The results are presented as the means $\pm$ standard deviations. The mean value was used for data analyses. Analysis of variance (ANOVA) was performed *via* the Duncan test, where a probability value <0.01 was considered statistically significant. The statistical analysis was performed using SPSS software (SPSS Inc, Chicago, IL, USA).

RESULTS AND DISCUSSION

Extraction and Yield of the Ethanol Extract

In this study, ethanol was used to extract phytochemical compounds from seaweed. The yield of the *G. gracilis* extract was 5.3%, and it increased to 6.1% in *G. latifolium*. The extract yield was relatively low in *H. dilatata* alga powder treated with ethanol, and the yield was 4.2%. The yield obtained in the present study was similar to the yield of polysaccharides from red seaweeds such as *Sarconema filiforme* (6.0%) and *Gracilaria birdiae* (6.50%) (Chiovitti *et al.* 1998; Maciel *et al.* 2008; Abou Zeid *et al.* 2014). The yield of extract and available phytochemical compounds varies depending on the solvent, extraction time, extraction temperature, and extraction method (Sobuj *et al.* 2021).

Antibacterial Activity

The antibacterial activity of the ethanol extracts of three different red seaweeds (*G. gracilis*, *G. latifolium*, and *H. dilatata*) was analyzed against various foodborne bacterial pathogens, as described in Table 1. The results revealed that all three red seaweed extracts have potential antibacterial activities and inhibit the growth of both Gram-negative and Gram-positive bacteria. *G. gracilis* had the maximum antibacterial activity, with zones of inhibition of 19 ± 2 mm and 18 ± 2 mm against *B. cereus*, and *S. enterica*, respectively. The antibacterial activity of *G. latifolium* extract was maximum against *B. cereus*, and the *E. coli*, and the zones of inhibition were 18 ± 0 mm and 17 ± 0 mm, respectively. Similarly, *H. dilatata* displayed a significant amount of antibacterial activity, with zones of inhibition of 17 ± 1 mm and 16 ± 0 mm against *B. cereus*, and *S. enterica* ($p < 0.01$) (Table 1). Marine macroalgae contain several bioactive secondary metabolites, such as flavonoids and phenolic compounds, which exhibit antimicrobial activities (Al-Saif *et al.* 2014; Jimenez-Lopez *et al.* 2021). In addition to other phytochemicals, the flavonoid content in the seaweed extract exhibited significant antimicrobial potential. The present findings revealed promising alternatives to antimicrobial substances for overcoming drug resistance. The findings were in line with those of El Shafay *et al.* (2016) and Lee *et al.* (2014), who reported that algae phenolic compounds or synergistic compounds have the potential to reduce the use of antibiotics, thus reducing the emergence of antimicrobial resistance among bacteria. *Gracilaria gracilis* extract has shown significant inhibitory activity against *Bacillus subtilis*, and a moderate inhibitory effect has been reported against *Vibrio fischeri* (Capillo *et al.* 2018). Compared with the methanol extract, the ethanol extract of *G. gracilis* exhibited significant activity, which was similar to the results of this study. In addition, *Gracilaria gracilis* extract has been shown to have antibacterial activity via the disk diffusion and broth dilution methods and is suggested for use as a natural fish feed additive (Afonso *et al.* 2021). The ethanolic and aqueous extracts of *Gelidium pusillum* exhibited antibacterial activity against *Aeromonas monascaviae* (Agarwal *et al.* 2021), and a sulfated galactan isolated from *Halymenia dilatata* exhibited antibacterial activity (Vinosha *et al.* 2024). Similarly, hexane and methanol extracts of the red seaweed *Halymenia durvillei* have shown significant activity against *Aeromonas hydrophila* and *Salmonella typhi*, and the zone of inhibition was >20 mm (Kasmiati *et al.* 2022). Seaweed extract showed antimicrobial activity by inhibiting protein synthesis, by disrupting bacterial cell membrane, and interfering with nucleic acid synthesis due to the presence of polysaccharides (Alodaini *et al.* 2025), and tannins and polyphenolic compounds (Baazeem *et al.* 2021; Al-Dhabi *et al.* 2020). These extracts suppress gene expression

related to antibiotic tolerance, and induced bacterial lysis, making them efficient against bacterial pathogens (Dhivya *et al.* 2025).

Table 1. Antimicrobial Activity of the Ethanol Extracts of Selected Seaweeds

Bacteria	Zone of Inhibition (mm)*			
	<i>G. gracilis</i>	<i>G. latifolium</i>	<i>H. dilatata</i>	Chloramphenicol**
<i>Staphylococcus aureus</i>	14 ± 1	16 ± 1	12 ± 0	20 ± 1
<i>Bacillus cereus</i>	19 ± 2	18 ± 0	17 ± 1	20 ± 1
<i>Streptococcus pyogenes</i>	16 ± 1	13 ± 0	10 ± 0	16 ± 1
<i>Enterobacter aerogenes</i>	15 ± 2	15 ± 2	12 ± 1	19 ± 2
<i>Escherichia coli</i>	16 ± 1	17 ± 0	13 ± 2	18 ± 1
<i>Salmonella enterica</i>	18 ± 2	16 ± 1	16 ± 0	21 ± 0

*The data are the means of three different experiments and are expressed as the zone of inhibition; **Positive control

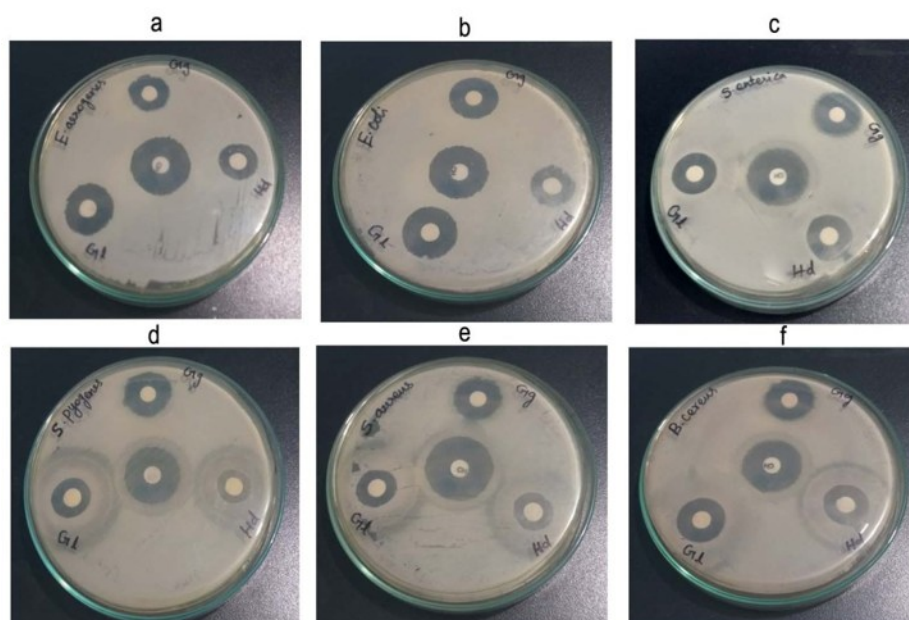


Fig. 1. Antimicrobial activity of the ethanol extracts of selected seaweeds against bacterial pathogens (*E. aerogenes* (a), *E. coli* (b), *S. enterica* (c), *S. pyogenes* (d), *S. aureus* (e), and *B. cereus* (f))

