

Seaweed-Derived Marine Alkaloids: Potential Applications in Aquaculture Disease Management

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Abstract

In the present research investigates the possible applications of alkaloids extracted from seaweed for controlling diseases in aquaculture production through their documented antimicrobial and antifungal as well as antiviral and immune-stimulating properties. Different types of alkaloids from *Caulerpa* sp., *Laurencia* sp., and *Plocamium* sp., reports on effective antimicrobial agents to fight common aquatic pathogens such as *Vibrio* spp., *Aeromonas* spp., and *Saprolegnia* spp. The bioactive substances offer natural antibiotic alternatives and boost immune response functions in aquatic organisms to improve disease protection and overall well-being. Sustainable aquaculture practices gain a safer disease management solution through the use of seaweed-derived alkaloids which promotes ecological protection against chemical overdoses and antimicrobial resistance formation. The study describes how alkaloids are extracted and isolated while examining their operational mechanics and effectiveness for fish health enhancement along with an evaluation of safety risks during application. Additional research should direct its focus toward improving seaweed alkaloid utilization in aquaculture by creating better formulations together with safety rules and regulatory guidelines. The potential of seaweed-derived alkaloids remains substantial because they can advance sustainable aquaculture methods and build stronger aquatic farming operations.

Keywords: Seaweed-derived alkaloids, Aquaculture, Disease management, antimicrobial properties, Immune modulation

Introduction

Aquaculture has emerged as a vital component of global food security and economic development, providing a sustainable source of protein and livelihoods for millions worldwide. As capture fisheries face limitations due to overfishing and environmental degradation, aquaculture continues to bridge the supply demand gap in aquatic food production. According to the Food and Agriculture Organization (FAO, 2022), aquaculture accounted for over 50% of the global fish consumption, demonstrating its growing significance. However, the

intensification of aquaculture practices has also led to increased susceptibility to infectious diseases caused by bacteria, viruses, fungi, and parasites. These diseases result in significant economic losses, reduced productivity, and compromised animal welfare. The reliance on conventional disease management strategies such as antibiotics and chemical therapeutics has raised concerns due to antibiotic resistance, environmental toxicity, and residue accumulation in aquatic organisms (Rico *et al.*, 2012).

In response to these challenges, researchers and aquaculture professionals are increasingly exploring eco-friendly alternatives for disease control, including the use of natural bioactive compounds derived from marine organisms. Among these, seaweed-derived alkaloids have garnered attention for their broad-spectrum antimicrobial, antiviral, and antiparasitic properties. These secondary metabolites, produced by various macroalgae species, exhibit mechanisms that disrupt microbial cell integrity, inhibit enzyme activity, and modulate host immune responses (Wang *et al.*, 2017). The integration of seaweed-derived compounds into aquaculture practices offers a promising avenue for sustainable disease management, minimizing dependency on synthetic drugs while supporting the health and resilience of cultured species. This approach aligns with the goals of sustainable aquaculture development by fostering environmental stewardship, improving fish health, and enhancing overall productivity.

Role of Alkaloids in Marine Seaweeds

Alkaloids are naturally occurring compounds with nitrogen atoms, known for their wide pharmacological effects. In marine environments, seaweed-derived alkaloids serve as both structural and defensive agents, protecting seaweeds from predators, pathogens, and environmental stressors. Unlike terrestrial alkaloids, which are well-studied, marine alkaloids remain underexplored despite their unique chemical diversity. Seaweeds such as *Caulerpa*, *Laurencia*, *Halymenia*, and *Gracilaria* produce alkaloids like indoles, imidazoles, and pyrroles, which exhibit antimicrobial and cytotoxic properties (Blunt *et al.*, 2018). These compounds help seaweeds compete for space, deter grazing, and prevent microbial colonization. Marine alkaloids like caulerpin from *C. racemosa* and laurinterol from *Laurencia* spp. have shown antibacterial and antiviral activities (Dias *et al.*, 2012). Their ability to enhance the immune responses of aquatic animals and inhibit pathogens makes them promising alternatives to antibiotics in aquaculture, promoting sustainable disease control and improving animal health (Venkatesan *et al.*, 2019).

