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Chemical composition, antimicrobial, and antioxidant activity of *Ulva reticulata* seaweed extracted with different solvents

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Abstract. *Djoh EFK, Meiyasa F, Ndahawali S, Tarigan N. 2024. Chemical composition, antimicrobial, and antioxidant activity of* Ulva reticulata *seaweed extracted with different solvents. Biodiversitas 25: 2943-2949. Ulva reticulata* Forsskal, 1775 is a green seaweed that has the potential to be developed in food, nutraceuticals, pharmaceuticals, and nutraceuticals; thus, studying the chemical composition and antimicrobial and antioxidant activities is necessary. *Ulva reticulata* samples were obtained from the waters of Hambuang, Haharu Sub-district, East Sumba Island, dried in the sun for three days, and floured for chemical composition analysis. In addition, water quality was tested regarding pH, Dissolved Oxygen (DO), and temperature in the Hambuang Waters. *Ulva reticulata* simplisia was extracted with three different solvents, namely methanol, ethyl acetate, and chloroform, and then tested for antimicrobial activity against *Staphylococcus aureus* Rosenbach, 1884 and *Escherichia coli* E and antioxidant activity. The results showed that the water quality of Hambuang was relatively good according to SNI standards with a pH value of 7.52, DO of 6.23 mg/L, and temperature of 31.30°C. Furthermore, the chemical composition of *U. reticulata* had a moisture content of 12.31%, ash of 23.32%, lipid of 3.04%, protein of 12.93%, and carbohydrate of 48.40%. The antioxidant activity of *U. reticulata* extract with methanol, ethyl acetate, and chloroform solvents were 235.31, 174.72, and 146.14 µg/mL, respectively. Furthermore, *U. reticulata* extract with methanol, ethyl acetate, and chloroform solvents had antimicrobial activity against *S. aureus* of 39.59, 33.81, 14.94 mm, and *E. coli* of 15.94, 17.93, 12.69 mm, respectively. Therefore, *U. reticulata* has the potential to be used as an ingredient in the food, nutraceutical, pharmaceutical, and cosmeceutical industries applications.

Keywords: Antimicrobial, antioxidant, chemical composition, *Ulva reticulata*

Abbreviations: DO: Dissolved Oxygen, DPPH: 2,2-diphenyl-1-picrylhydrazyl

INTRODUCTION

Seaweed is classified into three classes: red (Rhodophyta), green (Chlorophyta), and brown (Phaeophyta) algae (Nasr et al. 2024). Seaweed has been traditionally employed for medicinal purposes from ancient times (Honey et al. 2024). Over the past few decades, researchers have initiated investigations on the components contained in seaweed (Cotas et al. 2024; Langford et al. 2024; Pereira et al. 2024). Primary metabolites and secondary metabolites are key components found in seaweed (Langford et al. 2024; Meiyasa et al. 2024; Oppong-Danquah et al. 2023; Park et al. 2023; Syakri et al. 2024; Velasco-Clares et al. 2024). Primary metabolites include ash, protein, lipid, polysaccharides, vitamins, and minerals (Nova et al. 2023; Tarigan et al. 2023; Véliz et al. 2023). Secondary metabolites are chlorophyll, carotenoids, phenolics, tannins, flavonoids, alkaloids, steroids/terpenoids, sitosterols, stigmasterols, terpenes, terpenoids, and pigments (Ghaliaoui et al. 2024; Inoue et al. 2024; Meiyasa et al. 2024; Tarigan et al. 2023). These secondary metabolites act as anti-cancer, anti-fungal, anti-inflammatory, anti-cholesterol, anti-pruritic, anti-allergic, anti-viral, antibacterial, antioxidant, neuroprotective, chemoprotective, immunomodulatory, and hepatoprotective (Cotas et al. 2021).

The seaweed species Ulva spp. can be utilized in the fields of functional food, pharmaceuticals, cosmeceuticals, and nutraceuticals due to its wide variety of primary and secondary metabolites (Cindana Mo'o et al. 2020; Ruslan et al. 2021; Costa et al. 2024). Secondary metabolites or phytochemical compounds from seaweed play an important role in reducing oxidative stress in humans and animals by binding free radicals such as Reactive Oxygen Species (ROS) and nitrogen. In addition, antimicrobial activity testing ensures that seaweed can produce bioactive secondary metabolites (Sobuj et al. 2024). *Ulva reticulata* is a promising species, given its widespread presence in Indonesian seas, particularly in East Sumba (Meiyasa et al. 2020).

