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# Comparative Potential of Antibacterial Activity of Marine Plants for the Development of Natural Antimicrobial Agents: A Review

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**Abstract:** Antibiotic resistance remains a major global health concern, driven by the misuse and overuse of antibiotics, which has resulted in multidrug-resistant bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA) and extended-spectrum beta-lactamase-producing *Escherichia coli* (ESBL-*E. coli*), leading to increased morbidity, mortality, prolonged hospital stays, and rising healthcare costs. To address this challenge, the search for alternative antibacterial agents that are natural, sustainable, and environmentally friendly has become urgent. Marine plants, including red macroalgae (Rhodophyta), brown algae (Phaeophyta), green algae (Chlorophyta), and seagrasses, produce secondary metabolites such as flavonoids, alkaloids, terpenoids, tannins, and sulfated polysaccharides with promising antibacterial properties. This systematic review analyzed 320 articles from PubMed, Google Scholar, and ScienceDirect, of which eight met the inclusion criteria, to compare the antibacterial potential of marine plant extracts against Gram-positive and Gram-negative pathogenic bacteria. The findings indicated that species such as *Kappaphycus alvarezii*, *Corallina officinalis*, *Eucheuma spinosum*, *Sargassum polycystum*, *Caulerpa racemosa*, and *Padina australis* exhibited antibacterial activity ranging from weak to very strong depending on species, extraction methods, solvents, concentrations, and environmental conditions, with *K. alvarezii* showing the highest inhibition zone of up to 26 mm against *Bacillus subtilis* and *Vibrio* species. The antibacterial mechanism is believed to involve membrane disruption, alteration of permeability, and inhibition of protein and DNA synthesis. In conclusion, marine plants demonstrate strong potential as sources of natural antibacterial agents that may reduce dependence on conventional antibiotics and mitigate the global antibiotic resistance crisis, though further research is required to standardize extraction methods, isolate active compounds, and validate efficacy and safety through MIC, MBC, and in vivo studies before clinical and industrial application.

**Keywords:** Antibiotic Resistance; Antibacterial; Marine Plants; Natural Agents; Secondary Metabolites.

## Introduction

Over the past two decades, bacterial infections have increasingly been recognized as a serious threat to global public health [1-2]. The emergence of pathogenic bacterial strains capable of resisting multiple antibiotics, such as methicillin-resistant *Staphylococcus aureus* (MRSA) and extended-spectrum beta-lactamase-producing *Escherichia coli* (ESBL-*E. coli*), has created significant challenges in controlling infectious diseases [3-4]. The impact is not limited to higher morbidity and mortality rates but also includes prolonged hospital stays, increased medical costs, and disruption of healthcare systems. The World Health Organization (WHO) has even listed antibiotic resistance as one of the top ten threats to human health and global ecosystem sustainability [1],[5].

Conventional antibiotics have long been the mainstay of bacterial infection therapy, functioning by inhibiting vital bacterial processes or directly killing the bacteria [6-7]. However, high levels of antibiotic consumption in both hospitals and communities have accelerated the rate of resistance. In Indonesia, antibiotic use is reported to range between 40–60%, with most cases not meeting rational use criteria [8-9]. Incorrect dosages, inappropriate drug selection, and usage without clear indications contribute to natural selection favoring resistant bacteria, thereby limiting effective therapeutic options [10].

Bacterial resistance to antibiotics occurs through various adaptive mechanisms, one of which is the production of β-lactamase enzymes that can destroy the β-lactam structure in antibiotics, rendering them therapeutically ineffective [11-12]. The genes encoding these enzymes are often located on plasmids, enabling rapid horizontal gene transfer between bacteria [13-14]. This makes resistance not only confined to a single bacterial species but also capable of spreading widely to other pathogens [15].

The high threat of resistance has driven the search for alternative solutions that are more sustainable and environmentally friendly [16-17]. One increasingly explored approach is the utilization of marine biological resources, particularly marine plants, as natural antibacterial agents [18]. Marine plants, including red macroalgae (Rhodophyta), brown algae (Phaeophyta), green algae (Chlorophyta), and seagrass, are known to produce secondary metabolites such as polyphenols, terpenoids, flavonoids, alkaloids, and sulfated polysaccharides that play crucial roles in defending against pathogenic microorganisms in their environment [19-21]. These compounds have been reported to possess antibacterial activity capable of inhibiting or killing both Gram-positive and Gram-negative bacteria through various mechanisms, including cell membrane damage, protein

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synthesis inhibition, and enzymatic metabolic disruption [19],[22].