Minimum Inhibitory Concentration of the Ethanol Extract

To determine the MIC, the seaweed ethanol extract was diluted to various concentrations (250 to 1.25 µg/mL). The results revealed that the MIC value of *G. gracilis* was low against both Gram-negative and Gram-positive bacteria. The MIC of the *G. gracilis* extract ranged from 25 ± 1.25 to 75 ± 5 µg/mL, and the most susceptible bacteria were *B. cereus* ($p < 0.01$). The *G. latifolium* extract exhibited significant activity, and a low MIC value (37.5 ± 2.5 µg/mL) was detected against *E. aerogenes*. *H. dilatata* extract showed significant activity against *S. enterica*, and moderate activity was observed against *B. cereus* (Table 2). The present findings revealed the broad-spectrum antimicrobial

activity of seaweed extracts against selected bacterial pathogens. The seaweed extract of *Gracilaria changii* B.M. Xia & I.A. exhibited potential antibacterial activity against seven bacterial pathogens. The MIC values for *Bacillus subtilis* and *Pseudomonas aeruginosa* were reported previously and range from 3.125 to 6.25 mg/mL (Sasidharan *et al.* 2009). In the present study, ethanol was used to extract phytochemical compounds, and significant activity was detected. Similarly, Kim *et al.* (2023) extracted *Gracilaria verrucosa* with water, ethanol, and methanol, and significant activity was achieved with an ethanol extract. The MIC values ranged from 0.06 to 0.3 µg/µL, and the MBC values ranged from 0.1 to 0.5 µg/µL in *Gelidium* sp. The antimicrobial potential of *Gelidium corneum* has been established. The algal extract exhibited potential antibacterial activity against *Cutibacterium acnes*, *Staphylococcus epidermidis* and *Staphylococcus aureus* (Matias *et al.* 2022). The aqueous extract of *Gelidium* sp. exhibited antibacterial activity against bacteria such as *Klebsiella pneumoniae*, *Enterobacter pneumoniae*, *Escherichia coli*, *Bacillus subtilis*, and *Bacillus cereus* (Miranda *et al.* 2022). The red alga *Halymenia durvillei*, which was collected from the Philippines, exhibited antimicrobial effects. The ethyl acetate extract presented antimicrobial properties against Gram-positive and Gram-negative strains. The MIC values obtained in this study were similar to those reported by Padayao *et al.* (2023). Seaweed from the genus *Gelidium* exhibited several bioactive compounds, including, tannins, alkaloids, flavonoids, terpenoids, and saponins, have antibacterial activity (Meinita *et al.* 2023).

Table 2. Minimum Inhibitory Concentrations of Macroalgal Extracts Against Foodborne Bacterial Pathogens

Bacteria	Minimum Inhibitory Concentration (µg/mL)		
	<i>G. gracilis</i>	<i>G. latifolium</i>	<i>H. dilatata</i>
<i>Staphylococcus aureus</i>	50 ± 5	75 ± 1.25	250 ± 12.5
<i>Bacillus cereus</i>	25 ± 1.25	75 ± 5	75 ± 1.25
<i>Streptococcus pyogenes</i>	75 ± 5	125 ± 12.5	250 ± 5
<i>Enterobacter aerogenes</i>	75 ± 2.5	37.5 ± 2.5	125 ± 12.5
<i>Escherichia coli</i>	37.5 ± 2.5	50 ± 1.25	125 ± 12.5
<i>Salmonella enterica</i>	37.5 ± 5	50 ± 2.5	37.5 ± 2.5

Total Phenolic Content of the Seaweed Extracts

The search for natural antioxidants from natural sources has increased considerably in recent years. Polyphenolic compounds are the major natural antioxidant molecules reported in this study. The extraction yield, antioxidant properties, and total polyphenol content rely on the polarity of the selected solvent. The polyphenol compounds of seaweed protect it from environmental stress, reducing the oxidative stress that leads to the generation of reactive oxygen species (Messina *et al.* 2019). The present findings revealed that the polyphenol content was greatest in the ethanol extract of *G. gracilis* (0.29 ± 0.04 mg GAE/g DW), followed by the *H. dilatata* extract (0.25 ± 0.02 mg GAE/g DW) and the *G. latifolium* extract (0.09 ± 0.01 mg GAE/g DW) (Fig. 2). These findings show that ethanol is a suitable solvent for the extraction of polyphenols from natural sources (Hulkko *et al.* 2022). Ethanol and water are important solvents used for the extraction of natural antioxidant compounds because of their relatively low toxicity and possible use in the cosmeceutical and nutraceutical sectors (Vega *et al.* 2020). Generally, other organic

solvents are not used for food-grade applications. In addition to nontoxic aqueous and ethanol extraction, ultrasound-assisted extraction has been used for the extraction of phytochemicals from *Gelidium sesquipedale* (de la Coba *et al.* 2009).

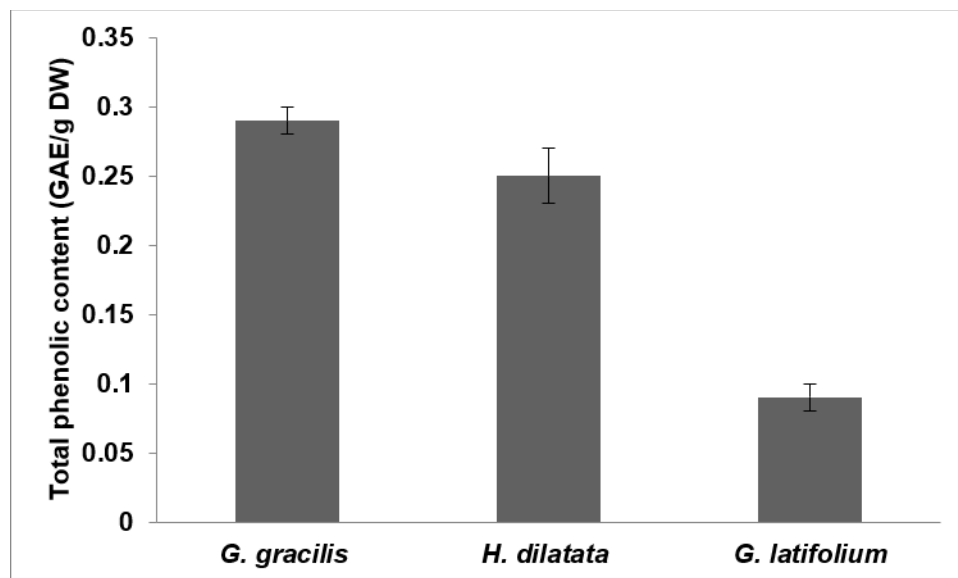


Fig. 2. Total phenolic content of the three selected seaweeds. The Ethanol extract was subjected to estimation, and the results are the means of three different experiments ($p < 0.01$).

