Utilizing Probiotics as a Sustainable Approach to Improve Aquatic Species Health and Growth

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Abstract. Probiotics have emerged as a vital component in aquaculture, demonstrating significant potential to enhance the health and growth of aquatic species. Currently, a variety of commercial probiotic products are available, derived from numerous bacterial species, including Bacillus, Lactobacillus, Enterococcus, Carnobacterium, and the yeast *Saccharomyces cerevisiae*, among others. These beneficial microorganisms play a crucial role in improving gut health, boosting immune responses, and mitigating stress in fish, ultimately leading to increased survival rates and productivity. This study adopts a literature review approach, critically analyzing existing knowledge, concepts, and findings from theoretically oriented and academic sources. The primary data sources for this research include reputable platforms such as Google Scholar, accredited scientific journals, and other relevant scholarly databases. By systematically gathering articles from these sources, the study ensures a comprehensive examination of the current state of research on the utilization of probiotics in aquaculture. This review elucidates the mechanisms through which probiotics can bolster fish health, improve growth rates, and promote overall ecosystem sustainability. The findings not only highlight the numerous benefits associated with probiotic usage but also address the challenges and future directions for research in this field. By fostering a deeper understanding of these microbial solutions, this study contributes to the ongoing discourse on sustainable aquaculture practices, paving the way for innovative approaches to fish farming that prioritize environmental stewardship.

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1 Introduction

Aquaculture has become a cornerstone of global food production, accounting for nearly half of the world's fish supply [1]. As the industry expands to meet growing demand, intensive aquaculture practices have introduced critical challenges related to animal health, environmental sustainability, and disease management. To address these concerns, probiotics live microorganisms that offer health benefits when administered in adequate amountsare emerging as a sustainable alternative for enhancing both aquaculture health and growth [2].

The widespread use of antibiotics in aquaculture has resulted in significant drawbacks, including the rise of antibiotic-resistant pathogens, which endanger aquatic species and human health alike. Additionally, antibiotics disrupt natural microbial ecosystems, causing environmental imbalances and contamination of water bodies. Consequently, there has been a growing shift toward probiotics as a more environmentally responsible approach to disease prevention and aquaculture health management [3].

Several probiotic bacterial strains have proven effective in aquaculture, each offering distinct advantages in supporting the health of aquatic organisms and improving water quality. Commonly used probiotic bacteria include species from the genera *Lactobacillus, Bacillus, Streptococcus, Enterococcus, Pseudomonas*, and *Vibrio*. These microorganisms enhance the intestinal microbiota of fish by improving nutrient digestion, outcompeting pathogenic bacteria, and producing antimicrobial compounds such as bacteriocins that inhibit harmful microbes. For example, *Lactobacillus* species, known for their lactic acid production, contribute to lowering gut pH and inhibiting the growth of pathogens, thus fostering a healthier gut environment. Similarly, Bacillus species, widely used in aquaculture, produce enzymes like proteases and amylases that improve the breakdown of feed, boosting feed efficiency. Additionally, *Streptococcus* and *Enterococcus* species have immunomodulatory effects, enhancing fish immune responses and strengthening resistance to diseases [4-7].

Probiotics not only improve the gut microbiota and nutrient absorption but also play a critical role in boosting the immune system, helping fish to better withstand diseases and environmental stress [8]. Furthermore, they prevent the proliferation of pathogenic bacteria through competitive exclusion, production of antimicrobial compounds, and modulation of immune responses [9]. These benefits contribute to healthier fish populations and enhanced growth performance, making probiotics an essential tool for increasing aquaculture productivity.Additionally, probiotics contribute to maintaining water quality by breaking down organic waste and reducing toxic compounds such as ammonia and nitrite, which are harmful to fish health [10-12]. This is particularly important in closed aquaculture systems where water quality management is vital for the sustainability of operations.

This review explores recent advancements in the use of probiotics to improve health and growth in aquaculture, emphasizing commonly used bacterial strains, their mechanisms of action, and their effectiveness across different aquaculture species. We also discuss the challenges and future research directions in this field, focusing on the potential of probiotics to transform sustainable aquaculture practices.

2 Research Method

This study adopts a literature review approach, critically analyzing existing knowledge, concepts, and findings from theoretically oriented and academic sources. The primary data sources for this research include reputable platforms such as Google Scholar, accredited scientific journals, and other relevant scholarly databases. By systematically gathering articles from these sources, the study ensures a comprehensive examination of the current state of research on the utilization of probiotics in aquaculture.