The potential of marine plants as a source of natural antibacterial compounds offers several advantages. Besides being abundant in coastal and tropical waters, such as in Indonesia, their sustainable production can be supported through cultivation without damaging ecosystems. Species variation, environmental growth conditions, extraction methods, and solvent types can influence the concentration and efficacy of bioactive compounds produced [23, 24].

However, despite numerous studies on the antibacterial properties of marine plants, the available research remains fragmented and varies widely in methodology, species studied, and target bacterial strains. Many studies focus on single species or specific extraction methods without cross-comparison, leading to inconsistent and difficult-to-generalize findings. Furthermore, the majority of investigations are limited to in vitro assays, with limited exploration of active compound isolation or standardized evaluation parameters such as Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC). This lack of integrative synthesis and methodological consistency represents a critical research gap in understanding the true antibacterial potential of marine plants across taxa.

Therefore, this study was conducted to systematically review and synthesize current research on the antibacterial activity of various marine plant species against Gram-positive and Gram-negative pathogenic bacteria. The review aims to identify species with the highest antibacterial potential, characterize their secondary metabolites, and analyze key factors influencing their effectiveness. By consolidating findings from recent studies, this research contributes to filling the existing gap in the literature and provides a scientific foundation for the development of marine plant-derived antibacterial agents that are effective, sustainable, and capable of reducing dependence on conventional antibiotics.

## Research Methods

The literature review process was conducted by searching PubMed, Google Scholar, and ScienceDirect using the keywords “Marine Plants” AND “Antibacterial Activity” AND “Gram-Positive” AND “Gram-Negative,” which yielded 320 articles. After removing duplicates, 201 articles remained. From this number, 136 articles were excluded based on title and abstract screening, leaving 65 articles for full-text review. Subsequently, 57 articles were excluded because they did not meet the inclusion criteria, resulting in a final set of eight eligible articles. Data from these eight studies were extracted and analyzed to identify marine plant species with antibacterial potential, their secondary metabolite composition, and the factors influencing their effectiveness. The synthesis process used a descriptive-comparative approach, in which parameters such as inhibition zone diameter, Minimum Inhibitory Concentration (MIC), Minimum Bactericidal Concentration (MBC), extraction solvents, and bacterial strains tested were compared across studies. The data were then grouped thematically according to metabolite type and bacterial classification (Gram-positive or Gram-negative) to determine the most influential bioactive components. These findings provide a scientific foundation for developing sustainable marine-derived antibacterial products.

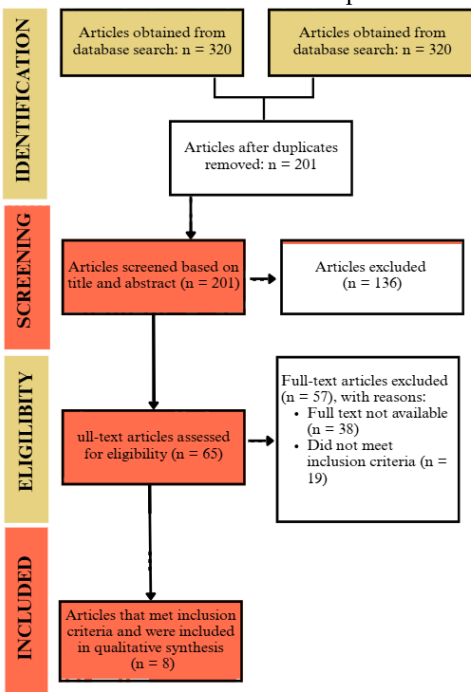


**Figure 1**. Reference Data Collection Phase

**Table 1.** PICO

| PICO | |
|---|---|
| Population (P) | Gram-positive and Gram-negative pathogenic bacteria |
| Intervention (I) | Marine plant extracts containing metabolites with antibacterial activity |
| Comparison © | Positive control and negative control |
| Outcome (O) | Antibacterial activity of marine plant extracts |

