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Utilizing probiotic supplementation in aquaculture to ensure the safety and health of fish stocks

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Abstract
Beyond its global contribution to protein security, the aquaculture industry is a cornerstone of national socio-economic stability. To satisfy the dietary needs of a burgeoning global population, the sector has shifted toward intensification. However, this has often led to the indiscriminate use of pesticides, disinfectants, and antibiotics to manage aquatic animal health. While the efficacy of probiotics in mitigating bacterial infections is well-documented, their role in managing viral outbreaks remains a subject of ongoing investigation. Research suggests that integrating probiotics throughout the entire production cycle rather than applying them reactively during disease events—significantly enhances yield. Consequently, incorporating probiotics into water, pond sediment, and feed is highly recommended, provided that practitioners carefully consider strain selection, dosage, management protocols, and timing for optimal results.

Keywords: Antibiotics, growth, immunity, aquatic, nutrient, aquatic

Introduction

The global aquaculture sector serves as a vital pillar of food security for millions, with data from the Food and Agriculture Organization (FAO, 2016, 2019) [1] highlighting that nearly 89% of all fish harvested in 2025 was destined for human consumption. Despite its importance, the industry faces significant productivity hurdles due to the prevalence of pathogenic outbreaks. Pathogenic threats are primarily driven by gram-negative bacteria, such as *Aeromonas salmonicida, A. hydrophila, Vibrio harveyi, V. anguillarum, Flavobacterium psychrophilum, Pseudomonas fluorescens, Citrobacter freundii*, and *Yersinia ruckeri* (Lewbart, 2001) [3], though gram-positive organisms like *Streptococcus spp.* also pose risks.

When these pathogens coincide with suboptimal environmental conditions, the resulting impact on output can be financially devastating for producers. Furthermore, sub-optimal management strategies such as overcrowding, improper feeding regimens, and degraded water quality frequently exacerbate the transmission of these diseases (Abarike *et al*., 2018; Hasan and Banerjee, 2020) [4, 18].

While antibiotics have traditionally been deployed to manage health issues and boost growth, their chronic application has fostered a concerning rise in antibiotic-resistant bacterial populations due to selective evolutionary pressure (Gao *et al*., 2012) [6]. The proliferation of these resistant strains poses a multifaceted threat, endangering the sustainability of aquaculture operations, the safety of end-consumers, and the integrity of local ecosystems (Elsabagh *et al*., 2018; Won *et al*., 2020) [7, 8]. Consequently, there is growing interest in the use of probiotics, implemented via feed or water supplementation, as a sustainable strategy to mitigate these risks and support the long-term viability of the industry (Zibiene and Zibas, 2019) [9].

According to Gismondo *et al*. (1999) [10], the etymology of "probiotic" originates from the Greek terms' "pro" and "bios," collectively meaning "for life." While the formal definition was first introduced by Parker (1974) [11], who described these microorganisms as agents that support intestinal microbial homeostasis, their utility has since expanded to various aquatic settings. Research by Mujeeb *et al*., (2010) and Vijayan *et al*., (2006) [12, 13] demonstrates their efficacy in freshwater, marine, and brackish environments. Among the various probiotics utilized, lactic acid bacteria (LAB) specifically genera such as *Leuconostoc*, *Pediococcus*, *Lactococcus*, *Oenococcus*, and *Enterococcus* are the most prevalent (Ouwehand *et al*., 2002) [14].

Organisms involved in aquatic probiotics

Within the aquaculture industry, probiotics serve as vital live nutritional additives, administered either as singular strains or in consortia to optimize aquatic environments and bolster the host's immunological defences. Research into effective probiotic agents encompasses a diverse array of microorganisms, such as yeasts, microalgae, bacteriophages, and various bacteria, regardless of whether they are Gram-positive or Gram-negative (Hai and Fotedar, 2015) [30].

