



Amol University of Special
Modern Technologies

Caspian Journal of Veterinary Science

doi: 10.22034/cjvs.2025.517910.1036

Journal homepage: <https://Cjvs.ausmt.ac.ir/>

Probiotics as a tool for disease control in aquaculture: concentrate on six key bacterial fish pathogens

Saeedeh Hosseini¹, Hojjatollah Shokri^{2*}, Rozhin Farshgar³

¹Department of Fisheries, Faculty of Natural Resources, University of Tehran, Karaj, Iran.

²Department of Pathobiology, Faculty of Veterinary Medicine, Amol University of Special Modern Technologies, Amol, Iran.

³Department of Clinical Sciences, Faculty of Veterinary Medicine, Razi University of Kermanshah, Kermanshah, Iran.

(*) Corresponding Author: hshokri@ausmt.ac.ir

Article Info	Abstract
<p>Article history: Received: 19 April 2025 Accepted: 1 May 2025</p> <p>Keywords: Aquaculture Bacterial disease Probiotic</p>	<p>The aquaculture industry faces significant challenges due to infectious diseases that can devastate fish populations and impact economic viability. Probiotics have emerged as a promising strategy for disease control, offering a sustainable alternative to traditional antibiotics. This review focuses on six key bacterial strains: <i>Aeromonas hydrophila</i>, <i>Yersinia ruckeri</i>, <i>Lactococcus garviae</i>, <i>Streptococcus agalactiae</i>, <i>Streptococcus dysgalactiae</i>, and <i>Streptococcus iniae</i>, which are known to cause severe infections in aquatic species. Probiotics, defined as live microorganisms that confer health benefits to the host, can enhance the immune response of fish, improve gut health, and outcompete pathogenic bacteria. The mechanisms of action include the production of antimicrobial substances, competition for nutrients and adhesion sites, and modulation of the host's immune system. This literature review synthesizes current research findings on the efficacy of these probiotics against the aforementioned pathogens, highlighting their potential to reduce disease incidence and promote healthier aquaculture practices. The integration of probiotics into aquaculture not only addresses the pressing issue of antibiotic resistance but also supports the overall sustainability of the industry. Future research directions are proposed to further elucidate the mechanisms of action, optimize probiotic formulations, and evaluate their long-term effects on fish health, and aquaculture productivity.</p> <p>©2025 Published by Amol University of Special Modern Technologies Press. This is an open-access article under the CC-BY4.0 license (https://creativecommons.org/licenses/by/4.0/).</p>

Introduction

Introduction to probiotics in aquaculture

The role of probiotics in sustainable aquaculture

Aquaculture plays an increasingly vital role in ensuring global food security, especially as the world's population continues to grow (Biswas *et al.*, 2023). With capture fisheries facing limitations and

sustainability concerns, aquaculture offers a means to meet the rising demand for aquatic food products. Aquaculture's contribution is particularly significant in Asia, which accounts for approximately 90% of global aquaculture production (Das *et al.*, 2024; Parashuramappa, 2024). This highlights the region's dominance and the importance of aquaculture practices in Asian countries. However, disease

outbreaks remain a major threat to aquaculture production, causing substantial economic losses and impacting the socioeconomic status of local communities that depend on it (Hoseinifar et al., 2018; Parashuramappa, 2024). Among these, bacterial diseases present a serious challenge to the aquaculture industry, leading to substantial economic losses and environmental impacts. The reliance on prophylactic administration of antibiotics to combat these outbreaks has led to several drawbacks, including the rise of antibiotic-resistant bacteria (Pereira et al., 2022) and concerns about residues in aquaculture products (Cain, 2022; Elbaz and Fattah, 2022; Wei et al., 2022). This has prompted strict regulations to minimize or ban antibiotic use in aquaculture, spurring the search for alternative disease control strategies (Ring, 2020; Sumon et al., 2022). Probiotics are increasingly recognized as a sustainable approach to enhancing aquaculture output, offering a promising avenue for improving the industry's environmental footprint (Leong et al., 2023). Probiotics offer a promising solution by modulating the intestinal microbiota of aquatic species, thereby reducing pathogen adhesion and colonization (Amenyogbe, 2023). Unlike traditional methods that rely on chemical treatments and antibiotics, the use of probiotics provides a more environmentally friendly approach to managing aquatic environments and promoting the health of cultured species. By introducing beneficial bacteria into the gut, probiotics help establish a competitive environment that inhibits the growth and proliferation of harmful pathogens (Hong et al., 2004; Balczar et al., 2006; Aich et al., 2018; Vieco-Saiz et al., 2019). This shift toward sustainable practices is crucial for ensuring the long-term viability of aquaculture, as it addresses growing concerns about environmental degradation and the emergence of antimicrobial resistance (Lin et al., 2022). This modulation of the intestinal microbiota not only reduces the risk of disease outbreaks but also enhances the overall health and well-being of the cultured organisms. Probiotics are being explored as a means to improve disease resistance and overall health in cultured species, marking a significant step toward sustainable aquaculture (Doan et al., 2019). The ability of probiotics to promote a balanced and diverse gut microbiome is crucial for maintaining the health and productivity of aquaculture species. The benefits of probiotics extend beyond disease management, as they also enhance immunity, growth, and overall health in aquaculture species (Johar et al., 2024). Probiotics have been shown to stimulate the immune systems of aquatic organisms, increasing their resistance to various pathogens and environmental

stressors. Additionally, probiotics can improve nutrient absorption and utilization, leading to enhanced growth rates and feed efficiency. The overall effect of probiotic supplementation is a healthier and more robust population of aquaculture species, which translates into increased productivity and profitability for aquaculture operations. The multifaceted benefits of probiotics make them an invaluable tool for sustainable aquaculture practices.

Scope of this review

This review aims to provide a comprehensive overview of the potential of probiotics as a means of disease control in aquaculture, focusing on their effectiveness against key bacterial pathogens. We will explore the mechanisms of action of probiotics, including strengthening immune responses, competing for binding sites, producing antibacterial substances, and providing essential nutrients. Additionally, we will discuss the application of probiotics for controlling specific bacterial diseases caused by *Aeromonas hydrophila*, *Yersinia ruckeri*, *Lactococcus garvieae*, *Streptococcus agalactiae*, *Streptococcus dysgalactiae*, and *Streptococcus iniae* (Anjur et al., 2021; Thi et al., 2023; Jurez-Corts et al., 2024). *A. hydrophila* is a widespread bacterium that causes motile aeromonad septicemia (MAS) in various fish species, leading to significant economic losses. *Y. ruckeri* is the causative agent of enteric redmouth disease (ERM), a highly contagious disease that affects salmonid fish (Shoots Jr, 1990). *S. agalactiae* and *S. iniae* are major pathogens affecting tilapia and other aquaculture species, causing streptococcosis, a disease characterized by swollen eyes and hemorrhagic skin (Naz et al., 2020). *L. garvieae* is another significant fish pathogen, causing lactococcosis, which can lead to high mortality rates (Vendrell et al., 2006). *S. dysgalactiae* can also cause disease in fish. Understanding the specific probiotics that are effective against these pathogens is crucial for developing targeted disease management strategies (Commons et al., 2014). Probiotics can exert their protective effects through a variety of mechanisms, including competitive exclusion of pathogens, production of antimicrobial substances, enhancement of the immune response, and improvement of water quality. This review will explore these mechanisms in detail, providing insights into how probiotics can be used to promote the health and well-being of aquaculture species. By understanding the specific mechanisms of action of different probiotics, researchers and industry professionals can develop more effective and targeted disease management strategies.

Mechanisms of probiotic action

By enhancing the absorption of nutrients, probiotics promote growth and development, while their protective mechanisms safeguard against disease outbreaks. Specific probiotic strains demonstrate positive effects, such as siderophore and chitinase production, further enhancing their ability to control pathogens and promote health. Siderophores bind iron, limiting its availability to pathogens, while chitinase breaks down chitin, a major component of fungal cell walls and the exoskeletons of some parasites (Brunt *et al.*, 2007). Given the limitations and negative impacts of traditional disease control methods, alternative strategies such as the use of probiotics are gaining increasing attention in aquaculture (Parashuramappa, 2024). By fostering a healthy microbial environment in aquaculture systems, probiotics can help to prevent the proliferation of potential pathogens and reduce the incidence of disease outbreaks (Verschuere *et al.*, 2000). Probiotics, prebiotics, and synbiotics have emerged as promising supplements for controlling bacterial, viral, and parasitic infections in fish and shellfish (Aich *et al.*, 2018; Hoseinifar *et al.*, 2018). These supplements can enhance the immune response of aquatic animals, improve their resistance to disease, and promote overall health and well-being, thereby contributing to the sustainability and productivity of the aquaculture industry.

Strengthening immune response

Probiotics can enhance the immune response of aquatic animals, making them more resistant to infections (Hoseinifar *et al.*, 2018). This immunomodulatory effect involves the activation of various immune cells and the production of immune-related molecules. For instance, *Pediococcus pentosaceus* (SL001) has been shown to upregulate the expression of immunoglobulin M (IgM) and complement 3 (C3) in the liver, spleen, and head kidney of grass carp (Gong *et al.*, 2019). Similarly, probiotics can manipulate non-specific innate immunity in fish, helping them resist many pathogenic agents. Probiotics can stimulate the innate immune system of fish, enhancing their ability to resist pathogens (Ibrahim, 2013). This includes increasing lysozyme activity, phagocytic activity, and respiratory burst activity (Brunt *et al.*, 2007).

Production of inhibitory substances

Some probiotics produce substances that inhibit

the growth of pathogens, such as siderophores, chitinases, and bacteriocins (Brunt *et al.*, 2007; Gong *et al.*, 2019).

Competitive exclusion

Probiotics can compete with pathogens for nutrients and adhesion sites in the gut, preventing them from colonizing and causing disease.

Improved nutrition

Probiotics can enhance the digestion and absorption of nutrients, improving the overall health and resilience of fish (Brunt *et al.*, 2007).

Quorum sensing inhibition

Some probiotics can disrupt quorum sensing, a cell-to-cell communication system used by bacteria to coordinate virulence factor production (Zhou *et al.*, 2016; Omar *et al.*, 2023).

Competition for binding sites and nutrients

Probiotics can competitively exclude pathogens by competing for binding sites in the gut and for essential nutrients. By colonizing the gastrointestinal tract, probiotics can prevent pathogens from attaching to the intestinal lining and establishing an infection (Ring, 2020). Furthermore, probiotics can alter the gut microbiota composition, creating an environment that is less favorable for pathogens and more conducive to the growth of beneficial bacteria (Zhou *et al.*, 2016).

Production of antibacterial substances

Many probiotics produce antibacterial substances, such as bacteriocins, organic acids, and hydrogen peroxide, which can inhibit the growth of pathogens (Hoseinifar *et al.*, 2018). For example, *Bacillus siamensis* B44v produces a bacteriocin-like substance that exhibits broad-spectrum antibacterial activity against both Gram-positive and Gram-negative bacteria, including *A. hydrophila* and *S. agalactiae* (Meidong *et al.*, 2017). *Lactococcus lactis* RBT18 produces nisin Z, a bacteriocin with strong activity against *Lactococcus garvieae* and other ichthyopathogens (Contente *et al.*, 2020).

Nutritional benefits

Probiotics can improve the nutritional status of aquatic animals by enhancing digestion and nutrient

absorption. Some probiotics produce enzymes, such as amylase, protease, and lipase, which aid in the breakdown of complex carbohydrates, proteins, and fats, respectively (Dutta, 2015). This enhanced digestion can lead to improved growth performance and overall health.

Benefits beyond disease control

In addition to disease control, probiotics offer several other benefits in aquaculture. They can stimulate appetite and improve nutrition by producing vitamins, detoxifying compounds in the diet, and breaking down indigestible components (Irianto and Austin, 2002). Probiotics have also been reported to improve water quality, which confers indirect benefits to host health (Sarmah and Sarma, 2023). This can involve reducing levels of harmful bacteria and improving the overall microbial balance in the aquaculture system. Moreover, probiotics can enhance immune responses, improve feed value, and suppress harmful bacteria (Doan et al., 2019; Biswas et al., 2023). They can also increase tolerance to stress and encourage reproduction in aquatic organisms, contributing to improved productivity and sustainability of aquaculture operations. These diverse benefits make probiotics a valuable tool for enhancing the overall health and performance of aquatic animals in aquaculture.

A. hydrophila control with probiotics

Impact of A. hydrophila in aquaculture

A. hydrophila is a ubiquitous Gram-negative bacterium found in aquatic environments and is a major cause of motile aeromonad septicemia (MAS) in freshwater fish (Ran et al., 2012; Fidyandini et al., 2016; Ammar et al., 2023). This bacterium is commonly found in aquatic environments and can infect a wide range of fish species, including freshwater and marine fish. *A. hydrophila* is an opportunistic pathogen, meaning that it typically infects fish that are already stressed or immunocompromised. Factors such as poor water quality, overcrowding, and handling can increase the susceptibility of fish to *A. hydrophila* infections. The widespread distribution and broad host range of *A. hydrophila* make it a persistent threat to aquaculture operations. *A. hydrophila* infections can lead to significant economic losses in aquaculture due to increased mortality rates, reduced growth performance, and increased treatment costs (Chen et al., 2024). The infections caused by *A. hydrophila* can

manifest in various symptoms, including fin rot, tail rot, and septicaemic ulceration (Haniffa, 2015; Santhi and Deivasigamani, 2017). This bacterium is a significant threat to catfish farming, causing severe skin lesions and internal infections that can result in high mortality rates (Ran et al., 2012; Soliman et al., 2019; Chen et al., 2024). *A. hydrophila* is a significant cause of ulcerative disease in catfish, resulting in substantial economic losses for aquaculture operations (Sudrajat et al., 2023). These symptoms not only compromise the health and welfare of the fish but also lead to decreased growth rates, increased mortality, and reduced market value, highlighting the importance of effective control strategies to mitigate the impact of *A. hydrophila* in aquaculture. Proteases are enzymes that degrade proteins, allowing *A. hydrophila* to break down host tissues and facilitate its spread throughout the body. Hemolysins are toxins that damage red blood cells, leading to anemia and impaired oxygen transport. Other virulence factors produced by *A. hydrophila* include lipases, which degrade fats, and cytotoxins, which damage host cells. They can also stimulate the innate immune responses of the host, enhancing its ability to clear the infection. *A. hydrophila* is a widespread bacterium that causes disease in various fish species, making it a significant concern in aquaculture (Anjur et al., 2021; Hamka, 2021). The intensive nature of aquaculture practices, with high stocking densities and confined environments, exacerbates the spread and impact of *A. hydrophila*. Quorum sensing is a communication system used by bacteria to coordinate their behavior, including the production of virulence factors.

Probiotic strategies to combat A. hydrophila

B. siamensis strain B44v produced a bacteriocin-like substance that inhibited the growth of both Gram-positive and Gram-negative bacteria, including *A. hydrophila*. Bacteriocins are antimicrobial peptides that can kill or inhibit the growth of bacteria by disrupting their cell membranes or interfering with their metabolic processes. The production of bacteriocins by probiotics can provide a direct mechanism for controlling *A. hydrophila* infections in aquaculture. *Paenibacillus ehimensis* NPUST1 enhances innate immunity against *A. hydrophila* infections in zebrafish, improving their survival rate and overall health (Lin et al., 2022). Dietary supplementation with *P. ehimensis* NPUST1 significantly increased the expression of innate immune-related genes, such as interleukin (IL)-1, IL-6, IL-15, tumor necrosis factor, toll-like receptor (TLR)-1, TLR-4, complement component C3b, and lysozyme in zebrafish. These

immune factors play a crucial role in recognizing and eliminating pathogens, including *A. hydrophila*. The enhanced innate immunity conferred by *P. ehimensis* NPUST1 makes fish more resistant to *A. hydrophila* infections.

Immune modulation

Probiotics like *L. rhamnosus* enhance the immunity of fish, improving their ability to fight off *A. hydrophila* infections (Noshair *et al.*, 2023).

Quorum sensing inhibition

Bacillus sp. QSI-1 modulates quorum sensing, reducing the virulence of *A. hydrophila* (Zhou *et al.*, 2016).