**Table 2.** Inclusion-Exclusion Criteria

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| Original research articles (in vitro or in vivo) specifically evaluating the antibacterial activity of marine plant extracts | Studies that do not use marine plants as the main subject or with extracts of unclear origin |
| Test subjects are Gram-positive or Gram-negative pathogenic bacteria, including strains reported to have antibiotic resistance | Studies that do not assess antibacterial activity, e.g., focusing only on antifungal, antiviral, or other biological activities |
| Articles report quantitative results of antibacterial activity, such as inhibition zone diameter, Minimum Inhibitory Concentration (MIC), or Minimum Bactericidal Concentration (MBC) | Publications such as reviews, editorials, conference abstracts, or articles that do not provide complete research data |
| Publications published between 2015–2025, in Indonesian or English, and peer-reviewed | Studies published outside the 2015–2025 range |

## Results and Discussion

This review identified several marine plant species with potential antibacterial activity against Gram-positive and Gram-negative bacteria. The level of activity varied depending on the species, metabolite content, extract concentration, and the testing methods used. A summary of the findings is presented in Table 3.

**Table 3.** Antibacterial Activity of Marine Plant Extracts Against Pathogenic Bacteria

| Marine Plant Source | Method | Type and Antibacterial Activity | Reference |
|---|---|---|---|
| (*Canavalia rosea)* | Disc Diffusion | Phytochemical analysis revealed the presence of alkaloids, saponins, flavonoids, polyphenols, and tannins. The ethyl acetate fraction showed significant antibacterial activity against *Staphylococcus aureus*. At a concentration of 9 mg/mL, the inhibition zone reached 20.31 ± 0.27 mm (strong category), whereas at 1.5 mg/mL, the inhibition zone was 5.13 ± 0.32 mm (weak category). | [24] |
| (*Eucheuma spinosum*) | Well Diffusion | Contains flavonoids, alkaloids, and saponins. Exhibited antibacterial activity against *Escherichia coli*. At 60% concentration, the inhibition zone = 16 mm (strong), 70% = 19 mm (strong), 80% = 21 mm (very strong), and 90% = 30 mm (very strong). | [25] |
| (*Caulerpa racemosa*) | Disc Diffusion | Contains bioactive compounds, including alkaloids, flavonoids, and tannins. Antibacterial activity against *Staphylococcus aureus* yielded inhibition zones of 8.4 mm (moderate)–15.7 mm (strong), while against *Salmonella typhi* 8.3 mm (moderate)–19.9 mm (strong). Activity increased with higher extract concentrations. | [45] |
| (*Padina australis*) | Disc Diffusion | Contains flavonoids, terpenoids, steroids, saponins, and alkaloids. Exhibited antibacterial activity against *Bacillus cereus* (10% extract, inhibition zone 7 mm, moderate) and *Escherichia coli* (60% extract, inhibition zone 11 mm, moderate). Activity was influenced by the synergistic effects of secondary metabolites. | [26] |
| *Sargassum polycystum* | Disc Diffusion | Phytochemical analysis revealed the presence of alkaloids, flavonoids, saponins, tannins, and steroids in the extract, with variations in compound composition across the different fractions. Antibacterial tests demonstrated significant activity ($p < 0.05$) against Staphylococcus aureus, with increasing inhibition at higher concentrations. Low concentrations showed weak to moderate activity (<10 mm), whereas high concentrations (80–100%) showed strong activity (10–20 mm). The ethyl acetate fraction exhibited the most prominent activity. | [26] |
| *Eucheuma cottonii* | Diffusion Method | Phytochemical analysis revealed the presence of phenolic compounds, specifically flavonoids. *E. cottonii* extract inhibited *Escherichia coli* growth. The highest inhibition zone was observed at 50% concentration (3.3 mm, moderate–weak category), while 5% concentration showed the lowest activity (0.1 mm, very weak). The positive control (7.8 mm) exhibited stronger inhibition, whereas the negative control showed no inhibitory activity. | [43] |
| *Corallina officinalis* | Well Diffusion | Phytochemical analysis revealed the presence of phenolic compounds, including flavonoids, alkaloids, and saponins. Antibacterial tests were conducted against Staphylococcus aureus, Citrobacter sp., and Klebsiella pneumoniae. The highest activity was demonstrated by the acetone extract at a concentration of 200 mg/mL against K. pneumoniae with an inhibition zone of 30.2 ± 0.08 mm (categorized as very strong). The lowest activity was demonstrated by the ethanol extract at 200 mg/mL against Citrobacter sp., with an inhibition zone of 15.9 ± 0.08 mm (categorized as strong). | [47] |