Previous research reported that *U. reticulata* ethanol extract from Moudolung Waters in East Sumba contains secondary metabolites such as alkaloids, flavonoids, saponins, tannins, phenols, steroids, sitosterols, and stigmasterols and has antioxidant activity with a strong category (IC_{50}) 53.00 ppm (Tarigan et al. 2023). The ethanol extract of *Ulva lactuca* L. from Lombok waters is also reported to have secondary metabolites such as phenolic compounds (5.33 mgGAEg-1) and flavonoids (28.053 mgREg-1) that function as antioxidants with an IC_{50} value of 522.23 µg/mL (Prasedya et al. 2019). In

addition, *U. lactuca* methanol extract contains alkaloid, flavonoid, phenol, tannin, terpenoid, glycoside, steroid, and protein compounds that exhibit antioxidant and antimicrobial against Gram-positive bacteria (*Bacillus subtilis* G, *Corynebacterium diphtheriae* (Kruse 1886) Lehmann and Neumann 1896, and *Staphylococcus aureus* Rosenbach 1884) and Gram-negative bacteria (*Escherichia coli* E, *Pseudomonas aeruginosa* A and *Salmonella paratyphi*). Furthermore, it has antimicrobial activity against *Aspergillus niger* Tiegh. and *Aspergillus fumigatus* Fresen. (Alagan et al. 2017). SM Abd El Hafez et al. (2020) also reported that *Ulva prolifera* O.F.Mull. from the Red Sea Hurghada contains 5.4% protein, 1.70% lipid, and 43% carbohydrate (dry weight). *Ulva prolifera* extract has secondary metabolites such as carotenoids, fucoidan, and phlorotannin. SM Abd El Hafez et al. (2020) reported that extracts of *U. prolifera* with varying solvents exhibit distinct antioxidant properties. Specifically, extracts obtained from hexane, ethyl acetate, and methanol have antioxidant capacities of 0.97, 1.23, and 1.63 mg, respectively. These extracts also demonstrate antibacterial activity against *S. aureus*, *Aeromonas hydrophila* (Chester 1901) Stanier 1943, *Vibrio anguillarum* Bergeman 1909, and *Edwardsiella tarda* Ewing and McWhorter 1965.

Prior research has demonstrated that antioxidant and antimicrobial activity are influenced by several parameters such as time, temperature, extraction method, solvent concentration, and solvent polarity. In addition, solvent polarity significantly affects yield, phenol solubility, and antioxidant activity of phenolic compounds in seaweed extract (Afrin et al. 2023; Lee et al. 2024; Rajapaksha et al. 2024). Safe solvents (GRAS: Generally Recognized as Safe) with low impact and toxicity, such as methanol, ethyl acetate, chloroform, and ethanol, are required for the extraction of bioactive compounds that will be used in the food, pharmaceutical, nutraceutical, and cosmeceutical industries (Amaro et al. 2022; Agrawal and Nirmal 2024). Therefore, this study aimed to analyze the chemical composition of *U. reticulata* seaweed, antioxidant activity, and antimicrobial compounds of *U. reticulata* extracts with different solvents.

MATERIALS AND METHODS

Sample collection

Ulva reticulata was harvested from the waters of Hambuang, Haharu Sub-district, East Sumba, Indonesia (Figure 1) during the dry season, at latitude -9.463138 and longitude 120.077491. The samples were then washed thoroughly and dried for three days under sunlight. Following the drying process, the seaweed was ground using a blender for chemical composition analysis (AOAC 2016). *Ulva reticulata* seaweed was prepared in a simplicia to evaluate its antioxidant and antimicrobial properties (Tenorio-Rodriguez et al. 2017).

Water quality parameters

Measurements were made on water quality in the waters of Hambuang, Haharu Sub-district, East Sumba District, East Nusa Tenggara, Indonesia including pH, temperature, and Dissolved Oxygen (DO) (Meiyasa et al. 2020). Three points were placed 10 m apart for the water quality testing and repeated three times.

Proximate analysis

The proximate analysis performed on *U. reticulata* included measuring moisture, ash, protein, fat, and carbohydrate content (carbohydrates based on differences) was conductedusing the Official Analytical Chemists (AOAC) methods (Da Costa et al. 2018).