The analysis follows a descriptive approach, wherein the collected data is organized and presented in a structured manner. This method enables a clear and coherent synthesis of information, offering a deeper insight into the trends, benefits, and challenges associated with the use of probiotics in improving fish health and growth. Through careful evaluation of the literature, the study aims to provide readers with an enhanced understanding of the topic, facilitating the assimilation of key concepts and recent advancements in the field.

3 Result and Discussion

Probiotics are live microorganisms that, when administered in adequate amounts, confer significant health benefits to the host, whether human or animal. These microorganisms typically consist of various types of bacteria and yeast that play a crucial role in maintaining the balance of gut microbiota. The presence of probiotics in the digestive system can enhance nutrient absorption, support immune function, and help address various digestive issues such as diarrhea, constipation, and irritable bowel syndrome. Thus, probiotics are considered essential elements in efforts to improve health and productivity, particularly concerning digestive health [13].

The term "probiotic" derives from the Greek words, where pro means "for" and bios means "life." This concept was first introduced by Dr. Elie Metchnikoff in the early 20th century when he observed that individuals consuming fermented milk, rich in lactic acid bacteria, enjoyed better health than those who did not. Metchnikoff argued that beneficial bacteria could improve gut flora, contribute to better digestion, and replace harmful microbes that could lead to disease [14].

Although the concept has existed for a long time, the term "probiotic" was officially used in 1965 by Lilly and Stillwell. They defined probiotics as agents that have the opposite function of antibiotics, supporting and enhancing the populations of beneficial microorganisms in the body. Over time, this definition has continued to evolve to encompass a variety of microorganisms, including several strains of bacteria from the genera *Lactobacillus, Bifidobacterium*, and *Saccharomyces*, all of which have been shown to provide significant health benefits [15].

Probiotics are also known to have various mechanisms of action that support health. For instance, they can improve gut permeability, produce organic acids that inhibit the growth of pathogenic bacteria, and compete for essential nutrients necessary for pathogen survival. Additionally, probiotics contribute to the regulation of the immune system, enhancing immune responses to infections and reducing inflammation. As understanding of the benefits of probiotics has increased, their use in various fields, including nutrition, human health, and particularly aquaculture, has garnered significant attention. In aquaculture, probiotics are commonly administered in concentrations ranging from 10^6 to 10^8 colony-forming units (CFU) per gram or milliliter to ensure sufficient colonization and beneficial effects [11]. These concentrations have been shown to effectively enhance the health and growth of fish while improving resistance to diseases, which, in turn, can boost the productivity and sustainability of aquaculture practices.

The application of probiotics in the field of aquaculture can be seen in Table 1, which summarizes the roles and mechanisms through which probiotics contribute to growth promotion, pathogen inhibition, nutrient digestion, water quality improvement, stress tolerance, and reproductive success in aquatic species.

Table 1. The application of probiotics in aquatic species

Application	Identity of Probiotic	Aquatic Species
Growth promoter	*Bacillus* sp.	*Penaeus monodon,* Catfish, Epinephelus coioides
	Carnobacterium divergens	*Gadus morhua*
	Alteromonas CA2	*Crassostrea gigas*
	Lactobacillus helveticus	*Scophthalmus maximus*
	L. lactis AR21	*Brachionus plicatilis*
	Streptococcus thermophilus	*Scophthalmus maximus*
	Streptomyces	*Xiphophorus helleri*
	L. casei	*Poeciliopsis gracilis*
	Bacillus NL 110, *Vibrio* NE 17	*Macrobrachium rosenbergii*
	Bacillus coagulans	*Cyprinus carpio* koi
	L. plantarum (TISTR 912)	*Labeo chrysophekadion*
	L. rhamnosus	*Oreochromis niloticus*
	L. pentosus BD6	*Litopenaeus vannamei*
	Saccharomyces cerevisiae	*Cyprinus carpio*
	Carnobacterium divergens	*Gadus morhua*
Pathogen inhibition	*Bacillus* sp.	Penaeids
	Enterococcus faecium SF 68	*Anguilla anguilla*
	L. rhamnosus ATCC53103	*Oncorhynchus mykiss*
	Micrococcus luteus A1-6	*Oncorhynchus mykiss*
	Pseudomonas fluorescens	*Oncorhynchus mykiss, Litopenaeus vannamei*
	Pseudomonas sp.	*Oncorhynchus mykiss*
	Roseobacter sp. BS. 107	Scallop larvae
	Saccharomyces cerevisiae, S.exiguous, Phaffia rhodozyma	*Litopenaeus vannamei*
	Vibrio alginolyticus	Salmonids
	V. fluvialis	*Oncorhynchus mykiss*
	Tetraselmis suecica	*Salmo salar*
	Carnobacterium sp. Hg4-03	*Hepialus gonggaensis*
	Lactobacillus acidophilus	*Clarias gariepinus*
	Bacillus spp., *Enterococcus*sp.	*Farfantepenaeus brasiliensis*
	Lactococcus lactis	*Epinephelus coioides*
	Lactobacillus plantarum (TISTR 912)	*Labeo chrysophekadion*
Nutrient digestibility	*L. helveticus*	*Scophthalmus maximus*
	Bacillus NL 110, *Vibrio* NE 17	*Macrobrachium rosenbergii*
	Carnobacterium sp. Hg4-03	*Hepialus gonggaensis* larvae

