A COMPREHENSIVE ANALYSIS OF METABOLITE PROFILE AND PHYTOCHEMICAL COMPOSITION OF *Ulva lactuca* MACROALGAE FROM THE COAST OF BANDA ACEH, INDONESIA

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Abstract: Marine macroalgae are known for their rich bioactive compounds, offering various pharmacological benefits. This research was conducted to analyze the phytochemical composition and metabolite profiles of *Ulva lactuca*, a marine macroalgae, along the coastal region of Banda Aceh, Indonesia. The research methodology encompassed three primary phases: assessment of antioxidant scavenging activity, determination of phytochemical composition, and in vivo metabolite profiling. The extract exhibited notable antioxidant activity, evidenced by its 47.22% inhibition rate. Spectral analysis via FTIR revealed prominent peaks at 1019 cm^{-1}, 1654 cm^{-1}, and 3352 cm^{-1}, indicative of the presence of ethers, carbonyls, and hydroxyl groups, respectively. GC-MS analysis, coupled with a literature review, identified a total of 30 phytochemical compounds within Ulva lactuca, several of which possess significant bioactive properties with potential applications as antibacterial agents in both human and animal contexts. Consequently, *Ulva lactuca* demonstrates promising prospects as a source of antibacterial agents. The implications of this study suggest that *Ulva lactuca* could be developed as a natural alternative for antibacterial treatments, potentially reducing dependence on synthetic antibiotics in both healthcare and aquaculture industries.

Keywords: antibacterial; antioxidant activity; macroalgae; phytochemical profiling; *Ulva lactuca*

Abstrak: Makroalga dikenal karena kandungan senyawa bioaktifnya yang kaya, yang menawarkan berbagai manfaat farmakologis. Penelitian ini dilakukan untuk menganalisis komposisi fitokimia dan profil metabolit dari *Ulva lactuca* di sepanjang wilayah pesisir Banda Aceh, Indonesia. Metodologi penelitian mencakup tiga fase utama: penilaian aktivitas antioksidan, penentuan komposisi fitokimia, dan profil metabolit *in vivo*. Ekstrak menunjukkan aktivitas antioksidan yang signifikan, dibuktikan dengan tingkat inhibisi sebesar 47,22%. Analisis spektral menggunakan FTIR mengungkapkan puncak pada 1019 cm^{-1}, 1654 cm^{-1}, dan 3352 cm^{-1}, yang menunjukkan adanya gugus eter, karbonil, dan hidroksi. Analisis GC-MS, yang dipadukan dengan tinjauan literatur, mengidentifikasi total 30 senyawa fitokimia dalam *Ulva lactuca*, beberapa di antaranya memiliki sifat bioaktif signifikan dengan potensi aplikasi sebagai agen antibakteri dalam konteks manusia dan hewan. Dengan demikian, *Ulva lactuca* menunjukkan prospek yang menjanjikan sebagai sumber agen antibakteri. Implikasi dari penelitian ini menunjukkan bahwa *Ulva lactuca* dapat dikembangkan sebagai alternatif alami untuk pengobatan antibakteri, yang berpotensi mengurangi ketergantungan pada antibiotik sintetis dalam industri kesehatan dan akuakultur.

Kata Kunci: antibakteri; aktivitas antioksidan; makroalga; profil fitokimia; *Ulva lactuca*

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Introduction

Indonesia, situated between the Pacific and Indian Oceans, spanning the continents of Asia and Australia, boasts a diverse archipelago that fosters rich biodiversity. Among its abundant natural resources are macroalgae, with approximately 1,500 known species documented in Indonesian waters (Moreira *et al.*, 2022). Algae, classified within the kingdom Protista (Filote *et al.*, 2021), exhibit plant-like characteristics, featuring thallus-shaped structures and containing chlorophyll pigments crucial for photosynthesis. These organisms thrive predominantly in coastal intertidal regions, the transitional zones between high and low tide, characterized by fluctuating environmental conditions conducive to a high degree of species diversity (Xiao *et al.*, 2021). Macroalgae, which occupy diverse substrates such as other plants, mollusk shells, wood, sandy areas, and rocks, can exist as epiphytes or free-living entities. They play a crucial role in the complex ecological tapestry of intertidal habitats (Schmitt *et al.*, 2022; Gurugubelli *et al*., 2023; Damat *et al*., 2022). Macroalgae, a valuable biological resource abundant in intertidal coastal areas, hold significant potential for development (Li *et al.*, 2022a). However, their susceptibility to natural environmental fluctuations such as wind, waves, currents, and seasonal variations poses a challenge to their habitat stability. Moreover, anthropogenic influences, including domestic and solid waste, urban activities, shipping frequency in bay areas, and coastal development projects, further impact macroalgae diversity (Mulas *et al.*, 2022).

Algae, distinguished by their pigmentation, are broadly categorized into four types of colour: blue-green, red, green, and brown (Vahtmäe *et al.*, 2023). Among these, brown, green, and red algae, collectively referred to as macroalgae, are of particular interest (AbouGabal *et al.*, 2022; Akbar and Khairunnisa 2024; Akbar and Hasan, 2024). Red algae, characterized by their red pigments, including phycocyanins, carotenoids, and chlorophyll, offer potential antioxidant and anticancer properties (Cikoš *et al.*, 2022). Deriving their brown coloration from phycoxanthin, brown algae, the largest among the three, contain a variety of bioactive compounds (El-Shafei *et al.*, 2021; Akbar and Mustari 2024).