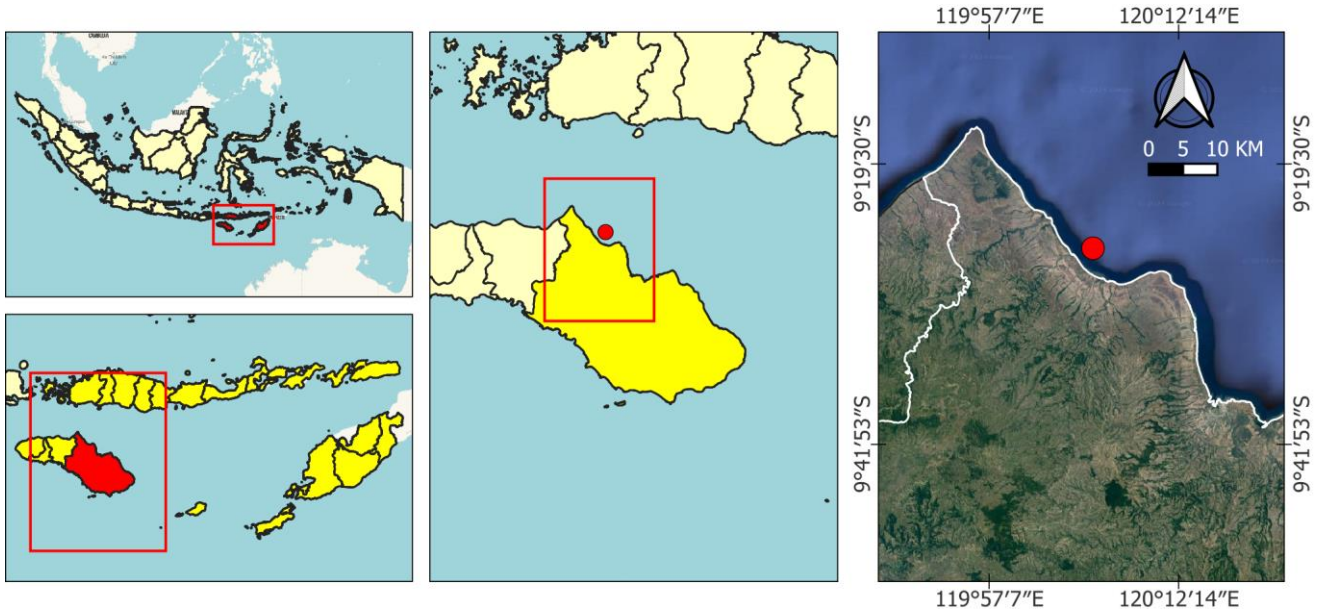


Figure 1. Sampling location for *Ulva reticulata* in Hambuang Waters, Haharu Sub-district, East Sumba District, East Nusa Tenggara, Indonesia

For quantitative determination of proximate composition of *U. reticulata* simplicia, moisture was determined using hot air oven (Association of Official Analytical Chemists; AOAC 952.08, 2016), dried *U. reticulata* simplicia at 105°C, until constant weight. Ash was determined according to gravimetric method (AOAC 930.30, 2016), incinerated *U. reticulata* simplicia at 550°C, until constant weight. Crude protein was determined according to the Kjeldahl method (AOAC 992.23, 2016); total nitrogen was multiplied by a protein factor of 6.25. Total fat was determined according to the acid hydrolysis method (AOAC 948.15, 2016), using Soxhlet extractor at 60°C, until constant weight. Total carbohydrate was determined according to the difference method by calculation. All experiments were performed in triplicate, and the data were expressed as the mean values of the experiments.

Extraction of *Ulva reticulata*

Approximately 500 g of *U. reticulata* simplicia were weighed and extracted using the maceration technique (5×24 h). A total of 100 g of *U. reticulata* simplicia was dissolved in 300 mL of solvent at 27°C. There solvents were used, namely 70% methanol, 70% ethyl acetate, and 70% chloroform, with a ratio of simplicia and solvent of 1:3. The extract was then filtered to separate the pulp and macerate. The macerate was concentrated with a rotary evaporator at 40°C until a thick extract was obtained (Tarigan et al. 2023; Meiyasa et al. 2024; Bhuyar et al. 2021). The resulting *U. reticulata* extract was tested for antioxidant and antimicrobial activity against *E. coli* and *S. aureus* bacteria.