Total Flavonoid Contents of the Seaweed Extracts

The TFCs of the seaweed extracts of *G. gracilis*, *G. latifolium*, and *H. dilatata* were analyzed, and the results are presented in Fig. 3. The amount of TFC ranged from 24.2 ± 1.8 mg QE/g to 37.2 ± 1.8 mg QE/g ($p < 0.01$). In this study, ethanol was used for the extraction of TFCs from algae. The results obtained in this study were similar to those of methanol extracts of edible seaweeds collected from the Irish coast (Cox *et al.* 2010). The flavonoid content of *H. dilatata* was lower (24.2 ± 1.8 mg QE/g) than that of the other two selected seaweeds, and this finding was consistent with previous findings on the red seaweed *Halymenia sporoides* (Manam and Subbaiah 2020). The present results revealed higher phenolic content in *G. gracilis* than other red seaweeds (Ganesan *et al.* 2008). This difference in phytochemical compounds may be due to differences in temperature, sample collection location, and stress tolerance (Fellah *et al.* 2017).

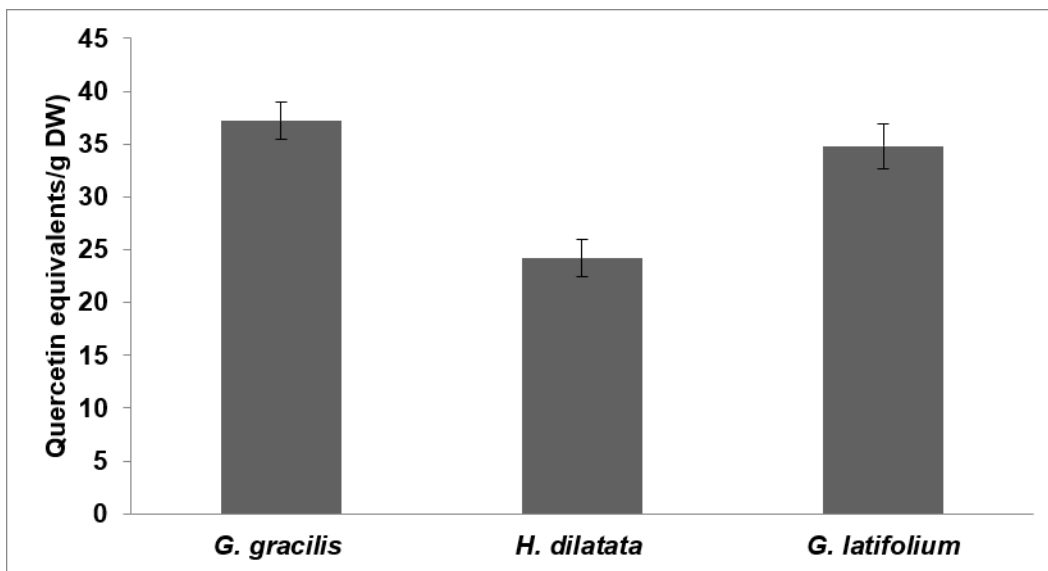


Fig. 3. Total flavonoid content (mg CE/g DW) of three selected seaweeds. The data are presented as the means of three triplicate experimental trials $\pm$ standard deviations ($p < 0.01$).

Antioxidant Activity

Flavonoids, polyphenols, and alkaloids have several health benefits and are considered the major sources of antioxidants. Flavonoids, polyphenols, and alkaloids in seaweed vary with several environmental factors, including the type of shore, tide, stress, temperature, and salinity. The antioxidant activity of three red seaweed extracts (*G. gracilis*, *G. latifolium*, and *H. dilatata*) was determined *via* the DPPH assay method. *G. gracilis* exhibited a maximum DPPH scavenging potential of $58.4 \pm 2.4\%$ inhibition, while *H. dilatata* presented $41.3 \pm 0.5\%$ inhibition activity; however, *G. latifolium* exhibited moderate DPPH scavenging activity, with $34.8 \pm 0.5\%$ inhibition ($p < 0.01$). The DPPH scavenging potential of the alcoholic seaweed extract was comparable to that of the ascorbic acid standard (Fig. 3). In antioxidant assays, the DPPH (1,1-diphenyl-2-picrylhydrazyl) assay is the most suitable free radical to assay reducing bioactive chemicals. Algae polyphenols, especially brown and red algae, are polyphenols and are considered free radical scavengers. The phytochemicals, such as phenolics, including flavonoids, are the major compounds responsible for the antioxidant activity of various marine macroalgae, such as *Gelidium* sp. (Park *et al.* 2025). The ethanol extract obtained from coastal China had good antioxidant activity (Xu *et al.* 2018). Similarly, seaweed obtained from the Moroccan Atlantic Ocean exhibited antioxidant activity (Grina *et al.* 2020). Red algae exhibited rich flavonoids, phenolic compounds and carbohydrates which showed antioxidant activity (Dhaouafi *et al.* 2024).