Macroalgae, including *Ulva lactuca*, are prominent resources in the intertidal zones of Ulee Lheue Waters, Banda Aceh. These marine organisms, valued for their economic and ecological significance, serve various purposes ranging from food and cosmetics to medicinal applications. Despite their potential benefits, there exists a gap in scientific understanding regarding the full extent of their utility. The coastal communities of Aceh have yet to fully capitalize on the potential of macroalgae due to limited scientific research. The *Ulva lactuca* could be developed as a natural alternative for antibacterial treatments, potentially reducing dependence on synthetic antibiotics in both healthcare and aquaculture industries.

Experimental

Study area

The *Ulva lactuca* was harvested from the intertidal zone at a depth of approximately 2 meters at of Ulee Lheue Beach in Banda Aceh City, and then meticulously processed to ensure their purity was maintained. Initial steps involved the removal of epiphytes, debris, and extraneous matter using clean water, followed by the excision of necrotic portions from the samples. Subsequently, the algae underwent thorough cleansing procedures using both fresh and saltwater solutions.

Materials and Tools

The simplicia *Ulva lactuca* was the material utilized in this study. The chemicals used for the analysis are $FeCl_3$, KI, distilled water, $NaBH_4$, HF, $HClO_4$, HNO_3, H_3BO_3, ascorbic acid, HCl, DPPH (2,2-diphenyl-2-picrylhydrazil) and Ethanol. Then, employed as tools were Aquamate 8100 UV-VIS spectrophotometer, Thermo Scientific Trace 1310 Gas Chromatograph, glassware, rotary vacuum evaporator (Buchi R-300), Thermo Scientific Mass Spectrometer, and Fourier Transform Infrared (FTIR) (Bruker alpha).

Macroalgae Sample Extraction

The *Ulva lactuca* samples obtained were dried in a shaded area for one day before being separated by species. Each batch, weighing up to 50 g of Simplicia, was placed in separate Erlenmeyer glasses. Maceration was carried out using ethanol at a 1:5 ratio, allowing the mixture to soak for 72 hours. After maceration, the mixture is filtered, then the ethanol solvent in the filtrate is removed using a rotary vacuum evaporator. The resulting concentrated extract is then stored at a temperature of 4°C (Akbar and Hasan, 2024).

Phytochemical Test

As per Kaushik *et al.* (2021), the phytochemical test conducted served as a preliminary assay aimed at determining the presence of various active chemical compounds within the macroalgae extract.

Functional Group Analysis

A sample of 0.0010 g of *Ulva lactuca* was weighed and then ground together with 0.1980 g of potassium bromide (KBr) until a homogeneous mixture was obtained. This mixture was made into a thin plate and then analyzed using FTIR. Measurements were taken at wavenumbers ranging from 400 to 4000 cm^{-1} at a temperature of 23°C (Akbar and Hasan, 2024).

Phenol Content Analysis

The phenol content was analyzed using the method by Starowicz *et al*., (2021) with slight modifications. This treatment is allowed to stand for five minutes for complete reaction. In a dark room, the mixture was homogenized for about 1 hour after adding one milliliter of 5% Na_2CO_3. At a wavelength of 725 nm, the absorbance value was calculated using a UV-VIS spectrophotometer.

Antioxidant Activity Analysis

As a positive control in the ultraviolet spectrum evaluation, ascorbic acid recorded an absorbance measurement of 0.108. The antioxidant activity was assessed using the DPPH technique with a reagent concentration of 0.1 mM (Munteanu *et al*., 2021).

$$\text{Inhibition (\%)}=\frac{\text{Blank absorbance-Sample Absorbance}}{\text{Blank absorbance}}\text{ x 100\% } \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

GC-MS Analysis

GC-MS analysis was conducted utilizing a PerkinElmer Clarus 680 GC equipped with an SQ8 MS, employing Elite-5MS columns featuring a stationary phase consisting of 5% diphenyl and 95% dimethyl polysiloxane. A solvent delay of 3.00 minutes was implemented. The scan parameters were set to 30.0 m x 250 µm, with a column ranging from 45 to 500 Da (Akbar and Hasan, 2024).

Water Quality Measurement

Water quality assessments encompassed several key parameters including nitrate, phosphate, dissolved oxygen, pH, salinity, and temperature (Akbar and Hasan, 2024).

Results And Discussion

Bioactive Components

The bioactive components identified in the macroalgae include alkaloids, polyphenols, flavonoids, steroids, and saponins (Table 2). Alkaloids, detected using the Wagner and Dragendorff reagents, exhibit antibacterial and anti-inflammatory properties, aiding in blood circulation, postpartum recovery, and infection prevention (Klimjit et al., 2021). Flavonoids, known for their antioxidant, anti-inflammatory, and cardiovascular protective effects, were also identified. These compounds help in neutralizing free radicals and reducing inflammation (Naiel et al., 2021). Steroids, another component found, are linked to hormone regulation and possess anti-inflammatory effects. Saponins, which tested positive, are known for their cholesterol-lowering and immune-boosting properties, contributing to overall health (El-Shafei et al., 2021). Both macroalgae samples also tested positive for polyphenols, which are recognized for their antioxidant, anti-carcinogenic, and anti-inflammatory roles, thus reducing the risk of chronic diseases. The presence of these bioactive substances underlines the macroalgae's significant health benefits.

