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Probiotic Applications for Improved Growth Performance and Disease Resistance in *Litopenaeus vannamei*

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The Pacific white shrimp (*Litopenaeus vannamei*) is the cornerstone of global shrimp aquaculture, contributing significantly to food security and economic development. However, intensification of production systems has heightened vulnerability to infectious diseases, environmental stress, and reduced feed efficiency. The global movement toward antibiotic-free aquaculture has accelerated interest in probiotics as sustainable functional feed additives. Probiotics enhance growth performance, modulate gut microbiota, stimulate innate immunity, and improve resistance against pathogenic bacteria, particularly *Vibrio* species. This review critically evaluates current knowledge on probiotic applications in *L. vannamei*, focusing on their role in improving growth parameters such as specific growth rate (SGR) and feed conversion ratio (FCR), while enhancing disease resistance and survival. Mechanisms of action, delivery methods, strain selection, and future research directions are discussed in the context of sustainable shrimp aquaculture.

Introduction

Over the past three decades, shrimp aquaculture has evolved into one of the fastest-growing sectors in animal protein production. *Litopenaeus vannamei* dominates global shrimp farming due to its rapid growth, adaptability to varying salinity, and high market acceptance. Despite these advantages, intensive farming practices have led to frequent disease outbreaks such as vibriosis, white spot syndrome virus (WSSV), and acute hepatopancreatic necrosis disease (AHPND). These challenges often compromise growth performance, survival, and farm profitability. Historically, antibiotics were widely used to prevent disease and promote growth. However, concerns about antimicrobial resistance, environmental contamination, and international trade restrictions have necessitated alternative strategies. Probiotics have emerged as promising biological tools capable of enhancing growth performance and strengthening disease resistance without negative environmental impacts. Probiotics are defined as live microorganisms that confer health benefits to the host when administered in adequate quantities. In shrimp aquaculture, they may be incorporated into feed or applied directly to pond water, influencing both host physiology and environmental microbial balance.

Probiotics and Growth Performance Enhancement

Growth performance in *L. vannamei* is generally assessed using parameters such as weight gain, specific growth rate (SGR), feed conversion ratio (FCR), and protein efficiency ratio (PER). Numerous studies demonstrate that probiotic supplementation significantly improves these indicators. One of the principal mechanisms underlying improved growth is enhanced digestive capacity. Many probiotic strains, particularly *Bacillus* spp., produce extracellular enzymes including proteases, amylases, and lipases. These enzymes complement endogenous digestive enzymes in shrimp, facilitating more efficient nutrient breakdown and absorption. Improved digestion leads to better feed utilization and lower FCR values, which directly

translate into economic benefits for farmers. Additionally, probiotics improve intestinal morphology and integrity. Histological studies have revealed increased microvilli length and epithelial cell health in probiotic-fed shrimp. Such structural improvements increase nutrient absorption surface area and promote efficient metabolic processes, resulting in higher SGR and overall biomass accumulation. Another important aspect is improved nitrogen retention. By enhancing protein digestion and reducing metabolic stress, probiotics increase the proportion of dietary protein converted into body tissue rather than being lost through excretion. This improvement in protein efficiency ratio is particularly valuable given the high cost of protein-rich aquafeeds.

Modulation of Gut Microbiota

The shrimp gastrointestinal tract harbors a complex microbial community that plays a critical role in digestion, nutrient assimilation, and immunity. Dysbiosis, or microbial imbalance, often predisposes shrimp to disease and reduced growth. Probiotics help establish a balanced gut microbiota by promoting beneficial bacterial populations and suppressing opportunistic pathogens. Competitive exclusion mechanisms prevent pathogenic bacteria from colonizing intestinal surfaces. Some probiotic strains produce antimicrobial compounds such as bacteriocins, organic acids, and hydrogen peroxide, further inhibiting harmful microbes. A stable and beneficial gut microbiome enhances metabolic efficiency and supports consistent growth performance, particularly under high-density farming conditions.

Enhancement of Disease Resistance

Disease outbreaks are among the most significant constraints in shrimp aquaculture. Probiotics enhance disease resistance through multiple mechanisms. First, probiotics stimulate the innate immune system of shrimp. Unlike vertebrates, shrimp rely on non-specific immunity, including hemocyte-mediated responses, phenoloxidase activation, antimicrobial peptide production, and respiratory burst activity. Probiotic supplementation has been shown to increase total hemocyte count and enhance phenoloxidase and lysozyme activities, strengthening the shrimp's ability to combat pathogens. Second, probiotics reduce pathogen load through competitive exclusion and direct antagonism. For example, *Bacillus* and *Lactobacillus* species have demonstrated inhibitory activity against *Vibrio harveyi* and *Vibrio parahaemolyticus*, major causative agents of vibriosis and AHPND. Third, probiotics enhance stress tolerance. Environmental stressors such as temperature fluctuations, salinity changes, and high stocking density often weaken shrimp immunity. Probiotic-fed shrimp exhibit improved antioxidant capacity and reduced oxidative stress, which contributes to higher survival rates during disease challenges.

Water Quality Management

Probiotics applied directly to culture water contribute to improved environmental conditions. Certain bacterial strains participate in nitrification and denitrification processes, reducing ammonia and nitrite concentrations. Others degrade organic matter and stabilize microbial communities within the pond ecosystem. Improved water quality reduces physiological stress and energy expenditure associated with detoxification processes. Consequently, more energy is allocated toward growth and immune function. The combined effects of feed-based and water-based probiotics create a synergistic improvement in overall farm productivity.

Methods of Probiotic Application

Probiotics can be administered through several approaches. Dietary supplementation ensures direct interaction with the gastrointestinal tract and is particularly effective for improving growth and gut health. Water application targets environmental microbial communities and enhances pond ecology. In hatchery systems, probiotics may also be applied during larval rearing to promote early microbial colonization and immune development. The choice of strain, dosage, and frequency of application significantly influences outcomes. Spore-forming bacteria such as *Bacillus* spp. are often preferred because they withstand feed processing temperatures and remain viable during storage.

Challenges and Research Gaps

Although probiotics offer significant benefits, their efficacy can vary depending on environmental conditions, host developmental stage, and strain specificity. Not all probiotic strains produce identical results, and some may be ineffective if improperly dosed. Standardized protocols for evaluating probiotic efficacy under commercial farming conditions are still needed. Future research should integrate advanced molecular tools, such as metagenomics and transcriptomics, to better understand host–microbe interactions and optimize strain selection.

Future Perspectives

The future of probiotic applications in shrimp aquaculture lies in precision microbiome management. Development of multi-strain consortia tailored to specific culture conditions may provide synergistic benefits. Encapsulation technologies can improve probiotic stability and targeted delivery within the gut. Integration of probiotics with prebiotics (synbiotics), phytogetic additives, and functional amino acids may further enhance growth and disease resistance. Such integrated nutritional strategies will support sustainable and antibiotic-free shrimp production systems.

Conclusion

Probiotic applications play a pivotal role in improving growth performance and disease resistance in *Litopenaeus vannamei*. By enhancing digestive efficiency, stabilizing gut microbiota, stimulating innate immunity, and improving water quality, probiotics contribute to higher specific growth rates, improved feed conversion ratios, and increased survival. As global aquaculture continues to transition toward sustainable practices, probiotics represent a scientifically validated and environmentally responsible solution for enhancing shrimp productivity and health.

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