

Antibacterial and Tyrosinase Inhibitory Activity of Red Algae and Green Algae: A Literature Review

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Abstract

Background: Bacterial infections and skin hyperpigmentation have been major health concerns due to increasing antibiotic resistance and the limitations of synthetic whitening agents.

Objective: This study aimed to review the antibacterial and tyrosinase inhibitory activities of red algae (*Eucheuma cottonii*) and green algae (*Ulva sp.*).

Methods: A systematic literature search was conducted through PubMed and Google Scholar for studies published between 2015 and 2025. Ten original research articles that met the inclusion and exclusion criteria were analyzed. The antibacterial activity was evaluated based on inhibition zone diameter, while tyrosinase inhibition was assessed using IC₅₀ values.

Results: The results showed that *Ulva sp.* exhibited stronger antibacterial effects, with inhibition zones up to >20 mm against *Escherichia coli*, *Staphylococcus aureus*, and *Vibrio harveyi*, categorized as strong to very strong. In contrast, *E. cottonii* demonstrated weaker activity, with inhibition zones generally <10 mm even at higher concentrations, except when methanol extracts were used, which showed stronger inhibition against *Pseudomonas aeruginosa*. Regarding tyrosinase inhibition, *E. cottonii* and *Ulva sp.* both showed moderate activity with an IC₅₀ value for *E. cottonii* of 234 µg/mL and *Ulva sp.* amounted to 127.74 µg/mL. Based on the IC₅₀ value, *Ulva sp.* showed stronger tyrosinase inhibitory activity than *E. cottonii*.

Conclusions: These findings indicate that *Ulva sp.* more effective as a natural antibacterial agent while also having better potential for tyrosinase inhibitory activity than *E. cottonii*. The potential of these two algae provides a scientific basis for the development of multifunctional natural bioactive compounds for safer and more sustainable dermatological applications.

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INTRODUCTION

Bacterial infections remain a significant global health concern and continue to pose substantial challenges due to the high prevalence of resistance to conventional antibiotics. The increasing resistance of bacteria to these antibiotics has led to a decline in the effectiveness of infection therapies and an elevated risk of treatment failure.¹ By 2030, antimicrobial resistance is projected to drive approximately 24 million people into extreme poverty, and by 2050, the estimated number of deaths associated with antimicrobial resistance could reach up to 10 million.² *Staphylococcus aureus* is one of the most significant pathogenic bacteria frequently implicated in skin and soft tissue infections, while *Propionibacterium acnes* is recognized as a key contributor to the pathogenesis of inflammatory acne in adolescents and young adults.³ Both species are Gram-positive bacteria commonly associated with persistent and recurrent infections.^{3,4} In the context of acne, *S. aureus* may act as an opportunistic pathogen contributing to secondary infection and exacerbation of acne lesions.⁵ Additionally, these bacteria are part of the skin microbiota, and their imbalance can influence the severity and persistence of acne-related inflammation.⁵

In addition, skin hyperpigmentation resulting from excessive melanin production catalyzed by the enzyme tyrosinase has emerged as a critical concern in the fields of healthcare, dermatology, and cosmetic science. The prevalence of hyperpigmentation in Asia is reported to be 21%, which is notably higher than that observed in Africa (9%), the Americas (8%), and Europe (4%).⁶ Within Asian populations, individuals of Malay and Indian ethnicities exhibit a higher incidence of post-inflammatory hyperpigmentation (PIH) compared to lighter-skinned groups such as those of

Chinese descent.⁶ Typically, hyperpigmentation can be addressed through the use of chemical agents that reduce melanin concentrations. However, synthetic skin-lightening agents such as hydroquinone have been associated with severe adverse effects, including skin irritation, and prolonged use at high doses has been linked to ochronosis and potential carcinogenicity.⁷ In addition, toxicological studies have reported that hydroquinone, as a benzene metabolite, exhibits hematotoxic and carcinogenic properties and may contribute to DNA damage and impaired immune responses.⁸ These findings further highlight the potential health risks associated with long-term exposure to hydroquinone.⁸ These circumstances underscore the urgent need to identify natural sources of active compounds that are safer, more environmentally sustainable, and ideally possess dual activity as antibacterial agents and tyrosinase inhibitors. Such a dual-action approach is considered more effective, economical, and sustainable, as it addresses two major health concerns simultaneously through a single bioactive compound.

