**Microbial Allies: Prebiotics and Probiotics in Modern Aquaculture**

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**Abstract**

Prebiotics and probiotics have become vital components of modern aquaculture, offering innovative solutions to the challenges of sustainable aquatic farming. This article delves into their role in enhancing the health and resilience of aquatic species, optimizing water quality, and fostering a balanced ecosystem. By minimizing reliance on antibiotics and mitigating disease risks, these microbial agents contribute to both environmental sustainability and economic efficiency. This discussion highlights their transformative potential, underscoring their significance in building a future-ready, eco-friendly aquaculture industry.

**Introduction**

The integration of prebiotics and probiotics in aquaculture has revolutionized this field by introducing innovative strategies to address challenges associated with sustainability, health, and productivity. These microbial agents play an essential role in promoting the stability of aquatic ecosystems by improving water quality, managing harmful pathogens, and enhancing the overall health and growth of aquatic organisms. Prebiotics, comprising non-digestible food components, serve as nourishment for beneficial gut bacteria, thereby stimulating their activity and proliferation. On the other hand, probiotics are live microorganisms that directly enrich the gut microbiota, creating a healthier intestinal environment in aquatic species. Together, these agents synergize to strengthen the immune response, boost digestive efficiency, and enhance the resilience of aquatic species, including fish and shellfish. A significant advantage of employing prebiotics and probiotics in aquaculture is their contribution to reducing the dependence on antibiotics. This shift is crucial in curbing the rise of antibiotic-resistant pathogens, promoting environmental safety, and ensuring the health of farmed aquatic populations. Additionally, these microbial solutions mitigate disease outbreaks, optimize feed utilization, and improve the growth performance of aquatic organisms, thus bolstering the economic sustainability of aquaculture practices. Adopting these eco-friendly approaches aligns with the global demand for sustainable seafood production, preserving aquatic biodiversity while meeting consumer needs. This discussion highlights the transformative potential of prebiotics and probiotics in redefining aquaculture as a more responsible and innovative industry. Continued research and development hold the key to unlocking their full potential, ensuring healthier aquatic environments and long-term productivity for future generations.

**Prebiotics**

Prebiotics are essential indigestible feed components that have gained widespread attention in aquaculture for their ability to stimulate beneficial gut microorganisms in fish, thus playing a pivotal role in enhancing their overall health and performance (Guerreiro et al., 2016). These compounds include effective combinations such as fructose, mannan oligosaccharides, and β-glucan, which are considered some of the most efficient prebiotics in aquaculture systems (Guerreiro, 2016). These prebiotics serve as a substrate for beneficial bacteria like *Bifidobacteria*, *Lactobacillus*, and *Bacteroides*, which ferment these compounds to produce short-chain fatty acids, fostering a healthier gut environment and improving digestive efficiency (Yousefianl and Amiri, 2009). Administered as feed supplements, prebiotics have demonstrated their ability to enhance the growth performance of aquatic species. The effectiveness of prebiotics, however, depends not only on their composition but also on the presence of specific beneficial bacterial populations in the aquatic environment and within the gut microbiome of the host species. In addition to promoting growth, prebiotics improve feed utilization, making them a cost-effective and sustainable alternative to traditional methods of fish farming.

Antibiotics, long used in the aquaculture industry to manage bacterial diseases, have raised concerns due to their contribution to antibiotic resistance and environmental contamination. To address these issues, the industry has turned to alternative measures, including prebiotics, as a sustainable and eco-friendly strategy. Prebiotics are particularly noted for their ability to enhance non-specific immune responses, reduce disease incidences, and support the development of healthier and more resilient fish populations (Guerreiro, 2016).

Furthermore, prebiotics have been linked to various physiological benefits, such as improving gut morphology, increasing intestinal enzyme activity, and enhancing intermediate metabolism. They also boost stress tolerance, making aquatic species more resilient to environmental fluctuations. The digestive tracts of aquatic animals, both vertebrates and invertebrates, provide habitats for diverse microbial communities that are integral to maintaining their health and promoting nutrient absorption. Prebiotic oligosaccharides are particularly effective in this regard, as they ferment in the colon to selectively stimulate the growth of beneficial bacterial populations while inhibiting pathogenic bacteria (Das et al., 2017; Yousefianl and Amiri, 2009).

Moreover, natural polysaccharides such as chitin and its derivative, chitosan, have been identified as valuable prebiotic agents in aquaculture. These compounds exhibit multiple benefits, including promoting beneficial gut bacteria, enhancing probiotic activity, improving immune responses, and inhibiting the growth of harmful pathogens. Their application contributes to a healthier aquatic environment and aligns with modern aquaculture's goal of fostering sustainable, productive, and eco-friendly practices (Suryawanshi et al., 2024).