Table 3. Antioxidant Activity of the Ethanolic Extracts of the Three Selected Seaweeds

Extract/positive control ($\mu\text{g/mL}$)	Antioxidant Activity (%)			
	Ascorbic Acid	<i>G. gracilis</i>	<i>H. dilatata</i>	<i>G. latifolium</i>
20	23 $\pm$ 0.9	5.3 $\pm$ 0.2	3.6 $\pm$ 0.2	6.4 $\pm$ 0.8
40	37 $\pm$ 3.2	18.3 $\pm$ 1.1	22.5 $\pm$ 0.9	10.4 $\pm$ 0.5
60	47.5 $\pm$ 1.9	33.7 $\pm$ 0.9	30.4 $\pm$ 1.1	19.2 $\pm$ 0.4
80	63.4 $\pm$ 2.2	42.5 $\pm$ 1.7	35.3 $\pm$ 0.8	25.4 $\pm$ 0.7
100	89.5 $\pm$ 1.4	58.4 $\pm$ 2.4	41.3 $\pm$ 0.5	34.8 $\pm$ 0.5

The antioxidant activity was determined via the DPPH assay, and the results are expressed as the percentage of radical scavenging activity

Shelf Life of Chicken Fillets Enriched with Seaweed Extract

The chicken fillets were experimentally inoculated with *S. enterica* and *B. cereus* and treated with equal proportions of all three seaweeds (*G. gracilis*, *G. latifolium*, and *H. dilatata* extracts) at various concentrations (0 to 8%). The findings of the present study revealed that seaweed extracts have potential bactericidal effects on chicken fillets stored at 4 °C. At 8% seaweed extract, significant reduction in *S. enterica* population was observed relative to the control ($p < 0.01$) (Table 4). The seaweed extracts had bactericidal effects on *B. cereus*, and the 6% and 8% extract significantly inhibited *B. cereus* population after 10 days of storage. As shown in Table 5, a higher concentration of seaweed extract was more effective at controlling *B. cereus* growth than a lower concentration. Ozogul *et al.* (2023) reported that macroalga (*Padina pavonica*) extracts exhibited significant antibacterial and antioxidant activity. The alga extract improved the shelflife of sea bass fillets and improved the shelflife to 18 days compared with untreated control. They reported that the presence of antioxidant compounds, especially phenolic compounds was attributed to food preserving properties. Furthermore, seaweed extracts can be applied as antibacterial and antioxidant agents in the food processing industry because they are able to improve the oxidative stability and antimicrobial activity of treated chicken fillets compared with control chicken fillets. Roohinejad *et al.* (2017) reported that macroalgae have potent sources of bioactive compounds with antioxidant and antibacterial activities. Phytochemicals, such as carotenoid pigments, phenolics, sulfated polysaccharides, and phlorotannins, are the major phytochemical compounds responsible for their bioactive properties. Seaweed powder and its solvent extracts, preferably nontoxic extracts (for example, water and ethanol), are used in the storage of meat fillets to reduce microbiological growth and slow the oxidation reaction. Gullón *et al.* (2020) reported that raw macroalgae and their extracts improve the quality of meat products. They reported that seaweed extract protected meat and meat products during storage in a concentration-dependent manner. They also reported the oxidative deterioration mechanism of meat products.

Table 4. Effects of Three Seaweed Extracts on the Bactericidal Activity of Chicken Fillets Artificially Inoculated with *S. enterica* After Storage for Two Weeks

Extract Conc.	Bacteria (Log ₁₀ CFU/g)							
	Day 0	Day 2	Day 4	Day 6	Day 8	Day 10	Day 12	Day 14
Negative control	0	0	0	0	0	0	0	0
Positive control	1 × 10 ⁸ ± 0.02 ^a	1 × 10 ⁸ ± 0.03 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.01 ^a
T1: 2 g/100 g	0.91 ± 0.03 ^b	1.34 ± 0.02 ^b	1.41 ± 0.01 ^b	1.53 ± 0.03 ^b	1.63 ± 0.03 ^b	1.63 ± 0.03 ^b	1.63 ± 0.03 ^b	1.63 ± 0.03 ^b
T2: 4 g/100 g	0.87 ± 0.01 ^c	1.03 ± 0.01 ^c	1.32 ± 0.01 ^c	1.43 ± 0.01 ^c	1.51 ± 0.01 ^c	1.51 ± 0.01 ^c	1.51 ± 0.01 ^c	1.51 ± 0.01 ^c
T3: 6 g/100 g	0.83 ± 0.03 ^c	0.91 ± 0.02 ^d	1.1 ± 0.03 ^d	1.2 ± 0.03 ^d	1.3 ± 0.03 ^d	1.5 ± 0.01 ^c	1.6 ± 0.02 ^b	1.7 ± 0.03 ^b
T4: 8 g/100 g	0.71 ± 0.01 ^d	0.85 ± 0.03 ^e	0.73 ± 0.01 ^e	1.1 ± 0.03 ^e	1.2 ± 0.02 ^d	1.3 ± 0.02 ^b	1.4 ± 0.01 ^d	1.6 ± 0.02 ^c

Different lower-case letters next to numerical value in the column indicate significant variation between control and treatment groups.

Table 5. Effects of Three Seaweed Extracts on the Bactericidal Activity of Chicken Fillets Artificially Inoculated with *Bacillus cereus* During Storage for Two Weeks

Extract Conc.	Bacteria (Log ₁₀ CFU/g)							
	Day 0	Day 2	Day 4	Day 6	Day 8	Day 10	Day 12	Day 14
Negative control	0	0	0	0	0	0	0	0
Positive control	1 × 10 ⁸ ± 0.31 ^a	1 × 10 ⁸ ± 0.04 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.02 ^a	1 × 10 ⁸ ± 0.03 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.01 ^a	1 × 10 ⁸ ± 0.01 ^a
T1: 2 g/100 g	1.03 ± 0.02 ^b	1.19 ± 0.04 ^b	1.58 ± 0.013 ^b	1.74 ± 0.05 ^b	1.77 ± 0.03 ^b	1.82 ± 0.01 ^b	1.88 ± 0.03 ^b	1.92 ± 0.2 ^b
T2: 4 g/100 g	0.92 ± 0.04 ^b	1.25 ± 0.09 ^c	1.48 ± 0.013 ^c	1.62 ± 0.025 ^c	1.84 ± 0.029 ^c	1.85 ± 0.022 ^b	1.87 ± 0.02 ^b	1.94 ± 0.02 ^b
T3: 6 g/100 g	0.86 ± 0.07 ^c	1.11 ± 0.06 ^d	1.18 ± 0.017 ^d	1.38 ± 0.02 ^d	1.39 ± 0.02 ^d	1.44 ± 0.3 ^c	1.47 ± 0.3 ^c	1.54 ± 0.3 ^c
T4: 8 g/100 g	0.69 ± 0.02 ^d	0.82 ± 0.05 ^e	0.89 ± 0.06 ^e	1.12 ± 0.04 ^e	1.23 ± 0.1 ^e	1.31 ± 0.2 ^c	1.43 ± 0.1 ^c	1.51 ± 0.3 ^c

Different lower-case letters next to numerical value in the column indicate significant variation between control and treatment groups.