Table 2. Observation of ethanol extracts of the macroalgae *Ulva lactuca* samples subjected to phytochemical tests

Metabolit/ Species	Flavonoids	Tanin	Polyphenol	Kuinon	Steroid	Triterpenoids	Saponin	**Alkaloid**	Mayer	Wagner	Dragendroff
Ulva lactuca	+	-	+	-	+	-	+		-	+	+

Description : (+) Positive Test, (-) Negative Test

FTIR And UV Vis Spectrum Characterization

The bonds were accurately identified through the examination of the infrared absorption spectra, as detailed in Figure 2 illustrates the Fourier Transform Infrared (FTIR) and Ultraviolet-visible (UV-Vis) spectra of the ethanol extract of *Ulva lactuca*, a macroalgae.

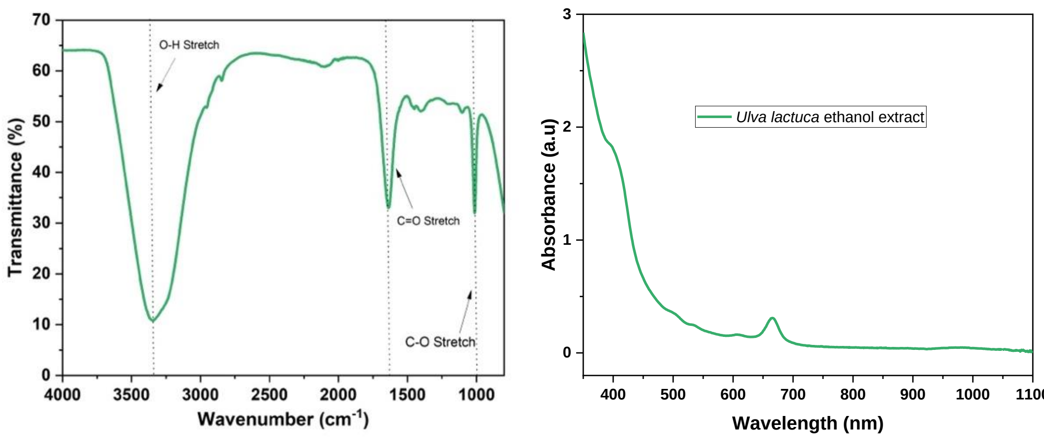

Figure 2. FTIR (a) and UV–VIS (b) spectra of *Ulva lactuca* ethanol extract. All extracts were analysed at 1 mg/mL.

In the FTIR analysis, strong vibrations were detected at 1019 cm^{-1}, 1654 cm^{-1}, and 3352 cm^{-1}. The FTIR spectrum at 1654 cm^{-1} exhibited a vibrational mode of medium character, indicating the presence of carbonyl (C=O) form with conjugated with C=C bonds from alkenes. Additionally, the vibrational peak at 1019 cm^{-1} confirmed the presence of C-O (Akbar and Hasan, 2024). According to Akbar *et al.* (2023), the peaks between 3677 and 3012 cm^{-1} correspond to hydroxyl O–H groups. These peaks might be associated with various polyphenol derivative compounds identified in Table 4. Furthermore, the stretching and bending of C–H were identified in the ranges of 2972–2936 cm^{-1} and 1420–1358 cm^{-1}. Additionally, the C–H vibration of benzene was determined between 2950 and 3180 cm^{-1} (Akbar *et al.,* 2023). The results of these FTIR measurements can confirm the presence of flavonoids and polyphenols as indicated by the phytochemical tests (Akbar and Hasan, 2024).

In the UV-vis spectrum of the *Ulva lactuca* extract, a prominent absorption peak was observed at a wavelength of 660 nm (λ_{max}). This electronic transition is attributed to the electron stabilized by the flavylium cation on the oxygen atom. Additionally, a minor peak at λ_{max} = 358 nm with relatively modest intensity indicates the electronic transition between the electrons surrounding benzene (Abdel-Aty *et al*., 2018). This data implies that the *Ulva lactuca* extract contains a polyphenol ring.

Antioxidant Activity And Total Phenol

The results of the antioxidant activity test on the ethanol extract of *Ulva lactuca* will be presented in Table 3. *Ulva lactuca* ethanol extracts demonstrate significant activity with IC_{50} values of 11.47 mg/L. According to Shen *et al,* (2022), antioxidant activity is classified as high when the IC_{50} value is less than 50 mg/L, moderate when it falls between 50-100 mg/L, weak when it ranges from 150-200 mg/L, and extremely weak when it surpasses 200 mg/L. A low IC_{50} value strongly suggests the extract's capacity to function as a hydrogen atom donor, as noted by Yang *et al.* (2021). As highlighted by Zhang *et al*. (2022), the presence of hydroxyl groups in phenolic compounds is attributed to this potent scavenging ability.