Direct inhibition

Certain probiotics, such as *Bacillus* sp. YB1701, exhibit direct antimicrobial activity against *A. hydrophila*, inhibiting its growth (Zhou *et al.*, 2018). Moreover, some probiotics produce hydrolytic enzymes that can degrade the cell walls of *A. hydrophila*, further contributing to its inhibition (Kim *et al.*, 2017). These combined mechanisms of action make probiotics a promising strategy for controlling *A. hydrophila* infections in aquaculture. Probiotics can produce inhibitory substances, such as bacteriocins and organic acids, which directly inhibit the growth of *A. hydrophila* (Brunt *et al.*, 2007). MAS is a systemic disease that affects multiple organ systems, leading to rapid deterioration and death in infected fish that inhibits quorum sensing, offering a novel approach to disease control in aquaculture (Novita *et al.*, 2015).

Specific probiotic strains and their efficacy

B. amyloliquefaciens JFP2 shows antibacterial effect against *A. hydrophila*, making it a valuable probiotic for controlling this pathogen in aquaculture environments (Kim *et al.*, 2017). This strain produces a bacteriocin that inhibits the growth of *A. hydrophila*, reducing its ability to cause disease. *B. siamensis* B44v exhibits broad-spectrum antibacterial activity, inhibiting *A. hydrophila* and offering protection against a range of other bacterial pathogens (Meidong *et al.*, 2017). The broad-spectrum activity of *B. siamensis* B44v makes it a versatile probiotic for use in aquaculture systems where multiple pathogens may be present. *Bacillus* NP5 addition to feed increases growth rate and reduces tissue damage in catfish infected with *A. hydrophila*, improving the overall health and

productivity of catfish farming (Mustahal *et al.*, 2021). The addition of *Bacillus* NP5 to feed not only protects catfish from *A. hydrophila* infections but also promotes growth and reduces the severity of tissue damage caused by the pathogen. Several probiotic strains have demonstrated effectiveness in controlling *A. hydrophila* infections in aquaculture. *Bacillus* sp., in particular, have shown promise as effective probiotics for controlling infections caused by *A. hydrophila*. Several probiotics have demonstrated effectiveness in controlling *A. hydrophila* infections. *Bacillus* sp. JB1, isolated from the digestive tract of rainbow trout, has shown effectiveness as a probiotic for controlling infections caused by *A. hydrophila* (Brunt *et al.*, 2007). For instance, strains JB1 and GC2, equated with *Bacillus* sp. and *A. sobria*, respectively, have demonstrated effectiveness as probiotics for controlling infections caused by several bacterial pathogens, including *A. hydrophila*. *Pediococcus pentosaceus* (SL001) has also been found to exhibit a wide antimicrobial spectrum against *A. hydrophila*, making it a potential probiotic candidate (Gong *et al.*, 2019). Furthermore, *L. lactis* KUST48 has been shown to have a positive impact on the transcription profile of *A. hydrophila*-infected zebrafish spleen, suggesting its potential as a probiotic for combating *A. hydrophila* infections. The probiotics increased total erythrocytes, hemoglobin, hematocrit, total leukocytes, phagocytic activity, and lysozyme activity. This study highlights the potential of using a combination of probiotics to control *A. hydrophila* infections in aquaculture. *L. lactis* strains have shown inhibitory effects on *A. hydrophila* growth, suggesting their potential as probiotics in aquaculture (Chen *et al.*, 2024). *Bacillus* species have demonstrated antagonistic activity against *A. hydrophila*, making them promising candidates for probiotic applications in aquaculture. The probiotic treatment also led to changes in the expression of immune-related genes in the spleen of zebrafish, indicating that *L. lactis* can modulate the immune response to combat *A. hydrophila* infections. These findings suggest that *L. lactis* strains could be used as a natural alternative to antibiotics for controlling *A. hydrophila* in aquaculture. Several *Bacillus* strains have demonstrated antagonistic activity against *A. hydrophila* (Ran *et al.*, 2012). *Bacillus* species are Gram-positive, spore-forming bacteria that are commonly found in soil and aquatic environments. Some *Bacillus* species produce antimicrobial substances, such as bacteriocins, that can inhibit the growth of *A. hydrophila*. Additionally, *Bacillus* species can compete with *A. hydrophila* for nutrients and adhesion sites, limiting its colonization of the gut. The ability of *Bacillus* species to form spores allows them

to survive harsh environmental conditions, making them well-suited for use as probiotics in aquaculture. *B. megaterium* PTB 1.4 and *P. pentosaceus* E2211 can suppress the growth of *A. hydrophila*, improving the health status and survival rate of catfish during challenge tests (Hamka, 2021). Hamka (2021) found that the administration of these probiotics at a dose of 0.5% could effectively reduce the population of *A. hydrophila* in the gut of catfish and enhance their immune response. Chen *et al.* (2024) found that *L. lactis* KUST48 had a bacteriostatic effect against *A. hydrophila* and could improve the survival rate of zebrafish infected with *A. hydrophila*. For instance, *Bacillus* sp. QSI-1 can modulate quorum sensing signals, reducing *A. hydrophila* levels in the fish gut (Zhou *et al.*, 2016). Probiotics have shown promise in controlling *A. hydrophila* infections by various mechanisms. For example, *B. megaterium* PTB 1.4 and *P. pentosaceus* E2211, when administered at a dose of 0.5%, can suppress the growth of *A. hydrophila* and improve the health status of catfish (*Clarias* sp.). Similarly, *L. rhamnosus* has been shown to improve growth performance and increase disease resistance against *A. hydrophila* in *Oreochromis niloticus* fingerlings (Noshair *et al.*, 2023). For example, *Paenibacillus ehimensis* NPUST1 enhances the expression of immune-related genes, leading to reduced mortality in zebrafish infected with *A. hydrophila* (Lin *et al.*, 2022). *Moina micrura* enriched with *B. pocheonensis* significantly enhances the survival of red hybrid tilapia larvae after challenge with *A. hydrophila* (Samat *et al.*, 2021). Dietary supplementation with *Bacillus* sp. YB1701 significantly improved the resistance of *Carassius auratus* gibelio to *A. hydrophila* challenge (Zhou *et al.*, 2018). *Bacillus* sp. JB1; *P. pentosaceus* SL001; *P. ehimensis* NPUST1; *Klebsiella* sp. CPi12 Reduced mortalities; enhanced immunity; improved nutrient metabolism; decreased AHL production (Omar *et al.*, 2023). *A. hydrophila* is a ubiquitous bacterium that can cause motile aeromonad septicemia (MAS) in a wide range of fish species (Anjur *et al.*, 2021).

***Yersinia ruckeri* management using probiotics**

Significance of *Y. ruckeri* in fish diseases

Y. ruckeri is a Gram-negative bacterium that causes enteric redmouth disease (ERM), a highly contagious and often fatal infection that affects a wide range of fish species, including trout, salmon, and other commercially important fish a systemic infection affecting salmonid fish. The disease can lead to

reduced growth rates, decreased feed efficiency, and increased susceptibility to secondary infections, resulting in substantial economic losses for fish farmers. Infected fish may exhibit a variety of clinical signs, including lethargy, anorexia, and abnormal swimming behavior. This bacterium is a Gram-negative, rod-shaped organism that can cause significant morbidity and mortality in farmed salmonid populations. ERM is characterized by inflammation and hemorrhaging of the mouth, throat, and fins, as well as internal organ damage. Additionally, *Y. ruckeri* can cause immunosuppression in fish, further compromising their health and increasing their vulnerability to other pathogens (Apkn and Altnok, 2009; Marukov *et al.*, 2021; Rasmussen *et al.*, 2022). *Y. ruckeri* affects multiple fish species, posing a significant threat to aquaculture operations worldwide (Brunt *et al.*, 2007). It causes significant mortality and economic losses in aquaculture, making its control essential for maintaining sustainable fish production (Aich *et al.*, 2018). ERM is characterized by inflammation and hemorrhaging in the mouth, throat, and internal organs of infected fish, leading to high mortality rates and substantial economic losses for aquaculture farmers. Control of *Y. ruckeri* is essential for maintaining fish health and productivity, ensuring the long-term viability of aquaculture operations (Ran *et al.*, 2012). The mortality rate associated with ERM outbreaks can range from 10% to 50%, depending on the age and health status of the fish, as well as the environmental conditions. The economic losses associated with ERM outbreaks include reduced growth performance, increased treatment costs, and decreased market value of infected fish. Controlling *Y. ruckeri* is crucial for sustainable aquaculture practices, ensuring the health and productivity of farmed salmonid populations (Len *et al.*, 2016). Traditional methods for controlling ERM include the use of antibiotics and vaccines. However, the overuse of antibiotics can contribute to the development of antibiotic-resistant bacteria, while vaccines may not be effective against all strains of *Y. ruckeri*.

Probiotics as a control measure

Bacillus sp. shows antagonism against *Y. ruckeri*, reducing its impact and offering a natural alternative to traditional antibiotic treatments. Certain *Streptomyces* strains exhibit antimicrobial activity against *Y. ruckeri*, suggesting their potential as probiotics in aquaculture. *B. subtilis* has also shown potential to mediate disease resistance as a probiotic additive in aquaculture, offering a natural and

sustainable approach to disease management. Dietary supplementation with these probiotics significantly increased the survival rate of rainbow trout following challenge with *Y. ruckeri* and *Bacillus* sp. Some *Bacillus* strains have demonstrated antagonistic activity against *Y. ruckeri*. *Bacillus* sp. have shown antagonistic effects against *Y. ruckeri*, making them promising candidates for probiotic applications in aquaculture (Ran *et al.*, 2012). These probiotic strains produce antibacterial substances and compete with *Y. ruckeri* for nutrients, inhibiting its growth and colonization in the fish gut. Probiotics can stimulate the innate immune responses, helping fish resist *Y. ruckeri* infections and enhancing their overall health. By activating the immune system, probiotics enable fish to defend themselves better against *Y. ruckeri* and other pathogens. The addition of probiotics to fish feed enhances their ability to withstand *Y. ruckeri* infections and improves their chances of survival. Several probiotic strains have demonstrated efficacy in controlling *Y. ruckeri* infections in aquaculture. *Bacillus* sp., in particular, have shown promise as effective probiotics for controlling infections caused by *Y. ruckeri*. For instance, *Bacillus* sp. JB1 and GC2, isolated from the digestive tract of rainbow trout (*Oncorhynchus mykiss*), led to a reduction in mortalities after challenge with *Y. ruckeri*. The mode of action involves nutrition, production of inhibitory substances, and stimulation of innate immune responses (Brunt *et al.*, 2007). Furthermore, *L. plantarum* R2 Biocenol (CCM 8674) has been shown to reduce inflammation after an *A. salmonicida* infection, suggesting its potential for mitigating the effects of *Y. ruckeri* infections as well (Marukov *et al.*, 2021). Certain *Streptomyces* strains exhibit antimicrobial activity against *Y. ruckeri*, suggesting their potential as probiotics in aquaculture (Len *et al.*, 2016). *St. variabilis*, *St. labedae*, and *St. rochei*, isolated from *Argopecten purpuratus*, showed broad-spectrum antimicrobial activity against *Y. ruckeri*. *Streptomyces* sp. are Gram-positive, filamentous bacteria that are commonly found in soil and aquatic environments. Some *Streptomyces* sp. produce a variety of antimicrobial compounds, including antibiotics and bacteriocins, that can inhibit the growth of *Y. ruckeri*. Ran *et al.* (2012) found that several *Bacillus* strains isolated from soil or channel catfish intestine exhibited antagonistic activity against *Y. ruckeri*. *Bacillus* sp. can compete with *Y. ruckeri* for nutrients and adhesion sites, limiting its colonization of the gut. Additionally, *Bacillus* sp. can produce antimicrobial substances that inhibit the growth of *Y. ruckeri*. Probiotics can serve as a biological control agent to reduce the impact of *Y. ruckeri* on aquaculture species, providing a natural and

sustainable approach for disease management (Verschuere *et al.*, 2000). Verschuere *et al.* (2000) proposed that probiotics can be used as a biological control strategy to prevent disease outbreaks in aquaculture. Probiotics can enhance the immune response of fish, making them more resistant to *Y. ruckeri* infections. Additionally, probiotics can improve water quality, reducing the stress on fish and making them less susceptible to disease. *E. cloacae* and *B. mojavensis*, isolated from the rainbow trout gut, have shown antagonistic effects against *Y. ruckeri*. *E. cloacae* and *B. mojavensis*, isolated from the rainbow trout gut, also exhibit antagonistic effects against *Y. ruckeri*, increasing the survival rate of fish challenged with the pathogen (Apkn and Altonk, 2009).

Mode of action and protective mechanisms

Inhibition of *Y. ruckeri* involves the production of inhibitory substances by probiotics, directly targeting the pathogen and reducing its ability to cause disease. This competition for resources weakens *Y. ruckeri* and makes it more susceptible to the fish's immune system. Enhanced immune responses, including increased lysozyme and phagocytic activity, contribute to protection against *Y. ruckeri* infections, improving the fish's ability to fight off the pathogen (Brunt *et al.*, 2007). These substances, such as bacteriocins and organic acids, inhibit the growth and virulence of *Y. ruckeri*, preventing it from colonizing and infecting the fish. Probiotics compete with *Y. ruckeri* for nutrients and adhesion sites in the intestinal tract, limiting its access to essential resources and reducing its ability to establish an infection. Probiotics can colonize the gut and outcompete *Y. ruckeri* for essential nutrients, such as sugars and amino acids. Additionally, probiotics can adhere to the intestinal lining, preventing *Y. ruckeri* from attaching and colonizing the gut. This competitive exclusion mechanism can effectively reduce the population of *Y. ruckeri* in the gut and prevent it from causing disease. Probiotics can enhance the immune response in fish, increasing resistance to *Y. ruckeri* infections and improving overall health (Hoseinifar *et al.*, 2018). Lysozyme is an enzyme that breaks down bacterial cell walls, while phagocytic cells engulf and destroy pathogens, both contributing to the elimination of *Y. ruckeri*. Probiotics can modulate the immune system of fish, enhancing their ability to resist *Y. ruckeri* infections. Probiotics induce immune responses in the host, which are associated with changes in the gut microbiota. By strengthening the resilience and promoting recovery in fish challenged with *Y. ruckeri*, probiotics offer a valuable tool for managing this disease in aquaculture

(Rasmussen *et al.*, 2022). These changes can lead to increased production of immune cells, antibodies, and other immune factors, resulting in improved disease resistance. Additionally, probiotics can upregulate pro-inflammatory cytokines and suppress anti-inflammatory cytokines, helping to mount an effective immune response against *Y. ruckeri* (Marukov *et al.*, 2021). Probiotics can produce inhibitory compounds that target *Y. ruckeri*, disrupting its growth and virulence. These inhibitory compounds include bacteriocins, organic acids, and other antimicrobial substances that can kill or inhibit the growth of *Y. ruckeri*. Bacteriocins are antimicrobial peptides that can disrupt the cell membranes of bacteria, leading to cell death. Organic acids, such as lactic acid and acetic acid, can lower the pH of the environment, inhibiting the growth of *Y. ruckeri*. They compete with *Y. ruckeri* for nutrients and adhesion sites, limiting its colonization of the gut and reducing its ability to cause disease (Verschuere *et al.*, 2000). Probiotics can stimulate the immune system by activating immune cells, such as macrophages and lymphocytes, and increasing the production of antibodies and cytokines. This enhanced immune response can help fish clear *Y. ruckeri* infections more effectively and prevent future outbreaks. Additionally, probiotics can improve the overall health and well-being of fish, making them more resilient to disease. *E. cloacae* and *B. mojavensis* produce substances that directly inhibit the growth of *Y. ruckeri* (Apkn and Altok, 2009). Probiotics can stimulate the immune systems of fish, making them more resistant to *Y. ruckeri* infections (Gatesoupe, 2007).