The antibacterial activity test

The antimicrobial activity of *U. reticulata* extract with methanol, ethyl acetate, and chloroform solvents was evaluated by the well diffusion method using Muller–Hinton agar (BBL 211438 Becton Dickinson, Sparks, MD, USA). Approximately 100 µL of 105 CFU/mL of diluted inoculum of bacterial culture was applied to the surface of Muller–Hinton agar plates. The Muller–Hinton agar well was made using a well borer (diameter 6 mm) under aseptic conditions and filled with *U. reticulata* extracts. The plates were incubated at 37°C for bacterial growth. The antibacterial activity of the seaweed samples was evaluated by measuring the zone of inhibition (mm) in relation to the tested pathogenic bacteria (*S. aureus* ATCC 10876; Gram-positive and *E. coli* ATCC 25922; Gram-negative). The pathogenic bacteria were acquired from the SEAFAST Center IPB. All experiments were performed in triplicate, and the data were expressed as the mean values of the experiments (Das et al. 2023).

The antioxidant activity test

The antioxidant activity tests were conducted following the methodology outlined by Batubara et al. (2009). The sample was dissolved in methanol solutions of different concentrations. A total of 100 µL of the sample solution and 100 µL of 125 µM 2,2-diphenyl-1-picrylhydrasil (DPPH) solution were added to a 96-well plate. The samples were then incubated at room temperature for 30 min. Absorbance was measured at a wavelength of 517 nm using a microplate reader. Ascorbic acid was used as the positive control.

Antioxidant activity was tested using a UV-visible spectrophotometer using the DPPH method. *U. reticulata* extract was prepared in different concentrations (20, 40, 60, 80, 100 mg/L). Ascorbic acid was employed as a positive control at 20, 40, 60, 80, and 100 mg/L doses. Next, the samples were transferred into a DPPH solution used in 96 transparent polystyrene microplate tubes at a ratio of 1:4. The resulting mixture was incubated at 37°C for 30 minutes. Then, the absorbance was measured at a wavelength of 517 nm using a microplate reader (Tenorio-Rodriguez et al. 2017). The extent of free radical inhibition was determined using Eq.1.

$$\%\ Inhibition = 1 - \frac{A_{sample} - A_{blanko}}{A_{control} - A_{blanko}}\ x\ 100$$

Data analysis

Data from water quality tests, chemical composition (water content, ash, lipid, protein, and carbohydrate), and antioxidant and antimicrobial activities were processed using the microsoft excel program application. Furthermore, the data were analyzed descriptively to determine the average value and standard deviation.

RESULTS AND DISCUSSION

Water quality in Hambuang Waters

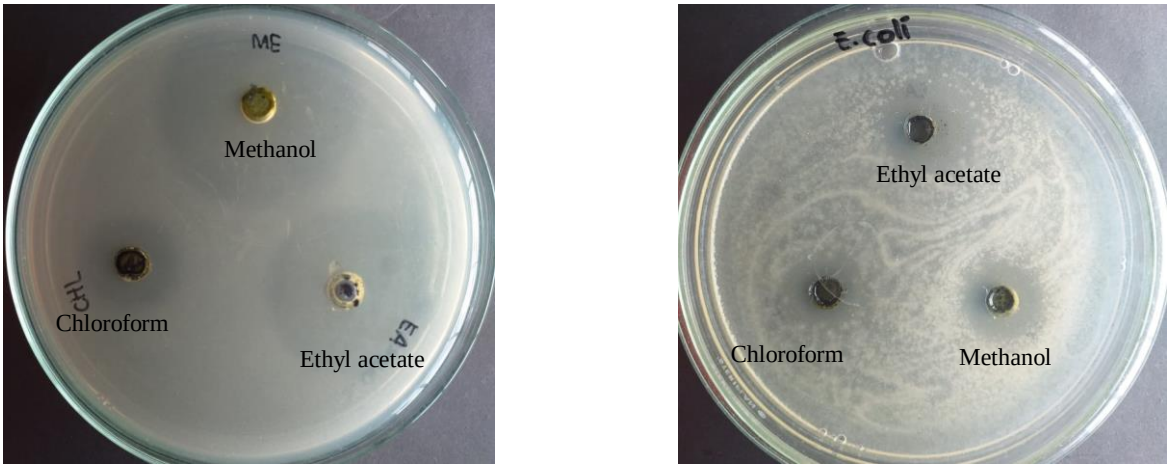
Optimal water quality is crucial for the ecological balance of a water body to support a healthy population of microorganisms. The observed water quality indicators on the coast of Hambuang, East Sumba, indicate a pH value of 7.52, a DO of 6.23 mg/L, and a temperature of 31.30°C (Table 1).