Table 3. Results of total phenols and antioxidant activity tests in macroalgae extracts

Species	***Antioxidant activity*** **(IC_{50})(mg/L)**	**Total Phenolic (mg GAE/g)**
Ulva lactuca	11,47	10,52 ± 1,38
Vitamin C	10.58	-

GC-MS Analysis

Figure 3 and Table 4 present the profiles of chemical components identified in the ethanol extract. Heptadecane stood out with a significantly higher percentage area value among the components, marking it as the predominant ingredient in the ethanol extract of *Ulva lactuca* macroalgae. Studies, including those by Suharti *et al*. (2023) and Kayode *et al*. (2018), have documented the antibacterial properties of heptadecane.

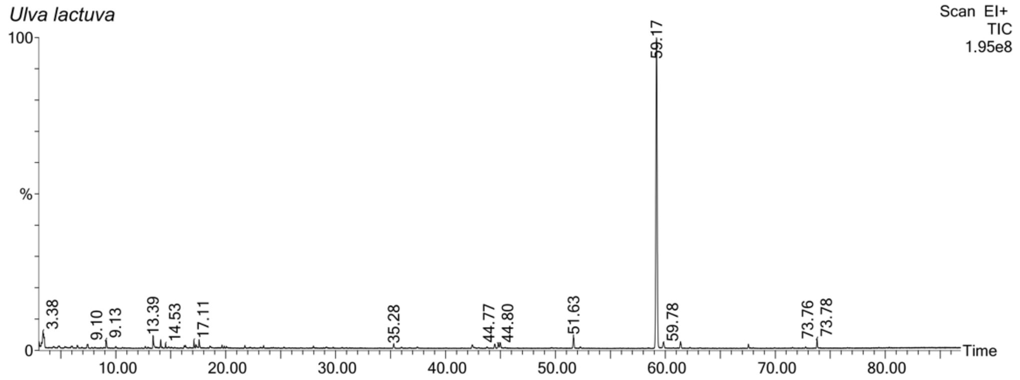

Figure 3. The ethanol extract chromatogram profile of the macroalgae *Ulva lactuca*

Table 4. The chemical composition percentage of ethanol extract from *Ulva lactuca*

RT	Compound Name	Height	Area	Area %
3.268	3-Nitro-2-butanol	2,994,423	225,723.9	0.433
3.384	Furan, 2-ethyl-	10,135,119	1,579,453.4	3.027
4.867	9-Octadecene, 1,1'-[1,2-	1,506,321	182,792.0	0.350
6.040	Ethyl iso-allocholate	1,386,484	138,634.0	0.266
7.429	1,6-Dimethylhepta-1,3,5-triene	2,563,929	171,203.7	0.328
7.464	10-Imino-12-phenyl-9,11-	2,690,473	145,625.7	0.279
9.127	Acetaldehyde, propylhydrazone	5,514,404	474,990.0	0.910
12.687	Benzoic acid 3-methyl-4-(1,3,3,3-tetrafluoro-	1,436,782	118,300.0	0.227
13.387	Aniline	8,083,105	696,134.7	1.334
14.094	Cyclotetrasiloxane, octamethyl-	5,316,858	345,540.8	0.662
14.525	cis-2-(2-Pentenyl)furan	3,115,465	192,431.6	0.369
16.218	Octadecanal, 2-bromo-	1,778,224	124,559.1	0.239
16.329	Eucalyptol	1,985,483	180,294.8	0.346
17.280	Cyclopentene, 1,5-dimethyl-	2,287,179	179,515.9	0.344
17.578	4-Methylcyclohexanol acetate	5,196,718	347,900.8	0.667
19.673	2-Carene	2,135,060	137,481.0	0.264
21.751	Cyclopentasiloxane, decamethyl-	1,897,058	127,441.1	0.244
23.449	N-Methyl-9-aza-tricyclo[6.2.2.0(2,7)]dodec-2,	1,837,640	120,227.4	0.230
35.279	3-Hexadecene, (Z)-	3,111,788	298,933.2	0.573
42.416	Naphthalene, 1,2,3,4-tetrahydro-1,4,6-trimethyl-	2,427,687	320,027.5	0.613
44.470	Ethyl 4-oxo-2-phenylpentanoate	2,800,736	295,362.9	0.566
44.774	Heptadecane, 2,6,10,15-tetramethyl-	2,577,827	220,055.8	0.422

RT	Compound Name	Height	Area	Area %
44.978	2,4-Di-tert-butylphenol	3,247,592	318,748.8	0.611
51.626	Cetene	8,497,097	769,312.1	1.475
59.177	8-Heptadecene	193,407,952	25,639,952.0	49.14
61.360	Heptadecane	4,394,920	465,138.8	0.892
67.535	5-Octadecene, (E)-	2,835,582	232,288.4	0.445
73.779	Hexadecanoic acid, methyl ester	6,344,759	449,982.7	0.863