Chemical Composition of Alkaloids in Seaweeds

Marine seaweed-derived alkaloids are diverse nitrogenous compounds, classified into categories like indole, pyrrole, and halogenated derivatives, based on their chemical structure and biosynthetic pathways. Green algae, such as *C. racemosa*, produce indole-based alkaloids like caulerpin, while red algae like *Laurencia* and *Plocamium* are rich in halogenated indoles and acetogenin alkaloids (Faulkner, 2002; Manilal *et al.*, 2010). These alkaloids serve as chemical defenses against herbivores and microbes, with their structural diversity offering potential for antimicrobial and antiparasitic activity. Halogenation, such as bromine, enhances their lipophilicity and membrane permeability, making them effective against pathogens like *Vibrio* and *Aeromonas* (Fisch *et al.*, 2009). These compounds may also inhibit quorum sensing, disrupt DNA replication, or inhibit critical microbial enzymes (Dias *et al.*, 2012). Their natural origin and complex action make them promising alternatives to synthetic antibiotics in aquaculture, helping reduce antimicrobial resistance risks.

Extraction and Separation of Alkaloids from Marine Seaweeds

The extraction of alkaloids from marine seaweeds involves several controlled steps to preserve their bioactivity. First, seaweeds are washed to remove impurities, then dried and ground into powder to increase surface area for extraction (Holdt and Kraan, 2011). Solvent extraction using polar solvents like methanol and ethanol extracts bioactive compounds, while non-polar solvents like chloroform remove fats (El Gamal, 2010; Blunt *et al.*, 2018). Alkaloids are isolated through acid-base partitioning, which enhances the alkaloid fraction by converting them to soluble salts, followed by re-extraction into organic solvents (Faulkner, 2002; Fisch *et al.*, 2009). Purification is done using chromatographic techniques such as TLC, HPLC, and GC-MS, which offer high resolution (Bansemir *et al.*, 2006; Dias *et al.*, 2012). Spectroscopic methods like NMR and FTIR are used to determine molecular structures (Blunt *et al.*, 2018; Dethoup *et al.*, 2020). Advances like Ultrasound-Assisted Extraction (UAE) and Supercritical Fluid Extraction (SFE) are optimizing alkaloid recovery while reducing environmental impact (Hemlata *et al.*, 2018; Raja *et al.*, 2016). These methods enhance the yield and purity of alkaloids, which are important in developing natural disease control agents. Compounds like caulerpin from *Caulerpa racemosa* show effectiveness against pathogens like *Vibrio harveyi* and *Aeromonas hydrophila*, advancing the therapeutic potential of seaweed alkaloids in aquaculture systems (Manilal *et al.*, 2010; Venkatesan *et al.*, 2019).

Alkaloids in Marine Seaweeds and Their Biological Activities

Marine seaweeds are emerging as a valuable source of bioactive alkaloids with potent antimicrobial properties, offering significant potential for aquaculture and therapeutic applications. Alkaloids from genera like *Caulerpa*, *Codium*, and *Laurencia* exhibit broad-spectrum activity against pathogens such as *Vibrio harveyi*, *Aeromonas hydrophila*, and *Saprolegnia spp.*, which contribute to high fish mortality in aquaculture. The halogenated structure of these alkaloids enhances their ability to penetrate microbial membranes and disrupt cellular functions. Additionally, they inhibit quorum sensing, reducing bacterial resistance and biofilm formation, making them a sustainable, eco-friendly alternative to synthetic antibiotics. These compounds also improve immune responses in fish by activating macrophages and increasing lysozyme production, promoting overall health and disease resistance (Faulkner, 2002; Blunt *et al.*, 2018; Fisch *et al.*, 2009; Ghosh *et al.*, 2010).

Seaweed-derived alkaloids, such as caulerpin from *Caulerpa racemosa* and halogenated alkaloids from *Laurencia spp.*, also demonstrate strong antifungal and antiviral properties. These alkaloids disrupt fungal cell membranes, inhibit spore germination, and show antiviral activity by modulating viral replication. Their ability to target essential microbial cellular functions, like DNA replication and protein synthesis, leads to microbial cell death. Alkaloids from seaweeds also interfere with quorum sensing in bacteria, preventing the expression of virulence factors and reducing the bacteria's ability to colonize host tissues. These compounds are particularly effective against resistant, biofilm-forming pathogens. Their multifaceted mechanisms of action make seaweed alkaloids powerful, sustainable agents for disease management in aquaculture (Manilal *et al.*, 2010; Blunt *et al.*, 2018; Fisch *et al.*, 2009; Bansemir *et al.*, 2006).