Chemical composition *of Ulva reticulata*

The chemical composition analysis showed that *U. reticulata* seaweed had a moisture content of 12.31%, ash content of 23.32%, lipid content of 3.04%, protein content of 12.93%, and carbohydrate content of 48.40% (Table 2).

Antimicrobial Activity of *Ulva reticulata* against *Staphylococcus aureus* and *Escherichia coli*

Antimicrobial activity testing was conducted using the well-diffusion technique against *S. aureus*, a representative of Gram-positive bacteria commonly found on the skin, and *E. coli*, a representative of Gram-negative bacteria commonly found in the digestive system. The results showed that *U. reticulata* extract has antimicrobial activity against *S. aureus* and *E. coli*. Furthermore, the results indicated that the antimicrobial activity varied depending on the solvent types. For example, methanol, ethyl acetate, and chloroform extracts had antimicrobial activities of 39.59, 33.81, 14.94 mm against *S. aureus* and 15.94, 17.93, and 12.69 mm against *E. coli*, respectively (Table 3).



A **B**

Figure 2. Antimicrobial activity of *Ulva reticulata* extracted with different solvents. A) *Staphylococcus aureus*; B) *Escherichia coli*

Table 1. Water quality of Hambuang Waters, East Sumba District, East Nusa Tenggara, Indonesia

Water quality	Value
pH	7.52 ± 0.23
Temperature (°C)	31.30 ± 0.45
DO (mg/L)	6.23 ± 0.37

Table 2. Chemical composition of *Ulva reticulata* from Hambuang Waters, East Sumba District, East Nusa Tenggara, Indonesia

Chemical composition (%)	*U.reticulata* (This Research)	*U.reticulata* (Tarigan et al. 2023)	*U.rigida* (Nova et al. 2023)	*U.lactuca* (Nurjanah et al. 2023)
Moisture	12.31 (± 0.01)	15.24	16.2	7.25
Ash	23.32 (± 0.02)	23.10	26,6	41.05
Lipid	3.04 (± 0.07)	0.33	0.08	0.83
Protein	12.93 (± 0.08)	10.68	19.5	7.33
Carbohydrates	48.40 (± 0.0)	33.82	27.9	43.55

Table 3. Antimicrobial activity of *Ulva reticulata* extract against *Staphylococcus aureus* and *Escherichia coli*

Solvent	Antimicrobial activity (mm)	
	Staphylococcus aureus	*Escherichia coli*
Methanol	39.59 ± 1.76	15.94 ± 0.55
Ethyl acetate	33.81 ± 1.42	17.93 ± 0.35
Chloroform	14.94 ± 0.88	12.69 ± 0.65

Table 4. Antioxidant activity of *Ulva reticulata* extract

Solvent	IC_{50} (µg/mL)
Methanol	235.31 ± 3.45
Ethyl acetate	146.14 ± 0.99
Chloroform	174.72 ± 1.97
Ascorbic Acid Standard	7.93 ± 1.23

Antioxidant activity

Antioxidants are compounds that can prevent oxidation. Table 4 shows that the ethyl acetate extract of *U. reticulata* had the highest activity, followed by chloroform and methanol, with antioxidant activity of 146.14, 174.72, and 235 µg/mL, respectively.

Discussion

Temperature, pH, and DO are important parameters that determine water quality in a water body. This is also closely related to the distribution and quality of seaweed, primary metabolites, and secondary metabolites contained in seaweed. Water quality, according to SNI criteria, should comply with a pH range of 6.8-8.2, a temperature range of 25-30°C, and DO >3.0. The results showed that the pH value (7.52) and DO (6.23 mg/L) met the SNI standards, whereas the temperature (31.30°C) did not meet SNI standards. However, the temperature range remained within the typical parameters for seaweed growth. This follows the report by Handayani et al. (2023) that a temperature of 31.30°C is still tolerant for seaweed growth. This also follows the research results of Lapu (2013) reported with a pH range of 7.2-8.2, temperatures around 24-36°C, and DO of 7.7 mg/L (Table 1).