The antimicrobial activity of 5-Octadecene, (E)- has been isolated from *Acacia nilotica* by bioactivity-directed fractionation of ethyl acetate extract from the air dried seeds and pod. Using *Acacia nilotica* extract with a concentration of 1000 µg/cm^3 from seed against *Salmonela typhi*, *Streptococcus feacalis*, *Escherichia coli*, *Candida krusei*, *Shigella dysentriae*, and *Staphylococcus aureus* with a zone of inhibition diameter of 9-29 mm (Garba *et al.*, 2016). The extract from the sea cucumber *Bohadschia* sp. was found to contain cyclopentasiloxane in its decamethyl form, which exhibits antibacterial properties. This study investigated *Bacillus subtilis*, *Escherichia coli*, *Staphylococcus aureus*, and *Vibrio eltor* as the microorganisms. The inhibitory zone diameter ranged from 7 to 13 mm (Rasyid, 2016). Moreover, olive (*Olea europaea* L.) leaf extract has been reported to show an inhibitory zone of 9-11 nm against various bacterial species (Anees *et al*., 2024; Rizwan *et al*., 2020). The bioactive compound 4-Methylcyclohexanol acetate was obtained from *Achillea fragrantissima*, *Artemisia judaica L.*, *Artemisia monosperma Delile*, *Pulicaria undulata L.*, *Artemisia herba-alba Asso*. and *Pulicaria incisa Lam* (Elbalola and Abbas, 2023). Antibacterial and antitumoral activities of methanesulfonylacetic acid from *Spirulina platensis* extracellular extract have been reported. Inhibition zones of 10, 8, 8, and 5 mm were observed for *Escherichia coli*, *Burkholderiacepatia*, *Staphylococcus aureus*, and *Pseudomonas stutzeri*, respectively, in the antibacterial activity of spirulina extract (25 g/ml).

Water Quality Parameters

The water temperatures at Ulee Lheue Beach in Banda Aceh City range from 29.8 to 30 ^{o}C, falling within the typical range for tropical waters. Ji and Gao (2021) identified this range as suitable for the growth of macroalgae in tropical environments, which typically ranges from 15 to 30 ^{o}C. Salinity is another crucial factor for macroalgal survival, as deviations from optimal levels can disrupt physiological processes. The saltwater salinities in these waterways, ranging from 29.4-31.5 %o, are still favorable for macroalgal growth (Table 1). While macroalgae typically thrive in waters with a salinity range of 30-32 %o, Borburema *et al.* (2021) suggest that many varieties can also survive in waters with a higher salinity range. The ideal salinity range for Eucheuma growth, according to Olli *et al.* (2023), is between 28-34 %o, which falls within the typical range of coastal regions' salinities observed in these waters.

Table 1. The table presents measurements of water quality

Parameters	Standard Value *	Measurement Results
Temperature (^oC)	28 – 30	29.8 – 30
Salinity (%o)	33 – 34	29.4 – 31.5
pH	7 – 8.5	7.81 – 7.96
Dissolved Oxygen (DO) (mg/L)	>5	7.85 – 8.2
Phosphate (mg/L)	0.015	0.1 – 0.46
Nitrate (mg/L)	0.008	0.2 – 0.5

Description: *Decree of the Minister of Environment No. 51/2004

The pH of the waters at Ulee Lheue Beach, ranging from 7.81 to 7.96, remains within a favorable range for macroalgal life. According to Wang *et al.* (2020), macroalgae can thrive consistently within a pH range of 7 to 8. Dissolved oxygen serves as a fundamental indicator of water fertility and a vital factor for marine life. Additionally, Correia and Smee (2022) indicate that the levels of dissolved oxygen in water bodies typically range between 6 to 14 ppm. The waters at Ulee Lheue Beach exhibit dissolved oxygen concentrations between 5.57 and 5.96 mg/L. Despite the fact that a minimum oxygen level of 2 ppm is sufficient to sustain aquatic species, an oxygen content of 5 ppm is generally considered to be relatively beneficial for fish life, especially within water temperatures ranging from 20 to 30 ^oC (Akbar *et al*. 2025). Based on observational data, phosphate and nitrate levels in the waters varied between 0.1 and 0.46 mg/L and 0.2 and 0.5 mg/L, respectively. These values exceed the benchmark for water quality. According to Farahdiba *et al.* (2020), phosphate levels between 0.051-0.1 mg/L are indicative of fertile waters, while moderately fertile waters typically exhibit phosphate levels between 0.0021 and 0.05 mg/L.

Conclusion

In conclusion, our research highlights the notable in vitro properties exhibited by the ethanol extract of *Ulva lactuca*. These evaluated extracts demonstrated promising antibacterial and antioxidant activities, likely attributed to their high phenolic content. Through GC-MS analysis, several substances with potential antioxidant and antibacterial properties were identified, suggesting the possibility of developing novel treatments or preventive measures for infectious diseases in fish. Among the 28 bioactive compounds analyzed, 9 were found to have potential antibacterial effects in fish, including 4-Methylcyclohexanol acetate, Cyclopentasiloxane, decamethyl-, Heptadecane, 2,6,10,15-tetramethyl-, 5-Octadecene, (E)-, and Hexadecanoic acid, methyl ester. Marine seaweed provides a novel and environmentally friendly approach to natural drug discovery that can be applied across various industries, including pharmaceuticals, nutraceuticals, and therapeutics, on a large scale.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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References

Abdel-Aty, A. M., Salama, W. H., Fahmy, A. S., & Mohamed, S. A. (2018). Impact of germination on antioxidant capacity of garden cress: New calculation for determination of total antioxidant activity. *Scientia Horticulturae*, *246*, 155–160. https://doi.org/10.1016/j.scienta.2018.10.062

AbouGabal, A. A., Khaled, A. A., Aboul-Ela, H. M., Aly, H. M., Diab, M. H., & Shalaby, O. K. (2022). Marine Macroalgal Biodiversity, Spatial Study for the Egyptian Mediterranean Sea, Alexandria Coast. *Thalassas: An International Journal of Marine Sciences*, *38*(1), 639–646. https://doi.org/10.1007/s41208-021-00370-9

