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**Review Article**

# RECENT ADVANCES IN PROBIOTIC APPLICATIONS FOR AQUACULTURE HEALTH MANAGEMENT

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## ABSTRACT

Probiotics have emerged as an important and sustainable alternative to antibiotics in aquaculture because they improve the health and productivity of cultured aquatic animals. Beneficial bacteria such as *Bacillus*, *Lactobacillus*, *Pediococcus*, and *Enterococcus* enhance growth performance by improving gut health, feed utilization, and nutrient digestion. In addition, probiotics promote gut microbial balance, stimulate innate immune responses, increase disease resistance against pathogenic *Vibrio* species, and improve water quality by reducing toxic metabolites. Recent advances in synbiotics, genomics, encapsulation technologies, and precision aquaculture have further expanded the applications of probiotics in shrimp farming. Although challenges remain regarding strain selection, stability, and field performance, probiotics provide an environmentally friendly strategy to improve aquaculture productivity while reducing dependence on antibiotics.

**Keywords:** Probiotics, Aquaculture, *Penaeus vannamei*, Growth performance, Immune response.

## INTRODUCTION

Probiotics in aquaculture exert beneficial effects on host health, growth, immunity, and environmental quality through several biological mechanisms. One of the primary mechanisms is competitive exclusion, in which beneficial microorganisms colonize the gastrointestinal tract and attachment sites, thereby preventing the establishment of pathogenic bacteria. This competition for nutrients and adhesion sites inhibits the growth of harmful bacteria, including *Vibrio harveyi*, *Vibrio parahaemolyticus*, and *Vibrio alginolyticus* (Verschuere *et al*., 2000; Ringø *et al*., 2020). Numerous probiotic bacteria produce antimicrobial compounds such as bacteriocins, organic acids, hydrogen peroxide, siderophores, and extracellular enzymes that suppress the growth of pathogens. These metabolites inhibit biofilm formation, reduce pathogen viability, and alter the intestinal pH, creating an unfavorable environment for pathogenic microorganisms. In addition, certain probiotic strains interfere with bacterial quorum sensing, thereby reducing the expression of virulence factors and toxin production (Defoirdt *et al*., 2011). Probiotics also enhance digestion by secreting extracellular enzymes, including proteases, lipases, cellulases, phytases, and amylases, which improve nutrient digestibility and feed utilization. Furthermore, they synthesize essential amino acids, short-chain fatty acids (SCFAs), and vitamins, including the B-complex vitamins and vitamin K, thereby supporting host nutrition and metabolism (Hai, 2015). Immune modulation is another important mechanism of probiotic action. In cultured shrimp, particularly *Litopenaeus vannamei* and *Penaeus monodon*, probiotics stimulate hemocyte activity, enhance phagocytosis, activate pattern-recognition receptors (PRRs), and promote the production of antioxidant enzymes and antimicrobial peptides. These responses strengthen innate immunity and increase resistance to environmental stress and infectious diseases (Hoseinifar *et al*., 2018).

### Criteria for Selection of Probiotic Strains

One of the most crucial factors influencing the effectiveness of probiotics in aquaculture is the selection of an appropriate probiotic strain. An ideal probiotic should possess several biological characteristics that ensure successful colonization, survival, and beneficial effects within the host. The selected microorganism must be non-pathogenic, non-toxic, and safe for aquatic animals,

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humans, and the environment. It should tolerate a wide range of environmental conditions, including fluctuations in temperature, pH, salinity, bile salts, and digestive enzymes. Furthermore, the probiotic should exhibit a strong ability to adhere to intestinal epithelial cells, enabling long-term colonization of the gastrointestinal tract.

Additionally, an ideal probiotic should produce vitamins, immunostimulatory compounds, antimicrobial substances, and extracellular digestive enzymes. It should maintain high viability during commercial production and preserve genetic stability throughout feed processing and storage. *Bacillus subtilis* and other spore-forming bacteria are particularly advantageous because they can withstand feed pelleting and prolonged storage without losing viability. Host-specific probiotics isolated from healthy shrimp, particularly *Litopenaeus vannamei* and *Penaeus monodon*, or other cultured fish species are generally more effective than non-host-derived commercial strains because they colonize the gastrointestinal tract more efficiently and interact more effectively with the host immune system (Ringo *et al*., 2020).

**Factors Affecting Probiotic Efficacy**

The efficacy of probiotics in aquaculture is influenced by numerous biological and environmental factors. These include the probiotic species and strain, dosage, duration of supplementation, mode of administration, water quality, feed composition, stocking density, and culture conditions. Environmental parameters such as temperature, dissolved oxygen, pH, salinity, ammonia concentration, and organic matter significantly affect probiotic survival and colonization. Poor water quality reduces probiotic activity and limits its beneficial effects on cultured shrimp, particularly *Litopenaeus vannamei* and *Penaeus monodon* (Hai, 2015). Host-related factors, including nutritional status, gut microbiota composition, immune status, and developmental stage, also influence probiotic performance. Larval and post-larval stages of *L. vannamei* and *P. monodon* generally respond more rapidly to probiotic supplementation because their intestinal microbial communities are still developing, allowing beneficial microorganisms to establish more effectively. The frequency of probiotic administration is another important factor determining efficacy. Continuous supplementation generally provides greater protection than intermittent feeding because beneficial bacteria become established within the gastrointestinal tract. However, prolonged supplementation does not always result in permanent colonization, making periodic re-administration necessary to maintain probiotic populations and their beneficial effects (Hai, 2015).