| | | | |
|---|---|---|---|
| *Kappaphycus Cymodocea serrulata (seagrass)* | Well Diffusion | The chloroform extracts of these two species contain flavonoids, tannins, phenolics, glycosides, steroids, and carbohydrates, with alkaloids detected only in *K. alvarezii*. Antibacterial testing at a concentration of 100 µg/mL showed strong to very strong inhibition zones against *Bacillus subtilis* (26–25 mm), *Klebsiella pneumoniae* (23–22 mm), *Vibrio alginolyticus* (22–20 mm), *Vibrio parahaemolyticus* (24–26 mm), and *Vibrio harveyi* (24–22 mm) | [49] |

**Antibacterial Activity of *Canavalia rosea***

The ethyl acetate fraction of *Canavalia rosea* exhibited significant, dose-dependent antibacterial activity, with inhibition zones increasing from 5.13 ± 0.32 mm at 1.5 mg/mL (weak) to 20.31 ± 0.27 mm at 9 mg/mL (strong). This finding is consistent with previous reports [24, 37], which linked the antibacterial effects of *Canavalia* species to secondary metabolites such as flavonoids, phenolics, and glycosides. The genus *Canavalia* therefore shows promising potential as a natural antibacterial source, particularly against Gram-positive bacteria like *Staphylococcus aureus*. Nonetheless, most studies are descriptive and limited to in vitro assays, leaving variations in efficacy unexplained—potentially influenced by factors such as extraction methods, solvents, plant parts, extract concentrations, and environmental conditions. Comparative studies among fractions or against more resistant Gram-negative bacteria are scarce, and antibacterial mechanisms remain underexplored. However, they likely involve the synergistic actions of secondary metabolites, such as flavonoids, phenolics, alkaloids, and lectin proteins, which disrupt cell membranes and inhibit DNA and protein synthesis. Further targeted research is needed, including standardized extraction, purification of active compounds, MIC and MBC determination, toxicity testing, and in vivo studies to confirm safety and effectiveness before clinical or industrial application [37].

**Antibacterial Activity of *Eucheuma spinosum***

Studies on *Eucheuma spinosum* have shown promising antibacterial activity against various pathogenic bacteria, including Escherichia coli, Staphylococcus epidermidis, Bacillus subtilis, and Staphylococcus aureus; however, efficacy varies among studies. Reported inhibition zones range from weak to very strong, reaching up to 30 mm against *E. coli* at high concentrations [22], [32], [41], [44]. Variations in activity are likely influenced by extraction methods, solvent type, extract concentration, the plant part used, and environmental conditions that affect secondary metabolite composition. The antibacterial mechanism is believed to involve bioactive compounds such as flavonoids, alkaloids, terpenoids, and saponins, which disrupt bacterial cell membranes, alter permeability, and inhibit protein synthesis. However, most studies remain limited to in vitro assays, without a detailed exploration of molecular mechanisms, so the clinical efficacy and safety are not yet established. Therefore, while *E. spinosum* demonstrates potential as a natural antibacterial agent; further targeted research is necessary, including standardized extraction, purification of active compounds, accurate MIC and MBC determination, and in vivo testing to confirm safety, efficacy, and broader application potential [22, 32, 41, 44].

**Antibacterial Activity *Caulerpa racemosa***

Extracts of *Caulerpa racemosa* have been reported to contain alkaloids, flavonoids, and tannins that contribute to antibacterial activity, exhibiting a dose-dependent inhibitory effect against both Gram-positive and Gram-negative bacteria. Using the disc diffusion method, inhibition zones ranged from 8.4–15.7 mm against *Staphylococcus aureus* and 8.3–19.9 mm against *Salmonella typhi*, with activity increasing at higher extract concentrations. Additional studies have reported inhibition zones of 7–13 mm against *Escherichia coli* and notable antibacterial effects against *Vibrio alginolyticus*, further supporting the broad-spectrum potential of *C. racemosa*. Differences in inhibition values among studies are likely influenced by extraction methods, solvent types, extract concentrations, and environmental factors affecting secondary metabolite production. The antibacterial mechanism is believed to involve synergistic interactions of flavonoids and phenolics that disrupt bacterial membranes, increase permeability, and inhibit protein and DNA synthesis. Nevertheless, most studies remain confined to in vitro testing without molecular or in vivo validation, leaving clinical efficacy and safety uncertain. Therefore, *C. racemosa* demonstrates significant promise as a natural antibacterial agent, yet further standardized extraction, compound purification, MIC and MBC determination, and in vivo testing are essential to confirm its safety, efficacy, and practical application [34, 38, 42, 45].