Akbar, S. A., & Hasan, M. (2024). Evaluation of Bioactive Composition and Phytochemical Profile of Macroalgae Gracilaria edulis and Acanthophora spicifera from the Banda Aceh Coast, Indonesia. *Science & Technology Asia*, *29*(1), 194. https://doi.org/10.14456/scitechasia.2024.14

Akbar, S. A., & Khairunnisa, K. (2024). Seaweed-based biosorbent for the removal of organic and inorganic contaminants from water: A systematic review. *The 5th International Conference on Fisheries, Aquatic, and Environmental Sciences (ICFAES 2023), Banda Aceh. Web of Conferences*, *87*, 02011. https://dx.doi.org/10.1051/bioconf/20248702011

Akbar, S. A., & Mustari, A. (2024). Food packaging based on biodegradable polymers from seaweeds: A systematic review. *The 5th International Conference on Fisheries, Aquatic, and Environmental Sciences (ICFAES 2023), Banda Aceh. Web of Conferences*, *87*, 01005. https://dx.doi.org/10.1051/bioconf/20248701005

Akbar, S. A., Lestari, A. N., Fazli, R. R., & Gunawan, G. (2025). Harnessing macroalgae for heavy metal phytoremediation: a sustainable approach to aquatic pollution control. In BIO Web of Conferences (Vol. 156, p. 02013). EDP Sciences.

Akbar, S. A., Hasan, M., Afriani, S., & Nuzlia, C. (2023). Evaluation of phytochemical composition and metabolite profiling of macroalgae Caulerpa taxifolia and C. peltata from the Banda Aceh coast, Indonesia. *Biodiversitas*, *24*(10), 5283. https://dx.doi.org/10.13057/biodiv/d241009

Anees, S., Manzoor, I., Fatima, K., Hamid, R., & Ganie, S. A. (2024). GC-MS analysis and potential therapeutic efficacy of extracts from Allium humile Kunth in lowering dyslipidemia in wistar rat models. *Journal of Ethnopharmacology*, *320*, 117478. https://doi.org/10.1016/j.jep.2023.117478

Azra, B. H., & Fatima, T. (2024). Zinc nanoparticles mediated by Costus pictus leaf extract to study GC-MS and FTIR analysis. *Plant Science Archives*, *9(1)*, 11-15. https://doi.org/10.5147/PSA.2024.9.1.11

Banaras, S., Javaid, A., & Khan, I. H. (2021). Bioassays guided fractionation of Ageratum conyzoides extract for the identification of natural antifungal compounds against Macrophomina phaseolina. *International Journal of Agriculture and Biology*, *25*(4), 761–767. https://dx.doi.org/10.17957/IJAB/15.1727

Becerril-Sánchez, A. L., Quintero-Salazar, B., Dublán-García, O., & Escalona-Buendía, H. B. (2021). Phenolic compounds in honey and their relationship with antioxidant activity, botanical origin, and color. *Antioxidants*, *10*(11), 1700. https://dx.doi.org/10.3390/antiox10111700

Borburema, H. D. D. S., Lima, R. P. D., & Miranda, G. E. C. D. (2021). Effects of ocean warming, eutrophication and salinity variations on the growth of habitat-forming macroalgae in estuarine environments. *Acta Botanica Brasilica*, *34*, 662–672. https://dx.doi.org/10.1590/0102-33062020abb0303

Cikoš, A. M., Šubarić, D., Roje, M., Babić, J., Jerković, I., & Jokić, S. (2022). Recent advances on macroalgal pigments and their biological activities (2016–2021). *Algal Research*, *65*, 102748. https://dx.doi.org/10.1016/j.algal.2022.102748

Correia, K. M., & Smee, D. L. (2022). Habitat suitability of drift macroalgae in two shallow coastal estuaries of the northern Gulf of Mexico. *Journal of Experimental Marine Biology and Ecology*, *557*, 151808. https://dx.doi.org/10.1016/j.jembe.2022.151808

El-Shafei, R., Hegazy, H., & Acharya, B. (2021). A review of antiviral and antioxidant activity of bioactive metabolite of macroalgae within an optimized extraction method. *Energies*, *14*(11), 3092. https://dx.doi.org/10.3390/en14113092

Elbalola, A. A., & Abbas, Z. K. (2023). Phytochemical Diversity, Classification and Antibacterial Activity of Some Medicinal Plant Species from Tabuk (Saudi Arabia). *Chemistry & Biodiversity*, *20*(7), e202300545. https://dx.doi.org/10.1002/cbdv.202300545

Essien, E. E., Walker, T. M., Ogunwande, I. A., Bansal, A., Setzer, W. N., & Ekundayo, O. (2011). Volatile constituents, antimicrobial and cytotoxicity potentials of three Senna species from Nigeria. *Journal of Essential Oil-Bearing Plants*, *14*(6), 722–730. https://dx.doi.org/10.1080/0972060X.2011.10643995

Farahdiba, A. U., Hidayah, E. N., Asmar, G. A., & Myint, Y. W. (2020). Growth and removal of nitrogen and phosphorus by a macroalgae Cladophora glomerata under different nitrate concentrations. *Nature Environment and Pollution Technology*, *19*(2), 809–813. https://dx.doi.org/10.46488/NEPT.2020.V19I02.038