**Commercial Applications of Probiotics in Shrimp Farming**

Probiotics are increasingly used in commercial shrimp farming as a routine management strategy to improve production efficiency and reduce disease outbreaks. They are available in various formulations, including feed additives, pond water treatments, spore powders, freeze-dried cultures, liquid suspensions, and encapsulated preparations. These probiotic products are widely applied during the culture of shrimp, particularly *Litopenaeus vannamei* and *Penaeus monodon*, to enhance growth, health, and environmental quality. Commercial probiotic formulations commonly contain *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus pumilus*, *Lactobacillus plantarum*, *Lactobacillus acidophilus*, *Pediococcus acidilactici*, *Enterococcus faecium*, *Saccharomyces cerevisiae*, and various nitrifying bacteria. These beneficial microorganisms stabilize pond ecosystems, improve feed conversion ratio (FCR), accelerate the decomposition of organic matter, reduce ammonia accumulation, suppress pathogenic *Vibrio* populations, and enhance shrimp survival. Consequently, many shrimp hatcheries and commercial farms routinely incorporate probiotics during the larval rearing, nursery, and grow-out stages to maintain stable microbial communities and maximize production efficiency.

**Limitations and Challenges of Probiotics**

Despite their numerous advantages, probiotics have several practical limitations in aquaculture. One of the major challenges is maintaining microbial viability during feed preparation, transportation, and long-term storage. High pelleting temperatures and moisture can significantly reduce the survival of beneficial bacteria. Another limitation is the inconsistency of field performance, as results obtained under laboratory conditions may not always be reproducible in commercial ponds due to variations in microbial ecology, management practices, and environmental conditions. The effectiveness of probiotics in cultured shrimp, particularly *Litopenaeus vannamei* and *Penaeus monodon*, is also influenced by strain interactions, host specificity, optimal dosage, and long-term ecological impacts, many of which remain insufficiently understood. Furthermore, some commercial probiotic products contain mixed bacterial populations whose efficacy is not adequately supported by scientific evidence. Quality control, accurate strain identification, standardization of probiotic formulations, and regulatory approval continue to be major challenges for the large-scale commercialization of probiotics.

**Recent Advances in Probiotic Research**

Recent advances in molecular biology have greatly improved the understanding of probiotic-host interactions in aquaculture. High-throughput sequencing, metagenomics, transcriptomics, proteomics, and metabolomics now enable comprehensive analysis of intestinal microbial communities and their functional roles in cultured shrimp, particularly *Litopenaeus vannamei* and *Penaeus monodon*. Genome sequencing has facilitated the identification of novel probiotic strains with enhanced digestive enzyme production, antimicrobial activity, and immunostimulatory properties.

Encapsulation technologies using alginate, chitosan, and nanomaterials have further improved probiotic stability and targeted delivery throughout the gastrointestinal tract. In addition, probiotic management is increasingly being integrated with biosensors, artificial intelligence (AI), and precision aquaculture technologies to enable real-time monitoring of pond microbial health and optimize feeding strategies.

### Future Perspectives

Future research should focus on the development of host-specific probiotics through genomic and microbiome-based approaches. Customized probiotic formulations designed specifically for cultured shrimp, such as *Litopenaeus vannamei* and *Penaeus monodon*, under different farming conditions have the potential to substantially improve production efficiency and disease resistance. Integrating probiotics with bacteriophage therapy, phytobiotics, biofloc technology, nanotechnology, immunostimulants, and precision feeding systems represents a promising strategy for sustainable aquaculture. Further research is required to elucidate the molecular mechanisms underlying probiotic-host interactions, optimize dosage regimens, evaluate long-term safety, and develop standardized commercial probiotic formulations. These advances are expected to reduce dependence on antibiotics, minimize antimicrobial resistance, and promote environmentally sustainable shrimp farming.

## CONCLUSION

Probiotics have emerged as an effective and sustainable tool for improving shrimp health, growth, immunity, and water quality in modern aquaculture. Their beneficial effects are achieved through competitive exclusion of pathogens, enhancement of digestive efficiency, immune modulation, and maintenance of a balanced gut microbiota. The successful application of probiotics depends on selecting suitable strains, optimizing environmental conditions, and ensuring proper formulation and administration. Although challenges such as strain stability, product standardization, and variable field performance remain, recent advances in genomics, microbiome research, and precision aquaculture are enhancing probiotic efficacy. Overall, integrating scientifically validated probiotics into shrimp farming offers a promising strategy to reduce antibiotic dependence, improve productivity, and support environmentally sustainable aquaculture.

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## CONFLICT OF INTERESTS

The authors declare no conflict of interest

## ETHICS APPROVAL

Not applicable

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## AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

## DATA AVAILABILITY

Data will be available on request

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