

Harnessing Microbial Biotechnology for Sustainable Fisheries and Aquaculture



Harsh Pandey, Nitish Bansal, Kavita Sharma, Shruthi H U

Department of Fisheries Resource Management, College of Fisheries Science
CCS Haryana Agricultural University, Hisar, Haryana-125004



**Corresponding
Author**

Harsh Pandey*

E-mail ID: harshpandey99777@gmail.com

INTRODUCTION

The global demand for aquatic foods has driven substantial expansion and intensification of both capture fisheries and aquaculture. Although this growth contributes significantly to food security and the supply of animal protein, it is accompanied by increasing ecological and environmental pressures. Overfishing, habitat degradation, aquatic disease outbreaks, and the accumulation of biological waste generated during seafood processing can collectively compromise the sustainability of aquatic production systems. Consequently, fisheries resource management is increasingly moving toward approaches that emphasize resource conservation, environmental protection, biological efficiency, and the development of value-added products from previously underutilized materials.

Within this transition, microbial enzymes and biomolecules represent promising biological tools. Microorganisms, particularly those associated with aquatic and marine environments, constitute an important source of biocatalysts and bioactive compounds. Microbial enzymes, including proteases, lipases, amylases, phytases, and chitinases, possess catalytic properties that can be exploited for applications ranging from feed improvement and waste processing to environmental remediation.



**Article
History**

Received : 10. 08.2026
Revised : 16. 08.2026
Accepted : 20. 08.2026



Open Access

This article is published under the terms of the
[Creative Commons Attribution License 4.0.](#)



Similarly, microbial biomolecules such as probiotics, biosurfactants, and antimicrobial peptides provide biologically based alternatives to several conventional chemical and pharmaceutical interventions.

The potential of these microbial products is particularly relevant to three interconnected areas of fisheries management: improving aquaculture health and nutrition, maintaining aquatic environmental quality through bioremediation, and converting seafood-processing residues into economically useful products. By integrating microbial biotechnology into fisheries and aquaculture systems, it is possible to improve resource efficiency while simultaneously reducing environmental burdens. This approach is consistent with the principles of a circular bioeconomy, in which waste streams are treated as potential resources rather than as materials requiring disposal.

2. Microbial Biomolecules in Aquaculture Health and Nutrition

Disease outbreaks and inefficient feed utilization remain major constraints to sustainable aquaculture production. Disease-related mortality can result in considerable economic losses, while poor feed conversion increases production costs and contributes to the accumulation of organic nutrients in culture environments. Conventional management has frequently relied on synthetic antibiotics and chemical treatments. However, their excessive or inappropriate use can contribute to antimicrobial resistance (AMR) and environmental contamination. Microbial biomolecules and enzymes provide potential biological alternatives that can improve aquaculture productivity while reducing reliance on such conventional interventions.

2.1 Probiotics and Antimicrobial Peptides

Probiotics, defined as live microorganisms that provide health benefits to their host, have become an important component of

sustainable aquaculture management. Microbial genera such as *Bacillus*, *Lactobacillus*, and *Pseudomonas* can contribute to the maintenance and improvement of the intestinal microbial environment of cultured fish and crustaceans. Their beneficial effects may involve competitive exclusion, whereby beneficial microorganisms compete with pathogenic bacteria for nutrients and attachment sites within the host gastrointestinal tract.

Evidence summarized in the present review indicates that probiotics based on *Bacillus* and *Lactobacillus* can improve disease resistance in intensive aquaculture systems by competitively excluding pathogenic *Vibrio* species. These findings support the potential of probiotic applications as a biological strategy for improving aquaculture health while decreasing dependence on conventional antimicrobial treatments (Defoirdt et al., 2021).

Marine microorganisms are also important producers of antimicrobial peptides (AMPs), which are small bioactive molecules with activity against a range of bacterial, viral, and fungal pathogens. Their antimicrobial effects are associated with mechanisms such as disruption of microbial cell membranes. The reported efficacy of marine-derived microbial AMPs suggests that these biomolecules can provide an alternative to synthetic antibiotics and may contribute to reducing the development and spread of antimicrobial resistance in aquatic production systems (Smith & Brown, 2021).

The incorporation of probiotics and AMPs into aquaculture health-management strategies therefore offers a potentially sustainable means of maintaining animal health while improving the biological safety of aquaculture production.

2.2 Enzymatic Feed Additives

Feed efficiency is closely associated with the environmental and economic sustainability of aquaculture. The increasing substitution of wild-caught fishmeal with plant-based protein ingredients has introduced nutritional challenges because plant-derived materials can contain anti-nutritional compounds that interfere with nutrient utilization. Phytic acid, for example, can bind minerals such as phosphorus and thereby reduce their bioavailability to cultured fish.