Ferdosi, M. F., Khan, I. H., Javaid, A., Hafiz, M. S., Butt, I., & Munir, A. (2021). GC-MS analysis and bioactive components of flowers of Bergenia ciliata, a weed of rock crevices in Pakistan. *Pakistan Journal of Weed Science Research*, *27*(4), 527. https://dx.doi.org/10.28941/pjwsr.v27i4.1012

Filote, C., Santos, S. C. R., Popa, V. I., Botelho, C. M. S., & Volf, I. (2021). Biorefinery of marine macroalgae into high-tech bioproducts: A review. *Environmental Chemistry Letters*, *19*, 969–1000. https://dx.doi.org/10.1007/s10311-020-01124-4

Garba, S., Shoge, M., & Salihu, L. (2016). Antimicrobial Activity Of N-Octadecanal Isolated From The Seeds And Pods Of Acacia nilotica Linn. *Bima Journal of Science and Technology*, *1*(1), 14–21. https://doi.org/10.56892/bima.v1i01.15

Graba-Landry, A. C., Loffler, Z., McClure, E. C., Pratchett, M. S. A., & Hoey, A. S. (2020). Impaired growth and survival of tropical macroalgae (Sargassum spp.) at elevated temperatures. *Coral Reefs*, *39*, 475–486. https://dx.doi.org/10.1007/s00338-020-01909-7

Ji, Y., & Gao, K. (2021). Effects of climate change factors on marine macroalgae: A review. *Advances in Marine Biology*, *88*, 91–136. https://dx.doi.org/10.1016/bs.amb.2020.11.001

Kaushik, B., Sharma, J., Yadav, K., Kumar, P., & Shourie, A. (2021). Phytochemical properties and pharmacological role of plants: Secondary metabolites. *Biosciences, Biotechnology Research Asia*, *18*(1), 23–35. https://dx.doi.org/10.13005/bbra/2894

Kayode, R. M., Azubuike, C. U., Laba, S. A., Dauda, A. O., Balogun, M. A., & Ajala, S. A. (2018). Chemical composition and anti-microbial activities of the essential oil of Adansonia digitata stem-bark and leaf on post-harvest control of tomato spoilage. *LWT - Food Science and Technology*, *93*, 58–63. https://dx.doi.org/10.1016/j.lwt.2018.03.014

Klimjit, A., Praiboon, J., Tiengrim, S., Chirapart, A., & Thamlikitkul, V. (2021). Phytochemical composition and antibacterial activity of brown seaweed, Padina australis against human pathogenic bacteria. *Journal of Fisheries and Environment*, *45*(1), 8–22. https://li01.tci-thaijo.org/index.php/JFE/article/view/220426

Kottage, C. D., & Patrick, A. E. S. (2023). Hydro-climatic consequences on zooplankton diversity and abundance in perennial Vavuniya reservoir and seasonal Thandikulam reservoir in Vavuniya, Sri Lanka. *Journal of Basic and Applied Zoology*, *84*(1), 1–13. https://dx.doi.org/10.1186/s41936-023-00328-8

Li, H., Kim, H., Shin, K., Hyun, B., Kim, Y. S., & Kim, J. H. (2022). Effects of temperature and light on the growth and reproduction of an endophytic pest alga Ectocarpus siliculosus (Ectocarpales) found in wild Gracilaria textorii (Gracilariales). *Aquaculture*, *560*, 738526. https://dx.doi.org/10.1016/j.aquaculture.2022.738526

Li, X., Chen, J., Li, J., Wang, K., Wang, Z., & Zhang, S. (2022). Determination of intertidal macroalgae community patterns using the power law model. *PLoS One*, *17*(11), e0277281. https://dx.doi.org/10.1371/journal.pone.0277281

Lin, S. (2023). Phosphate limitation and ocean acidification co-shape phytoplankton physiology and community structure. *Nature Communications*, *14*(1), 2699. https://dx.doi.org/10.1038/s41467-023-38381-0

Liu, J., Jin, Q., Geng, J., Xia, J., Wu, Y., & Chen, H. (2023). Fast capture and efficient removal of bloom algae based on improved dielectrophoresis process. *International Journal of Environmental Research and Public Health*, *20*(1), 832. https://dx.doi.org/10.3390/ijerph20010832

Meier, H. S., Schuman, I. J., Layden, T. J., Ritz, A., Kremer, C. T., & Fey, S. B. (2022). Temperature-mediated transgenerational plasticity influences movement behaviour in the green algae Chlamydomonas reinhardtii. *Functional Ecology*, *36*(12), 2969–2982. https://dx.doi.org/10.1111/1365-2435.14214

Moreira, A., Cruz, S., Marques, R., & Cartaxana, P. (2022). The underexplored potential of green macroalgae in aquaculture. *Reviews in Aquaculture*, *14*(1), 5–26. https://dx.doi.org/10.1111/raq.12580

Mulas, M., Silverman, J., Guy-Haim, T., Noe, S., & Rilov, G. (2022). Thermal vulnerability of the Levantine endemic and endangered habitat-forming macroalga, Gongolaria rayssiae: Implications for reef carbon. *Frontiers in Marine Science*, *9*, 862332. https://dx.doi.org/10.3389/fmars.2022.862332