	Lactobacillus acidophilus	*Clarias gariepinus*
	Shewanella putrefaciens Pdp11	*Solea senegalensis*
Water quality	*Bacillus* NL 110, *Vibrio* sp. NE 17	*Macrobrachium rosenbergii*
	Lactobacillus acidophilus	*Clarias gariepinus*
	B. coagulans SC8168,	*Pennaeus vannamei*
	Bacillus sp., *Saccharomyces* sp.	*Penaeus monodon*
Stress tolerance	*Lactobacillus delbrueckii*	*Dicentrarchus labrax*
	Alteromonas sp.	*Sparus auratus*
	B. subtilis, L. acidophilus, S. cerevisiae	*Paralichthys olivaceus*
	L. casei	*Poecilopsis gracilis*
	Pediococcus acidilactici	*Litopenaeus stylirostris*
	Shewanella putrefaciens Pdp11	Makimaki
Reproduction improvement	*Bacillus subtilis*	*Poecilia reticulata, Xiphophorus maculatus*
	L. rhamnosus	*Danio rerio*
	L. acidophilus, L. casei, Enterococcus faecium, Bifidobacterium thermophilum	*Xiphophorus helleri*

3.1 Growth Promoter

Probiotics serve as growth promoters in aquaculture, aiming to enhance the growth rate of aquatic animals through strategies such as feed management, health optimization, and environmental improvements. Key factors influencing growth include nutritious feed quality, optimal water conditions, and good animal health, with gut microbiota balance playing a vital role. Probiotics are critical agents for promoting growth through several mechanisms. Firstly, they aid digestion by breaking down complex nutrients, which enhances nutrient absorption and reduces feed conversion into waste, allowing more energy to be directed towards growth. Secondly, probiotics promote beneficial bacteria and suppress pathogens, ensuring gut health and improving feed efficiency, thereby enhancing nutrient absorption and disease resistance. Thirdly, they stimulate antibody production and enhance immune cell activity, enabling animals to effectively combat infections and redirect energy to growth. Furthermore, probiotics help mitigate metabolic stress caused by environmental fluctuations, allowing aquatic animals to allocate more energy to growth rather than coping with discomfort. They also improve water quality by decomposing harmful compounds like ammonia and nitrites, creating a more conducive environment for growth [2].

3.2 Inhibition of Pathogens

Probiotics play a crucial role in protecting aquatic species from pathogens through various interrelated mechanisms. One primary strategy is nutrient competition, where probiotic microorganisms such as *Bacillus* spp. and *Carnobacterium* divergens effectively compete with pathogens for essential growth nutrients. By reducing the availability of these nutrients for pathogenic bacteria, probiotics can inhibit the proliferation of harmful microbes. Additionally, probiotics produce natural antibacterial compounds, such as bacteriocins and organic acids, which have been shown to be effective against pathogens like *Vibrio* spp. and *Escherichia coli*. Microorganisms such as *Lactobacillus helveticus* and *Lactobacillus plantarum* contribute to lowering the pH in the gastrointestinal tract, creating an unfavorable environment for pathogen growth.

3.3 Improvement in Nutrient Digestion

Probiotics aid the digestive process by enhancing the breakdown and absorption of essential nutrients found in feed, such as proteins, lipids, and carbohydrates. The effects of probiotics on nutrient digestion not only benefit the animals themselves but also have positive environmental implications by reducing organic waste output.

Microorganisms such as *Lactobacillus helveticus, Bacillus* NL 110, *Vibrio* NE 17, *Carnobacterium* sp., *Lactobacillus acidophilus*, and *Shewanella putrefaciens* have shown significant improvements in nutrient digestion across various aquatic species. By boosting digestive enzyme activity, optimizing feed breakdown, and maintaining a balanced gut microbiota, these microorganisms are essential for enhancing feed utilization and fostering the growth of aquatic species while promoting sustainable practices in aquaculture.