Sensory Analysis of Chicken Fillets

The seaweed extract-treated chicken fillet was stored at 4 °C during the experimental trials. According to the results from the experimental groups, the sensory properties were more or less similar in the chicken fillets treated with seaweed extracts. Seaweed extract-treated seaweed showed acceptable scores (>7) at almost all concentrations. This finding reveals that at the tested seaweed extract concentrations (0% to 8%), applying up to 8% may not have a negative effect on the sensory properties of the chicken fillet. The overall acceptability score was >7 for all the treatments (Table 6). The results of the sensory analysis revealed the potential application of seaweed extract as a food enhancer. The acceptability of the chicken fillet was significantly greater than that of the untreated control. The appearance, color, and odor of chicken fillets enriched with

seaweed extract (0% to 8%) were greater than those of the untreated control. Seaweeds and their extracts can be considered natural preservative agents to regulate sensory properties during storage. The meat fortification properties of the seaweed extract agreed with those of the seaweed reported by Gullón *et al.* (2020). They reported that seaweed is a potential source of bioactive compounds and nutrients with novel bioactive properties and novel functional properties. Seaweeds and their extracts can be considered natural preservatives in the meat industry to manage the original properties of meat and meat products.

Table 6. Sensory Properties of Uninoculated Chicken Fillets Enriched with Seaweed Extract at Various Concentrations

Extract Conc. (g/100 g)	Sensory Properties					Overall Acceptability
	Appearance	Color	Odor	Texture	Taste	
Negative control	6.92 ± 0.02	7.02 ± 0.04	8.02 ± 0.07	7.61 ± 0.04	7.92 ± 0.01	7.49 ± 0.15
*T1: 2 g/100 g	7.02 ± 0.02	7.29 ± 0.24	7.93 ± 0.08	7.72 ± 0.02	8.04 ± 0.03	7.6 ± 0.24
T2: 4 g/100 g	7.08 ± 0.03	7.25 ± 0.05	8.05 ± 0.72	7.54 ± 0.01	8.19 ± 0.05	7.7 ± 0.18
T3: 6 g/100 g	7.25 ± 0.05	7.09 ± 0.01	8.04 ± 0.07	7.81 ± 0.04	8.02 ± 0.05	7.64 ± 0.11
T4: 8 g/100 g	7.31 ± 0.48	7.21 ± 0.04	8.12 ± 0.014	7.69 ± 0.04	8.13 ± 0.07	7.67 ± 0.09
*T1 to T4: Treatments 1 to 4; Log ₁₀ CFU/g: Colony-forming unit						

CONCLUSIONS

1. Seaweed extracts of *Gracilaria gracilis*, *Gelidium latifolium*, and *Halymenia dilatata* showed potential antibacterial and antioxidant activities. These extracts exhibited antibacterial activity against the tested bacteria, especially *Salmonella enterica* and *Bacillus cereus*.
2. The mixture of all three seaweed extracts inhibited bacterial growth in chicken millet during storage. The findings revealed that concentration- and time-dependent antibacterial activity controlled the growth of the chicken fillets during storage.
3. Sensory analysis revealed that the seaweed extract from chicken fillets was a good product.

ACKNOWLEDGMENTS

The authors extend their appreciation to the Ongoing Research Funding program (ORF - 2026 - 224) King Saud University, Riyadh, Saudi Arabia.

Conflict of Interest

The authors do not have any conflict of interest in publication of this research article.

Use of Generative AI

Authors did not use any AI tools in the preparation of text, and data analysis.

REFERENCES CITED

- Abou Zeid, A. H., Aboutabl, E. A., Sleem, A. A., and El-Rafie, H. M. (2014). "Water soluble polysaccharides extracted from *Pterocladia capillacea* and *Dictyopteris membranacea* and their biological activities," *Carbohydrate Polymers* 113, 62-66. <https://doi.org/10.1016/j.carbpol.2014.06.004>
- Afonso, C., Correia, A. P., Freitas, M. V., Mouga, T., and Baptista, T. (2021). "In vitro evaluation of the antibacterial and antioxidant activities of extracts of *Gracilaria gracilis* with a view into its potential use as an additive in fish feed," *Applied Sciences* 11(14), article 6642. <https://doi.org/10.3390/app11146642>
- Agarwal, P., Kayala, P., Chandrasekaran, N., Mukherjee, A., Shah, S., and Thomas, J. (2021). "Antioxidant and antibacterial activity of *Gelidium pusillum* (Stackhouse) against *Aeromonas caviae* and its applications in aquaculture," *Aquaculture International* 29, 845-858. <https://doi.org/10.1007/s10499-021-00661-1>
- Al-Dhabi, N. A., ValanArasu, M., Vijayaraghavan, P., Esmail, G. A., Duraipandiyan, V., Kim, Y. O., Kim, H., and Kim, H. J. (2020). "Probiotic and antioxidant potential of *Lactobacillus reuteri* LR12 and *Lactobacillus lactis* LL10 isolated from pineapple puree and quality analysis of pineapple-flavored goat milk yoghurt during storage," *Microorganisms* 8(10), article 1461. <https://doi.org/10.3390/microorganisms8101461>
- Alodaini, H. A., Sheeja, R. R., Joselin, J., Hatamleh, A. A., Al-Dosary, M. A., Rani, S. A., Vijayaraghavan, P., and Arokiyaraj, S. (2025). "Agro-industrial residues: Low-cost biomass for the production of bioactive extracellular polysaccharides by *Lactobacillus plantarum* in solid state fermentation," *BioResources* 20(3), 7358-7377. <https://doi.org/https://doi.org/10.15376/biores.20.3.7358-7377>
- Al-Saif, S. S. A. L., Abdel-Raouf, N., El-Wazanani, H. A., and Aref, I. A. (2014). "Antibacterial substances from marine algae isolated from Jeddah coast of Red sea, Saudi Arabia," *Saudi Journal of Biological Sciences* 21(1), 57-64. <https://doi.org/10.1016/j.sjbs.2013.06.001>
- Antolovich, M., Prenzler, P. D., Patsalides, E., McDonald, S., and Robards, K. (2002). "Methods for testing antioxidant activity," *Analyst* 127(1), 183-198. <https://doi.org/10.1039/B009171P>
- Baazeem, A., Almanea, A., Manikandan, P., Alorabi, M., Vijayaraghavan, P., and Abdel-Hadi, A. (2021). "In vitro antibacterial, antifungal, nematocidal and growth promoting activities of *Trichoderma hamatum* FB10 and its secondary metabolites," *Journal of Fungi* 7(5), article 331. <https://doi.org/10.3390/jof7050331>
- Barros, F. C., da Silva, D. C., Sombra, V. G., Maciel, J. S., Feitosa, J. P., Freitas, A. L., and de Paula, R. C. (2013). "Structural characterization of polysaccharide obtained from red seaweed *Gracilaria caudata* (J Agardh)," *Carbohydrate Polymers* 92(1), 598-603. <https://doi.org/10.1016/j.carbpol.2012.09.009>
- Bazaid, A. S., Alsalamah, S. A., Alsaif, G., Barnawi, H., Aldarhami, A., Qanash, H., Alruhaili, M. H., Almuhayawi, M. S., Tarabulsi, M. K., Jaouni, S. K. A., and Selim, S. (2025). "Extraction of *Thymus vulgaris* at different levels of pressure and their effect against food-born microorganisms with antioxidant and anti-diabetic