The nutrient content of seaweed is closely related to the nutrients in the surrounding waters, and some of these environmental parameters can affect the biosynthesis of some nutrients due to seasonal changes in ecological conditions (Khairy and El-Sheikh 2015). The chemical composition of *U. reticulata* in this study was 12.31% moisture, 23.32% ash, 3.04% lipid, 12.93% protein, and 48.40% carbohydrate (Table 2). Tarigan et al. (2023) also reported that *U. reticulata* from Moudolung Waters in East Sumba contained moisture of 15.24%, ash of 23.10%, lipid of 0.33%, protein of 10.68%, and carbohydrate of 33.82% (Table 2). Furthermore, *Ulva rigida* C.Agardh contained 16.2% moisture, 26.6% ash, 0.08% lipid, 19.5% protein, and 27.9% carbohydrates (Nova et al. 2023). In addition, Nurjanah et al. (2023) reported that *U. lactuca* contained 7.25% moisture, 41.05% ash, 0.83% lipid, 7.33% protein, and 43.55% carbohydrates. The chemical composition of

the seaweed produced has varying values. Differences in the chemical composition of seaweeds are influenced by several factors, including sampling locations, species, age, size, reproduction, water quality (pH, DO, temperature), depth, salinity, available nutrients, sun exposure, and season (Costa et al. 2024; Duan et al. 2023; Xie et al. 2023; Menaa et al. 2020). All of these factors have a significant influence on the chemical composition of the seaweed.

The protein contained in *U. reticulata* can be used as part of a healthy diet and utilized as a novel seaweed product. Moreover, the carbohydrates found in *U.* reticulata consist of significant and biologically active compounds, such as polysaccharides. These polysaccharides serve as a major source of dietary fiber, which is a crucial nutritional component due to its resistance to complete degradation by human digestive enzymes. Consequently, they provide benefits to the human gut microbiota and the overall health of the host. Furthermore, it is also known that *U. reticulata* is low in calories and lipids, making it excellent for a healthy diet (Nova et al. 2023).

This study analyzed the antimicrobial activity of *U. reticulata* against *S. aureus* and *E. coli* bacteria. It can be seen in Table 3 that the methanol extract of *U. reticulata* has the highest antimicrobial activity with an inhibition zone of 39.59 mm, followed by the ethyl acetate extract (inhibition zone of 33.81 mm) and chloroform (inhibition zone of 14.94 mm) (Figure 2). The findings of this work suggest that the methanol and ethyl acetate extracts of *U. reticulata* exhibit very strong inhibitory effects. The chloroform extract of *U. reticulata* showed a strong inhibitory activity. This follows the category of inhibition below 5 mm in the weak category, inhibition of 5-10 mm in the moderate category, inhibition of 10-20 mm in the strong category, and more than 20 mm in the very strong category (Rani et al. 2023). The results showed that using different solvents (methanol, ethyl acetate, chloroform) produced different antimicrobial activities. Afrin et al. (2023) reported that methanol extracts of *Padina tetrastromatica*, *Sargassum muticum* (Yendo) Fensholt, and *Hydroclathrus clathratus* (C.Agardh) M.Howe showed the highest activity against *S. aureus* and *E. coli* compared to other solvents (ethanol and acetone). Mishra et al. (2018) found that the methanol extract of *U. lactuca* exhibited greater antibacterial activity against *P. aeruginosa* (8.0 mm) and *S. aureus* (6.0 mm) compared its ethyl acetate extract. Furthermore, the ethyl acetate extract of *U. reticulata* exhibited the highest antibacterial activity (17.93 mm) against *E. coli* in comparison to the extracts of methanol (15.94 mm) and chloroform (12.69 mm).