3.4 Improvement of Water Quality

The role of probiotics in aquaculture extends beyond improving the health and growth of aquatic species; they also play a crucial part in enhancing water quality. Probiotics can help mitigate the adverse effects of organic waste and harmful compounds, creating a more sustainable environment for aquaculture operations. By introducing beneficial microorganisms into aquatic systems, the balance of the ecosystem can be maintained, leading to healthier fish and shrimp.

Furthermore, the combination of *Bacillus* sp. and *Saccharomyces* sp. in black tiger shrimp (*Penaeus monodon*) is noteworthy. These probiotics work synergistically to enhance the breakdown of organic waste while also outcompeting pathogenic microorganisms. This competitive exclusion helps maintain a balanced microbial community, reducing the likelihood of disease outbreaks and promoting better water quality.

Overall, the incorporation of probiotics such as *Bacillus* NL 110, *Vibrio* sp. NE 17, *L. acidophilus, Bacillus*, and *Saccharomyces* sp. in aquaculture systems has a multifaceted impact on water quality. By breaking down organic waste, reducing harmful compounds, and fostering a balanced microbial ecosystem, these beneficial microorganisms contribute significantly to the sustainability and productivity of aquaculture operations

3.5 Stress Tolerance

The use of probiotics in aquaculture has brought about significant benefits, especially when it comes to helping aquatic species cope with stress. Fish and shrimp often face stress from various sources, including changes in water quality, temperature fluctuations, handling, and disease outbreaks. By incorporating probiotics into their diets, we can enhance their resilience and overall health.

Another fascinating case is *Alteromonas* sp., which benefits gilthead seabream (*Sparus auratus*). This probiotic not only helps with nutrient digestion but also keeps the gut healthy, essential during times of stress. When fish have a robust digestive system, they can absorb nutrients more effectively, allowing them to better cope with challenging conditions. For olive flounder (*Paralichthys olivaceus*), a combination of Bacillus subtilis, Lactobacillus acidophilus, and *Saccharomyces cerevisiae* has shown remarkable results. These probiotics enhance digestion and promote a strong immune response. This combination helps fish manage stress by boosting their production of stress-related hormones, allowing them to adapt to adverse conditions, such as temperature changes or disease threats.

In summary, incorporating probiotics like *Lactobacillus delbrueckii, Alteromonas sp., Bacillus subtilis, Lactobacillus acidophilus, Saccharomyces cerevisiae, Lactobacillus casei, Pediococcus acidilactici, and Shewanella putrefaciens* Pdp11 in aquaculture can significantly boost stress tolerance in various aquatic species. By enhancing gut health and improving immune function, these probiotics play a vital role in ensuring that fish and shrimp remain healthy and resilient, even when faced with environmental challenges.

3.6 Effect on Reproduction of Aquatic Species

The application of probiotics in aquaculture has garnered significant attention for its positive effects on the reproductive performance of various aquatic species. By enhancing gut health and boosting immune function, probiotics contribute to improved fertility, egg quality, and overall reproductive success in fish and shrimp.

In the case of *Xiphophorus helleri*, a combination of *Lactobacillus acidophilus, L. casei, Enterococcus faecium,* and *Bifidobacterium thermophilum* has demonstrated significant benefits for reproductive health. This multi-strain probiotic approach helps improve the overall health of the fish, leading to increased fertility rates and better egg quality. The diverse range of beneficial bacteria helps to balance the gut microbiota, which can enhance nutrient absorption and boost the fish's resilience against stressors that might otherwise hinder reproductive success.

The positive effects of these probiotics on reproductive improvement in aquatic species highlight the importance of maintaining a healthy gut microbiome. By supporting digestion, enhancing nutrient uptake, and improving overall health, probiotics can play a crucial role in optimizing reproductive performance. The incorporation of probiotics like *B. subtilis, L. rhamnosus, L. acidophilus, L. casei, Enterococcus faecium*, and *Bifidobacterium thermophilum* in aquaculture not only enhances reproductive outcomes but also contributes to the sustainability and productivity of fish farming practices. Ultimately, leveraging the benefits of probiotics can lead to healthier populations of aquatic species, with improved growth and reproduction, thus supporting the future of aquaculture.