- activities,” *Journal of Food Measurement and Characterization* 1-16.
<https://doi.org/10.1007/s11694-025-03722-8>
- Bobo-García, G., Davidov-Pardo, G., Arroqui, C., Vírveda, P., Marín-Arroyo, M. R., and Navarro, M. (2015). “Intra-laboratory validation of microplate methods for total phenolic content and antioxidant activity on polyphenolic extracts, and comparison with conventional spectrophotometric methods,” *Journal of the Science of Food and Agriculture* 95(1), 204-209. <https://doi.org/10.1002/jsfa.6706>
- Čagalj, M., Skroza, D., Razola-Díaz, M. D. C., Verardo, V., Bassi, D., Frleta, R., GeneralićMekinić, I., Tabanelli, G., and Šimat, V. (2022). “Variations in the composition, antioxidant and antimicrobial activities of *Cystoseira compressa* during seasonal growth,” *Marine Drugs* 20(1), article 64.
<https://doi.org/10.3390/md20010064>
- Capillo, G., Savoca, S., Costa, R., Sanfilippo, M., Rizzo, C., Lo Giudice, A., Albergamo, A., Rando, R., Bartolomeo, G., Spanò, N., *et al.* (2018). “New insights into the culture method and antibacterial potential of *Gracilaria gracilis*,” *Marine Drugs* 16(12), article 492. <https://doi.org/10.3390/md16120492>
- Chang, C. C., Yang, M. H., Wen, H. M., and Chern, J. C. (2002). “Estimation of total flavonoid content in propolis by two complementary colorimetric methods,” *Journal of Food and Drug Analysis* 10(3), 178-182. <https://doi.org/10.38212/2224-6614.2748>
- Chiovitti, A., Bacic, A., Craik, D. J., Kraft, G. T., Liao, M. L., Falshaw, R., and Furneaux, R. H. (1998). “A pyruvated carrageenan from Australian specimens of the red alga *Sarconema filiforme*,” *Carbohydrate Research* 310(1-2), 77-83.
[https://doi.org/10.1016/S0008-6215\(98\)00170-0](https://doi.org/10.1016/S0008-6215(98)00170-0)
- Cox, S., Abu-Ghannam, N., and Gupta, S. (2010). “An assessment of the antioxidant and antimicrobial activity of six species of edible Irish seaweeds,” *International Food Research Journal* 17, 205-220. <https://doi.org/10.21427/D7HC92>
- Das, R. S., Tiwari, B. K., Selli, S., Kelebek, H., and Garcia-Vaquero, M. (2025). “Exploring pilot scale ultrasound-microwave assisted extraction of organic acids and phytochemicals from brown seaweed *Alaria esculenta*,” *Algal Research* 86, article 103896. <https://doi.org/10.1016/j.algal.2025.103896>
- De la Coba, F., Aguilera, J., Figueroa, F. L., De Gálvez, M. V., and Herrera, E. (2009). “Antioxidant activity of mycosporine-like amino acids isolated from three red macroalgae and one marine lichen,” *Journal of Applied Phycology* 21, 161-169.
<https://doi.org/10.1007/s10811-008-9345-1>
- Dehkordi, F. S., Gandomi, H., Basti, A. A., Misaghi, A., and Rahimi, E. (2017). “Phenotypic and genotypic characterization of antibiotic resistance of methicillin-resistant *Staphylococcus aureus* isolated from hospital food,” *Antimicrobial Resistance and Infection Control* 6, 1-11. <https://doi.org/10.1186/s13756-017-0257-1>
- Dhaouafi, J., Nedjar, N., Jridi, M., Romdhani, M., and Balti, R. (2024). “Extraction of protein and bioactive compounds from Mediterranean red algae (*Sphaerococcus coronopifolius* and *Gelidium spinosum*) using various innovative pretreatment strategies,” *Foods* 13(9), article 1362. <https://doi.org/10.3390/foods13091362>
- Dhivya, L. S., Chagaleti, B. K., Saravanan, V., Pushparaj, S., Manikandan, P., Aloyuni, S., Al Othaim, A., Ismail, A., Vijayaraghavan, P., Veluchamy, A. and Arockiaraj, J. (2025). “Anti-bacterial activity of furan chalcone derivatives against mycobacterium tuberculosis: Design, synthesis, anti-bacterial screening, pharmacokinetic properties, and toxicity parameters,” *Current Microbiology* 82(8), article 373.
<https://doi.org/10.1007/s00284-025-04319-6>