These probiotic candidates are typically recovered from both the host's endogenous microbial community and external environments (Ferreira *et al*., 2015) [31]. Primary biological reservoirs for these microbes often include the mucosal layers and gastrointestinal systems of aquatic species (Ramesh *et al*., 2015; Tapia *et al*., 2012) [32, 33]. Furthermore, they can be harvested from surrounding aquatic habitats, such as bottom sediments, water columns, or microbial biofloc systems (Ferreira *et al*., 2015; Delduca *et al*., 2013) [31, 34]. Host-derived probiotics are frequently favored because they often possess unique biochemical traits that provide a competitive advantage in colonization (Lazdo *et al*., 2011). Consequently, strains cultivated from the intestinal tracts of both land-based and aquatic animals remain the most frequently utilized sources for commercial aquaculture applications (Hai and Fotedar, 2010) [36].

Challenges to the Aquaculture

Nomoto (2005) [15] stated that global outbreaks of bacterial, fungal, and viral diseases have resulted in enormous financial losses and it has been documented that unfavorable environmental conditions, imbalanced diet, toxin production and hereditary variables all contribute significantly to stock mortality. The use of different medications, particularly antibiotics, has been the main strategy for preventing and controlling animal diseases in recent decades. However, this

approach poses serious threats to health of the community because it encourages the choice, spread as well as perseverance of bacterial resilient strains. It is anticipated that aquaculture would supply the constantly increasing need instead of catch fisheries. In their aquatic culture ponds, fish growers raise the stockings to unachievable levels due to the excessive demand. They become more vulnerable to opportunistic infections and disease outbreaks as a result of the stress caused by overcrowding. Antimicrobial resistance develops and spreads in aquatic systems as a result of excessive administration of antibiotics prompted by the increasing incidence of number of diseases and therapeutic interventions (Nayak *et al*., 2023) [16].

Need for the Probiotics Nair *et al*. (2017) [17] explained the idea to overcome all the above-mentioned challenges with a new emerging approach that is being used named as probiotics. The definition of probiotics is, a live microbial supplement that exerts beneficial effect through various mechanisms by modifying the microbial community associated with the host, improving the feed utilization, increasing its dietetic value, boosting the host's response to diseases or enhancing the overall quality of the host's ambient environment. Probiotics are a vast range of organisms that include yeast, bacteria, fungus, microalgae and their products. Probiotics are becoming more and more popular as a preventive and therapeutic measure because of the growing risk of antimicrobial resistance brought on by the widespread applications of antibiotics (Hasan and Banerjee, 2020) [5]. Probiotics are being used more frequently and have been shown to be helpful in reducing the incidence of disease through a number of mechanisms, including better nutrient utilization through the breakdown of complex substances in the environment and feed, the mineralization process, participation in the biogeochemical cycles, preservation of water quality, and enhancement of immunological parameters (Melo-Bolivar *et al*., 2020) [20]. Probiotic benefits its host as well as the environment through different ways as elaborated in this definition. Probiotics always prefer the importance of health for their hosts along with the characteristics i.e., their proper utilization to feed, better nutrition and a host's healthy environment. According to the updated definition, the idea of possible uses of probiotics and their advantages are illustrated more precisely even from the diverse context (Anadon *et al*., 2019) [19].

Commercial Preparations

The interest in probiotics as an environmentally friendly alternative is increasing and its application is both empirical and scientific. According to Soccol *et al*., 2010[21], the global market for probiotic ingredients, supplements and foods, reached US $15,900 million in 2008 and is projected to increase to US $19,600 million in 2023, representing an annual growth rate of 4.3%. At present, there are several commercial preparations of probiotics that contain one or more live microorganisms, which have been introduced to improve the cultivation of aquatic organisms. Probiotics can be used as a food additive added directly to the culture tank or mixed with food.