Red algae (*Eucheuma cottonii*) and green algae (*Ulva* sp.) are groups of marine macroalgae widely distributed in tropical and subtropical waters, including the biodiverse marine ecosystems of Indonesia. Both groups are known to contain a wide range of secondary bioactive metabolites with reported biological activities. Red algae are particularly rich in sulphated polysaccharides such as carrageenan, phlorotannin, and pigments, including phycobiliproteins and carotenoids, which demonstrate antioxidant, anti-inflammatory, and antibacterial properties.⁹ Conversely, green algae are abundant in ulvan, flavonoids, and phenolic compounds, which possess strong antioxidant potential and enzyme inhibitory activities.¹⁰ Nevertheless, most previous studies have investigated these biological activities independently, without exploring the dual functional potential of these algal groups in an integrated manner. Consequently, existing data remain fragmented and incomplete, hindering the development of comprehensive scientific conclusions. This knowledge gap represents a significant research challenge, as the optimal utilization of algae as a source of multifunctional bioactive compounds requires a thorough and integrative literature synthesis.

Recent scientific evidence indicates that several *in vitro* studies have identified key bioactive compounds from algae that contribute to antibacterial activity, such as phenolics and sulphated polysaccharides, as well as compounds responsible for tyrosinase inhibition, including flavonoids and carotenoids.^{11,12} However, to date, there has been no comprehensive literature review that compiles, analyzes, and compares data on both activities in red and green algae within a unified framework. An integrated review is essential to identify research gaps, map the bioactive potential of these species, and provide a robust scientific foundation for the development of algae-based products with both antibacterial and natural skin-brightening properties. The urgency of this research is further underscored by Indonesia's vast marine biodiversity, which presents a strategic opportunity for exploring algae as a sustainable source of bioactive compounds. Therefore, the present study aims to conduct a comprehensive literature review on the antibacterial and tyrosinase inhibition activities of red and green algae, identify their key bioactive constituents, compare their respective potentials, and establish a scientific basis for future research and the development of innovative algae-derived products.

RESEARCH METHODS

The literature search was conducted systematically to identify publications relevant to the research topic through the PubMed and Google Scholar databases. The keywords used in the search included "red algae (*Eucheuma cottonii*) antibacterial activity," "red algae (*Eucheuma cottonii*) tyrosinase inhibitory activity," "green algae (*Ulva* sp.) antibacterial activity," and "green algae (*Ulva* sp.) tyrosinase inhibitory activity." Articles included in this review were original research articles or primary studies focusing on antibacterial activity assays and tyrosinase enzyme inhibition of red and green algae. The inclusion criteria comprised research articles published within the last 10 years (2015–2025), studies reporting inhibition zone activity, inhibition assays, and IC₅₀ values (if available). Articles were excluded if they were review papers, conference proceedings, theses, dissertations, or did not provide analyzable data. To ensure data accuracy, duplicate articles retrieved from the two databases were identified and removed through manual screening based on titles, authors, and publication details. Data extracted from each article included the type of extract, tested bacterial strains, inhibition zone activity, tyrosinase enzyme inhibition activity, and IC₅₀ values (if available). All data meeting the inclusion criteria were compiled, and a total of 10 articles were selected and summarized in a table to facilitate analysis and comparison.