- El Shafay, S. M., Ali, S. S., and El-Sheekh, M. M. (2016). "Antimicrobial activity of some seaweeds species from Red sea, against multidrug resistant bacteria," *Egyptian Journal of Aquatic Research* 42(1), article 65-74.
<https://doi.org/10.1016/j.ejar.2015.11.006>
- Fakayode, O. A., Aboagarib, E. A. A., Zhou, C., and Ma, H. (2020). "Copyrolysis of lignocellulosic and macroalgae biomasses for the production of biochar – A review," *Bioresource Technology* 97, article 122408.
<https://doi.org/10.1016/j.biortech.2019.122408>
- FDA (Food and Drug Administration) (2001). "Staphylococcus aureus toxin formation in hydrated batter mixes," in: *Fish and Fisheries Products Hazards and Controls Guidance*, Food and Drug Administration Center for Food Safety and AMP, Applied Nutrition, Washington, D.C., USA, pp. 201–208.
- Fellah, F., Louaileche, H., Dehbi-Zebboudj, A., and Touati, N. (2017). "Seasonal variations in the phenolic compound content and antioxidant activities of three selected species of seaweeds from Tiskerth islet, Bejaia, Algeria," *Journal of Materials and Environmental Sciences* 8(12), 4451-4456.
<https://doi.org/10.26872/jmes.2017.8.12.470>
- Ganesan, P., Kumar, C. S., and Bhaskar, N. (2008). "Antioxidant properties of methanol extract and its solvent fractions obtained from selected Indian red seaweeds," *Bioresource Technology* 99(8), 2717-2723.
<https://doi.org/10.1016/j.biortech.2007.07.005>
- Grina, F., Ullah, Z., Kaplaner, E., Moujahid, A., Eddoha, R., Nasser, B., Terzioğlu, P., Yilmaz, M.A., Ertas, A., Öztürk, M., et al. (2020). "In vitro enzyme inhibitory properties, antioxidant activities, and phytochemical fingerprints of five Moroccan seaweeds," *South African Journal of Botany* 128, 152-160.
<https://doi.org/10.1016/j.sajb.2019.10.021>
- Gullón, B., Gagaoua, M., Barba, F. J., Gullón, P., Zhang, W., and Lorenzo, J. M. (2020). "Seaweeds as promising resource of bioactive compounds: Overview of novel extraction strategies and design of tailored meat products," *Trends in Food Science and Technology* 100, 1-18. <https://doi.org/10.1016/j.tifs.2020.03.039>
- Hamad, G. M., Omar, S. A., Mostafa, A. G., Cacciotti, I., Saleh, S. M., Allam, M. G., El-Nogoumy, B., Abou-Alella, S. A. E., and Mehany, T. (2022). "Binding and removal of polycyclic aromatic hydrocarbons in cold smoked sausage and beef using probiotic strains," *Food Research International* 161, article 111793.
<https://doi.org/10.1016/j.foodres.2022.111793>
- Hulkko, L. S., Chaturvedi, T., and Thomsen, M. H. (2022). "Extraction and quantification of chlorophylls, carotenoids, phenolic compounds, and vitamins from halophyte biomasses," *Applied Sciences* 12(2), article 840.
<https://doi.org/10.3390/app12020840>
- Jimenez-Lopez, C., Pereira, A. G., Lourenço-Lopes, C., García-Oliveira, P., Cassani, L., Fraga-Corral, M., Prieto, M. A., and Simal-Gandara, J. (2021). "Main bioactive phenolic compounds in marine algae and their mechanisms of action supporting potential health benefits," *Food Chemistry* 341, article 128262.
<https://doi.org/10.1016/j.foodchem.2020.128262>
- Kasmiati, K., Nurunnisa, A. T., Amran, A., Resya, M. I., and Rahmi, M. H. (2022). "Antibacterial activity and toxicity of *Halymenia durvillei* red seaweed from Kayanganisland, South Sulawesi, Indonesia," *Fisheries and Aquatic Sciences* 25(8), 417-428. <https://doi.org/10.47853/FAS.2022.e38>

- Kim, J. S., Choi, C., and Lee, H. H. (2023). "Changes in the biological activities of *Gracilaria verrucosa* extracted using different extraction solvents," *Applied Sciences* 13(22), article ID 12314. <https://doi.org/10.3390/app132212314>
- Lajili, S., Ammar, H. H., Mzoughi, Z., Amor, H. B. H., Muller, C. D., Majdoub, H., and Bouraoui, A. (2019). "Characterization of sulfated polysaccharide from *Laurencia obtusa* and its apoptotic, gastroprotective and antioxidant activities," *International Journal of Biological Macromolecules* 126, 326-336. <https://doi.org/10.1016/j.ijbiomac.2018.12.089>
- Lee, J., Lee, S., Kim, S. L., Choi, J. W., Seo, J. Y., Choi, D. J., and Park, Y. I. (2014). "Corn silk maysin induces apoptotic cell death in PC-3 prostate cancer cells via mitochondria-dependent pathway," *Life Sciences* 119(1-2), 47-55. <https://doi.org/10.1016/j.lfs.2014.10.012>
- Maciel, J. S., Chaves, L. S., Souza, B. W., Teixeira, D. I., Freitas, A. L., Feitosa, J. P., and de Paula, R. C. (2008). "Structural characterization of cold extracted fraction of soluble sulfated polysaccharide from red seaweed *Gracilaria birdiae*," *Carbohydrate Polymers* 71(4), 559-565. <https://doi.org/10.1016/j.carbpol.2007.06.026>
- Malar, T. J., Antonyswamy, J., Vijayaraghavan, P., Kim, Y. O., Al-Ghamdi, A. A., Elshikh, M. S., Hatamleh, A. A., Al-Dosary, M. A., Na, S. W., and Kim, H. J. (2020). "In vitro phytochemical and pharmacological bioefficacy studies on *Azadirachta indica* A. Juss and *Melia azedarach* Linn for anticancer activity," *Saudi Journal of Biological Sciences* 27(2), 682-688. <https://doi.org/10.1016/j.sjbs.2019.11.024>
- Manam, D. V. K., and Subbaiah, M. (2020). "Phytochemical, amino acid, fatty acid and vitamin investigation of marine seaweeds *Colpomenia sinuosa* and *Halymenia porphyroides* collected along southeast coast of Tamilnadu, India," *World Journal of Pharmaceutical Research* 9, 1088-1102. <https://doi.org/10.20959/wjpr20204-17091>
- Martín-Martín, R. P., Carcedo-Forés, M., Camacho-Bolós, P., García-Aljaro, C., Angulo-Preckler, C., Avila, C., Lluch, J. R., and Garreta, A. G. (2022). "Experimental evidence of antimicrobial activity in Antarctic seaweeds: Ecological role and antibiotic potential," *Polar Biology* 45(5), 923-936. <https://doi.org/10.1007/s00300-022-03036-1>
- Massawe, H. F., Mdegela, R. H., and Kurwijila, L. R. (2019). "Antibiotic resistance of *Staphylococcus aureus* isolates from milk produced by smallholder dairy farmers in Mbeya Region, Tanzania," *International Journal of One Health* 5(5), 31-7. <https://doi.org/10.14202/IJOH.2019.31-37>
- Matias, M., Pinteus, S., Martins, A., Silva, J., Alves, C., Mouga, T., Gaspar, H., and Pedrosa, R. (2022). "Gelidiales are not just agar—Revealing the antimicrobial potential of *Gelidium corneum* for skin disorders," *Antibiotics* 11(4), article 481. <https://doi.org/10.3390/antibiotics11040481>
- Meinita, M. D. N., Harwanto, D., Amron, Hannan, M. A., Jeong, G. T., Moon, I. S., and Choi, J. S. (2023). "A concise review of the potential utilization based on bioactivity and pharmacological properties of the genus *Gelidium* (Gelidiales, Rhodophyta)," *Journal of Applied Phycology* 35(4), 1499-1523. <https://doi.org/10.1007/s10811-023-02956-7>
- Messina, C. M., Renda, G., Laudicella, V. A., Trepos, R., Fauchon, M., Hellio, C., and Santulli, A. (2019). "From ecology to biotechnology, study of the defense strategies of algae and halophytes (from Trapani Saltworks, NW Sicily) with a focus on antioxidants and antimicrobial properties," *International Journal of Molecular Sciences* 20(4), article 881. <https://doi.org/10.3390/ijms20040881>