**Antibacterial Activity *Padina australis***

Extracts of *Padina australis* containing flavonoids, terpenoids, steroids, saponins, and alkaloids exhibit significant antibacterial activity as demonstrated through the disc diffusion method. The extracts inhibited *Bacillus cereus* with a minimum inhibitory concentration (MIC) of 10% producing a 7 mm inhibition zone, and *Escherichia coli* at 60% MIC with an 11 mm zone, both indicating moderate activity. Comparable inhibition zones of 10–11.8 mm have also been reported against *Aeromonas hydrophila*, *Staphylococcus aureus*, *Streptococcus mutans*, and *E. coli*, reflecting strong antibacterial potential. Variations in inhibition values among studies are likely attributed to differences in extraction methods, solvent types, extract concentrations, and environmental factors influencing secondary metabolite composition. The antibacterial mechanism is believed to be mediated by the synergistic interactions of these metabolites, which disrupt bacterial membranes, increase permeability, and inhibit protein and DNA synthesis. However, as most studies remain limited to

in vitro assays without molecular or in vivo validation, the clinical efficacy and safety of *P. australis* extracts remain uncertain. Further comprehensive research, including standardized extraction, purification of active compounds, accurate MIC and MBC determination, and in vivo evaluation, is therefore essential to assess the full potential of *P. australis* as a natural antibacterial agent [31], [40], [46].

**Antibacterial Activity *Sargassum polycystum***

Extracts of *Sargassum polycystum* contain alkaloids, flavonoids, saponins, tannins, and steroids that contribute to its antibacterial properties, particularly against *Staphylococcus aureus*. The inhibition zones increase with concentration, ranging from weak to moderate (<10 mm) at low concentrations to strong (10–20 mm) at higher levels, with the ethyl acetate fraction showing the greatest activity. Comparative analyses of related species also demonstrate moderate inhibition against *Staphylococcus epidermidis* and strong inhibition zones of 18–21 mm against *Escherichia coli* and *S. aureus*, indicating the significant antibacterial potential of the genus *Sargassum*. Differences in inhibition values across studies are likely influenced by extraction methods, solvent types, concentrations, and environmental factors affecting secondary metabolite composition. The antibacterial mechanism is presumed to involve synergistic actions of bioactive compounds that damage bacterial cell membranes, alter permeability, and inhibit protein and DNA synthesis. Nevertheless, as current findings are primarily limited to in vitro assays, further studies involving standardized extraction, purification of active compounds, MIC and MBC determination, and in vivo testing are required to verify the safety, efficacy, and potential of *S. polycystum* as a natural antibacterial agent [27], [29], [41].

**Antibacterial Activity *Eucheuma cottonii***

Extracts of *Eucheuma cottonii* containing flavonoids exhibit antibacterial activity against Escherichia coli, with inhibition zones ranging from 0.1 mm at a 5% concentration to 3.3 mm at a 50% concentration, indicating weak to moderate effects [32], [43-44]. Positive controls generally exhibit stronger inhibition, while negative controls show no activity, confirming the specificity of the extract's antibacterial effect. Comparative findings on *Eucheuma spinosum* indicate higher inhibition zones of 16–30 mm against *E. coli* and 26.5 mm against *Staphylococcus epidermidis*, suggesting interspecies variation in antibacterial potency within the *Eucheuma* genus. These variations are likely influenced by differences in secondary metabolite content, extraction method, concentration, and environmental factors. The antibacterial mechanism is believed to involve phenolic compounds and flavonoids that disrupt bacterial cell membranes, alter permeability, and inhibit protein and DNA synthesis. Although current research remains limited to in vitro assays, *E. cottonii* demonstrates potential as a natural bioactive source for antibacterial development. Further studies, including standardized extraction, purification of active compounds, determination of MIC and MBC values, and in vivo evaluation, are required to validate its efficacy and safety for broader applications [32, 43, 44].