RESULT AND DISCUSSION

Antibacterial Activity of Red Algae and Green Algae

The investigation of the antibacterial activity of red and green algae reveals a distinct difference in their respective potencies. In general, antibacterial activity is evaluated using the disc diffusion method. The parameter used to assess antibacterial activity was the inhibition zone diameter, with activity classified according to **Table 1**. The data presented in **Table 2** indicate that green algae, particularly *Ulva sp.*, tend to exhibit stronger antibacterial activity compared to red algae, as evidenced by their larger inhibition zone diameters against several bacterial strains. Ethanol extracts of *Ulva sp.* have been shown to produce relatively large inhibition zones against various bacterial strains. For instance, against *Escherichia coli* strain FNCC 194, the ethanol extract of *Ulva sp.* with large leaves formed an inhibition zone of 20.45 mm at a concentration of 0.5 mg/mL, which is categorized as strong.¹³ Similar activity was observed against *Staphylococcus aureus*, with an inhibition zone of 17.17 ± 4.25 mm at a concentration of 1 mg/mL, and against *Vibrio harveyi*, with an inhibition zone of up to 21 ± 0.577 mm at a concentration of 4 mg/mL, categorized as very strong.^{14,15} These findings indicate that *Ulva sp.* possesses a broad antibacterial spectrum, targeting both Gram-positive and Gram-negative bacteria, and therefore holds significant potential as a natural antibacterial candidate. In relation to acne pathogenesis, antibacterial activity against *S. aureus* is particularly relevant, as this bacterium can act as an opportunistic pathogen that exacerbates inflammatory lesions and contributes to secondary infection.¹⁶ Moreover, the ability to inhibit a broad range of bacteria may help restore skin microbiota balance, which is increasingly recognized as an important factor in the development and persistence of acne.¹⁶

Table 1. Classification of inhibition zone diameter¹⁷

Clear Zone Diameter (mm)	Inhibitory Activity
≤ 5	Weak
5-10	Medium
11-20	Strong
≥ 21	Very Strong

Conversely, the antibacterial activity of red algae appears to be relatively weaker. *E. cottonii* in the form of an aqueous extract, produced an inhibition zone of only 10.03 ± 0.06 mm against *S. aureus* at a much higher extract concentration (200 mg/mL), which is categorized as moderate.¹⁸ Similarly, both crude ethanol and hot water extracts exhibited weak activity against *Bacillus cereus*, with inhibition zones < 10 mm even at concentrations of 1–2 mg/mL.¹⁹ However, different results were observed when methanol was used as the extraction solvent, where *E. cottonii* demonstrated stronger inhibition against *Pseudomonas aeruginosa*, with an inhibition zone diameter of 17.17 ± 4.5 mm. This activity is considered strong and suggests that the type of solvent significantly influences the extraction of certain bioactive compounds, which may be more soluble in polar organic solvents such as methanol.²⁰

Red algae are known to be rich in sulfated polysaccharides such as carrageenan, phenolics, and phlorotannin, which primarily act by forming a protective layer on the bacterial cell surface, thereby inhibiting adhesion and biofilm formation.²¹ Sulphated polysaccharides can disrupt bacterial cell membrane integrity by binding to positively charged surfaces, increasing membrane permeability, and causing leakage of cellular contents.²² Additionally, phenolic compounds exert antibacterial effects by denaturing membrane proteins and inhibiting essential enzymes involved in bacterial metabolism. This mechanism is bacteriostatic, meaning that it slows bacterial growth rather than killing the cells directly.^{23,24}

Meanwhile, green algae such as *Ulva sp.* contain phenolic compounds, flavonoids, and the glycoprotein ulvan, which can penetrate the bacterial lipid membrane, increase permeability, cause cellular leakage, and induce cell lysis.²⁵ Phenolic compounds are also known to inhibit essential bacterial enzymes through hydrogen bonding interactions with the active sites of proteins.²⁶ Furthermore, flavonoids and tannins, which are abundant in *Ulva*, can interact with the bacterial cell wall by precipitating proteins and forming metal ion complexes, ultimately inhibiting bacterial cell division.²⁷ Flavonoids are also capable of disrupting the function of DNA gyrase, a key enzyme in bacterial DNA replication, thereby suppressing the growth and multiplication of Gram-negative bacteria.²⁸