- Miranda, J. M., Trigo, M., Barros-Velázquez, J., and Aubourg, S. P. (2022). "Antimicrobial activity of red alga flour (*Gelidium* sp.) and its effect on quality retention of *Scomber scombrus* during refrigerated storage," *Foods* 11(7), article 904. <https://doi.org/10.3390/foods11070904>
- Ozogul, F., Durmuş, M., Kosker, A. R., Özkütük, A. S., Kuley, E., Yazgan, H., Yazgan, R., Simat, V., and Ozogul, Y. (2023). "The impact of marine and terrestrial based extracts on the freshness quality of modified atmosphere packed sea bass fillets," *Food Bioscience* 53, article 102545. <https://doi.org/10.1016/j.fbio.2023.102545>
- Padayao, M. H. R., Padayao, F. R. P., Patalinghug, J. M., Raña, G. S., Yee, J., Geraldino, P. J., and Quilantang, N. (2023). "Antimicrobial and quorum sensing inhibitory activity of epiphytic bacteria isolated from the red alga *Halymenia durvillei*," *Access Microbiology* 5(12), article 000563-v4. <https://doi.org/10.1099/acmi.0.000563.v2>
- Park, S. W., Park, J. S., Ali, M. S., Chamika, W. A. S., Kim, J. W., and Chun, B. S. (2025). "Subcritical water treatment of *Gelidium amansii* for the integrated utilization of agar and non-agar components: Physicochemical and *in vitro* bioactive properties," *Food and Bioprocess Technology* 18(8), 7416-7430. <https://doi.org/10.1007/s11947-025-03867-w>
- Phan, A., Mijar, S., Harvey, C., and Biswas, D. (2025). "Staphylococcus aureus in foodborne diseases and alternative intervention strategies to overcome antibiotic resistance by using natural antimicrobials," *Microorganisms* 13(8), article 1732. <https://doi.org/10.3390/microorganisms13081732>
- Pirian, K., Moein, S., Sohrabipour, J., Rabiei, R., and Blomster, J. (2017). "Antidiabetic and antioxidant activities of brown and red macroalgae from the Persian Gulf," *Journal of Applied Phycology* 29, 3151-3159. <https://doi.org/10.1007/s10811-017-1152-0>
- Ristivojević, P., Jovanović, V., Opsenica, D. M., Park, J., Rollinger, J. M., and Velicković, T. Č. (2021). "Rapid analytical approach for bioprofiling compounds with radical scavenging and antimicrobial activities from seaweeds," *Food Chemistry* 334, article 127562. <https://doi.org/10.1016/j.foodchem.2020.127562>
- Roohinejad, S., Koubaa, M., Barba, F. J., Saljoughian, S., Amid, M., and Greiner, R. (2017). "Application of seaweeds to develop new food products with enhanced shelf-life, quality and health-related beneficial properties," *Food Research International* 99, 1066-1083. <https://doi.org/10.1016/j.foodres.2016.08.016>
- Salem, A., Abou El Roos, N., and Nassar, Y. (2019). "Antimicrobial effects of some essential oils on the foodborne pathogen campylobacter jejuni," *Benha Veterinary Medical Journal* 36(1), 65-70. <https://doi.org/10.21608/bvmj.2019.83232>
- Sasidharan, S., Darah, I., and Noordin, M. K. M. J. (2009). "Screening antimicrobial activity of various extracts of *Gracilaria changii*," *Pharmaceutical Biology* 47(1), 72-76. <https://doi.org/10.1080/13880200802434161>
- Shalaby, E. (2011). "Algae as promising organisms for environment and health," *Plant Signaling and Behavior* 6(9), 1338-1350. <https://doi.org/10.4161/psb.6.9.16779>
- Sobuj, M. K. A., Islam, M. A., Islam, M. S., Islam, M. M., Mahmud, Y., and Rafiquzzaman, S. M. (2021). "Effect of solvents on bioactive compounds and antioxidant activity of *Padina tetrastromatica* and *Gracilaria tenuistipitata* seaweeds collected from Bangladesh," *Scientific Reports* 11(1), article ID 19082. <https://doi.org/10.1038/s41598-021-98461-3>
- Vega, J., Álvarez-Gómez, F., Güenaga, L., Figueroa, F. L., and Gómez-Pinchetti, J. L. (2020). "Antioxidant activity of extracts from marine macroalgae, wild-collected and

- cultivated, in an integrated multitrophic aquaculture system,” *Aquaculture* 522, article 735088. <https://doi.org/10.1016/j.aquaculture.2020.735088>
- Vinosh, M., Palanisamy, S., Jeneeta, S., Rajasekar, P., Marudhupandi, T., Karthikeyan, M., Mohandoss, S., You, S., and Prabhu, N. M. (2024). “Antibacterial, anticancer and antioxidant effects of sulfated galactan from *Halymenia dilatata*: *In vitro* and *in vivo* analysis,” *Food Bioscience* 60, article 104420. <https://doi.org/10.1016/j.fbio.2024.104420>
- Xu, P., Tan, H., Jin, W., Li, Y., Santhoshkumar, C., Li, P., and Liu, W. (2018). “Antioxidative and antimicrobial activities of intertidal seaweeds and possible effects of abiotic factors on these bioactivities,” *Journal of Oceanology and Limnology* 36(6), 2243-2256. <https://doi.org/10.1007/s00343-019-7046-z>
- Yang, Y., Zhang, M., Alalawy, A. I., Almutairi, F. M., Al-Duais, M. A., Wang, J., and Salama, E. S. (2021). “Identification and characterization of marine seaweeds for biocompounds production,” *Environmental Technology and Innovation* 24, article 101848. <https://doi.org/10.1016/j.eti.2021.101848>
- Zhang, X., Esmail, G. A., Alzeer, A. F., Arasu, M. V., Vijayaraghavan, P., Choi, K. C., and Al-Dhabi, N. A. (2020). “Probiotic characteristics of *Lactobacillus* strains isolated from cheese and their antibacterial properties against gastrointestinal tract pathogens,” *Saudi Journal of Biological Sciences* 27(12), 3505-3513. <https://doi.org/10.1016/j.sjbs.2020.10.022>

Article submitted: July 01, 2025; Peer review completed: November 22, 2025; Revisions accepted: May 18, 2026; Published: May 22, 2026.

DOI: 10.15376/biores.21.3.6297-6314