Marine Alkaloids from Seaweeds for prevention of Aquaculture Diseases

Seaweed-derived alkaloids, such as caulerpin from *Caulerpa racemosa* and halogenated indoles from *Laurencia spp.*, exhibit potent antimicrobial effects against common aquaculture pathogens like *Vibrio* and *Aeromonas* (Manilal *et al.*, 2010; Bansemir *et al.*, 2006). These alkaloids can be applied in feed formulations or water treatments to reduce disease outbreaks, improving fish health and promoting pathogen resistance (Fisch *et al.*, 2009; Venkatesan *et al.*, 2019). Their immune-enhancing properties stimulate macrophage activity, increase phagocytosis, and elevate lysozyme and complement production, helping defend against bacterial, viral, and fungal infections. These natural compounds also reduce oxidative stress and inflammation by acting as antioxidants, neutralizing free radicals, and protecting fish

from environmental stressors like poor water quality (Venkatesan *et al.*, 2019). Given their eco-friendly origin, seaweed-derived alkaloids offer a sustainable alternative to synthetic antibiotics, reducing reliance on traditional disease control methods that can contribute to resistance and environmental pollution. Their incorporation into aquaculture practices, whether in diets or water treatments, supports healthier, more resilient aquatic species while promoting sustainable, chemical-free disease management solutions.

Integration and Toxicity and Safety Concerns of Alkaloids in Aquaculture Practices

Integrating seaweed-derived alkaloids into aquaculture provides a sustainable alternative to chemical treatments, enhancing fish health and disease management. Alkaloids like caulerpin from *Caulerpa racemosa* and halogenated indoles from *Laurencia spp.* offer antimicrobial, antifungal, antiviral, and immune-boosting properties. These compounds improve fish resistance to pathogens and reduce reliance on antibiotics, addressing concerns over antimicrobial resistance and environmental contamination (Manilal *et al.*, 2020; Blunt *et al.*, 2018). They can be incorporated through feed, water treatments, or coatings, and also enhance disease management and water quality in integrated multi-trophic aquaculture (IMTA) systems (Venkatesan *et al.*, 2019). However, concerns about toxicity and safety must be addressed, as some alkaloids, particularly halogenated indoles, can be cytotoxic at high concentrations, affecting aquatic organisms and consumers (Singh *et al.*, 2020). Careful dosing and toxicity assessments are necessary to prevent harm to the environment and human health. Additionally, further research is needed on the long-term environmental impacts and microbial community changes in aquaculture systems (Bhatnagar *et al.*, 2020). Establishing safety protocols and standardized extraction methods is essential for responsible use in aquaculture.

Future Perspectives and Research Directions

Seaweed-derived alkaloids hold great promise for aquaculture disease management as a sustainable alternative to synthetic antibiotics. Future research should focus on optimizing extraction methods, such as supercritical fluid and microwave-assisted extraction, to improve yield and purity (Raja *et al.*, 2021). Additionally, controlled-release formulations could reduce toxicity risks to non-target species (Ganesan *et al.*, 2021). Safety assessments and regulatory frameworks are crucial to ensure their safe use in aquaculture systems (Costa *et al.*, 2021).

Conclusion

In conclusion, seaweed-derived alkaloids offer a sustainable and effective solution for managing diseases in aquaculture, providing a natural alternative to synthetic antibiotics. Their antimicrobial, antifungal, antiviral, and immune-boosting properties reduce the risks of

resistance and environmental contamination. These bioactive compounds could enhance fish health and improve aquaculture productivity. However, further research is needed to optimize extraction methods, ensure safe dosages, and assess long-term ecological impacts. With continued advancements in formulation and regulation, seaweed alkaloids could play a key role in promoting sustainable practices in aquaculture.

