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Impact of Probiotics on Growth Efficiency and Survival in *Litopenaeus vannamei*

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The Pacific white shrimp (*Litopenaeus vannamei*) accounts for the largest share of global shrimp aquaculture production. Intensification of farming systems, while improving productivity, has also increased vulnerability to disease outbreaks, environmental stress, and poor feed efficiency. In recent years, probiotics have gained prominence as sustainable and eco-friendly alternatives to antibiotic growth promoters. The present review critically examines the impact of probiotic supplementation on growth efficiency and survival of *L. vannamei*. Emphasis is placed on improvements in weight gain, specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER), and survival under both normal and stress conditions. Mechanisms underlying probiotic action, including gut microbiota modulation, digestive enzyme enhancement, immune stimulation, and water quality improvement, are discussed in detail. The review highlights the potential of probiotics as integral components of precision shrimp nutrition and sustainable aquaculture practices.

Introduction

The rapid expansion of shrimp aquaculture has transformed *Litopenaeus vannamei* into one of the most economically important crustacean species worldwide. Its fast growth rate, tolerance to a wide range of salinity conditions, and suitability for high-density culture systems have made it the preferred species in many producing countries. However, the intensification of culture systems has led to increased incidence of microbial diseases, suboptimal water quality, stress-induced immunosuppression, and inconsistent growth performance. Feed costs constitute a substantial portion of total production expenses, and even small improvements in feed utilization efficiency can significantly enhance farm profitability.

For decades, antibiotics were incorporated into shrimp feeds to promote growth and control bacterial infections. Growing concerns regarding antimicrobial resistance, drug residues in seafood, and environmental impacts have resulted in regulatory restrictions on antibiotic usage. Consequently, research has increasingly focused on functional feed additives, particularly probiotics, as natural growth promoters and health enhancers.

Probiotics are live microorganisms that confer health benefits to the host when administered in adequate amounts. In shrimp aquaculture, probiotics may be delivered through feed or directly into the culture water, targeting both the gastrointestinal tract and the surrounding aquatic environment. Their role extends beyond disease control, encompassing improvements in digestion, nutrient absorption, immune competence, and stress tolerance.

Influence of Probiotics on Growth Efficiency

Growth efficiency in *L. vannamei* is typically assessed through parameters such as weight gain, specific growth rate (SGR), feed conversion ratio (FCR), and protein efficiency ratio (PER). Numerous experimental studies have reported significant improvements in these indicators following dietary probiotic supplementation.

One of the primary mechanisms through which probiotics enhance growth efficiency is by stimulating digestive processes. Certain probiotic strains, particularly species belonging to the genus *Bacillus*, produce extracellular enzymes such as proteases, amylases, and lipases. These enzymes complement the endogenous digestive enzymes of shrimp, leading to improved breakdown of dietary proteins, carbohydrates, and lipids. Enhanced digestion results in greater nutrient availability and absorption, ultimately translating into higher weight gain and improved SGR.

Feed conversion ratio, which represents the amount of feed required to produce a unit of biomass, is a critical economic indicator in shrimp farming. Probiotic supplementation often results in lower FCR values, indicating more efficient feed utilization. Improved nutrient assimilation reduces feed wastage and decreases nitrogen excretion into the culture environment, thereby also contributing to better water quality.

Protein efficiency ratio reflects the effectiveness with which dietary protein is converted into shrimp biomass. Given that protein is the most expensive component of aquafeed, improvements in PER have substantial economic implications. Probiotics enhance nitrogen retention and reduce metabolic losses, allowing more dietary protein to be directed toward muscle deposition and growth rather than immune or stress responses.

Effects on Survival and Health Status

Survival rate is a key determinant of production success in shrimp aquaculture. Mortality in intensive systems is often associated with opportunistic pathogens, particularly *Vibrio* species. Probiotics exert protective effects through competitive exclusion, whereby beneficial bacteria occupy ecological niches in the shrimp gut and inhibit colonization by pathogenic microorganisms. Some probiotic strains produce antimicrobial compounds such as bacteriocins, hydrogen peroxide, and organic acids that suppress pathogen proliferation.