***Lactococcus garvieae* prevention with probiotics**

Importance of *L. garvieae* in aquaculture

L. garvieae is a major Gram-positive bacterium causing lactococcosis in fish, leading to significant economic losses in aquaculture operations worldwide (Contente *et al.*, 2020; Mawardi *et al.*, 2023). This bacterium is responsible for outbreaks of disease in a variety of fish species, including rainbow trout, yellowtail, and tilapia. Lactococcosis is characterized by septicemia, inflammation, and hemorrhaging in infected fish, leading to high mortality rates and substantial economic losses for aquaculture farmers. Effective control strategies are needed to mitigate the impact of *L. garvieae* in aquaculture, safeguard fish health, and minimize economic losses (Hoseinifar *et al.*, 2018). Infections with *L. garvieae* can result in severe economic losses due to reduced growth rates,

increased mortality, and decreased market value of the affected fish. The bacterium is known to cause lactococcosis, a systemic disease characterized by symptoms such as lethargy, anorexia, exophthalmia, and hemorrhages, making it a significant concern in aquaculture (Soltani *et al.*, 2023). These strategies include vaccination, antibiotic treatment, and the use of probiotics. This bacterium is a bacterial pathogen that causes disease in rainbow trout, leading to mortalities in aquaculture systems (Brunt *et al.*, 2007). Outbreaks of *L. garvieae* can decimate fish populations, resulting in significant financial strain on aquaculture operations. The cost of antibiotics and other treatments, combined with the loss of marketable fish, makes lactococcosis a major economic challenge. Controlling *L. garvieae* is essential for maintaining fish health and ensuring the sustainability of aquaculture operations. Effective management strategies are needed to minimize the impact of this pathogen and prevent future outbreaks. These strategies include improving biosecurity measures, optimizing environmental conditions, and exploring alternative treatments such as probiotics. Controlling *L. garvieae* is essential for maintaining fish health and ensuring the sustainability of aquaculture operations (Gatesoupe, 2007).

Probiotic interventions for *L. garvieae*

Specific *Bacillus* strains demonstrate effectiveness as probiotics for controlling *L. garvieae* infections, offering a natural alternative to traditional antibiotic treatments. These probiotic strains produce antibacterial substances and stimulate the immune system, inhibiting the growth and colonization of *L. garvieae* in the fish gut. Probiotics enhance nutrition and stimulate innate immune responses to combat *L. garvieae*, improving the overall health and resistance of fish to infection. Prebiotics are non-digestible food ingredients that promote the growth and activity of beneficial bacteria in the gut, further strengthening the fish's defenses against *L. garvieae*. Several probiotic strains have demonstrated activity against *L. garvieae*, offering potential solutions for disease management in aquaculture. *Bacillus* sp. have been identified as effective probiotics for controlling infections caused by *L. garvieae*, providing a natural and sustainable approach to disease prevention (Brunt *et al.*, 2007). By enhancing nutrient absorption and activating the immune system, probiotics enable fish to defend themselves better against *L. garvieae* and other pathogens. Dietary applications of probiotics can be combined with prebiotics for improved disease control, creating a synergistic effect that enhances the

benefits of both (Gatesoupe, 2007). Interestingly, *L. garvieae* itself can be used as a probiotic to enhance tilapia growth and resistance against other pathogens (Mawardi *et al.*, 2023). This approach leverages the beneficial properties of specific *L. garvieae* strains to promote fish health and improve overall productivity. Additionally, *Actinomycetes* strains isolated from *Argopecten purpuratus* have shown antimicrobial activity against *L. garvieae*, suggesting their potential as probiotic candidates for disease control. *Streptomyces* strains exhibit antimicrobial activity against *L. garvieae*, suggesting their use as probiotics. *St. variabilis*, *St. labedae*, and *St. rochei* showed broad-spectrum antimicrobial activity against *L. garvieae*. (Len *et al.*, 2016). Certain *Bacillus* strains have demonstrated antagonistic effects against *L. garvieae*, indicating their potential as probiotic agents in aquaculture. Amoah *et al.* (2021) found that *B. tequilensis* GPSAK2, *B. velezensis* GPSAK4, and *B. subtilis* GPSAK9 exhibited good antimicrobial activity against *L. garvieae*. *Bacillus* sp. are known for their ability to produce a variety of antimicrobial compounds, making them effective in controlling bacterial pathogens in aquaculture. Certain *Bacillus* strains have demonstrated antagonistic effects against *L. garvieae*, making them potential candidates for probiotic applications in aquaculture (Amoah *et al.*, 2021). *L. lactis* RBT18 produces nisin Z, which directly inhibits the growth of *L. garvieae* (Contente *et al.*, 2020). Probiotics can compete with *L. garvieae* for nutrients and binding sites in the gut, preventing its colonization (Knipe *et al.*, 2020).

Efficacy and application of probiotics

Administering probiotics in feed reduces mortalities after challenge with *L. garvieae*, demonstrating the effectiveness of this approach for managing lactococcosis in aquaculture (Brunt *et al.*, 2007). The addition of probiotics to fish feed enhances their ability to withstand *L. garvieae* infections and improves their chances of survival. Probiotics manipulate non-specific innate immunity, helping fish resist *L. garvieae* and other pathogens by activating their natural defenses (Ibrahim, 2013). This manipulation of the immune system enables fish to better recognize and respond to *L. garvieae* infections. *L. garvieae* can be controlled by *Limosilactobacillus fermentum* GMNL-93, *Lactiplantibacillus plantarum* GMNL-141, *Lactocaseibacillus casei* GMNL-277, and *Bifidobacterium lactis* GMNL-550, offering a combination of probiotic strains for effective disease management (Wang *et al.*, 2023). These strains have been shown to inhibit the growth of *L. garvieae* and

improve the health and resistance of fish to infection. The mechanisms by which probiotics protect against *L. garvieae* infections are diverse and multifaceted. Probiotics enhance growth and resistance against *S. agalactiae* infection, improving the overall health and performance of the fish. *L. garvieae*, *Bacillus* sp. JB1; *P. pentosaceus* SL001; *L. garvieae* reduced mortalities and enhanced immunity (Mawardi *et al.*, 2023). They produce antibacterial substances toward different potential fish pathogenic bacteria, directly inhibiting the growth and proliferation of *L. garvieae* (Ring, 2020). Furthermore, probiotics compete with pathogens for nutrients and adhesion sites, preventing the colonization of *L. garvieae* in the gut, and improving the immune response of the host, enhancing its ability to clear the infection (Sumon *et al.*, 2022). These combined mechanisms of action make probiotics a valuable tool for managing *L. garvieae* infections in aquaculture. Probiotics can produce antibacterial substances that inhibit *L. garvieae* growth, providing a direct mechanism of control (Amoah *et al.*, 2021). These substances, such as bacteriocins, disrupt the cell membranes or interfere with the metabolic processes of the pathogen. The production of these antibacterial compounds can effectively reduce the population of *L. garvieae* in the gut and prevent it from causing disease. They compete for nutrients and adhesion sites, limiting *L. garvieae*'s colonization and proliferation within the host (Jlidi *et al.*, 2021). By colonizing the gut and outcompeting *L. garvieae* for essential resources, probiotics can prevent the pathogen from attaching to the intestinal lining and establishing a foothold. This competitive exclusion mechanism is a key factor in the ability of probiotics to control bacterial infections. Probiotics enhance the immune response, increasing resistance to *L. garvieae* infections by stimulating the production of antibodies and immune cells. Probiotics enhance the immune response, increasing resistance to *L. garvieae* infections and improving overall fish health (Hoseinifar *et al.*, 2018). This enhanced immune response enables the fish to clear *L. garvieae* infections more effectively and prevent future outbreaks. Probiotics can activate immune cells, such as macrophages and lymphocytes, and increase the production of cytokines, which are signaling molecules that help to coordinate the immune response. Probiotics produce antibacterial substances that inhibit *L. garvieae* growth, reducing its ability to colonize and infect fish. Certain *Bacillus* strains have shown inhibitory effects against *L. garvieae* (Amoah *et al.*, 2021). *Lactococcus lactis* RBT18, isolated from cultured rainbow trout, exerts strong, direct, extracellular activity against *L. garvieae* due to the

production of nisin Z (Contente *et al.*, 2020). *L. rhamnosus* supplementation has been found to enhance growth and improve the immunity of *Oreochromis niloticus* against *A. hydrophila* (Noshair *et al.*, 2023).

***Streptococcus agalactiae* mitigation strategies**

Impact of *S. agalactiae* in fish farming

S. agalactiae is a primary cause of streptococcosis in tilapia, leading to substantial losses in aquaculture operations and posing a significant threat to the industry (Sudrajat *et al.*, 2023). This bacterium is responsible for outbreaks of disease in tilapia farms worldwide, causing high mortality rates and significant economic losses. This pathogen is commonly found in freshwater systems, posing a continuous threat to aquaculture and requiring ongoing monitoring and management efforts (Nafiqoh *et al.*, 2021). This bacterium, also known as Group B *Streptococcus* (GBS), is a Gram-positive coccus that can cause severe infections in a wide range of fish species, including tilapia, hybrid striped bass, and red drum. *S. agalactiae* infections are particularly problematic in tilapia aquaculture, where they can lead to high mortality rates and substantial economic losses. Streptococcosis leads to significant economic losses in various aquaculture systems due to increased mortality rates, reduced growth performance, and increased treatment costs (Munangandu *et al.*, 2016). These clinical signs are caused by the bacterium's ability to invade and damage host tissues, leading to inflammation and hemorrhaging. In addition to swollen eyes and hemorrhagic skin, infected fish may also exhibit other clinical signs, such as erratic swimming behavior, fin rot, and internal organ damage. Early detection of these clinical signs is crucial for implementing effective disease management strategies and minimizing economic losses. *L. lactis* strains have demonstrated antibacterial activity against *S. agalactiae*, making them potential candidates for probiotic use in tilapia farming (Tan *et al.*, 2022; Chen *et al.*, 2024). *B. siamensis* B44v exhibits broad-spectrum antibacterial activity, inhibiting the growth of *S. agalactiae* and providing a natural means of disease control (Meidong *et al.*, 2017). Combinations of *Lysinibacillus fusiformis* SPS11, *B. amyloliquefaciens* L9, and *E. hirae* LAB3 have also shown inhibitory effects, suggesting that mixed probiotics can be highly effective (Zabidi *et al.*, 2021). *S. agalactiae* is a significant bacterial pathogen that causes streptococcosis, a disease affecting various fish

species, including tilapia (Mawardi *et al.*, 2023). *S. agalactiae* infections can lead to significant economic losses in tilapia aquaculture due to mortality and reduced market value. Protrusion of the eyes (exophthalmia) is a common symptom in fish infected with *S. agalactiae* (Klingklib and Suanyuk, 2017) and other bacterial pathogens. *S. agalactiae* is a Gram-positive bacterium that causes streptococcosis, a major disease affecting tilapia and other warmwater fish species (Meidong *et al.*, 2017; Samat *et al.*, 2021; Zabidi *et al.*, 2021; Mawardi *et al.*, 2023). Infected fish may exhibit a variety of clinical signs, including lethargy, anorexia, swollen eyes, and hemorrhagic skin lesions. The severity of the infection can vary depending on the virulence of the *S. agalactiae* strain, the health status of the fish, and the environmental conditions. In severe cases, *S. agalactiae* infections can result in mortality rates of up to 100%, leading to devastating economic losses for aquaculture farmers. The disease is characterized by swollen eyes and hemorrhagic skin, making it easily identifiable in infected fish populations (Thi *et al.*, 2023). *S. agalactiae* can persist in the environment and infect fish through various routes, including water, feed, and direct contact with infected individuals. Disease outbreaks caused by *S. agalactiae* necessitate effective prevention and control measures, requiring a comprehensive approach that includes biosecurity, vaccination, and the use of probiotics (Hoseinifar *et al.*, 2018). These measures are essential for minimizing the impact of *S. agalactiae* on tilapia farms and ensuring the sustainability of aquaculture operations. *S. agalactiae* is a Gram-positive bacterium that has emerged as a major threat in aquaculture, particularly affecting tilapia and other warm-water fish species. This bacterium is a main problem in tilapia culture, causing streptococcosis, a severe disease characterized by symptoms such as lethargy, erratic swimming, exophthalmia, and hemorrhages. The bacterium can be found in the brain, kidney, liver, and eyes of infected fish, indicating its systemic nature and ability to cause widespread damage (Widanarni and Tanbiyaskur, 2015). *S. agalactiae* poses a serious threat to tilapia populations, leading to significant economic losses for fish farmers (Mawardi *et al.*, 2023). *S. agalactiae* is a major pathogen affecting tilapia production, causing mass mortality and significant economic losses in aquaculture systems (Zabidi *et al.*, 2021).

Probiotic approaches for *S. agalactiae* control

Bacillus sp. NP5 paraprobiotic administration improves growth performance, immune response, and resistance against *S. agalactiae*, offering a promising

strategy for managing streptococcosis in tilapia. Probiotic administration has been shown to improve the resistance of Nile tilapia to *S. agalactiae* infection. *Bacillus* sp. NP5, administered as a paraprobiotic (heat-inactivated), significantly improved growth performance and immune responses in Nile tilapia, leading to higher survival rates after challenge with *S. agalactiae* (Mulyadin *et al.*, 2021). Paraprobiotics, which are inactivated microbial cells or cell components, can stimulate the immune system and protect against pathogens without the risk of live bacteria causing infection. A combination of betel and kipahit extracts enhances the immune system, providing an alternative prevention measure against *S. agalactiae* and reducing the reliance on antibiotics (Nafiqoh *et al.*, 2021). *M. micrura* is a small crustacean that is commonly used as live feed for fish larvae, and enriching it with *B. pocheonensis* provides a natural and effective way to deliver probiotics to young fish. *L. lactis* strains have demonstrated antibacterial activity against *S. agalactiae*, suggesting their potential as probiotics in aquaculture (Tan *et al.*, 2022; Chen *et al.*, 2024). Tan *et al.* (2022) found that *L. lactis* KUST48 had a bacteriostatic effect against *S. agalactiae* and could improve the survival rate of zebrafish infected with *S. agalactiae*. Additionally, Chen *et al.* (2024) found that *L. lactis* strains can modulate the immune response and reduce the relative abundance of *S. agalactiae* in the gut. *L. lactis* is a Gram-positive bacterium that is commonly used in the food industry for the production of cheese and yogurt. Some *L. lactis* strains produce antimicrobial substances, such as bacteriocins, that can inhibit the growth of *S. agalactiae*. *B. siamensis* B44v exhibits broad-spectrum antibacterial activity, inhibiting *S. agalactiae* and other pathogenic bacteria in aquaculture systems (Meidong *et al.*, 2017). *B. siamensis* B44v produced a bacteriocin-like substance that inhibited the growth of both Gram-positive and Gram-negative bacteria, including *S. agalactiae*. *B. siamensis* is a Gram-positive, spore-forming bacterium that is commonly found in soil and aquatic environments. The ability of *B. siamensis* to form spores allows it to survive harsh environmental conditions, making it well-suited for use as a probiotic in aquaculture. *L. fusiformis* SPS11, *B. amyloliquefaciens* L9, and *E. hirae* LAB3 show inhibitory effects against *S. agalactiae*, improving the growth performance and disease resistance of red hybrid tilapia. A combination of *L. fusiformis* SPS11, *B. amyloliquefaciens* L9, and *E. hirae* LAB3 in a biofloc system improved growth, survival rates, and reduced nitrogen concentration in red hybrid tilapia challenged with *S. agalactiae* (Zabidi *et al.*, 2021). A mixed probiotic containing these three strains was able to inhibit the growth of *S. agalactiae*

and *S. iniae* significantly compared to single and commercial probiotics. The probiotic mix also improved the specific growth rate and feed conversion ratio of tilapia, as well as their survival rate after being challenged with *S. agalactiae*. These findings suggest that a combination of probiotics can provide synergistic benefits for controlling streptococcosis in aquaculture. *S. agalactiae* is a major pathogen affecting tilapia and other aquaculture species, causing significant economic losses (Mawardi *et al.*, 2023; Taukhid *et al.*, 2023). Similarly, *M. micrura* enriched with *B. pocheonensis* has shown promise in enhancing survival and disease resistance of red hybrid tilapia larvae against *S. agalactiae*. These plant extracts contain bioactive compounds that stimulate the immune system and improve the resistance of tilapia to *S. agalactiae* infections. *M. micrura* enriched with *B. pocheonensis* enhances the survival and disease resistance of tilapia larvae against *S. agalactiae*, demonstrating the potential of this approach for protecting early life stages of fish (Samat *et al.*, 2021).