Apart from laboratory preparation of bacteria, some commercially available products are now available. One of the first evaluations of commercial products focussed on a bacterial preparation called Bio start that is derived from Bacillus isolates. It was used during the production of cultured catfish studying the effect of inoculum concentration (Queiroz and Boyd 1998). In 1998[22], Moriarty reported that the use of commercial viability of pond-raised shrimp (Moriarty, 1998) Meanwhile, Chang and Liu, (2002) [23, 24] evaluated the effect of *Enterococcus faecium* SF68 and Bacillus toyoi isolates present in Cernivet LBC and Toyocerin, respectively, to decrease the mortality of the European eel because of the edwardsielosis, ensuring greater efficiency with E. faecium SF68. It is relevant to note that E. faecium has long been known as a probiotic for humans, whereas B. toyoi has been used with terrestrial animals. Moreover, a B. subtilis strain combined with hydrolytic enzymes to produce Biogen, was used to supplement the feed of Oreochromis niloticus, obtaining significant increases in productivity (Haroun *et al*., 2006) [25].

Disease and stress resistance

The interaction between fish and their environment is much more complex than that of terrestrial animals. According to Irianto and Austin (2003), microbial interaction with its host does not only occur in the digestive tract but also the gills, skin, or environment Probiotics that are administered toward the suitable target will play an important role in improving host growth. This happens because probiotic bacteria act as microbial balance controllers in the digestive tract, enhancing the absorption of feed nutrients and improving the nutritional value of feed (Hasyimi *et al*., 2020). According to Agustina *et al*. (2018) [26, 27], the *in vitro* bacterial inhibition test stage analysis refers to the diameter of antibiotic inhibition. Staphylococcus edaphicus is one of the potential probiotics that can increase the immunity component in Kelabau fish (Osteochilus melanopleurus) after a challenge test with bacteria A. hydrophila AH-1 and Pseudomonas sp. PS-1. The best results showed that the addition of intestinal bacteria isolates (Staphylococcus edaphicus) can increase the survival rate by 86.67% in fish compared to control 56.67%. Interestingly, previously conducted research by Istiqomah *et al*. (2019) [9] showed that Staphylococcus sp. strain JC20 could also be a potential aquaculture probiotic. After isolating and characterizing the bacterial strain Staphylococcus sp., it was proven to have strong cellulolytic activity and had the potential to be used as a candidate probiotic for fish.

Use of probiotics for sustainable aquaculture

Now a days there is rising interest in the use of beneficial bacteria, probiotics, as an alternative approach to antimicrobial compounds for disease prevention and control. These naturally occurring bacteria utilize their beneficial effects on the host by revising the microbial community associated with host, by guaranteeing improved use of the feed or enhancing its nutritional value, or by enhancing the host response towards diseases. The probiotic increase the growth and survival of fish and shrimp by modifying the host associated or ambient microbial community (Suguna 2020) [37].

Role of probiotic in improvement of feed utilization

The probiotic used in aquaculture is a live microbial addition, supplied through feed which yields beneficial effect by modifying the gut microflora by enhancing feed absorption, nutrition and immunity against the pathogenic bacteria in the gut. The probiotic bacteria normally produce antimicrobial agents like bacteriocins and organic acids which complete with pathogens and cease the adhesion of

pathogens in the Gastro Intestinal Tract (GIT) of aquatic animals. Hence, the probiotics bacteria are called as friendly or health bacteria. potentially GIT harbours various pathogenic bacteria like Escherichia coli, Listeria and Salmonella along with other probiotic bacteria. The other probiotic bacteria which are commonly found in GIT are Canbobacterium, gram positive Bacillus, Enterococcus, Lactobacillus and gram negative facultative anaerobic such as vibrio and pseudomonas and yeasts, fungi and algae (Suguna 2020) [37].

Conclusion

Probiotics have demonstrated efficacy in improving the growth performance, feed utilization, disease resistance, and water quality management in various aquaculture systems. The mechanisms underlying these effects, which include improving gut health, modulating immune responses, and reducing environmental stressors, position probiotics as an essential tool in promoting sustainable aquaculture.

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