**Probiotics**

According to Parker (1974), probiotics are defined as chemicals or organisms that help maintain the balance of gut microbial populations in host organisms. The term "probiotic" originates from the Greek words "Pro" and "bios," meaning "for life," symbolizing their role in promoting the overall wellness of the host (Gismondo et al., 1999). The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) refined this definition to describe probiotics as live microorganisms which, when administered in sufficient quantities, provide tangible health benefits to the host (FAO, 2001).

Over time, the scope of probiotics in aquaculture has expanded, encompassing bacteriophages, microalgae, yeast, and both Gram-positive and Gram-negative bacteria. This inclusive approach by FAO/WHO acknowledges the significant health advantages of orally administered probiotics, which have proven especially useful in controlling diseases in aquaculture, particularly in developing nations (Irianto and Austin, 2002b; Balcázar et al., 2006a; Nayak, 2010; FAO/WHO, 2001; Kazun and Kazun, 2014). However, despite their potential, the viability of probiotic cultures added to feed often lacks thorough evaluation, resulting in possible inaccuracies in the assessment of their health benefits.

The presence of antinutritional factors (ANFs) in plant-based aquafeed, including protease inhibitors, phytates, and tannins, poses a significant challenge by hindering nutrient absorption and digestion in aquatic organisms (Vishal and Shalu, 2024a). Probiotics have demonstrated their ability to counteract these effects by enhancing the digestive efficiency of aquatic species, breaking down complex compounds, and improving nutrient bioavailability (Vishal and Shalu, 2024b). The processing of feed—whether through granulation, pelleting, or extrusion—can impact probiotic efficacy. For example, extruded diets containing probiotics were found to boost nonspecific immunity in Nile tilapia more effectively than granulated or pelleted diets (Skjermo et al., 2006).

Probiotics also play a crucial role in strengthening the immune system of aquatic species. They stimulate nonspecific host defense mechanisms by acting as immune stimulants, thereby increasing resistance to disease and supporting host growth (Magnadóttir et al., 2006). The innate immune system, comprising physical barriers along with cellular and humoral components, acts as a robust line of self-defense in fish (Fooks et al., 1999). Live probiotic bacteria not only serve as alternatives to antibiotics and chemical treatments but also function as signaling molecules that activate immune responses. This role in immune modulation has been extensively studied and reviewed in both humans and animals (Galdeano and Perdigon, 2006; Aly et al., 2008).

From the perspective of sustainable aquaculture, the importance of probiotics cannot be overstated. They enhance growth performance, improve disease resistance, and support the overall health of aquatic organisms (Dawood MAO and Koshio S, 2016). Probiotic bacteria secrete biochemical substances in the host's intestinal tract, inhibiting the growth of opportunistic pathogens (Martínez Cruz and Ibáñez, 2012). The benefits of probiotics include improved feed utilization, enhanced enzymatic activity, suppression of pathogenic bacteria, anti-mutagenic properties, and an overall improved immune response (Van Hai and Ngo, 2015).

**Types of probiotics in frequently used in aquaculture**

* **Soil Probiotics:** These are beneficial microorganisms applied to pond soil to improve its quality, reduce harmful compounds like ammonia and hydrogen sulfide, and create a healthier environment for aquatic species (e.g., *Bacillus subtilis*, *Bacillus amyloliquefaciens*).
* **Water Probiotics:** These probiotics are introduced into the water to maintain its quality by balancing microbial populations, reducing pathogenic bacteria, and enhancing the overall aquatic environment (e.g., *Nitrosomonas*, *Nitrobacter*).
* **Gut Probiotics:** These are administered through feed to improve the gut health of aquatic species, enhance digestion, boost immunity, and promote better growth and disease resistance (e.g., *Lactobacillus*, *Bifidobacterium*, *Bacillus licheniformis*).

**Conclusion**

The application of probiotics and prebiotics has developed a crucial part of aquaculture practices for refining growth performance levels and disease tolerance. For fish, probiotics are essential for enhancing water quality, feed value, growth rates, weight, immunological response, and disease prevention. Similarly, the prebiotic system has several beneficial impacts, namely in fish nutrition and disease tolerance. The usage of probiotics and prebiotics enhances the live bacterial dietary supplement's presence and establishment in the host's digestive system. In place of more antiquated immunological and disease control techniques like immunizations, antibiotics, and immunostimulants, biotic practices are essential for improving fish health and production. In addition to the health advantages of eating these biotics, the variation in growth and feed consumption may depend on the type of fish, the amount of feeding, and the dosage of supplements.

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