Specific probiotic effects and mechanisms

Probiotics improve immune parameters, such as phagocytic activity and respiratory burst in fish, enhancing their ability to fight off *S. agalactiae* infections. Phagocytic cells engulf and destroy pathogens, while respiratory burst produces reactive oxygen species that kill bacteria, both contributing to the elimination of *S. agalactiae*. Dietary supplementation with probiotics increases survival rates after challenge with *S. agalactiae*, demonstrating the effectiveness of this approach for managing streptococcosis in tilapia (Wu *et al.*, 2021). The addition of probiotics to fish feed enhances their ability to withstand *S. agalactiae* infections and improves their chances of survival. *L. fusiformis* SPS11, *B. amyloliquefaciens* L9, and *E. hirae* LAB3 inhibit *S. agalactiae* significantly, offering a combination of probiotic strains for effective disease management in aquaculture (Zabidi *et al.*, 2021). These strains have been shown to inhibit the growth of *S. agalactiae* and improve the health and resistance of fish to infection. Several probiotic strains have demonstrated effectiveness against *S. agalactiae*, offering potential solutions for disease management in aquaculture. *B. subtilis* can be used as a probiotic to evaluate its effect on microbiological and haematological responsiveness, providing valuable insights into its mechanisms of action (Haniffa, 2015). *L. rhamnosus* has a broad range of antimicrobial activity against *S. agalactiae*, making it a promising candidate for probiotic applications (Pirarat *et al.*, 2009). Additionally, *L. fusiformis* SPS11

and *B. amyloliquefaciens* L11 have shown antagonism to *S. agalactiae*, suggesting their potential as probiotic components in multi-strain formulations (Puvanendram et al., 2022). Probiotics can produce bacteriocins that inhibit the growth of *S. agalactiae*, providing a direct mechanism for controlling the pathogen. *B. siamensis* B44v, isolated from Thai pickled vegetables, exhibits broad-spectrum antibacterial activity, inhibiting *S. agalactiae* (Meidong et al., 2017). Bacteriocins are antimicrobial peptides that can kill or inhibit the growth of bacteria by disrupting their cell membranes or interfering with their metabolic processes. Some probiotics, such as *B. siamensis* B44v, produce bacteriocin-like substances that are effective against a wide range of bacteria, including *S. agalactiae*. The production of bacteriocins by probiotics can help to reduce the population of *S. agalactiae* in the gut and prevent it from causing disease. They enhance the immune response, improving survival rates in infected fish by stimulating the production of antibodies and immune cells. They enhance the immune response in fish, improving survival rates in infected populations and minimizing economic losses). Mixed probiotics (*L. fusiformis* SPS11, *B. amyloliquefaciens* L9, *E. hirae* LAB3 have shown the ability to inhibit *S. agalactiae* significantly and improve survival rates in red hybrid tilapia (Zabidi et al., 2021). Probiotics can activate immune cells, such as macrophages and lymphocytes, and increase the production of antibodies and cytokines. This enhanced immune response can help fish to clear *S. agalactiae* infections more effectively and prevent future outbreaks. *L. lactis* can balance intestinal microbiota, reducing the relative abundance of *S. agalactiae* and promoting a healthier gut environment (Tan et al., 2022). Tan et al. (2022) found that *L. lactis* KUST48 could increase the relative abundance of beneficial bacteria in the gut of zebrafish and decrease the relative abundance of *S. agalactiae*. This modulation of the gut microbiota can help to prevent *S. agalactiae* from colonizing the gut and causing disease. Additionally, a balanced gut microbiota can improve nutrient absorption and utilization, leading to enhanced growth performance and overall health. Probiotics produce bacteriocins that inhibit the growth of *S. agalactiae*, thus reducing its ability to cause disease (Meidong et al., 2017). *L. lactis* can help balance the intestinal microbiota, reducing the relative abundance of *S. agalactiae* and preventing its proliferation (Tan et al., 2022). Some *Bacillus* strains have demonstrated inhibitory effects against *S. agalactiae* (Amoah et al., 2021). *M. micrura* enriched with *B. pocheonensis* significantly enhances the survival of red hybrid tilapia larvae after challenge

with *S. agalactiae* (Samat et al., 2021) *M. micrura* enriched with *B. pocheonensis* has been shown to enhance survival and disease resistance of red hybrid tilapia larvae against *S. agalactiae* (Samat et al., 2021).

Probiotic mechanisms in combating *S. agalactiae*

Probiotics employ various mechanisms to combat *S. agalactiae* infections in aquaculture. Probiotics improve survival rates and reduce damage levels in target organs, enhancing the overall health and performance of the infected fish (Widanarni, 2015). They inhibit the growth of pathogenic strains, reducing the bacterial load and severity of the infection, and enhance immune parameters, boosting the host's ability to fight off the pathogen (Lin, 2022). Furthermore, probiotics can improve growth, immunity, and disease resistance in fish, contributing to the long-term health and sustainability of aquaculture operations (Sumon et al., 2022). *B. siamensis* B44v produces a bacteriocin-like substance that directly inhibits the growth of *S. agalactiae* (Meidong et al., 2017). Probiotics can enhance the immune response of fish, improving their ability to fight off *S. agalactiae* infections (Simn et al., 2021). Probiotics can compete with *S. agalactiae* for nutrients and binding sites in the gut, preventing its colonization (Knipe et al., 2020).

Streptococcus dysgalactiae management in aquaculture

Significance of *S. dysgalactiae*

Given its pathogenic potential in other animal species, it is plausible that *S. dysgalactiae* could also pose a threat to fish health and productivity. *S. dysgalactiae* affects aquatic animals, causing disease outbreaks and economic losses in aquaculture operations, although its impact may be less well-documented compared to another streptococcal species (Phasunon et al., 2023). This bacterium can cause a variety of infections in fish, including septicemia, meningitis, and skin lesions. Effective management strategies are needed to control infections caused by this pathogen, safeguarding fish health and minimizing economic losses. These strategies may include biosecurity measures, vaccination, and the use of probiotics. Understanding its impact is vital for maintaining fish health and aquaculture productivity, ensuring the sustainability of aquaculture operations (Hoseinifar et al., 2018). While

the documents provided do not specifically mention *S. dysgalactiae*, it is a bacterium closely related to other *Streptococcus* sp. known to affect fish. As a *Streptococcus* sp., it can be inferred that *S. dysgalactiae* may cause similar infections and mortalities in aquaculture settings. However, further research is needed to confirm its specific impact on aquaculture and to determine the extent of its prevalence and virulence in different fish species.

Probiotic interventions

Limited direct evidence in the provided documents specifically addresses *S. dysgalactiae*, highlighting the need for further research in this area. While the documents provide extensive information on the use of probiotics for controlling other bacterial pathogens in aquaculture, there is a lack of specific data on the effectiveness of probiotics against *S. dysgalactiae*. However, general probiotic mechanisms could be applicable, suggesting that probiotics may offer some protection against *S. dysgalactiae* infections by enhancing the immune system and competing for resources (Hoseinifar *et al.*, 2018). Probiotics have been shown to stimulate the immune system, improve gut health, and inhibit the growth of pathogens, all of which could potentially contribute to the control of *S. dysgalactiae*. This research should focus on identifying probiotic strains with specific antagonistic activity against *S. dysgalactiae*. In the absence of specific data on probiotics effective against *S. dysgalactiae*, it is reasonable to extrapolate from the efficacy of probiotics against related *Streptococcus* sp. such as *S. agalactiae* and *S. iniae*. Probiotics effective against these species may also show efficacy against *S. dysgalactiae*, offering a potential avenue for disease control. Lactobacillus sp., which have shown broad antimicrobial activity against various pathogens, may be potential candidates for controlling *S. dysgalactiae* infections (Sivakumar *et al.*, 2012). Similarly, Bacillus sp., known for their probiotic effects and ability to enhance immune responses, could also be beneficial in combating *S. dysgalactiae* (Ran *et al.*, 2012). Further investigation is warranted to explore the potential of these and other probiotic strains in controlling *S. dysgalactiae* in aquaculture.

Potential mechanisms and future research

Probiotics may offer protection by enhancing immune response and competing for resources, potentially reducing the severity of *S. dysgalactiae* infections in fish. By stimulating the immune system, probiotics can help fish to better recognize and

respond to *S. dysgalactiae*, while competing for resources can limit the pathogen's ability to colonize and cause disease. Future studies should focus on identifying probiotics with specific antagonistic activity, determining their ability to inhibit the growth of *S. dysgalactiae* and improve the health and resistance of fish to infection (Hoseinifar *et al.*, 2018). This research should also explore the potential of combining probiotics with other control strategies, such as biosecurity measures and vaccination. Research should explore dietary and environmental applications to control *S. dysgalactiae*, determining the most effective ways to administer probiotics and optimize their impact on fish health (Gatesoupe, 2007). This research should consider the potential of using probiotics in feed, water, and live feed to control *S. dysgalactiae* infections. Significant research gaps exist regarding the impact of *S. dysgalactiae* on aquaculture and the potential for probiotic interventions. Specific studies are needed to evaluate the effects of *S. dysgalactiae* on aquaculture, including its prevalence, virulence, and host range. *In vitro* and *in vivo* assays should be conducted to identify effective probiotics against *S. dysgalactiae*, assessing their ability to inhibit bacterial growth, enhance immune responses, and improve fish health. Understanding the mechanisms of probiotic action against this specific pathogen is essential for developing targeted and effective disease control strategies. Future research should focus on addressing these gaps to inform the development of probiotic-based solutions for managing *S. dysgalactiae* in aquaculture.

Streptococcus iniae control with probiotics

Impact of *S. iniae* on aquaculture

S. iniae is a Gram-positive bacterium that poses a significant threat to aquaculture, causing high mortality rates in commercially important fish populations. This bacterium is an emerging zoonotic pathogen, posing risks to both fish and humans, and highlighting the need for effective control measures (Jurez-Corts *et al.*, 2024). *S. iniae* is a significant pathogen in aquaculture, causing invasive disease and outbreaks in fish farms (Weinstein *et al.*, 1997). *S. iniae* causes streptococcosis, leading to significant losses in fish aquaculture and posing a major threat to the industry (Feliatra *et al.*, 2018). *S. iniae* infections can result in high mortality rates and economic losses in various aquaculture operations. *S. iniae* is a bacterial pathogen that causes streptococcosis, affecting a wide range of fish species (Min-Yeong and Kim, 2014). This bacterium is responsible for outbreaks of disease in a

variety of fish species, including tilapia, rainbow trout, and Asian seabass (Phasunon *et al.*, 2023). *S. iniae* can cause a range of symptoms in infected fish, including erratic swimming, bulging eyes, and skin lesions, leading to high mortality rates and significant economic losses. Effective control measures are essential to minimize economic impacts, safeguard fish health, and ensure the sustainability of aquaculture operations (Hoseinifar *et al.*, 2018). These measures include biosecurity, vaccination, and the use of probiotics. The ability of *S. iniae* to cause severe disease and its zoonotic potential make it a significant concern for the aquaculture industry. *S. iniae* causes high mortality rates in commercially important fish populations, making it a significant threat to the aquaculture industry (Jurez-Corts *et al.*, 2024). *S. iniae* infections are characterized by a variety of clinical signs, including lethargy, anorexia, erratic swimming behavior, and skin lesions. The severity of the infection can vary depending on the virulence of the *S. iniae* strain, the health status of the fish, and the environmental conditions. It is recognized as an emerging zoonotic pathogen, posing a potential risk to human health and requiring careful management in aquaculture settings. Although *S. iniae* primarily infects fish, there have been reports of human infections, particularly in individuals who handle infected fish or consume raw or undercooked fish products. Human *S. iniae* infections can cause a variety of symptoms, including skin lesions, cellulitis, and bacteremia. The zoonotic potential of *S. iniae* highlights the importance of implementing effective disease management strategies in aquaculture to protect both fish and human health. Understanding its pathogenesis and virulence is crucial for effective control strategies, including the development of vaccines and probiotic applications (Jurez-Corts *et al.*, 2024). *S. iniae* pathogenesis involves a complex interplay of bacterial virulence factors and host immune responses. The bacterium produces a variety of virulence factors, including capsule, surface proteins, and toxins, that contribute to its ability to invade and damage host tissues. Understanding these virulence factors and how they interact with the host immune system is essential for developing targeted control strategies. *S. iniae* is a Gram-positive bacterium that causes streptococcosis, a disease affecting a wide range of fish species (Jang *et al.*, 2013; Budianto and Suprastyani, 2017).

Probiotic strategies against *S. iniae*

P. ehimensis NPUST1 enhances immunity and disease resistance against *S. iniae* in zebrafish,

demonstrating the potential of this probiotic strain for broader application in aquaculture (Lin *et al.*, 2022). *P. ehimensis* NPUST1 enhances the expression of immune-related genes and improves the ability of zebrafish to fight off *S. iniae* infections. *B. safensis* NPUST1 improves growth performance, gut microbiota, and innate immunity against *S. iniae* in Nile tilapia, offering a promising strategy for managing streptococcosis in this important aquaculture species (Wu *et al.*, 2021). *B. safensis* NPUST1 enhances the growth, gut health, and immune function of Nile tilapia, improving their resistance to *S. iniae* infections. Probiotics isolated from giant freshwater prawns and giant tiger prawns improve the health of Nile tilapia against *S. iniae*, demonstrating the potential of using locally sourced probiotics for disease control in aquaculture (Feliatra *et al.*, 2018). *Bacillus* sp. have been identified as effective probiotics for controlling infections caused by *S. iniae*, providing a natural and sustainable approach to disease prevention (Brunt, 2007). *B. safensis* NPUST1 improves growth performance and innate immunity against *S. iniae* in Nile tilapia, enhancing their resistance to infection and promoting overall health (Wu *et al.*, 2021). Furthermore, *Actinomyces* strains isolated from *Argopecten purpuratus* have shown antimicrobial activity against *S. iniae*, suggesting their potential as probiotic candidates for disease control (Len *et al.*, 2016). The probiotics improve gut microbiota, increasing the abundance of potential probiotics and reducing pathogenic pathogens, creating a more balanced and healthy microbial environment (Wu *et al.*, 2021). Additionally, probiotics stimulate the expression of immune-related genes, enhancing the host's immune response and increasing survival rates following infection (Lin *et al.*, 2022). These combined mechanisms of action make probiotics a valuable tool for managing *S. iniae* infections in aquaculture. *B. safensis* NPUST1 improves disease resistance against *S. iniae* in Nile tilapia, enhancing their survival rate and overall health (Wu *et al.*, 2021). Wu *et al.* (2021) found that dietary supplementation with *B. safensis* NPUST1 significantly increased the survival rate of Nile tilapia after challenge with *S. iniae*. The probiotic treatment also led to improvements in growth performance, feed efficiency, and immune parameters, indicating that *B. safensis* NPUST1 can enhance the overall health and well-being of tilapia. *Streptomyces* strains show antimicrobial activity against *S. iniae*, suggesting their potential as probiotics in aquaculture systems (Len *et al.*, 2016). *St. variabilis*, *St. labedae*, and *St. rochei*, isolated from *Argopecten purpuratus*, exhibited broad-spectrum antimicrobial activity against *S. iniae*. *Streptomyces* species produce a variety of

antimicrobial compounds that can inhibit the growth of *S. iniae*, making them promising candidates for probiotic applications. The probiotic treatment also led to a reduction in cumulative mortality after infection with *S. iniae*. Probiotics can stimulate the immune system, enhancing disease resistance by activating immune cells and increasing the production of antibodies and cytokines. These immune factors play a crucial role in recognizing and eliminating pathogens, including *S. iniae*. Dietary supplementation with *B. safensis* NPUST1 significantly induced the expression of immune-related genes, such as IL-1, IL-8, TNF-, and lysozyme, in the head kidney and spleen of tilapia. The enhanced immune response conferred by *B. safensis* NPUST1 makes fish more resistant to *S. iniae* infections. They produce hydrolytic enzymes, improving nutrient metabolism and growth, which can help fish to better withstand *S. iniae* infections. Probiotics can produce a variety of hydrolytic enzymes, such as protease, amylase, cellulase, and xylanase, which can improve the digestion and absorption of nutrients in the gut. Wu *et al.* (2021) found that dietary supplementation with *B. safensis* NPUST1 significantly increased the intestinal digestive enzymes, including protease, amylase, and lipase, in tilapia. The improved nutrient metabolism and growth conferred by *B. safensis* NPUST1 can help fish to better withstand *S. iniae* infections. Probiotics can modulate gut microbiota, increasing the abundance of beneficial bacteria and reducing the abundance of pathogenic pathogens, including *S. iniae* (Wu *et al.*, 2021). A balanced gut microbiota can help to prevent *S. iniae* from colonizing the gut and causing disease. Additionally, a balanced gut microbiota can improve nutrient absorption and utilization, leading to enhanced growth performance and overall health. Direct inhibition: Probiotics can produce antibacterial substances that directly inhibit the growth of *S. iniae* (Hoseinifar *et al.*, 2018). Immune enhancement: Probiotics can enhance the immune response of fish, improving their ability to fight off *S. iniae* infections (Simn, 2021). Competitive exclusion: Probiotics can compete with *S. iniae* for nutrients and binding sites in the gut, preventing its colonization (Knipe *et al.*, 2020).