In addition to the types of compounds present, antibacterial effectiveness is also highly influenced by the choice of extraction solvent. Polar solvents such as water only extract hydrophilic compounds, such as sulphated polysaccharides, which are generally bacteriostatic and therefore exhibit relatively weak inhibitory activity. In contrast, semi-polar solvents such as ethanol or methanol are effective in extracting phenolics, flavonoids, and terpenoids, which

act more aggressively by disrupting bacterial cell membranes, increasing permeability, and inactivating essential enzymes.²⁹ Consequently, ethanol or methanol extracts of algae often demonstrate stronger antibacterial activity than aqueous extracts. Thus, the choice of solvent not only determines the types of metabolites extracted but also directly influences the dominant antibacterial mechanisms present in the extract.³⁰

Table 2. Antibacterial Activity of Red Algae and Green Algae

No	Plant of Material	Type of Extract	Method	Against	Bacterial Classifications	Activity		Category	Ref.
						Positive Control	Extract		
1.	Red Algae (<i>Euclima cottonii</i>)	Aqueous extract*	disc diffusion method	<i>Staphylococcus aureus</i>	Gram-positive	Vancomycin (30 µg/mL): 18.10 ± 0.10 mm	Inhibition zone (200 mg/mL): 10.03 ± 0.06 mm	Medium	18
2.	Red Algae (<i>Euclima cottonii</i>)	Crude Ethanolic Extract*	disc diffusion method	<i>Bacillus cereus</i>	Gram-positive	Ampicillin (10 µg): >10 mm	Inhibition zone (1 mg/mL): <10 mm (2 mg/mL): <10 mm	Medium	19
		Crude Hot Water Extract*		<i>Bacillus cereus</i>	Gram-positive	Ampicillin (10 µg): >10 mm	Inhibition zone (2 mg/mL): <10 mm	Medium	
3.	Red Algae (<i>Euclima cottonii</i>)	Methanolic extract*	disc diffusion method	<i>Pseudomonas aeruginosa</i>	Gram-negative	n.d	Inhibition zone (10 mg/mL): 17.17 ± 4.25 mm	Strong	20
4.	Green Algae (<i>Ulva sp.</i>)	Ethanolic extract*	disc diffusion method	<i>Staphylococcus aureus</i>	Gram-positive	Medi-kin (0.1 mg/mL): 24.66 ± 2.51	Inhibition zone (1 mg/mL): 17.17 ± 4.25 mm	Strong	14
5.	Green Algae (<i>Ulva sp.</i>) (small leaves)	Ethanolic extract*	agar well diffusion method	<i>Escherichia coli</i> FNCC 194	Gram-negative	Ampicillin (0.5 mg/mL): 27.80 mm	Inhibition zone (1.0 mg/mL): 5.40 mm	Medium	13
	Green Algae (<i>Ulva sp.</i>) (large leaves)	Ethanolic extract*	agar well diffusion method	<i>Escherichia coli</i> FNCC 194	Gram-negative	Ampicillin (0.5 mg/mL): 27.80 mm	Inhibition zone (0.5 mg/mL): 20.45 mm	Strong	
6.	Green Algae (<i>Ulva sp.</i>)	Ethanolic extract*	disc diffusion method	<i>Vibrio harveyi</i>	Gram-negative	n.d	Inhibition zone (2 mg/mL): 15 ± 0.577 (4 mg/mL): 21 ± 0.577	Very Strong	15

Information:

n.d: no data;