Table 3 revealed that the antibacterial activity of *U. reticulata* extract was greater against *S. aureus* (Gram-positive bacteria) than against *E. coli* (Gram-negative bacteria). This is due to the cell wall structure and chemical composition of *S. aureus*, which has a thicker membrane than *E. coli* (Mishra et al. 2018). Secondary metabolites contained in *U. reticulata* extract such as alkaloids, flavonoids, saponins, tannins, phenols (1H-Benzimidazole), steroids (9,19-Cyclolanost-24-en-3-ol acetate), phytol (terpenoids), sitosterol, stigmasterol, 3, 5-bis (1, 1-dimethyl ethyl), and hentriacontane play a role as antimicrobials (Dhanya et al. 2016; Tarigan et al. 2023; Meiyasa et al. 2024). In addition, lipid and fatty acids contained in the ethanol extract of *U reticulata*, such as palmitic acid, 3,7,11,15-tetramethyl-2-hexadecen-1-ol neophytadiene, 1,2-benzenedicarboxylic acid, 9,12,15-Octadecatrienoic acid, and hexadecanoic acid plays a vital role in the formation of bioactive secondary metabolites that act as antimicrobials (Dhanya et al. 2016; Tarigan et al. 2023; Yiwa and Meiyasa 2023).

The antioxidant activity of *U. reticulata* extract was also studied with three different solvents (methanol, ethyl acetate, and chloroform). This antioxidant activity test aims to determine the antioxidant activity of *U. reticulata* extracted with several different solvents. The antioxidants function as an antidote to free radicals, which in excessive amounts can lead to lipid peroxidation, alterations in the structure of body biomolecules that result in cellular diseases, premature aging, mutation, or cell death (Gomez-Zavaglia et al. 2019). Table 4 shows that the IC_{50} values of methanol, ethyl acetate, and chloroform extracts have different antioxidant activities. It can be observed that the ethyl acetate extract has the lowest IC_{50} value of 146.14 µg/mL than chloroform extract (174.72 µg/mL) and methanol extract (235.31 µg/mL). Molyneux (2004) classified antioxidant activity into four distinct categories: very strong, strong, moderate, and weak. Very strong antioxidants have IC_{50} values less than 50 µg/mL (<50 ppm), strong antioxidants have IC_{50} values in the range of 50-100 µg/mL (50-100 ppm), moderate antioxidants have IC_{50} values ranging from 100-150 µg/mL (100-150 ppm), and weak antioxidants have a range of 150-200 µg/mL (150-200 ppm). The reported results indicate that the ethyl acetate solvent is categorized as a moderate antioxidant with an IC_{50} value of 146.14 µg/mL. The extract from methanol solvents is classified as a weak antioxidant with an IC_{50} value in the range of 174.72. The extract from chloroform surpasses this classification with an IC_{50} value in the range of 235.31 µg/mL. Additionally, Tarigan et al. (2023) reported that ethanol extract of *U. reticulata* from Moudolung Waters has strong antioxidant activity (IC_{50}; 53 ppm). Furthermore, Ainiyah et al. (2023) also reported that ethanol extract of *U. lactuca* from Pidakan Pacitan Waters has strong antioxidant activity (IC_{50}; 47.99 ppm). Those results showed that different solvents have different antioxidant activity values, and differences can be influenced by bioactive secondary metabolites contained in the seaweed (Al Monla et al. 2021). Furthermore, the extract of *U. reticulata* has antioxidant properties due to the presence of bioactive secondary metabolites, including tetradecane, dodecanal, diphenylamine, heptadecane, phytol, butanoic acid, 2-hydroxy-, ethyl ester, dodecane, and benzene. In addition, *U. reticulata* extract contains compounds such as hexadecanoic acid, palmitic acid, 3,7,11,15-tetramethyl-2-hexadecen-1-ol neophytadiene, 9,12,15-octadecatrienoic acid, and 1,2-Benzenedicarboxylic acid which act as antioxidants (Das et al. 2023; Tarigan et al. 2023). Furthermore, the testing method for bioactive compounds and extraction variables (type and volume of solvent, technique, temperature, and extraction time) affect the antioxidant activity value, thus

providing information on the performance of different activities (Meiyasa et al. 2024).

The results showed that the Hambuang Waters are still in the good category. This is distinguished by the abundance of seaweed, including *U. reticulata*, which spreads throughout these waters and has a relatively high chemical composition, including ash, protein, and carbohydrates. In comparison to the other solvents (methanol, ethyl acetate, chloroform), the ethyl acetate extract of *U. reticulata* exhibited the highest antioxidant and antimicrobial properties. This study revealed that *U. reticulata* extract has antioxidant and antimicrobial activities that may be beneficial in the food, nutraceutical, pharmaceutical, and cosmeceutical industries.

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