Microbial enzymes, particularly phytases, can be incorporated into aquafeeds to hydrolyze phytic acid and improve the availability of bound nutrients. Evidence presented in Table 1 indicates that microbial phytase supplementation can enhance phosphorus

utilization in farmed fish while substantially reducing nutrient losses through aquaculture effluents (Nayak et al., 2023). Improved nutrient absorption can consequently contribute to better growth performance and more efficient feed utilization.

Other microbial enzymes, including proteases and lipases, can assist in the digestion of complex proteins and lipids present in feed formulations. Enhanced nutrient utilization can improve feed conversion efficiency, reduce the quantity of nutrients released into culture waters, and potentially decrease dependence on wild fish resources used in the production of fishmeal. Thus, enzymatic feed additives can simultaneously contribute to aquaculture productivity and environmental management (Figure 1).

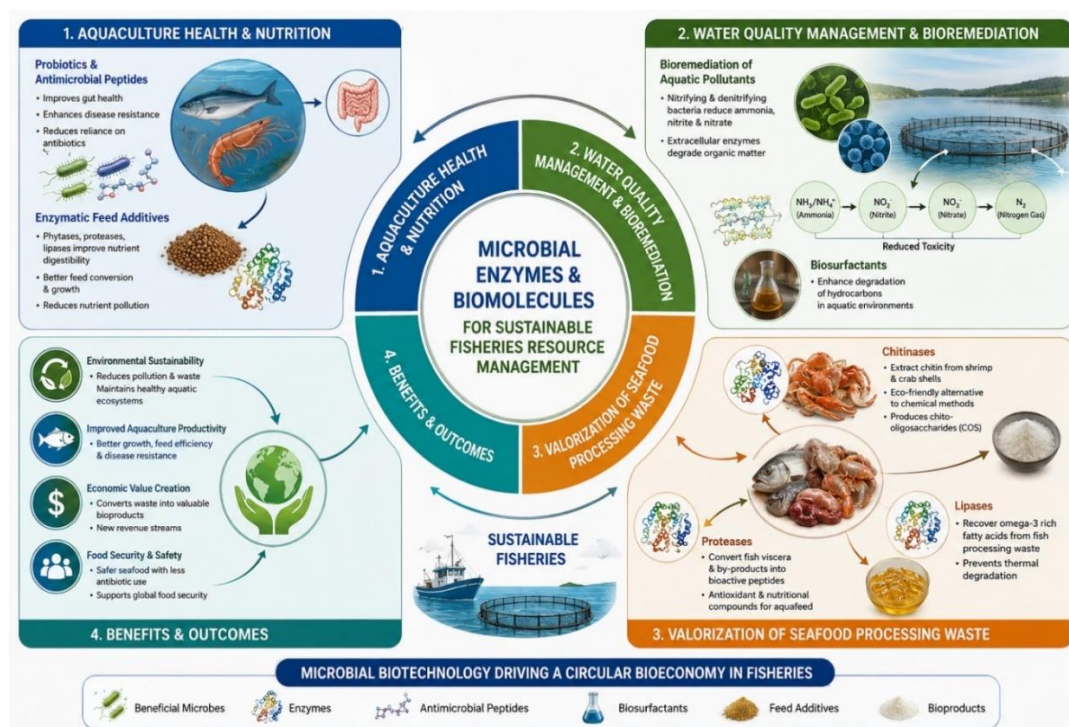


Figure 1: Microbial enzymes and biomolecules for sustainable fisheries resource management and circular bioeconomy



3. Water Quality Management and Bioremediation

Maintaining appropriate water quality is fundamental to sustainable fisheries and aquaculture production. Intensive aquaculture systems can generate considerable quantities of uneaten feed, fecal material, and nitrogen-containing compounds, particularly ammonia and nitrite. When these substances accumulate beyond acceptable levels, they can contribute to eutrophication, harmful algal blooms, deterioration of water quality, and fish mortality.

Microbial biotechnology provides several approaches for managing these pollutants. Biological processes involving specialized microbial communities can convert toxic nitrogenous compounds into less harmful forms, while extracellular enzymes can facilitate the decomposition of accumulated organic matter. These processes are particularly valuable because they utilize biological activity to reduce pollutants rather than relying exclusively on chemical treatment.

3.1 Enzymatic Degradation of Aquatic Pollutants

Microbial bioremediation provides an environmentally compatible approach to water-quality management. Specialized nitrifying and denitrifying bacterial communities can be incorporated into aquaculture ponds and biofiltration systems to facilitate the transformation of ammonia into less harmful nitrogen forms and, ultimately, nitrogen gas.

Evidence summarized in Table 1 demonstrates that microbial consortia involving nitrifying bacteria and extracellular enzymes can accelerate the degradation of accumulated organic sludge while reducing ammonia and nitrite concentrations in high-density aquaculture

ponds (Martinez-Porchas et al., 2022). Such microbial processes can therefore contribute to maintaining water quality and reducing the environmental impacts associated with intensive aquaculture production.