* : semi liquid extract

Tyrosinase Inhibitory Activity of Red Algae and Green Algae

In addition to antibacterial activity, the literature also confirms the presence of tyrosinase inhibitory activity in both groups of algae (**Table 4**). The parameter used to assess this activity is the IC₅₀ value, with activity classified according to **Table 3**. Research findings indicate that, in general, the tyrosinase inhibitory activity of both algal groups is significantly weaker compared to the positive control, kojic acid, which has an IC₅₀ of approximately 11 µg/mL. *Euclima cottonii* shows variable results across different studies. A study by Chang and Teo (2016) reported an IC₅₀ of 234.33 ± 21.85 µg/mL, classified as moderate. However, another study by Dolorosa et al. (2019) reported much higher IC₅₀ values (around 2,600 µg/mL, depending on the substrate used).^{31,32} This suggests that the assay method and substrate type (monophenolase or diphenolase) significantly influence the results obtained.

Table 3. Classification of IC₅₀³³

IC ₅₀ (µg/mL)	Inhibitory Tyrosinase Activity
< 50	Very Strong
50-100	Strong
100-250	Medium
250-500	Weak
> 500	Very Weak
< 1,000	Active
> 1,000	Not Active

Meanwhile, *Ulva sp.* exhibited an IC₅₀ of 1,783 µg/mL in the crude methanolic extract, but after fractionation, the n-hexane fraction showed enhanced activity with an IC₅₀ of 584.34 µg/mL, classified as active though not particularly strong.³⁴ On the other hand, the n-hexane fraction derived from the ethanol extract showed an IC₅₀ of 127.74 ± 6.47 µg/mL, categorized as moderate.³⁵ These findings of Gazali et al. further support this observation, where ethanol extracts and non-polar fractions of *Ulva sp.* consistently demonstrated moderate to strong activity. Although the values remain significantly higher than those of kojic acid, these results indicate the presence of potential lipophilic compounds in *Ulva* that are more effective as tyrosinase inhibitors compared to crude extracts. Therefore, fractionation may serve as an important strategy to enhance the bioactive potential of these compounds.

The differences in tyrosinase inhibitory effectiveness are likely related to variations in the active metabolite content between the two algal groups. Red algae are known to contain bioactive components that can interact with copper ions at the active site of the tyrosinase enzyme, thereby reducing its activity. This mechanism is similar to that of competitive inhibitors, where active compounds occupy the substrate binding site, thus inhibiting the oxidation of L-DOPA into dopaquinone.³⁶ In contrast, in green algae, lipophilic fractions such as terpenoids or sterols are thought to play a greater role in inhibiting tyrosinase activity through allosteric mechanisms or by decreasing enzyme stability.³⁷ The fact that fractionation enhances the activity of *Ulva sp.* further supports the hypothesis that specific bioactive compounds could serve as key targets for developing tyrosinase inhibitors from green algae.³⁸

Table 4. Tyrosinase Inhibitory Activity of Red Algae and Green Algae

No	Plant of Material	Type of Extract	Activity		Category	Ref.
			Positive Control (kojic acid)	Extract		
1.	Red Algae (<i>Eucheuma cottonii</i>)	Methanolic extract*	n.d	IC ₅₀ : 234.33 ± 21.85 µg/mL	Medium	31
2.	Red algae (<i>Eucheuma cottonii</i>)	Methanolic extract*	IC ₅₀ : 15.566 µg/mL (monophenolase)	IC ₅₀ : 2691.478 µg/mL (monophenolase, L-tyrosine substrate)	Not active	32
			IC ₅₀ : 29.156 µg/mL (diphenolase)	IC ₅₀ : 2631.648 µg/mL (diphenolase, L-DOPA substrate).	Not active	
3.	Green algae (<i>Ulva sp.</i>)	Methanolic extract*	IC ₅₀ = 11.07±0.86 µg/mL	IC ₅₀ = 1783.06 ± 63.90 µg/mL	Not active	34
		n-Hexane fraction of methanolic extract*	IC ₅₀ = 11.07±0.86 µg/mL	IC ₅₀ = 584.34 ± 35.07 µg/mL	Active	
4.	Green Algae (<i>Ulva sp.</i>)	Ethanol extract*	IC ₅₀ = 11.07±0.86 µg/mL	IC ₅₀ = 148.19±3.24 µg/mL	Medium	35
		n-Hexane fraction of ethanol extract*	IC ₅₀ = 11.07±0.86 µg/mL	IC ₅₀ = 127.74±6.47 µg/mL	Medium	