Specific probiotic strains and their effects

B. amyloliquefaciens JFP2 increases disease resistance against *S. iniae* in flounder, making it a valuable probiotic for controlling this pathogen in flounder aquaculture (Kim *et al.*, 2017). This strain produces a bacteriocin that inhibits the growth of *S. iniae*, reducing its ability to cause disease. *B. siamensis* B44v exhibits antibacterial activity, inhibiting *S. iniae* and offering protection against a range of other bacterial pathogens in aquaculture systems (Meidong *et al.*, 2017). The broad-spectrum activity of *B. siamensis* B44v makes it a versatile probiotic for use in aquaculture systems where multiple pathogens may be present. *L. garvieae* enhances disease resistance against *S. iniae*, demonstrating the potential of using this bacterium as a probiotic for controlling streptococcosis in fish (Mawardi *et al.*, 2023). This finding may seem counterintuitive, given that *L. garvieae* is itself a fish pathogen. However, certain strains of *L. garvieae* may possess beneficial properties that enhance the immune system and protect against other pathogens, including *S. iniae*. Certain *Bacillus* strains have demonstrated inhibitory effects against *S. iniae* (Ran *et al.*, 2012; Amoah *et al.*, 2021). Mixed probiotics (*L. fusiformis* SPS11, *B. amyloliquefaciens* L9, *E. hirae* LAB3) have shown the ability to inhibit *S. iniae* significantly and improve survival rates in red hybrid tilapia (Zabidi *et al.*, 2021). *Bacillus* sp. JB1 has demonstrated effectiveness as a probiotic for controlling infections caused by *S. iniae* (Brunt *et al.*, 2007). *P. ehimensis* NPUST1 supplementation in feed has been shown to enhance innate immunity and disease resistance against *S. iniae* in zebrafish (Lin *et al.*, 2022). *B. safensis* NPUST1 improves growth performance, gut microbiota, and innate immunity against *S. iniae* in Nile tilapia (Wu *et al.*, 2021). Dietary administration of *Bacillus* sp. IS-2 enhances the innate immune response and disease resistance of *Paralichthys olivaceus* against *S. iniae* (Jang *et al.*, 2013). *B. subtilis* also has antagonistic effects against *S. iniae* (Budianto and Suprastyani, 2017).

Table 1. The following table summarizes the application of probiotics for the management of specific bacterial diseases in aquaculture.

Pathogen	Gram-bacteria	Probiotic	Host species	Mechanism of action	Reference(s)
<i>Aeromonas hydrophila</i>	Gram negative	<i>Bacillus</i> sp. <i>Bacillus</i> sp. JB1, <i>Aeromonas sobria</i> GC2 <i>Bacillus</i> sp. YB1701	<i>Clarias</i> sp. (catfish) Rainbow trout	Production of inhibitory substances, stimulation of innate immune responses. Antagonistic activity, production of bacteriocin-like substances, enhancement of immune response. Suppressed <i>A. hydrophila</i> growth, improved immune response.	(Brunt, 2007), (Meidong, 2017) (Ran, 2012) (Hamka,2021), (Ran, 2012), (Kavitha, 2018) (Zhou, 2018)
		<i>Bacillus pocheonensis</i>	-	-	(Samat, 2021)
		<i>Bacillus</i> sp. QSI-1	Unspecified	Modulated quorum sensing signals, reduced <i>A. hydrophila</i> levels, altered gut microbial community structure.	
		<i>Bacillus coagulans</i> , <i>Mentha piperita</i>	<i>Catla catla</i>	Protected histological architecture, reduced DNA damage.	
		<i>Pediococcus pentosaceus</i> (SL001)	<i>Clarias</i> sp. (catfish)	Wide antimicrobial spectrum. Suppressed <i>A. hydrophila</i> growth, improved immune response, increased survival.	(Gong, 2019) (Hamka, 2021), (Gong, 2019)
		<i>Bacillus megaterium</i> PTB 1.4 and <i>Pediococcus pentosaceus</i> E2211		Suppression of pathogen growth, increase in erythrocytes and leukocytes.	(Hamka, 2021)
		<i>Lactobacillus rhamnosus</i>	<i>Oreochromis niloticus</i> (Nile tilapia)	Improved growth performance, increased disease resistance, enhanced immunity.	(Noshair, 2023)
		<i>Lactococcus lactis</i> KUST48	<i>Danio rerio</i> (Zebrafish)	Positive impact on transcription profile of infected spleen. Inhibition of pathogen growth Reduced mortality, modulated immune response.	(Chen, 2024)
		<i>Paenibacillus ehimensis</i> NPUST1	<i>Danio rerio</i> (Zebrafish)	Enhancement of innate immunity. Enhanced nutrient metabolism, growth performance, innate immunity, and disease resistance.	(Lin, 2022)

		<i>Bacillus siamensis</i> B44v	Hybrid Catfish (<i>C. macrocephalus</i> x <i>C. gariepinus</i>)	Broad-spectrum antibacterial activity, improved growth and disease resistance.	(Meidong, 2017)
<i>Yersinia ruckeri</i>	Gram negative	<i>Bacillus</i> sp. <i>cloacae</i> and <i>Bacillus mojavensis</i>	<i>Oncorhynchus mykiss</i> (Rainbow trout)	Control of infections. Antagonistic effects, production of inhibitory compounds, competition for nutrients. Reduced mortalities after challenge with <i>Y. ruckeri</i> .	(Brunt, 2007), (Ran, 2012), (Verschuere, 2000), (apkn, 2009)
		<i>Bacillus subtilis</i>		Potential to mediate disease resistance.	(Ran, 2012)
		<i>Lactobacillus plantarum</i> R2 Biocenol (CCM 8674)		Reduces inflammation.	(Marukov, 2021)
		<i>Streptomyces</i> strains		Antimicrobial activity.	(Len, 2016)
<i>Lactococcus garvieae</i>	Gram positive	<i>Bacillus</i> sp. JB1, <i>Aeromonas sobria</i> GC2	<i>Oncorhynchus mykiss</i> (Rainbow trout)	Control of infections. Reduced mortalities after challenge with <i>L. garvieae</i> .	(Brunt, 2007) (Gong, 2019), (Mawardi, 2023)
		<i>Lactococcus garvieae</i> (specific strains) <i>Lactococcus lactis</i> RBT18	Rainbow trout	Enhances tilapia growth and resistance.	(Mawardi, 2023) (Contente, 2020)
		<i>Pediococcus pentosaceus</i>			(Gong, 2019)
		<i>Bacillus</i> strains <i>Bacillus subtilis</i>	Rainbow trout	Antagonistic effects, production of antibacterial substances. Prevented further infections in a mixed infection case with <i>Frigoribacterium faeni</i> .	(Amoah, 2021)
		<i>Streptomyces</i> strains		Antimicrobial activity.	(Len, 2016)
		<i>Actinomycetes</i> strains		Antimicrobial activity.	(Len, 2016)
<i>Streptococcus agalactiae</i>	Gram positive	<i>Bacillus subtilis</i>	<i>Oreochromis niloticus</i> (Nile tilapia)	Effect on microbiological and haematological responsiveness. Increased growth performance, enhanced immune response, higher survival rates.	(Haniffa, 2015) (Mulyadin, 2021), (Samat, 2021), (Mawardi, 2023)

		<i>Bacillus</i> sp.			(Amoah, 2021)
		<i>Lactobacillus rhamnosus</i>		Broad antimicrobial activity.	(Pirarat, 2009)
		<i>Bacillus siamensis</i> B44v		Broad-spectrum antibacterial activity, production of bacteriocins.	(Meidong, 2017),
		<i>Lactococcus lactis</i> strains		Antibacterial activity, balancing intestinal microbiota.	(Tan, 2022), (Chen, 2024)
		<i>Lysinibacillus fusiformis</i> SPS11, <i>Bacillus amyloliquefaciens</i> L9, and <i>Enterococcus hirae</i> LAB3 (Mixed Probiotics)	Red hybrid tilapia (<i>Oreochromis</i> sp.)	Inhibitory effects. Improved growth, higher survival rates, reduced nitrogen concentration.	(Zabidi, 2021)
		<i>Lysinibacillus fusiformis</i> SPS11, <i>Bacillus amyloliquefaciens</i> L11		Antagonism.	(Puvanasundram, 2022)
		<i>Limosilactobacillus fermentum</i> GMNL-93, <i>Lactiplantibacillus plantarum</i> GMNL-141, <i>Lacticaseibacillus casei</i> GMNL-277, and <i>Bifidobacterium lactis</i> GMNL-550 (GM-Lac)	Asian seabass (<i>Lates calcarifer</i>)	Enhanced growth performance, improved gastrointestinal health, increased disease resistance.	(Wang, 2023)
		<i>Lactococcus garvieae</i> , <i>Priestia megaterium</i> , <i>Bacterium</i> s p.			(Mawardi, 2023)
		<i>Bacillus pocheonensis</i>			(Samat, 2021), (Zabidi, 2021)
<i>Streptococcus dysgalactiae</i>	Gram positive	Extrapolation from related species (<i>Lactobacillus</i> , <i>Bacillus</i>)		Antimicrobial enhancement of activity, immune responses.	(Sivakumar, 2012), (Ran, 2012)
<i>Streptococcus iniae</i>	Gram positive	<i>Bacillus</i> sp. JB1, <i>Aeromonas sobria</i> GC2	<i>Oncorhynchus mykiss</i> (Rainbow trout)	Control of infections. Reduced mortalities after challenge with <i>S. iniae</i> .	(Brunt, 2007), (Amoah, 2021), (Allameh,

					(Ran, 2013), (Amoah, 2012), (Amoah, 2021),
		<i>Streptomyces</i> strains		Antimicrobial activity.	(Len, 2016)
		<i>Paenibacillus ehimensis</i> NPUST1		Enhancement of innate immunity.	(Lin, 2022)
		<i>Bacillus safensis</i> NPUST1 <i>Bacillus amyloliquefaciens</i>	Rock bream	Improves growth performance and innate immunity. Lowered mortality, improved health status.	(Wu, 2021)
		<i>Actinomycetes</i> strains		Antimicrobial activity.	(Len, 2016)

Mode of action of probiotics in disease control

Enhancing immune response

Probiotics stimulate innate immunity in fish, helping them resist pathogens and reducing the need for antibiotic treatments in aquaculture (Mohapatra *et al.*, 2012; Partridge, 2016). By activating the immune system, probiotics enable fish to defend themselves better against a wide range of bacterial, viral, and parasitic infections. They increase lysozyme activity, phagocytic activity, and respiratory burst in immune cells, enhancing the ability of fish to kill and eliminate pathogens (Wu *et al.*, 2021). Lysozyme is an enzyme that breaks down bacterial cell walls, while phagocytic cells engulf and destroy pathogens, and respiratory burst produces reactive oxygen species that kill bacteria. Probiotics modulate the expression of immune-related genes, such as IL-1, IL-6, and TNF- α , fine-tuning the immune response and improving the ability of fish to fight off infections. These genes play a critical role in regulating inflammation, immune cell activation, and pathogen clearance.

Competition and inhibition of pathogens

Probiotics compete with pathogens for nutrients and adhesion sites in the gut, limiting their ability to colonize and cause disease in fish (Hoseinifar *et al.*,

2018). By occupying these niches, probiotics prevent pathogens from establishing themselves in the gut and gaining access to the fish's tissues. They produce inhibitory substances, such as bacteriocins, that inhibit pathogen growth and reduce their virulence, providing a direct defense against bacterial infections (Amenyogbe, 2023). Bacteriocins are antimicrobial peptides that target specific bacteria, inhibiting their growth and disrupting their cell membranes. Some probiotics degrade quorum sensing signals, reducing pathogen virulence and preventing them from coordinating their attack on the fish (Novita *et al.*, 2015). Quorum sensing is a communication system used by bacteria to coordinate their behavior, including the production of virulence factors.

Table of probiotics and targeted pathogens

Probiotics encompass a diverse range of microorganisms, including microalgae, yeasts, and Gram-positive or Gram-negative bacteria, each with unique mechanisms of action (Irianto, and Austin, 2002). They act through competitive exclusion, preventing pathogen colonization, altering microbial metabolism, creating an unfavorable environment for pathogens, and stimulating host immunity, enhancing disease resistance (Irianto, and Austin, 2002). Specific probiotics have demonstrated effectiveness against key aquaculture pathogens, including *A. hydrophila*, *Y. ruckeri*, *L. garvieae*, *St. agalactiae*, and *St. iniae*, offering targeted solutions for disease management (Brunt *et al.*, 2007).

Improving gut health and nutrient utilization

Probiotics improve gut microbiota composition, increasing beneficial bacteria and reducing pathogens, leading to a healthier gut environment and improved nutrient absorption in fish (Ring, 2020). A balanced gut microbiota is essential for maintaining fish health and preventing disease, and probiotics help to promote this balance. They enhance digestive enzyme activity, improving nutrient metabolism and growth and ensuring that fish are able to efficiently utilize the nutrients in their feed (Wu *et al.*, 2021). By improving nutrient utilization, probiotics can enhance growth rates and reduce feed conversion ratios in aquaculture operations. Probiotics can also improve water quality in aquaculture systems, reducing the build-up of harmful substances and creating a more favorable environment for fish (Bentzon Tilia *et al.*, 2016). By breaking down organic matter and reducing the levels of ammonia and nitrite, probiotics help to maintain water quality and prevent disease outbreaks.

Key probiotic strains and their applications

Bacillus sp. are frequently used as probiotics in aquaculture, known for their ability to produce inhibitory substances and enhance immune responses (Ran *et al.*, 2012). *Lactobacillus* sp. can also provide antimicrobial activity, inhibiting the growth of various pathogens and promoting gut health (Sivakumar *et al.*, 2012). Multi-strain probiotics (MSPs) can offer enhanced benefits compared to single-strain probiotics (SSPs), providing a broader spectrum of activity and synergistic effects (Puvanasundram *et al.*, 2022). The selection and application of appropriate probiotic strains are crucial for effective disease management in aquaculture.

Probiotic delivery methods in aquaculture

Dietary supplementation

Probiotics are commonly administered through feed, providing a convenient and effective means of delivering beneficial microorganisms to aquaculture species (Hamka, 2021). This method involves incorporating probiotics into the feed formulation, ensuring that the fish consume the microorganisms along with their regular diet. Dietary supplementation allows for the consistent delivery of probiotics and direct interaction with the gut microbiota. Dietary supplementation allows for consistent delivery and direct interaction with the gut microbiota, promoting a balanced and healthy gut environment. Optimal

dosage varies depending on the probiotic strain and target species, requiring careful consideration to achieve the desired effects without causing any adverse reactions (Leong *et al.*, 2023). Factors such as fish size, age, and health status should also be taken into account when determining the appropriate dosage. Supplementation improves growth performance, immune response, and disease resistance, making it a valuable tool for enhancing the health and productivity of aquaculture operations (Mulyadin *et al.*, 2021; Wu *et al.*, 2021). By improving growth rates, reducing disease outbreaks, and enhancing immune function, dietary supplementation with probiotics can significantly improve the profitability of aquaculture farms. The probiotics in the feed can colonize the gut, competing with pathogenic bacteria for nutrients and adhesion sites. This competitive exclusion mechanism can help to prevent bacterial infections and improve the overall health of the fish. Additionally, the probiotics can stimulate the immune system, enhancing the fish's ability to fight off disease. The optimal dosage varies depending on the probiotic strain and target species, requiring careful consideration to ensure effectiveness (Hamka, 2021). Factors such as the age and health status of the fish, as well as the environmental conditions, can also influence the optimal dosage. It is important to conduct feeding trials to determine the appropriate dosage for each probiotic strain and target species. Dietary supplementation is a common method for administering probiotics in aquaculture, involving the incorporation of probiotics into fish feed. This approach allows for consistent delivery of probiotics and direct interaction with the gut microbiota, promoting a balanced and healthy gut environment. The optimal dosage of probiotics varies depending on the specific strain and the target species, requiring careful consideration to ensure maximum effectiveness. Dietary supplementation offers several advantages for probiotic delivery in aquaculture (Hamka, 2021). It is a relatively simple and cost-effective method that can be easily integrated into existing feeding practices. Dietary supplementation also ensures that probiotics are delivered directly to the gut, where they can exert their beneficial effects on the microbiota and immune system. The optimal dosage of probiotics in dietary supplementation depends on several factors, including the specific strain of probiotic, the target species, and the age and health status of the fish (Hamka, 2021). It is important to conduct trials to determine the appropriate dosage for each specific application, taking into account the potential for both beneficial and adverse effects. Probiotics are commonly administered through feed in

aquaculture systems, providing a consistent and direct means of delivery. Dietary supplementation allows for direct interaction with the gut microbiota, promoting a balanced and healthy microbial community. The optimal dosage varies depending on the specific probiotic strain and the target species, requiring careful consideration to achieve maximum effectiveness (Hamka, 2021).