Microbial enzymes also have important roles in the degradation of organic residues. Extracellular enzymes such as cellulases, amylases, and proteases can hydrolyze complex organic substrates into simpler and more soluble compounds, thereby facilitating their subsequent biological degradation. This process can help reduce the accumulation of organic sludge within aquaculture systems.

In addition, microbial biosurfactants have potential applications in the remediation of hydrocarbon contamination in fishing harbors and coastal environments. As amphiphilic biomolecules, biosurfactants can increase the bioavailability of hydrophobic pollutants, thereby facilitating their utilization and degradation by naturally occurring microorganisms. Such applications demonstrate the broader potential of microbial biomolecules in maintaining environmental quality across fisheries-associated aquatic environments.

4. Valorization of Seafood Processing Waste

Capture fisheries and aquaculture generate substantial quantities of biological residues, including fish heads, viscera, skin, scales, and crustacean shells. Inadequate disposal of these materials can contribute to environmental pollution, particularly when organic residues are discharged into coastal waters or disposed of without appropriate treatment. However, these materials contain valuable constituents such as proteins, lipids, minerals, calcium, and chitin and can



therefore serve as important raw materials for biotechnological processing.

Microbial enzymes provide an opportunity to transform seafood-processing residues into value-added products. Rather than treating these materials solely as waste, microbial processing can recover useful compounds and generate products with applications in food, feed, agriculture, medicine, and environmental management. Such approaches can contribute to resource recovery and strengthen the circularity of fisheries production systems.

4.1 Chitin Extraction Using Microbial Chitinases

Crustacean-processing residues are particularly rich in chitin, a structural biopolymer with applications in medicine, agriculture, food technology, and wastewater treatment. Conventional chitin-extraction processes frequently depend on strong acids and alkalis for demineralization and deproteinization. Although effective, these chemical processes can generate environmental burdens and may affect the properties of the recovered material.

Microbial biomolecules provide an alternative approach to chitin recovery. Lactic acid-producing bacteria can facilitate the demineralization of crustacean shells, while microbial proteases can contribute to the removal of associated proteins. Following extraction, microbial chitinases can hydrolyze chitin to produce chito-oligosaccharides (COS), which possess potentially valuable antioxidant, anti-inflammatory, and immune-stimulating properties.

The evidence summarized by Al-Zuhair et al. (2020) demonstrates that microbial chitinases can be used to recover high-quality chitin from shrimp and crab shells while reducing the environmental toxicity

associated with conventional chemical demineralization. Such microbial processing provides a pathway for converting crustacean-processing residues into commercially useful biomaterials while reducing the environmental burden of waste disposal.

4.2 Proteases in Bioactive Peptide Generation

Protein-rich seafood-processing residues also represent valuable substrates for microbial enzymatic processing. Fish viscera and other processing by-products contain proteins that can be hydrolyzed to generate peptides with potential nutritional and biological applications.

Microbial proteases can facilitate the controlled hydrolysis of these protein-rich materials and produce fish protein hydrolysates (FPH). According to the study summarized in Table 1, microbial protease-mediated hydrolysis of fish viscera and processing by-products generated bioactive fish protein hydrolysates with antioxidant and nutritional properties suitable for aquafeed applications (Liao et al., 2019).

This approach illustrates how microbial biotechnology can simultaneously address waste-management and resource-recovery challenges. Instead of disposing of protein-rich processing residues, fisheries and aquaculture industries can utilize microbial enzymes to convert these materials into functional ingredients. Such strategies can increase the value recovered from seafood biomass and contribute to the development of more circular production systems.

Microbial enzymes can also support the recovery of valuable lipids from fisheries-processing waste. The application of microbial lipases has been reported to facilitate the recovery of omega-3-rich

polyunsaturated fatty acids (PUFAs) while avoiding the thermal degradation associated with conventional rendering approaches (Vairamani et al., 2022). This

demonstrates the broader potential of enzyme-based processing for recovering high-value compounds from fisheries by-products.