Beyond direct antagonism, probiotics enhance the innate immune response of shrimp. Unlike vertebrates, shrimp rely primarily on non-specific immune mechanisms, including hemocyte activity, phenoloxidase cascade, and antimicrobial peptide production. Probiotic supplementation has been shown to increase total hemocyte count, stimulate phenoloxidase activity, and enhance respiratory burst responses. These immunological enhancements contribute to improved disease resistance and higher survival rates, particularly during pathogenic challenges.

Stress conditions such as sudden salinity changes, high stocking density, temperature fluctuations, and poor water quality often suppress growth and increase mortality. Probiotic-treated shrimp frequently exhibit improved physiological resilience under such conditions. This resilience is attributed to reduced oxidative stress, better gut integrity, and improved metabolic stability.

Modulation of Gut Microbiota and Intestinal Health

The gastrointestinal tract of *L. vannamei* harbors a complex microbial community that plays a central role in digestion and immunity. Disruptions in microbial balance, commonly referred to as dysbiosis, can impair nutrient absorption and predispose shrimp to disease. Probiotics help restore microbial equilibrium by increasing beneficial bacterial populations while suppressing opportunistic pathogens.

Histological examinations of probiotic-fed shrimp often reveal improvements in intestinal morphology, including increased epithelial integrity and enhanced microvilli development. These structural improvements increase the absorptive surface area of the gut, facilitating more efficient nutrient uptake. A healthy intestinal barrier also prevents translocation of pathogens into systemic circulation, thereby reducing infection risk.

Improvement of Water Quality

In addition to direct effects on the host, probiotics applied to pond water contribute to improved environmental conditions. Certain bacterial strains degrade organic matter, reduce ammonia and nitrite concentrations, and stabilize microbial communities within the culture

system. Improved water quality reduces stress-related metabolic expenditure, allowing more energy to be allocated toward growth. The interaction between host-associated probiotics and environmental microbiota creates a more balanced ecosystem within intensive shrimp farms. This holistic effect underscores the importance of integrating feed-based and water-based probiotic strategies.

Factors Influencing Probiotic Efficacy

Despite promising outcomes, the effectiveness of probiotics varies depending on strain specificity, dosage, mode of administration, and environmental conditions. Spore-forming bacteria such as *Bacillus* species are generally preferred due to their stability during feed processing and storage. Multi-strain formulations may provide synergistic effects, but optimal combinations require further investigation.

Standardization of probiotic evaluation protocols remains a challenge. Differences in experimental design, shrimp developmental stage, and culture systems contribute to variability in reported results. Therefore, large-scale farm trials and long-term studies are essential to validate laboratory findings.

Future Perspectives

Advances in molecular biology and microbiome research are providing new insights into host–microbe interactions in shrimp. Metagenomic approaches allow identification of beneficial microbial consortia tailored to specific culture environments. Encapsulation technologies are being developed to enhance probiotic stability and targeted delivery within the gastrointestinal tract. Future research should emphasize precision nutrition strategies that integrate probiotics with other functional additives such as prebiotics, enzymes, and phytonutrients. Such integrated approaches may yield synergistic improvements in growth efficiency and survival while maintaining environmental sustainability.

Conclusion

Probiotics play a significant role in enhancing growth efficiency and survival in *Litopenaeus vannamei*. By improving digestive enzyme activity, modulating gut microbiota, stimulating immune responses, and enhancing water quality, probiotics contribute to better feed utilization and higher survival rates. As the aquaculture industry continues to shift toward antibiotic-free production systems, probiotics represent a scientifically sound and economically viable strategy for sustainable shrimp farming. Continued research and field validation will further optimize their application and maximize their benefits in commercial aquaculture.

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