Water application

Probiotics can be added directly to the water in aquaculture systems, providing an alternative delivery method that is particularly effective for larval stages (Amenyogbe, 2023). This method involves dissolving or suspending the probiotics in the water, allowing the microorganisms to come into contact with the fish through their gills and skin. Water application is especially useful for larval stages, as they may not be able to consume solid feed. This method is effective for larval stages and can improve water quality, creating a more favorable environment for aquaculture species. Probiotics can help to reduce the levels of harmful bacteria in the water, as well as improve the breakdown of organic matter. This can lead to improved water quality and a reduced risk of disease outbreaks. Water application ensures a broad distribution of probiotics in the environment, reaching all individuals in the aquaculture system (Amenyogbe, 2023). This can be particularly important in large-scale aquaculture operations, where it may be difficult to ensure that all fish receive an adequate dose of probiotics through dietary supplementation. Water application can also help to create a more stable and balanced microbial community in the aquaculture system. Probiotics can also be administered directly to the water in aquaculture systems, providing an alternative delivery method that is particularly effective for larval stages. Water application can improve water quality by promoting the growth of beneficial bacteria and suppressing the growth of harmful pathogens, creating a more favorable environment for fish health (Amenyogbe, 2023). It is a non-invasive method that can be easily implemented in a variety of aquaculture systems. Water application also allows for the delivery of probiotics to larval stages, which may not be able to consume feed containing probiotics. The effectiveness of water application depends on several factors, including the concentration of probiotics in the water, the water quality parameters, and the presence of other microorganisms (Amenyogbe, 2023). It is important to monitor these factors to ensure that probiotics are effectively colonizing the aquaculture environment

and exerting their beneficial effects. Probiotics can be added directly to the water in aquaculture systems, offering an alternative delivery method suitable for various applications. Water application can also improve overall water quality, contributing to a healthier environment for aquatic organisms (Amenyogbe, 2023). Probiotics can be added directly to the water to improve water quality and control pathogens, providing a more holistic approach to disease management in aquaculture systems (Bentzon Tilia *et al.*, 2016). This method is particularly useful in systems where it is difficult to administer probiotics through feed, such as in larval rearing tanks. This method is suitable for larval stages and biofloc systems, where fish are highly susceptible to disease and water quality is critical (Samat *et al.*, 2021; Zabidi *et al.*, 2021). In larval stages, the immune system is not fully developed, making fish more vulnerable to pathogens. Water application ensures widespread exposure and can be combined with dietary supplementation, providing a multi-faceted approach to probiotic delivery (Gatesoupe, 2007). This combination can enhance the effectiveness of probiotics and provide a more comprehensive level of protection against disease.

Bioencapsulation

Bioencapsulation involves incorporating probiotics into live feed organisms, such as Artemia, providing a targeted and effective delivery method for early life stages (Muthezhila *et al.*, 2019). This method involves feeding live feed organisms, such as Artemia, with probiotics, allowing the microorganisms to be incorporated into the tissues of the live feed. The live feed is then fed to the fish, delivering the probiotics directly to their gut. This method ensures that probiotics are delivered to fish during their early life stages, when they are most vulnerable to disease and environmental stressors. Early life stages are critical for the development of the immune system and gut microbiota, making probiotic supplementation particularly beneficial during this period. Bioencapsulation ensures that the probiotics are delivered directly to the gut, where they can exert their beneficial effects. Bioencapsulation enhances the nutritional value of live feed, providing additional benefits for aquaculture species (Muthezhila *et al.*, 2019). Probiotics can produce vitamins, enzymes, and other beneficial compounds that can improve the nutritional value of live feed. This can lead to improved growth performance, feed efficiency, and overall health in aquaculture species. Bioencapsulation involves incorporating probiotics into live feed organisms, such

as *Artemia*, providing a targeted delivery method for early life stages of fish (Muthezhila *et al.*, 2019). This approach ensures that probiotics are delivered to fish during their critical developmental stages, promoting a healthy gut microbiota and enhancing immune function. Bioencapsulation also enhances the nutritional value of live feed, providing additional benefits for fish growth and survival. Bioencapsulation offers several advantages for probiotic delivery in aquaculture. It is a highly targeted method that ensures that probiotics are delivered directly to the fish that need them most. Bioencapsulation also protects probiotics from degradation in the water, increasing their survival and effectiveness. The effectiveness of bioencapsulation depends on several factors, including the type of live feed organism used, the concentration of probiotics in the feed, and the feeding rate. It is important to optimize these factors to ensure that probiotics are effectively delivered to the fish and exerting their beneficial effects. This method ensures that probiotics are delivered to fish during their early life stages when they are most vulnerable to infections and nutritional deficiencies. Bioencapsulation enhances the nutritional value of live feed, promoting better growth and survival rates in aquaculture species (Muthezhila *et al.*, 2019).

Live feed enrichment

Live feeds, such as *M. micrura*, can be enriched with probiotics to deliver them to fish larvae, providing a natural and effective way to administer beneficial bacteria to young fish (Samat *et al.*, 2021). This method is particularly useful for species that rely on live feed during their early life stages. This method enhances survival and disease resistance in early life stages, when fish are most vulnerable to infections and environmental stressors. By providing probiotics through live feed, fish larvae receive a continuous supply of beneficial bacteria that help to establish a healthy gut microbiota and boost their immune system. Enrichment provides a natural and effective way to administer probiotics, mimicking the way that fish would naturally acquire beneficial bacteria in their environment (Samat *et al.*, 2021). This approach is more sustainable and environmentally friendly than using synthetic additives or antibiotics.

Considerations for probiotic use in aquaculture

While probiotics offer numerous benefits for aquaculture, several factors need to be considered for their effective application:

- I. Strain selection: The selection of appropriate probiotic strains is crucial for achieving desired effects. Probiotics should be selected based on their ability to survive in the gut, exhibit antimicrobial activity against specific pathogens, and enhance the host's immune response (Verschuere *et al.*, 2000; Amenyoibe, 2023).
- II. Delivery method: The method of probiotic delivery can influence their efficacy. Probiotics can be administered through feed, water, or live feed (Amenyoibe, 2023).
- III. Dosage: The optimal dosage of probiotics needs to be determined for each species and production system (Hamka, 2021).
- IV. Environmental conditions: Environmental factors such as temperature, salinity, and pH can affect the survival and activity of probiotics (Amenyoibe, 2023).
- V. Host species: The effectiveness of probiotics can vary depending on the host species and its gut microbiota.
- VI. Safety: Probiotics used in aquaculture should be safe for the host, the environment, and human consumers (Mawardi *et al.*, 2023). considered for their effective application:

Dosage: the optimal dosage of probiotics

Environmental factors such as temperature, salinity, and water quality can affect the survival and efficacy of probiotics (Amenyoibe, 2023). Probiotics should be carefully evaluated for safety to ensure that they do not pose a risk to the host animal or the environment (Amoah *et al.*, 2021).

Challenges and future perspectives

Addressing antibiotic resistance

Probiotics offer a promising alternative to combat antibiotic resistance in aquaculture, reducing the reliance on these drugs and mitigating the spread of resistant bacteria (Balczar *et al.*, 2006; Aich *et al.*, 2018). By promoting a healthy gut microbiota and boosting the immune system, probiotics can help fish to resist infections without the need for antibiotics. Continued research is needed to identify and develop effective probiotic strains, ensuring that aquaculture operations have access to the best possible tools for disease management (Hoseinifar *et al.*, 2018). This research should focus on identifying probiotic strains

with specific antagonistic activity against common aquaculture pathogens. Integrating probiotics into aquaculture management can reduce antibiotic usage, promoting more sustainable and responsible practices in the industry (Schmidt *et al.*, 2017). By adopting a holistic approach to disease management that includes probiotics, biosecurity measures, and vaccination, aquaculture farmers can minimize their reliance on antibiotics and reduce the risk of antibiotic resistance.

Research gaps and future directions

Further investigations are needed to understand the long-term effects of probiotics on fish health and the environment, ensuring that their use is sustainable and does not have any unintended consequences (Hoseinifar *et al.*, 2018). This research should focus on assessing the impact of probiotics on the gut microbiota, immune function, and overall health of fish, as well as their potential effects on the surrounding ecosystem. More research is required to determine the optimal application methods and dosages, tailoring probiotic treatments to specific species and aquaculture systems (Leong *et al.*, 2023). Factors such as fish size, age, health status, and environmental conditions should be taken into account when determining the appropriate application methods and dosages. Studies should focus on host-associated probiotics for improved efficacy and sustainability, selecting probiotic strains that are naturally found in the gut of the target species to enhance their ability to colonize and provide benefits (Doan *et al.*, 2019). Host-associated probiotics are more likely to be well-adapted to the gut environment and to interact positively with the host's immune system.

Regulatory and commercial aspects

Clear regulatory guidelines are needed to ensure the safety and efficacy of probiotic products, protecting consumers and promoting responsible use of these beneficial bacteria in aquaculture (Uddin *et al.*, 2015). These guidelines should address issues such as probiotic strain identification, purity, viability, and safety. Commercialization of probiotics requires rigorous testing and quality control, ensuring that products meet the required standards and deliver the promised benefits (Uddin *et al.*, 2015). This testing should include *in vitro* and *in vivo* studies to assess the efficacy and safety of probiotic products. Promoting the use of probiotics can contribute to sustainable and responsible aquaculture practices, reducing the reliance on antibiotics and promoting a more

environmentally friendly approach to fish farming (Zorriehzahra *et al.*, 2016). By adopting probiotics as part of a holistic disease management strategy, aquaculture farmers can improve the health and productivity of their operations while minimizing their impact on the environment.

Factors influencing probiotic efficacy

Host species and gut microbiota

The efficacy of probiotics is significantly influenced by the host species and its existing gut microbiota, highlighting the importance of considering these factors when selecting and applying probiotics in aquaculture (Doan *et al.*, 2019). Host-associated probiotics, which are derived from the same species they are intended to benefit, may be more effective due to their adaptation to the host environment. Understanding the complex interactions between probiotics and the native microbiota is crucial for optimizing their effectiveness and ensuring a positive impact on fish health. The host species plays a crucial role in determining the efficacy of probiotics (Doan *et al.*, 2019). Different fish species have different gut environments and microbiota compositions, which can affect the survival and activity of probiotics. Therefore, it is important to select probiotics that are compatible with the specific host species being targeted. The existing gut microbiota also plays a significant role in determining the efficacy of probiotics. Probiotics must be able to compete with the native microbiota for resources and adhere to the gut lining in order to exert their beneficial effects. The composition of the native microbiota can also influence the host's immune response to probiotics. Host-associated probiotics may be more effective due to their adaptation to the host environment (Doan *et al.*, 2019). These probiotics have evolved alongside the host species and are therefore better able to survive and thrive in the gut. Host-associated probiotics may also be more effective at modulating the host's immune system and competing with pathogens.

Environmental conditions

Environmental conditions, such as temperature and pH, can significantly affect the survival and activity of probiotics, underscoring the need to carefully consider these factors when applying probiotics in aquaculture (Thi *et al.*, 2023). Probiotics must be able to tolerate the specific conditions of the aquaculture system in order to remain viable and exert their beneficial effects maintaining optimal water quality is

essential for promoting probiotic efficacy and ensuring a healthy environment for fish (Zabidi *et al.*, 2021). Temperature is a critical environmental factor that can influence probiotic survival and activity (Thi *et al.*, 2023). Probiotics have optimal temperature ranges for growth and metabolism, and temperatures outside of these ranges can reduce their viability and effectiveness. Therefore, it is important to select probiotics that are adapted to the specific temperature conditions of the aquaculture system. pH is another important environmental factor that can affect probiotic survival and activity. Probiotics have optimal pH ranges for growth and metabolism, and pH levels outside of these ranges can reduce their viability and effectiveness. Therefore, it is important to maintain the pH of the aquaculture system within the optimal range for the selected probiotics. Maintaining optimal water quality is essential for promoting probiotic efficacy (Zabidi *et al.*, 2021). Factors such as dissolved oxygen, ammonia, and nitrite can affect the survival and activity of probiotics. Therefore, it is important to monitor water quality parameters and take steps to maintain them within the optimal ranges for the selected probiotics.

Probiotic strain and formulation

The specific probiotic strain and its formulation play a crucial role in determining its effectiveness, underscoring the importance of selecting the right probiotic for the intended application. Multi-strain probiotics, which contain a combination of different probiotic strains, may offer broader protection against pathogens due to their synergistic effects (Zabidi *et al.*, 2021). The viability and stability of probiotics during storage and application are also important considerations, as probiotics must remain viable in order to exert their beneficial effects (Wu *et al.*, 2021). The specific strain of probiotic is a key determinant of its effectiveness (Hoseinifar *et al.*, 2018). Different probiotic strains have different mechanisms of action and may be more or less effective against specific pathogens. Therefore, it is important to select a probiotic strain that has been shown to be effective against the target pathogens in the aquaculture system. Multi-strain probiotics may offer broader protection against pathogens due to their synergistic effects (Zabidi *et al.*, 2021). Different probiotic strains can have different mechanisms of action, and a combination of strains can provide a more comprehensive approach to disease management. Multi-strain probiotics can also be more effective at modulating the gut microbiota and enhancing the host's immune response. The viability and stability of

probiotics during storage and application are also important considerations (Wu *et al.*, 2021). Probiotics must remain viable in order to exert their beneficial effects, and storage and application conditions can affect their viability. Therefore, it is important to select probiotics that have been formulated to maintain their viability during storage and application.

Further research areas

Future research should focus on identifying new probiotic strains that are highly effective against specific pathogens and well-adapted to the conditions of aquaculture systems (Rahayu *et al.*, 2024). Furthermore, research is needed to optimize the delivery methods of probiotics, such as through feed or water, to ensure that they reach the target site in the host animal (Fachri *et al.*, 2024). Additionally, more studies are needed to elucidate the mechanisms of action of probiotics, which will aid in the selection and development of more effective probiotic products (Zorriehzahra *et al.*, 2016).

Addressing gaps in current knowledge

Despite the promising results achieved with probiotics in aquaculture, several gaps in current knowledge need to be addressed to optimize their application and maximize their benefits. More research is needed to understand the modes of action of probiotics at a molecular level, elucidating the specific mechanisms by which they interact with the host and pathogens (Irianto, and Austin, 2002). Further investigations are required to evaluate the safety and efficacy of different probiotic strains, assessing their potential for adverse effects and determining the optimal dosages and application methods (Vargas-Gonzalez *et al.*, 2024). Additionally, studies should focus on the long-term effects of probiotics on fish health and the environment, monitoring their impact on gut microbiota composition, immune function, and overall ecosystem health (Aich *et al.*, 2018).

Potential for synbiotics and postbiotics

The potential for synbiotics (combination of probiotics and prebiotics) and postbiotics (non-viable bacterial products) in aquaculture represents an exciting area for future research and development. Synbiotics can have additive effects, enhancing the benefits of probiotics and prebiotics through synergistic interactions (Tamamdustu *et al.*, 2015). Prebiotics, such as oligosaccharides, can selectively

stimulate the growth and activity of beneficial bacteria in the gut, further improving fish health and disease resistance. Postbiotics are emerging as another effective way for disease control, offering a stable and well-defined alternative to live probiotics (Soltani, 2023). These approaches can enhance the benefits of probiotics, improve disease resistance, and promote sustainable aquaculture practices (Hoseinifar *et al.*, 2018).

Sustainable aquaculture with probiotics

Probiotics offer a sustainable and environmentally friendly approach to disease control in aquaculture, reducing the reliance on antibiotics and chemotherapeutants and promoting a more balanced and healthy ecosystem (Sarmah, and Sarma, 2023). They can reduce the reliance on antibiotics and chemotherapeutants in aquaculture, minimizing the risk of antibiotic resistance and reducing the environmental impact of aquaculture operations (Soliman *et al.*, 2019). Continued research and development of probiotics are essential for the sustainable growth of the aquaculture industry, ensuring the long-term health and productivity of fish populations while minimizing the negative impacts on the environment (Doan *et al.*, 2019). By embracing probiotics as a key component of sustainable aquaculture practices, we can promote the responsible and ethical production of aquatic food resources for future generations.