**Antibacterial Activity *Corallina officinalis***

Extracts of *Corallina officinalis* containing flavonoids, alkaloids, and saponins exhibit significant antibacterial activity when tested using the agar well diffusion method, with inhibition zones ranging from 11 to 30 mm depending on solvent type and concentration [30, 36, 47]. Acetone extracts generally show the highest inhibition against *Klebsiella pneumoniae*, while ethanol and methanol–chloroform extracts also demonstrate strong activity against *Bacillus cereus*, *Staphylococcus aureus*, *Streptococcus mutans*, and *Escherichia coli*. Variations in antibacterial efficacy among studies are influenced by extraction methods, solvent polarity, concentration, and environmental factors affecting secondary metabolite content. The antibacterial mechanism is believed to involve the synergistic actions of flavonoids, alkaloids, and saponins, which disrupt bacterial cell membranes, alter permeability, and inhibit protein and DNA synthesis. Although current findings are limited to in vitro experiments, *C. officinalis* demonstrates strong potential as a natural source of antibacterial compounds. Further research, including standardized extraction, purification of bioactive compounds, MIC and MBC determination, and in vivo studies, is necessary to confirm its efficacy and safety for broader pharmacological applications [30, 36, 47].

**Antibacterial Activity *Kappaphycus alvarezii***

Studies on *Kappaphycus alvarezii* indicate that its chloroform extracts exhibit strong to very strong antibacterial activity, with inhibition zones of 25–26 mm against *Bacillus subtilis*, 22–23 mm against *Klebsiella pneumoniae*, 20–22 mm against *Vibrio alginolyticus*, 24–26 mm against *Vibrio parahaemolyticus*, and 22–24 mm against *Vibrio harveyi* [49]. This is supported by previous studies reporting that *Kappaphycus cottonii* extracts inhibited *Escherichia coli* with zones of 0.1–3.3 mm [32], and that methanol extracts of *K. alvarezii* produced 8 mm inhibition against *Staphylococcus aureus*, 7 mm against *E. coli*, and 5 mm against *B. subtilis* [41]. Critically, variations in inhibition zones among studies suggest that antibacterial effectiveness is influenced by extraction methods, solvent type, concentration, and environmental conditions affecting secondary metabolite content. The antibacterial mechanism is likely mediated by flavonoids, alkaloids, and other phenolic compounds that disrupt cell membranes, alter permeability, and inhibit bacterial protein and DNA synthesis. Although most studies are limited to in vitro assays, the research consistently demonstrates that the *Kappaphycus* genus contains important secondary metabolites with antibacterial activity, indicating significant potential as a natural source of bioactive compounds for health and industrial applications. Therefore, further research, including standardized extraction, purification of active compounds, MIC and MBC determination, and in vivo testing, is required to ensure efficacy and safety of application [48-49].

## Conlusion

This systematic review demonstrates that marine plants have strong potential as sources of natural

antibacterial agents against Gram-positive and Gram-negative pathogenic bacteria. Several species, including *Kappaphycus alvarezii*, *Corallina officinalis*, *Eucheuma spinosum*, *Sargassum polycystum*, *Caulerpa racemosa*, and *Padina australis*, exhibited varying levels of antibacterial activity, with *K. alvarezii* showing the highest inhibition zones, particularly against *Bacillus subtilis* and *Vibrio* species. The antibacterial effects are attributed to secondary metabolites, including flavonoids, alkaloids, phenolics, terpenoids, saponins, and tannins, which act by disrupting bacterial cell membranes, altering membrane permeability, and inhibiting protein and DNA synthesis. However, most studies were limited to in vitro assays and showed variations due to differences in extraction methods, solvents, concentrations, plant parts, and environmental factors. Therefore, further research is needed to standardize extraction techniques, purify active compounds, determine MIC and MBC values, and conduct in vivo studies to ensure safety and efficacy. By addressing these gaps, marine plant-derived compounds could provide sustainable, eco-friendly alternatives to conventional antibiotics and play a vital role in combating the global antibiotic resistance crisis.

**Author's Contribution**

Nazila Nazwa Zikria: Conceptualized the research, conducted literature search, and contributed to the overall study design. And Nurhadis: Developed the research framework, organized and synthesized the literature, and drafted the manuscript.

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