3.7 Safety Considerations for Probiotics in Aquaculture Practices

The use of probiotics in aquaculture offers various benefits for the health of aquatic species and the environment, but safety considerations must be carefully addressed to ensure their safe and sustainable application. The selection of probiotic microorganism strains should be based on evidence that they are non-pathogenic to both aquatic species and humans. A rigorous selection process is required to avoid the risk of infections or toxicity caused by inappropriate strains. Additionally, food safety for consumers is a primary concern. Probiotic microorganisms must not produce toxic or allergic effects when consumed through aquaculture products, necessitating toxicological and allergenicity studies to ensure that probiotic residues do not pose health risks to humans.

Proper dosage and application methods must also be determined to avoid disrupting the balance of the microbiota in aquatic species. Excessive use of probiotics can harm the health of cultured species. In vivo testing is necessary to establish safe and effective probiotic dosages. Overall, while probiotics hold great potential in supporting sustainable aquaculture, safety considerations—including strain selection, toxicological testing, ecological impacts, and genetic monitoring—are critical to ensuring safe application for aquatic species, consumers, and the environment.

4 Conclusion

Probiotics play an essential role in enhancing the health and growth of aquatic species, establishing themselves as a key component in sustainable aquaculture practices. This review highlights how various probiotic strains, including those from the genera Bacillus, Lactobacillus, Enterococcus, Carnobacterium, *Saccharomyces cerevisiae*,and among others contribute to improving gut health, boosting immune responses, and alleviating stress in aquatic organisms. By enhancing nutrient absorption and overall well-being, probiotics not only lead to increased survival rates but also enhance productivity in fish farming.

The evidence presented in this study demonstrates that the incorporation of probiotics can foster healthier aquatic populations, thereby supporting the sustainability of aquaculture ecosystems. However, it is crucial to consider the appropriate selection and application of probiotic strains, as well as their dosages, to maximize their effectiveness and prevent any potential adverse effects on the aquatic environment. As the industry seeks innovative approaches to meet the growing demand for seafood while prioritizing environmental stewardship, probiotics offer a promising solution.

References

1. L. W. Herrmann, L. A. J. Letti, R. de O. Penha, V. T. Soccol, C. Rodrigues, and C. R. Soccol, Biotechnol. Adv. **70**, 108300 (2024)
2. C. Tran, I. E. Cock, X. Chen, and Y. Feng, Antibiotics **11**, (2022)
3. Y. Yusra, H. Syandri, Y. Efendi, and N. Huda, F1000Research **11**, 1139 (2022)
4. C. Ripolles-Avila, M. Martinez-Garcia, A. S. Hascoët, and J. J. Rodríguez-Jerez, CYTA - J. Food **17**, 408 (2019)
5. M. R. Asadi Karam, M. Habibi, and S. Bouzari, Mol. Immunol. **108**, 56 (2019)
6. N. Ningsih, A. N. Respati, D. Astuti, T. Triswanto, L. Purnamayanti, A. A. Yano, R. P. Putra, A. Jayanegara, A. Ratriyanto, and A. Irawan, Poult. Sci. **102**, 102923 (2023)
7. F. George, S. Mahieux, C. Daniel, M. Titécat, N. Beauval, I. Houcke, C. Neut, D. Allorge, F. Borges, G. Jan, B. Foligné, and A. Garat, Microorganisms **9**, 1 (2021)
8. S. Subagiyo, S. Margino, T. Triyanto, and W. A. Ari Setyati1,2, ILMU Kelaut. Indones. J. Mar. Sci. **20**, 187 (2015)
9. Sami-ul-Haq, Huma Shafique, Sadia Ahmad, and Arslan Zaidi, Lahore Garrison Univ. J. Life Sci. **8**, 79 (2024)
10. V. H. Smith, Environ. Sci. Pollut. Res. **10**, 126 (2003)
11. M. F. Johnson, L. K. Albertson, A. C. Algar, S. J. Dugdale, P. Edwards, J. England, C. Gibbins, S. Kazama, D. Komori, A. D. C. MacColl, E. A. Scholl, R. L. Wilby, F. de Oliveira Roque, and P. J. Wood, Wiley Interdiscip. Rev. Water 1 (2024)
12. A. Khaled, A. Hessein, A. M. Abdel-Halim, and F. M. Morsy, Egypt. J. Aquat. Res. **40**, 363 (2014)
13. J. Geist and S. J. Hawkins, Aquat. Conserv. Mar. Freshw. Ecosyst. **26**, 942 (2016)
14. T. I. Moiseenko and N. A. Gashkina, Environ. Res. Lett. **15**, (2020)
15. J. Umashankari, D. Inbakandan, T. T. Ajithkumar, and T. Balasubramanian, Aquat. Biosyst. **8**, 1 (2012)