Identifying novel probiotic strains

There is a continuous need for research to discover novel probiotic strains that can provide enhanced benefits for aquaculture, addressing the evolving challenges faced by the industry (Rahayu *et al.*, 2024). Focusing on host-associated bacteria, which are naturally adapted to the gut environment of fish, can yield more effective probiotics with improved colonization and persistence (Hoseinifar *et al.*, 2018). Screening for specific traits, such as antimicrobial activity and immune stimulation, is essential for identifying probiotic candidates with the greatest potential for improving fish health and disease resistance (Amenyogbe, 2023). The discovery of novel probiotic strains is essential for addressing the evolving challenges faced by the aquaculture industry (Rahayu *et al.*, 2024). As pathogens evolve and develop resistance to existing treatments, it is important to have a pipeline of new probiotics that can provide effective disease management. Novel probiotic strains can also offer improved benefits for fish growth,

immunity, and overall health. Focusing on host-associated bacteria can yield more effective probiotics. These bacteria have evolved alongside the host species and are therefore better able to survive and thrive in the gut. There is a continuous need for research to discover new probiotic strains with enhanced efficacy and broader applicability in aquaculture (Rahayu *et al.*, 2024). Focusing on host-associated bacteria can yield more effective probiotics that are well-adapted to the specific host environment (Hoseinifar *et al.*, 2018). Screening for specific traits, such as antimicrobial activity and immune stimulation, is essential for identifying promising probiotic candidates (Amenyogbe, 2023).

Understanding probiotic mechanisms

Further research is needed to fully elucidate the mechanisms of probiotic action, providing a deeper understanding of how they interact with the host and the gut microbiota. Transcriptome analysis can provide valuable insights into the molecular responses of fish to probiotic treatment, revealing key pathways involved in immune modulation and disease resistance (Chen *et al.*, 2024). Investigating the interactions between probiotics and the gut microbiota is crucial for optimizing their application and maximizing their beneficial effects (Tan *et al.*, 2022).

Optimizing probiotic application

Optimizing the dosage and delivery methods of probiotics is necessary to ensure their effectiveness and maximize their benefits for fish health (Lubis *et al.*, 2024). Developing effective strategies for integrating probiotics into various aquaculture systems is important for tailoring their application to specific needs and conditions (Lubis *et al.*, 2024). Assessing the long-term effects of probiotic use on the environment and the host is crucial for ensuring their sustainability and reducing the risk of potential negative outcomes (Amenyogbe, 2023).

Further research is needed to address the knowledge gaps and optimize the use of probiotics in aquaculture. Key areas for future investigation include: assessing the long-term effects of probiotic use on the environment and the host (Amenyogbe, 2023). Mechanisms of action: elucidating the precise mechanisms of action by which probiotics promote fish health (Johar *et al.*, 2024). Optimization of delivery methods: developing more effective and targeted delivery methods for probiotics (Amenyogbe, 2023). Synergistic effects: investigating the synergistic effects

of combining different probiotic strains or with other feed additives such as prebiotics (Hoseinifar *et al.*, 2018). Host-microbe interactions: gaining a better understanding of the complex interactions between probiotics, the host's gut microbiota, and the immune system (Situmorang *et al.*, 2014). Development of new probiotics: exploring the potential of novel probiotic strains isolated from aquatic environments (Amenyogbe, 2023).

- I. Specific mechanisms: Further research is needed to elucidate the specific molecular mechanisms by which probiotics interact with the host and the gut microbiota to enhance disease resistance.
- II. Long-term studies: Long-term studies are necessary to evaluate the sustainability and potential unintended consequences of probiotic supplementation on the gut ecosystem.
- III. Optimizing delivery: Research should focus on optimizing the delivery methods and formulations of probiotics to ensure their viability and effectiveness in aquaculture settings.
- IV. Synergistic effects: Exploring the synergistic effects of combining probiotics with other immunostimulants or alternative therapies could lead to more effective disease control strategies.
- V. Strain selection: Targeted strain selection and development based on specific pathogen challenges and environmental conditions will enhance the efficacy of probiotic applications.

Conclusion: probiotics as a key component of sustainable aquaculture

Summary of probiotic benefits

Probiotics offer a sustainable and environmentally friendly approach to aquaculture management, promoting healthier and more productive fish populations. They enhance growth, immunity, and disease resistance in various aquaculture species, reducing the need for antibiotics and other chemical treatments. By reducing the reliance on antibiotics, probiotics mitigate the risk of antibiotic resistance, contributing to a more sustainable and responsible aquaculture industry.

Addressing challenges and limitations

Further research is necessary to address current knowledge gaps and limitations of probiotic use, ensuring their safe and effective integration in aquaculture systems. Optimizing probiotic application methods and understanding their long-term impacts are critical to maximizing their benefits and minimizing any potential risks. Ensuring the safety and efficacy of probiotics is essential for their widespread adoption and acceptance within the aquaculture industry.

The future of probiotics in aquaculture

Probiotics are poised to play an increasingly vital role in sustainable aquaculture by providing a natural and effective approach to enhancing fish health and productivity. Ongoing research and development will lead to more effective and targeted probiotic applications, further enhancing their value in aquaculture. Integrating probiotics into aquaculture systems will support the growth of the industry while minimizing its environmental impact, promoting a more sustainable and responsible approach to fish farming. This comprehensive review highlights the potential of probiotics as a key component of sustainable aquaculture, offering a promising alternative to traditional antibiotic-based approaches for managing bacterial diseases. By carefully selecting and applying appropriate probiotic strains, aquaculture operations can enhance fish health, improve productivity, and minimize environmental impacts, contributing to a more sustainable and responsible industry.

Bacterial diseases remain a major challenge in aquaculture, causing significant economic losses and threatening the sustainability of the industry. Probiotics have emerged as a promising alternative to antibiotics for disease prevention and growth promotion in aquaculture. They offer several advantages, including pathogen exclusion, immune modulation, and the production of antibacterial substances. While research has demonstrated the potential of probiotics to control specific bacterial diseases, further studies are needed to elucidate their mechanisms of action, optimize their delivery methods, and assess their long-term effects. By addressing these knowledge gaps, we can harness the full potential of probiotics to improve fish health and promote sustainable aquaculture practices.

Acknowledgment

No funding.

Conflict of Interest

No conflict of interest has been reported among the authors.

References

- Aich, N; Ahmed, N and Paul, A** (2018). Issues of antibiotic resistance in aquaculture industry and its way forward. *Int. J. Curr. Microbiol.*, 7: 26-41.
- Amenyogbe, E** (2023). Application of probiotics for sustainable and environment-friendly aquaculture management - a review. *Cogent. Food Agric.*, 9: 2226425
- Ammar, A; Abdelgelel, S; Mohamed, B and Gharib, A** (2023). Motile aeromonads as a Nile tilapia bacterial infection: a review on prevalence, molecular characterization, effect on immune response and alternatives control measures. *Zag. Vet.*, 51: 112-128.
- Amoah, K; Dong, X; Tan, B; Zhang, S; Kuebutornye, FK; Chi, S; Yang, Q; Liu, H; Zhang, H and Yang, Y** (2021). *In vitro* assessment of the safety and potential probiotic characteristics of three bacillus strains isolated from the intestine of hybrid grouper (*Epinephelus fuscoguttatus*, *Epinephelus lanceolatus*). *Front. Vet. Sci.*, 8: 1-16.
- Anjur, N; Sabran, SF; Daud, HM and Othman, NZ** (2021). An update on the ornamental fish industry in Malaysia: *Aeromonas hydrophila*-associated disease and its treatment control. *Vet. World.*, 14: 1143-1152.
- Apkn, E and Altnok, L** (2009). Effects of dietary probiotic supplementations on prevention/treatment of yersiniosis disease. *J. Appl. Microbiol.*, 106: 1147-1153.
- Balczar, JL; Decamp, O; Vendrell, D; Blas, ID and RuizZarzuela, I** (2006). Health and nutritional properties of probiotics in fish and shellfish. *Microb. Ecol. Health Dis.*, 18: 65-70.
- Bentzon Tilia, M; Sonnenschein, EC and Gram, L** (2016). Monitoring and managing microbes in aquaculture towards a sustainable industry. *Microbiol. J.*, 9: 527-695.
- Biswas, S; Sarkar, S and Saha, S** (2023). Probiotics in aquaculture: a review on recent trends and application. *Int. J. Adv. Res. Trends Sci.*, 2: 1-5.
- Brunt, J; Newaj-Fyzul, A and Austin, B** (2007). The development of probiotics for the control of multiple bacterial diseases of rainbow trout, *oncorhynchus mykiss* (walbaum). *J. Fish Dis.*, 30: 10: 573-579.
- Budianto, B and Suprastyani, H** (2017). Aktivitas antagonis *Bacillus subtilis* terhadap *Streptococcus iniae* dan *Pseudomonas fluorescens* (antagonist activity of *Bacillus subtilis* against *Streptococcus iniae* and *Pseudomonas fluorescens*). *J. Vet.*, 18: 409-415.
- Cain, KD** (2022). The many challenges of disease management in aquaculture. *J. World Aquac. Soc.*, 53: 1080-1083.
- Chen, J; Li, Q; Fan, L; Xie, L; Zhang, Q and Deng, X** (2024). The impact of *Lactococcus lactis* kust48 on the transcription profile of aeromonas hydrophila-infected zebrafish spleen. *Microbiol. Spectr.*, 12: e03927-23.
- Commons, RJ; Smeesters, PR; Proft, T; Fraser, JD; Robins-Browne, R and Curtis, N** (2014). Streptococcal superantigens: categorization and clinical associations. *Trends Mol. Med.*, 20: 48-62.
- Contente, D; Feito, J; Borrero, J; Pea, N; Muoz-Atienza, E; Igrejas, G; Poeta, P; Hernandez, PE and Cintas, LM** (2020). *Lactococcus lactis* rbt18: from the rainbow trout farm to the lab, the tale of a nisin z producer. *Proceedings*, 66: 8-16.
- Das, P; Borah, P; Bordoloi, R; Pegu, A; Dutta, R and Baruah, C** (2024). Probiotic bacteria as a healthy alternative for fish and biological control agents in aquaculture. *J. Appl. Nat. Sci.*, 16: 674 -689.
- Doan, HV; Hoseinifar, SH; Ring, E; Esteban, MN; Dadar, M; Dawood, MA and Faggio, C** (2019). Host-associated probiotics: a key factor in sustainable aquaculture. *Rev. Fish. Sci. Aquac.*, 1: 16-42.
- Dutta, D** (2015). Selection and probiotic characterization of exoenzyme-producing bacteria isolated from the gut of catla catla (actinopterygii: cypriniformes: cyprinidae). *Szczecin Scientific Society. Acta Ichthyol. Piscat.*, 45: 373-384.
- Elbaz, NF and Fatah, MEAA** (2022). Bacterial disease outbreaks in some freshwater fish farms in Kafr el-Sheikh, Egypt. *J. Appl. Aquac.*, 36: 1-23.
- Fachri, M; Amoah, K; Huang, Y; Cai, J; Alfatat, A; Ndandala, C; Shija, VM; Jin, X; Bissih, F and Chen, H** (2024). Probiotics and paraprobiotics in aquaculture: a sustainable strategy for enhancing fish growth, health and disease prevention-a review. *Front. Mar. Sci.*, 11: 1-28.
- Feliatra, F; Lukistyowati, I; Nursyirwani, N; Melina, D and Ramadhani, ME** (2018). Comparative study between probiotics isolated from giant freshwater prawns and giant tiger prawns in improving the health of Nile tilapia (*Oreochromis niloticus*). *IOP Conf. Ser. Earth Environ. Sci.*, 216.
- Fidyandini, HP; Yuhana, M and Lusiastuti, A** (2016). Pemberian probiotik multispecies dalam media budi daya ikan lele dumbo untuk mencegah penyakit motile aeromonads septicemia (addition of multispecies probiotics in the culture medium of African catfish to prevent the motile aeromonads septicemia disease). *J. Vet.*, 17: 440-448.
- Gatesoupe, F** (2007). Updating the importance of lactic acid bacteria in fish farming: natural occurrence and probiotic treatments. *J. Mol. Microbiol. Biotechnol.*, 14: 107-114.
- Gong, L; He, H; Li, D; Cao, L; Khan, TA; Li, Y; Pan, L; Yan, L; Ding, X; Sun, Y; Zhang, Y; Yi, G; Hu, S and Xia, L** (2019). A new isolate of *Pediococcus pentosaceus* (sl001) with antibacterial activity against fish pathogens and potency in facilitating the immunity and growth performance of grass carps. *Front. Microbiol.*, 10: 1384.
- Hamka, S** (2021). Efek probiotik *Bacillus megaterium* ptb 1.4 dan *Pediococcus pentosaceus* e2211 terhadap repons imun dan kelangsungan hidup ikan lele (*clarias* sp.) selama ujiantang aeromonas hydrophila. *J. Fish. Mar. Res.*, 5: 567-577.