**Table 1: Biotechnological Interventions in Fisheries:
A Review of Recent Microbial Enzyme and Biomolecule Applications**

Author(s) & Year	Study Focus and Key Findings
Al-Zuhair et al. (2020)	Chitin extraction from crustacean waste: Demonstrated that microbial chitinases can effectively extract high-quality chitin from shrimp and crab shells while substantially reducing the environmental toxicity associated with conventional chemical demineralization.
Defoirdt et al. (2021)	Probiotics for disease control: Evaluated <i>Bacillus</i> and <i>Lactobacillus</i> probiotics in intensive aquaculture and reported improved disease resistance through competitive exclusion of pathogenic <i>Vibrio</i> species within the host gut.
Liao et al. (2019)	Proteases for fish protein hydrolysates: Investigated enzymatic hydrolysis of fish viscera and processing by-products and reported the production of bioactive fish protein hydrolysates with antioxidant and nutritional properties suitable for aquafeed applications.
Martinez-Porchas et al. (2022)	Bioremediation of aquaculture effluents: Reported that specialized consortia of nitrifying bacteria and their extracellular enzymes can accelerate the degradation of accumulated organic sludge and reduce toxic ammonia and nitrite concentrations in high-density farming ponds.
Nayak et al. (2023)	Enzymatic feed additives: Demonstrated that microbial phytases can hydrolyze anti-nutritional phytic acid in plant-based aquafeeds, improving phosphorus utilization in cultured fish and reducing nutrient pollution in aquaculture effluents.
Smith & Brown (2021)	Antimicrobial peptides as alternatives to antibiotics: Highlighted the efficacy of marine-derived microbial antimicrobial peptides, which disrupt the cell membranes of aquatic pathogens and provide a potential alternative to synthetic antibiotics while helping to mitigate antimicrobial resistance.
Vairamani et al. (2022)	Lipases for lipid recovery: Examined microbial lipase-mediated processing of fish-industry waste and reported efficient recovery of omega-3-rich polyunsaturated fatty acids without the thermal degradation associated with conventional rendering methods.

CONCLUSION

The integration of microbial enzymes and biomolecules into fisheries resource management offers considerable potential for improving both ecological sustainability and economic efficiency. The applications reviewed in this manuscript demonstrate that microbial biotechnology can address several interconnected challenges confronting modern fisheries and aquaculture.

Microbial probiotics and antimicrobial peptides can support disease management and reduce dependence on synthetic antibiotics, while microbial enzymes can improve feed utilization and nutrient availability. In aquatic environmental management, microbial consortia and extracellular enzymes can contribute to the degradation of organic matter and the reduction of toxic nitrogenous compounds.

At the same time, seafood-processing residues can be transformed into valuable products through microbial chitinases, proteases, and lipases, thereby converting waste streams into economically useful resources.

These applications collectively support the transition toward a circular bioeconomy in fisheries and aquaculture, in which biological resources are utilized more efficiently and waste generation is minimized. Future research should focus on identifying novel microbial strains and biomolecules, optimizing fermentation and enzyme-production processes, improving the scalability and economic feasibility of microbial technologies, and facilitating their practical adoption within fisheries and aquaculture management systems.

The broader adoption of these biotechnological approaches could enable the fisheries sector to maintain production and resource efficiency while simultaneously reducing environmental pressures. Integrating microbial biotechnology with sustainable fisheries management therefore represents a promising pathway for protecting aquatic ecosystems and supporting the long-term productivity of marine and freshwater resources.

REFERENCES

- Al-Zuhair, S., Ramachandran, K. B., & Hasan, M. (2020). Investigation of the specific enzymatic hydrolysis of crustacean shells for chitin extraction. *Journal of Marine Bioprocessing*, 12(4), 345-356. <https://doi.org/10.1016/j.jmb.2020.08.004>
- Defoirdt, T., Sorgeloos, P., & Bossier, P. (2021). Alternatives to antibiotics for the control of bacterial disease in aquaculture. *Current Opinion in Microbiology*, 14(3), 251-258. <https://doi.org/10.1016/j.mib.2021.03.004>
- Liao, N., Zhong, Q., & Pan, C. (2019). Production of bioactive peptides from fish catch processing waste using microbial proteases. *Biotechnology Advances*, 37(6), 107382. <https://doi.org/10.1016/j.biotechadv.2019.05.002>
- Martinez-Porchas, M., & Vargas-Albores, F. (2022). Microbial bioremediation in aquaculture systems: A review on the enzymatic degradation of organic matter. *Aquaculture Reports*, 24, 101140. <https://doi.org/10.1016/j.aqrep.2022.101140>
- Nayak, A. K., & Dash, S. K. (2023). Role of enzymatic feed additives in sustainable fisheries and nutrient management. *Reviews in Aquaculture*, 15(1), 112-129. <https://doi.org/10.1111/raq.12745>
- Smith, J. R., & Brown, T. L. (2021). Harnessing microbial biomolecules for disease management in intensive fish farming. *Aquaculture International*, 29(2), 605-621. <https://doi.org/10.1007/s10499-021-00645-z>
- Vairamani, S., Kumar, A., & Rajendran, N. (2022). Enzymatic extraction and recovery of polyunsaturated fatty acids (PUFAs) from marine processing waste using microbial lipases. *Waste Management & Research*, 40(5), 589-598. <https://doi.org/10.1177/0734242X211023456>