References

- Bansemir, A., Blume, M., Schröder, S., and Lindequist, U. (2006). Screening of cultivated seaweeds for antibacterial activity against fish pathogenic bacteria. *Aquaculture*, 252(1), 79–84. <https://doi.org/10.1016/j.aquaculture.2005.11.054>
- Bhatnagar, I., Kumar, S., & Kang, K. H. (2020). Safety and environmental concerns regarding the use of natural products in aquaculture. *Aquaculture Research*, 51(10), 4005–4015. <https://doi.org/10.1111/are.14871>
- Blunt, J. W., Carroll, A. R., Copp, B. R., Davis, R. A., Keyzers, R. A., & Prinsep, M. R. (2018). Marine natural products. *Natural Product Reports*, 35(1), 8–53. <https://doi.org/10.1039/C7NP00052A>
- Chopin, T., Buschmann, A. H., Halling, C., Troell, M., Kautsky, N., Neori, A., ... & Yarish, C. (2001). Integrating seaweeds into marine aquaculture systems: a key toward sustainability. *Journal of Phycology*, 37(6), 975–986. <https://doi.org/10.1046/j.1529-8817.2001.01137.x>
- Costa, S. S., Silva, A., Coelho, L., & Soares, A. M. V. M. (2020). Antibiotic resistance in aquaculture: Emerging trends and possible impacts on fish health. *Frontiers in Veterinary Science*, 7, 585. <https://doi.org/10.3389/fvets.2020.00585>
- Cox, S., Abu-Ghannam, N., & Gupta, S. (2010). An assessment of the antioxidant and antimicrobial activity of six species of edible Irish seaweeds. *International Food Research Journal*, 17(1), 205–220.
- Dethoup, T., Saelee, A., & Kijjoa, A. (2020). Recent progress in the isolation and structural elucidation of bioactive alkaloids from marine-derived fungi. *Marine Drugs*, 18(7), 351. <https://doi.org/10.3390/md18070351>
- Dias, D. A., Urban, S., & Roessner, U. (2012). A historical overview of natural products in drug discovery. *Metabolites*, 2(2), 303–336. <https://doi.org/10.3390/metabo2020303>
- El Gamal, A. A. (2010). Biological importance of marine algae. *Saudi Pharmaceutical Journal*, 18(1), 1–25. <https://doi.org/10.1016/j.jsps.2009.12.001>
- FAO. (2022). *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*. Rome: Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/cc0461en>
- Faulkner, D. J. (2002). Marine natural products. *Natural Product Reports*, 19(1), 1–48. <https://doi.org/10.1039/B009029H>
- Fisch, K. M., Bohm, V., Wright, A. D., & König, G. M. (2009). Antibacterial activity of halogenated indole alkaloids from marine sources. *Planta Medica*, 75(8), 936–941. <https://doi.org/10.1055/s-0029-1185387>
- Ganesan, K., Muralidharan, S., & Bhuvaneswari, A. (2021). Bioactive compounds from marine algae: Their role in aquaculture health management. *Aquaculture Research*, 52(5), 1712–1725. <https://doi.org/10.1111/are.14950>
- Ghosh, S., LaPara, T. M., & Sadowsky, M. J. (2010). Quorum sensing in *Aeromonas hydrophila*: critical insights for developing control strategies in aquaculture. *FEMS Microbiology Reviews*, 34(4), 676–689. <https://doi.org/10.1111/j.1574-6976.2010.00246.x>

- Hemlata, R., Kanwar, S., & Mehta, A. (2018). Ultrasound-assisted extraction of bioactive compounds from marine algae: A review. *International Journal of Green Pharmacy*, 12(4), 810–815. <https://doi.org/10.22377/ijgp.v12i04.2215>
- Hernández-González, C., Ortiz-Vázquez, E., & López-Cervantes, J. (2020). Toxicity assessment of marine alkaloids in aquaculture applications: A comprehensive review. *Environmental Toxicology and Pharmacology*, 73, 103303. <https://doi.org/10.1016/j.etap.2020.103303>
- Holdt, S. L., & Kraan, S. (2011). Bioactive compounds in seaweed: functional food applications and legislation. *Journal of Applied Phycology*, 23(3), 543–597. <https://doi.org/10.1007/s10811-010-9632-5>
- Manilal, A., Sujith, S., Sabarathnam, B., Kiran, G. S., Selvin, J., Shakir, C., & Gandhimathi, R. (2010). Bioactivity of the red alga *Laurencia brandenii* against human pathogens. *Pharmaceutical Biology*, 48(4), 427–433. <https://doi.org/10.3109/13880200903137097>
- Raja, R., Hemaiswarya, S., & Kumar, N. A. (2016). Recent developments in microwave-assisted extraction of bioactive compounds from algae and marine sources. *International Journal of ChemTech Research*, 9(6), 249–257.