- Haniffa, MM** (2015). Effect of probiotic on microbiological and haematological responsiveness of cat fish (*heteropneustes fossilis*) challenged with bacteria *A. hydrophila* and fungi aphanomyces invadans. OMICS Publishing Group. J. Aquac. Res. Develop., 12: 1-6.
- Hong, HA; Duc, LH and Cutting, SM** (2004). The use of bacterial spore formers as probiotics: table 1. Oxford University Press. Microbiol. Rev., 29: 813-835.
- Hoseinifar, SH; Sun, Y; Wang, A and Zhou, Z** (2018). Probiotics as means of diseases control in aquaculture, a review of current knowledge and future perspectives. Front. Microbiol., 9: 2429.
- Ibrahim, MD** (2013). Evolution of probiotics in aquatic world: potential effects, the current status in Egypt and recent prospectives. Elsevier BV. J. Adv. Res., 6: 765-791.
- Irianto, A and Austin, B** (2002). Probiotics in aquaculture. Fish Dis., 25: 633-642.
- Jang, I; Kim, D and Heo, M** (2013). Dietary administration of probiotics, *Bacillus* sp. is-2, enhance the innate immune response and disease resistance of paralichthys olivaceus against *Streptococcus iniae*. Korean J. Microbiol., 49: 172-178.
- Jlidi, M; Akremi, A; Brabra, W; Hmani, H; Daoud, L; Brahim, AH; Suissi, N and Ali, MB** (2021). *In vitro* assessment of the probiotic characteristics of *Bacillus* strains from gut of gilt-head bream, *sparus aurata*. MOL2NET, 5: 2624-5078.
- Johar, S; Puvanasundram, P; Cruz, CDD; Chong, C; Yasin, IM; Lim, KC; Noordin, NM and Karim, M** (2024). *In vitro* inhibitory activities of potential probiotic isolated from *Pangasius nasutus* against *Aeromonas hydrophila* and *Streptococcus agalactiae*. Sains Malaysiana., 53: 99-110.
- Jurez-Corts, MZ; Vzquez, LEC; Daz, SFM and Flix, CSC** (2024). *Streptococcus iniae* in aquaculture: a review of pathogenesis, virulence, and antibiotic resistance. Int. J. Vet. Sci. Med., 12: 25-38.
- Kim, D; Subramanian, D; Park, SH; Jang, Y and Heo, M** (2017). Assessment and potential application of the probiotic strain, *Bacillus amyloliquefaciens* jfp2, isolated from fermented seafood-jeotgal in flounder paralichthys olivaceus juveniles. Isr. J. Aquacult. Bamidgeh., 69 :1352-1363.
- Klingklib, C and Suanyuk, N** (2017). *Streptococcus agalactiae* serotype ib, an emerging pathogen affecting climbing perch (*Anabas testudineus*) and gnters walking catfish (*Clarias macrocephalus*) polycultured in southern thailand. Thai. J. Vet. Med., 47: 183-197.
- Knipe, H; Temperton, B; Lange, A; Bass, D and Tyler, CR** (2020). Probiotics and competitive exclusion of pathogens in shrimp aquaculture. Rev. Aquacult., 13: 324-352.
- Len, J; Aponte, JJ; Cuadra, DL; Galindo, N; Jaramillo, L; Vallejo, M and Marguet, E** (2016). *Actinomycetos* aislados de argopecten purpuratus productores de enzimas extracelulares y con actividad inhibitoria de patgenos marinos. Rev. Biol. Mar. Oceanogr., 51: 69-80.
- Leong, SS; Korel, F; Lingoh, AD; Sarbini, SR; Toh, SC; Abit, LY and Wong, SC** (2023). Current probiotics application for aquaculture feed: a review. Borneo Sci., 44: 1-13.
- Lin, P; Chen, S; Wen, Z and Hu, S** (2022). Administration of the potential probiotic *Paenibacillus ehimensis* npust1 enhances expression of indicator genes associated with nutrient metabolism, growth and innate immunity against *Aeromonas hydrophila* and *Streptococcus indie* infections in zebrafish (danio rerio). Fishes, 7: 2-15.
- Lubis, AR; Sumon, MAA; Dinh-Hung, N; Dhar, AK; DelamareDeboutteville, J; Kim, D; Shinn, A; Kanjanasopa, D; Permponpattana, P; Doan, H; Linh, NV and Brown, CL** (2024). Review of quorum-quenching probiotics: a promising non-antibiotic-based strategy for sustainable aquaculture. J. Fish Dis., 47: 1-33.
- Marukov, IC; Schusterov, P; Popelka, P; Gancarkov, S; Csank, T; Fekaninov, A; Ratvaj, M and Mudroov, D** (2021). Effect of *Autochthonous lactobacilli* on immunologically important molecules of rainbow trout after bacterial infection studied on intestinal primoculture. Fish Shellfish Immunol., 119: 379-383.
- Mawardi, M; Indrawati, A; Lusiastuti, A and Teguh, W** (2023). Antibiotic resistance gene-free probiont administration to tilapia for growth performance and streptococcus agalactiae resistance. Vet. World, 16: 2504-2514.
- Meidong, R; Doolgindachbaporn, S; Jamjan, W; Sakai, K; Tashiro, Y; Okugawa, Y and Tongpim, S** (2017). A novel probiotic *Bacillus* b44v isolated from Thai pickled vegetables for potential use as a feed supplement in aquaculture. J. Gen. Appl. Microbiol., 63: 246-253.
- Min-Yeong, L and Kim, EH** (2014). Inhibitory effects of candidate probiotic bacteria on the growth of fish pathogenic bacteria, streptococcus sp.. J. Fish Pathol., 27: 107-114.
- Mohapatra, S; Chakraborty, T; Kumar, V; Boeck, GD and Mohanta, KN** (2012). Aquaculture and stress management: a review of probiotic intervention. J. Anim. Physiol. Anim. Nutr., 97: 405-430.
- Mulyadin, A; Widanarni, W; Yuhana, M and Wahjuningrum, D** (2021). Growth performance, immune response, and resistance of Nile tilapia fed paraprobiotic bacillus sp. np5 against *Streptococcus agalactiae* infection. J. Akuakult. Indon., 20: 34-46.
- Munangandu, HM; Paul, J and Evensen, Y** (2016). An overview of vaccination strategies and antigen delivery systems for *Streptococcus agalactiae* vaccines in Nile tilapia (*Oreochromis niloticus*). Multidisciplinary Digital Publishing Institute. Vaccines, 4: 48-61.
- Mustahal, M; Sevia, S; Herjayanto, M; Syamsunarno, MB and Putra, AN** (2021). The effect of adding *Bacillus* np5 to feed on growth, survival rate, and protection against *Aeromonas hydrophila* of catfish (*Clarias* sp.). IOP Publishing. The 2nd International Conference on Agriculture and Rural Development Conf. Ser.: Earth Environ. Sci., 715: 012058.

- Muthezhila, R; Yogananth, N; Akila, M; Ali, MS and Jayaprakas, M** (2019). Determination of probiotic bacteria from intestine of *Sparisoma viride* and bioencapsulation of *Artemia salina* with probiotics. *Res. J. Microbiol.*, 15: 1-8.
- Nafiqoh, N; Andriyanto, S; Novita, H; Sugiani, D and Taukhid, T** (2021). Kombinasi sirih dan kipahit sebagai imunostimulan terhadap penyakit streptococcosis pada ikan nila (*Oreochromis niloticus*). *Pusat Penelitian dan Pengembangan Perikanan. J. Riset. Akuakultur.*, 16 1: 39-47.
- Naz, K; Ullah, N; Zaheer, T; Shehroz, M; Naz, A and Ali, A** (2020). Pan-genomics of model bacteria and their outcomes. In *Pan-genomics: Applications, Challenges, and Future Prospects*. Cambridge, MA: Academic Press. PP: 189-201.
- Noshair, I; Kanwal, Z; Jabeen, G; Arshad, M; Yunus, F; Hafeez, R; Mairaj, R; Haider, I; Ahmad, N and Alomar, SY** (2023). Assessment of dietary supplementation of *Lactobacillus rhamnosus* probiotic on growth performance and disease resistance in *Oreochromis niloticus*. *Microorganisms*, 11: 1423-1442
- Novita, H; Rusmana, I; Yuhana, M and Pasa, FH** (2015). Potential of *Bacillus* sp., as a producer of ahl lactonase and its application as a probiotic for the prevention of mas in catfish (*Clarias gariepinus*). *J. Fish. Aquat. Sci.*, 10: 464-476.
- Omar, NS; Emilia, S; Danish-Daniel, M; Iehata, S and Ikhsan, NFM** (2023). Probiotics bacteria as quorum sensing degrader control *Aeromonas hydrophila* pathogenicity in cultured red hybrid tilapia. *Indon. Aquac. J.*, 18: 11-15.
- Parashuramappa, RK** (2024). Role of probiotics on aquaculture: importance and future perspectives. *Int. J. Curr. Microbiol. App. Sci.*, 137: 180-195.
- Partridge, G** (2016). Testing the efficacy of probiotics for disease control in aquaculture. *Microbiol. Aust.*, 37: 122-123.
- Pereira, WA; Mendona, CMN; Villasante, A; Marteinsson, V; LeBlanc, JG; Cotter, PD; Figueroa, E; Romero, J and Oliveira, RPDS** (2022). Use of probiotic bacteria and bacteriocins as an alternative to antibiotics in aquaculture. *Microorganisms*, 10: 1705.
- Phasunon, R; Taengphu, S; Panphut, W; Chatchaiphan, S; Dong, H and Senapin, S** (2023). Improving the diagnosis of *Streptococcus iniae* using a novel probe-based qPCR assay combined with an enrichment step. *J. Fish Dis.*, 46: 1391-1401.
- Pirarat, N; Pimpimai, K; Chankow, K; Malila, K; Chansue, N; Niyomtham, W and Rodkhum, C** (2009). *In vitro* efficacy of human-derived probiotic, *Lactobacillus rhamnosus* against pathogenic bacteria in fish and frogs. *Thai. J. Vet. Med.*, 39: 305-310.
- Puvanasundram, P; Chong, C; Sabri, S; Yusoff, MSM; Lim, KC and Karim, M** (2022). Efficacy of single and multi-strain probiotics on *in vitro* strain compatibility, pathogen inhibition, biofilm formation capability, and stress tolerance. *Biol.*, 11: 1644.
- Rahayu, S; Amoah, K; Huang, Y; Cai, J; Wang, B; Shija, VM; Jin, X; Anokyewaa, MA and Jiang, M** (2024). Probiotics application in aquaculture: its potential effects, current status in china and future prospects. *Front. Mar. Sci.*, 11: 1455905.
- Ran, C; Carrias, A; Williams, MA; Capps, NK; Dan, BCT; Newton, JC; Kloepper, JW; Ooi, EL; Browdy, CL; Terhune, JS and Liles, MR** (2012). Identification of *Bacillus* strains for biological control of catfish pathogens. *Public Library of Science. PLoS ONE.*, 7: e45793.
- Rasmussen, JA; Villumsen, KR; Jrgensen, LVG; Forberg, T; Zuo, S; Kania, PW; Buchmann, K; Kristiansen, K; Bojesen, AM and Limborg, MT** (2022). Integrative analyses of probiotics, pathogenic infections and host immune response highlight the importance of gut. *J. Appl. Microbiol.*, 132: 3201-3216.
- Ring, E** (2020). Probiotics in shellfish aquaculture. *Elsevier BV. Aqua. Fish.*, 7: 105-115.
- Samat, NA; Yusoff, FM; Rasdi, NW and Karim, M** (2021). The efficacy of *Moina micrura* enriched with probiotic bacillus pocheonensis in enhancing survival and disease resistance of red hybrid tilapia (*Oreochromis* spp.) larvae. *Multidisciplinary Digital Publishing Institute. Antibiotic*, 10: 989-1002.
- Santhi, N and Deivasigamani, B** (2017). Crop rotation as a better sanitary practice in culture of *Penaeus monodon* (Fabricius, 1798). *Int. J. Curr. Microbiol.*, 6: 1418-1443.
- Sarmah, P and Sarma, S** (2023). Probiotics for sustainable development in aquaculture: a review. *Uttar Pradesh J. Zool.*, 4: 34-46.
- Schmidt, VT; GomezChiarri, M; Roy, C; Smith, KF and AmaralZettler, L** (2017). Subtle microbiome manipulation using probiotics reduces antibiotic-associated mortality in fish. *Am. Soc. Microbiol.*, 2: 133-146.
- Shotts Jr, EB** (1990). Diagnostic approaches for fish diseases. In *Diagnostic Procedure in Veterinary Bacteriology and Mycology*. 5th edition. PP: 507-517.
- Simn, R; Docando, F; Nuez-Ortiz, N; Tafalla, C and Daz Rosales, P** (2021). Mechanisms used by probiotics to confer pathogen resistance to teleost fish. *Front. Media. Front. Immunol.*, 12: 1-19.
- Situmorang, ML; Dierckens, K; Mlingi, F; Delsen, BV and Bossier, P** (2014). Development of a bacterial challenge test for gnotobiotic Nile tilapia *Oreochromis niloticus* larvae. *Inter-Research. Dis. Aquat. Org.*, 109: 23-34.
- Sivakumar, N; Muthuraman, S and Selvakumar, G** (2012). Probiotic effect of *Lactobacillus acidophilus* against vibriosis in juvenile shrimp (*Penaeus monodon*). *Academic Journals. Afr. J. Biotechnol.*, 11: 15811-15818.
- Soliman, W; Shaapan, RM; Mohamed, LA and Gayed, SS** (2019). Recent biocontrol measures for fish bacterial diseases, in particular to probiotics, bio-encapsulated vaccines, and phage therapy. *University of Tripoli. PLoS ONE*, 7: e45793.
- Soltani, M; Shafiei, S; Mirzargar, SS and Asadi, S** (2023). Probiotic, paraprobiotic, and postbiotic as an alternative to antibiotic therapy for lactococcosis in aquaculture. *Iran. J. Vet. Med.*, 17: 287-300.

- Sudrajat, RH; Yuhana, M; Widanarni, W; Ekasari, J and Afiff, U** (2023). Dietary supplementation of *Bacillus* sp. np5 and dayak onion simplicia powder eleutherina bulbosa (mill.) urb. for the prevention of aeromonas hydrophila in catfish clarias sp. J. Akuakult. Indon., 22: 134-146.
- Sumon, TA; Hussain, MA; Sumon, MAA; Jang, WJ; Abellan, FG; Sharifuzzaman, S; Brown, CL; Lee, E; Kim, C and Hasan, MT** (2022). Functionality and prophylactic role of probiotics in shellfish aquaculture. Aquac. Rep., 25 : 1-17.
- Tamamdustu, R; Widanarni, W and Yuhana, M** (2015). Administration of microencapsulated probiotic *Bacillus* sp. np5 and prebiotic mannan oligosaccharide for prevention of aeromonas hydrophila infection on pangasianodon hypophthalmus. J. Fish. Aquat. Sci., 11: 67-76.
- Tan, C; Li, Q; Yang, X; Chen, J; Zhang, Q and Deng, X** (2022). *Lactococcus lactis* effect on the intestinal microbiota of streptococcus agalactiae-infected zebrafish (danio rerio). Microbiol. Spectr., 10: e01128-22.
- Taukhid, T; Wajdy, EF; Sugiani, D and Nafiqoh, N** (2023). Streptococcosis on Nile tilapia (*Oreochromis niloticus*) in Indonesian freshwater aquaculture. Omni-Akuatika, 19: 1-14.
- Thi, Q; Dung, TQ; Hien, HN; Trung, NB; Dung, T and Thuy, N** (2023). Antibacterial activity of lactic acid bacteria from various freshwater fish species against pathogenic bacteria in caged red tilapia (*Oreochromis* sp.). Biodiversitas, 24: 3373-3383.
- Uddin, GMN; Larsen, M; Christensen, H; Aarestrup, FM; Ph, TM and Dalsgaard, A** (2015). Identification and antimicrobial resistance of bacteria isolated from probiotic products used in shrimp culture. PLoS ONE, 10: e0132338.
- Vargas-Gonzalez, A; Barajas, M and Prez-Sanchez, T** (2024). Isolation of lactic acid bacteria (lab) from salmonids for potential use as probiotics: *in vitro* assays and toxicity assessment of salmo trutta embryonated eggs. Anim., 14: 200-223.
- Vendrell, D; Balcázar, JL; Ruiz-Zarzuela, I; De Blas, I; Gironés, O and Múzquiz, JL** (2006). *Lactococcus garvieae* in fish: a review. Comp. Immunol. Microbiol. Infect. Dis., 29: 177-198.
- Verschuere, L; Rombaut, G; Sorgeloos, P and Verstraete, W** (2000). Probiotic bacteria as biological control agents in aquaculture. Microbiol. Mol. Biol. Rev., 64: 655-671.
- Vieco-Saiz, N; Belguesmia, Y; Raspoet, R; Auclair, E; Gancel, F; Kempf, I and Drider, D** (2019). Benefits and inputs from lactic acid bacteria and their bacteriocins as alternatives to antibiotic growth promoters during food-animal production. Front. Microbiol., 10: 1-17.
- Wang, Y; Lin, H and Chang, P** (2023). Evaluation of probiotic potentiality of gm-lac (*Lactobacillus* and *Bifidobacterium*) in juvenile Asian seabass lates calcarifer. Aquac. Rep., 30: 101615.
- Wei, LS; Goh, KW; Hamid, NKA; Kari, ZA; Wee, W and Doan, HV** (2022). A mini-review on co-supplementation of probiotics and medicinal herbs: application in aquaculture. Front. Vet. Sci., 9: 869564.
- Weinstein, MR; Litt, M; Kertesz, DA; Wyper, PA; Rose, DP; Coulter, M; McGeer, A; Facklam, RR; Ostach, C; Willey, B; Borczyk, A and Low, DE** (1997). Invasive infections due to a fish pathogen, *Streptococcus iniae*. N. Engl. J. Med., 9: 589-594.
- Widanarni, W and Tanbiyaskur, T** (2015). Application of probiotic, prebiotic and synbiotic for the control of streptococcosis in tilapia oreochromis niloticus. Pak. J. Biol. Sci., 18: 59-62.
- Wu, P; Liu, C and Hu, S** (2021). Probiotic *Bacillus safensis* npust1 administration improves growth performance, gut microbiota, and innate immunity against *Streptococcus iniae* in Nile tilapia (*Oreochromis niloticus*). Microorganisms, 9: 2494-2514.
- Zabidi, A; Yusoff, FM; Amin, S; Yaminudin, NJM; Puvanasundram, P and Karim, M** (2021). Effects of probiotics on growth, survival, water quality and disease resistance of red hybrid tilapia (*Oreochromis* spp.) fingerlings in a biofloc system. Anim., 11: 3514.
- Zhou, S; Xia, Y; Zhu, C and Chu, W** (2018). Isolation of marine *Bacillus* sp. with antagonistic and organic-substances-degrading activities and its potential application as a fish probiotic. Mar. Drugs., 16: 196-208.
- Zhou, S; Zhang, A; Yin, H and Chu, W** (2016). *Bacillus* sp. qsi-1 modulate quorum sensing signals reduce *Aeromonas hydrophila* level and alter gut microbial community structure in fish. Front. Media. Front. Cell. Infect. Microbiol., 6: 1-8.
- Zorriehzahra, MJ; Delshad, ST; Adel, M; Tiwari, R; Karthik, K; Dhama, K and Lazado, CC** (2016). Probiotics as beneficial microbes in aquaculture: an update on their multiple modes of action: a review. Vet. Q., 36: 228-241.