Munteanu, I. G., & Apetrei, C. (2021). Analytical methods used in determining antioxidant activity: A review. *International Journal of Molecular Sciences*, *22*(7), 3380. https://dx.doi.org/10.3390/ijms22073380

Naiel, M. A., Alagawany, M., Patra, A. K., El-Kholy, A. I., Amer, M. S., & Abd El-Hack, M. E. (2021). Beneficial impacts and health benefits of macroalgae phenolic molecules on fish production. *Aquaculture*, *534*, 736186. https://dx.doi.org/10.1016/j.aquaculture.2020.736186

Olli, K., Tamminen, T., & Ptacnik, R. (2023). Predictable shifts in diversity and ecosystem function in phytoplankton communities along coastal salinity continua. *Limnology and Oceanography*, *8*(1), 173–180. https://dx.doi.org/10.1002/lol2.10242

Pal, A., Kulkarni, M. B., Gupta, H., Ponnalagu, R. N., Dubey, S. K., & Goel, S. (2021). Portable and autonomous device for real-time colorimetric detection: Validation for phosphorous and nitrite detection. *Sensors and Actuators A: Physical*, *330*, 112896. https://dx.doi.org/10.1016/j.sna.2021.112896

Rasyid, A. (2016). Analysis of secondary metabolites, antibacterial activity and compound composition in the sea cucumber Bohadschia sp. extract. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *8*(2), 645–653. https://dx.doi.org/10.28930/jitkt.v8i2.15831

Rizwan, S., Siddiqui, G., Shoaib, M., Mahmood, K., & Ul-Hassan, H. (2020). Antibacterial activity of Ulva intestinalis, U. faciata and U. lactuca against biofilm-associated bacteria. *Egyptian Journal of Aquatic Biology and Fisheries*, *24*(7), 669–676. https://dx.doi.org/10.21608/EJABF.2020.141318

Schmitt, R. J., Holbrook, S. J., Brooks, A. J., & Adam, T. C. (2022). Evaluating the precariousness of coral recovery when coral and macroalgae are alternative basins of attraction. *Limnology and Oceanography*, *67*, S285–S297. https://dx.doi.org/10.1002/lno.11929

Shen, N., Wang, T., Gan, Q., Liu, S., Wan, L., & Jin, B. (2022). Plant flavonoids: Classification, distribution, biosynthesis, and antioxidant activity. *Food Chemistry*, *383*, 132531. https://dx.doi.org/10.1016/j.foodchem.2022.132531

Starowicz, M., Ostaszyk, A., & Zieliński, H. (2021). The relationship between the browning index, total phenolics, color, and antioxidant activity of polish-originated honey samples. *Foods*, *10*(5), 967. https://dx.doi.org/10.3390/foods10050967

Suharti, W. S., Tini, E. W., & Istiqomah, D. (2023). Antimicrobial activity of Kaempferia galanga against plant pathogen on rice. *Biodiversitas*, *24*(2), 1320–1326. https://dx.doi.org/10.13057/biodiv/d240275

Vahtmäe, E., Kotta, J., Orav-Kotta, H., Kotta, I., Pärnoja, M., & Kutser, T. (2021). Predicting macroalgal pigments (chlorophyll a, chlorophyll b, chlorophyll a+b, carotenoids) in various environmental conditions using high-resolution hyperspectral spectroradiometers. *International Journal of Remote Sensing*, *39*(17), 5716–5738. https://dx.doi.org/10.4324/9781003191193-7

Vedhagiri, K., Manilal, A., Valliyammai, T., Shanmughapriya, S., Sujith, S., Selvin, J., & Natarajaseenivasan, K. (2009). Antimicrobial potential of a marine seaweed Asparagopsis taxiformis against Leptospira javanica isolates of rodent reservoirs. *Annals of Microbiology*, *59*, 431–437. https://dx.doi.org/10.1007/BF03175127

Wang, L., Jiang, H., Zou, D., & Ye, C. (2020). Effects of increased pH and inorganic carbon on growth and photosynthesis in the macroalga Gracilaria lemaneiformis (Gigartinales, Rhodophyta). *Phycologia*, *59*(3), 218–226. https://dx.doi.org/10.1080/00318884.2020.1732716

Xiao, J., Wang, Z., Liu, D., Fu, M., Yuan, C., & Yan, T. (2021). Harmful macroalgal blooms (HMBs) in China's coastal water: Green and golden tides. *Harmful Algae*, *107*, 102061. https://dx.doi.org/10.1016/j.hal.2021.102061

Yang, B., Si, H., & Zhai, H. (2021). QSAR Studies on the IC50 of a class of thiazolidinone/thiazolide based hybrids as antitrypanosomal agents. *Letters in Drug Design & Discovery*, *18*(4), 406–415. https://dx.doi.org/10.2174/1570180817999201102200015

Zhang, Y., Li, H., Ji, S., Lu, Y., Peng, Y., Zhao, L., & Wang, X. (2022). Cannabidiol protects against Alzheimer's disease in C. elegans via ROS scavenging activity of its phenolic hydroxyl groups. *European Journal of Pharmacology*, *919*, 174829. https://dx.doi.org/10.1016/j.ejphar.2022.174829