Information:

n.d : no data

* : semi liquid extract

From an application perspective, tyrosinase inhibitory activity classified as moderate to weak does not preclude its potential use, especially when combined with the strong antibacterial activity demonstrated by *Ulva sp.* A multifunctional combination approach could even provide a competitive advantage in dermatological applications, for instance, in skincare products targeting acne-prone skin that is also at risk of post-inflammatory hyperpigmentation. However, to achieve effectiveness comparable to or approaching that of standard agents such as kojic acid, further strategies including active compound isolation, structural modification, or synergistic formulation with other tyrosinase inhibitors are required.³⁹

Limitation

This study has several limitations that should be considered when interpreting the findings. First, there is notable methodological heterogeneity among the included studies, particularly in terms of extraction methods, solvent types, and variations in extract concentrations used in antibacterial assays, which may affect the comparability of the reported inhibition zones. Second, the number of studies included in this review is relatively limited (n = 10), which may restrict the generalizability and robustness of the conclusions drawn. Third, all included studies were conducted using *in vitro* approaches, which do not fully represent the complexity of biological systems *in vivo*, including factors such as bioavailability, metabolism, and skin permeability. Therefore, the findings presented should be interpreted with caution, and further studies incorporating standardized methodologies and *in vivo* models are required to validate and strengthen the current evidence.

CONCLUSION

Based on the literature review, it can be concluded that red and green algae possess significant bioactive potential in dermatological applications, particularly in preventing microbial skin infections and regulating hyperpigmentation. The findings indicate that *Ulva sp.* (green algae) shows more promising potential due to its strong antibacterial activity combined with moderate tyrosinase inhibition, which, although not yet optimal, can be further enhanced. This highlights its potential as a multifunctional natural ingredient capable of targeting acne-causing bacteria while simultaneously preventing post-inflammatory hyperpigmentation within a single formulation. An important aspect identified is the influence of solvent type on extract effectiveness, as it determines the classes of metabolites extracted and directly impacts their bioactivity. Additionally, strategies such as fractionation or isolation of active compounds, along with optimized extraction conditions, are key to improving bioactive potential. Furthermore, the physical form of the extract or fraction (e.g. dry, semi-solid, or liquid) is also very important because the presence of residual solvent and the consistency of the extract can affect the results of antibacterial activity. Therefore, further research employing more advanced pharmaceutical-chemical approaches is necessary to identify the primary active compounds, elucidate their molecular mechanisms, and develop effective, stable, and safe topical formulations. Such efforts will not only expand the utilization of algae as a valuable natural resource but also contribute to the development of more efficient, natural, and multifunctional dermatological products.

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GENERATIVE AI DISCLOSURE STATEMENT

The authors confirm that no Generative Artificial Intelligence (AI) or AI-assisted technologies were utilized in the writing, data analysis, or preparation of this manuscript.

AUTHOR CONTRIBUTION STATEMENT

Putu Pradnya Indreswari: Conceptualization, Methodology, Investigation, Writing—Original Draft; **Luh Putu Mirah Kusuma Dewi:** Data Curation, Formal Analysis, Resources, Visualization, Review and Editing; **Ni Made Puspawati:**

Data Curation, Formal Analysis, Resources, Visualization, Review and Editing; **Putu Oka Samirana**: Supervision, Project Administration, Validation, Review and Editing, Corresponding Author.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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