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Role of Gut Microbes on Growth and Health of Fish

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ABSTRACT

The gut microbiome of fish is essential for their overall health, immunity, and digestion. Despite its importance, fish gut microbes are less studied compared to those of ruminants. This microbiome comprises both autochthonous and allochthonous bacteria and differs based on species, diets, and habitats. For example, freshwater fish commonly contain genera such as Aeromonas and Clostridium, while marine species typically host Vibrio and Micrococcus. The increasing use of plant-protein-based aquafeeds has raised concerns about anti-nutritional factors (ANFs) that may disrupt gut health and the composition of the microbiota, which can, in turn, affect fish immunity and growth. Microbial populations are known to adapt to their gut environments, which are influenced by factors like pH gradients and the developmental stages of the fish, playing vital roles in digestion, nutrient metabolism, and immune regulation. Probiotics, such as Lactobacillus and Bacillus, contribute positively to gut health by competing against pathogens, producing antimicrobial substances, and bolstering the gut-associated lymphoid tissue (GALT). However, while plant-based feeds can change gut structure and microbial balance, potentially leading to dysbiosis, the addition of probiotics can help alleviate these issues. Understanding gut microbiomes is critical for sustainable aquaculture, as it allows for the optimization of fish diets. Future research should focus on exploring how microbial-host-environment interactions work, the ways microbes contribute to fish health, and the development of customized microbiota suited for various aquaculture systems to boost fish resilience and productivity.

Introduction

Research on gut microbiota in fish is still in its early stages and remains underexplored compared to ruminant microbes, where microbial digestion is well-studied. Although the focus from 1950 to 1970 was on the impact of dietary composition on fish gut microbes, it has become clear that, rather than primarily aiding digestion, these microbes play a more significant role in the health and immunity of fish. The gut serves as the main entry point for pathogens, highlighting the importance of understanding its microbial community for improving fish health. Gut microorganisms are classified into two types: autochthonous and allochthonous. Autochthonous bacteria are able to grow on the epithelial surface of the intestinal wall. whereas allochthonous bacteria are located in the gut lumen, primarily deriving from dietary sources. Dietary components have a significant impact on the composition of gut microbes. As a result, the overall health of fish is closely connected to their diet. The structure of the gut varies significantly across fish species, with differences influenced by feeding habits, habitat, and physiology. These structural variations lead to distinct microbial populations in different gut segments. Carnivorous fish, for instance, often have shorter and more acidic digestive tracts adapted for digesting protein-rich diets, which harbor microbial communities distinct from those found in herbivorous fish. Herbivorous fish, on the other hand, possess longer, more complex intestines designed for the fermentation and breakdown of plant material, fostering a microbial composition that includes bacteria specialized in digesting cellulose and other plant-derived polysaccharides. Differences are also notable between freshwater and seawater species. The environmental conditions of their habitats, such as salinity, temperature, and nutrient availability, play a role in shaping

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the microbial communities present in the gut. For instance, freshwater fish often host microbes better adapted to lower salinity, while marine species have microbiota suited for high-salt environments. Furthermore, the chemical environment within the gut also influences microbial composition. In fish with stomachs, the acidic pH creates a selective environment, favoring microbes that tolerate low pH. As gut contents progress to the distal intestine, the pH gradually becomes alkaline, fostering a different microbial community. Stomach less fishes, which lack this acidic environment, exhibit unique microbial profiles that are evenly distributed along the gut. When plant protein sources are used in aquafeed instead of animal protein sources, the microbial makeup becomes crucial. The immune system of fish has been weakened by the irregular availability of fish meal and fish oil as well as the usage of plant-protein-based feed additives. According to Francis et al. (2001); Mohanta (2012); and Ghosh et al. (2019), plant proteins offer a good nutritional profile, they also contain inherent anti-nutritional factors (ANFs) such as tannins, phytates, trypsin inhibitors, lectins, saponins, alkaloids, and glucosinolates. These ANFs can negatively impact fish growth and health by disrupting digestive enzyme activity, reducing nutrient bioavailability, and altering the gut microbiome (Ringo et al., 2016). In freshwater fish, the major gut microbiota genera include Aeromonas, Pseudomonas, Flavobacterium, Lactococcus, Acinetobacter, and Clostridium. In contrast, marine fish predominantly host Aeromonas, Pseudomonas, Flavobacterium, Vibrio, and Micrococcus species (Gomez & Balcazar, 2008). These microorganisms form a symbiotic relationship with the host, contributing to digestion, metabolism, growth, and immunity by providing essential nutrients and aiding in various physiological processes. Generally, a nutrient-rich gut environment is considered highly favorable for microbial attachment and growth, with a density of around 108 microorganisms per gram of tissue (Ray et al., 2012; Wong et al., 2013; Merrifield and Rodiles, 2015). These gut-associated microbes secrete digestive enzymes and assist in the digestion process (Ringo et al., 2012; Hoseinifar et al., 2015; Banerjee et al., 2019).

Gut microbiota plays a crucial role in controlling appetite, feed intake, digestion, absorption, and growth (Fetissov, 2017; Read & Holmes, 2017). Duca et al. (2012) found that mice with a healthy gut microbiome grew better than those without one. Mice lacking gut microbes had lower levels of ghrelin and leptin, hormones involved in hunger and appetite control. In fish, feeding Lactobacillus rhamnosus did not affect zebra fish feed intake, but rohu (Labeo rohita) showed changes in gut microbiota when fed fructo-oligosaccharides (Falcinelli et al., 2018; Kim & Claire, 2018). Gut microbiota also affect metabolism in grass carp, zebrafish, and Japanese flounder, helping with the absorption, transport, and metabolism of fats (Semova et al., 2012; Sheng et al., 2018). The fish gut microbiome changes with developmental stages: Proteobacteria and Bacteroidetes dominate in the eggs and larvae of grass carp, while adults show greater diversity with groups like Fusobacteria, Proteobacteria, Bacteroidetes, and Firmicutes becoming more common (Wang et al., 2015; Yan et al., 2016).

Immune responses

The fish intestine plays a pivotal role in immune defense as it hosts a diverse microbiota, including non-pathogenic, pathogenic, and commensal bacteria. The balance between these microbial populations plays a critical role in maintaining the fish's immune system and overall health. The gut microbiota contributes significantly to the regulation of energy balance and protection against harmful pathogens, earning it the recognition of being an "extra organ" for the host due to its indispensable role (O'Hara & Shanahan, 2006). One of the primary defenses in the fish intestine is the mucus layer produced by the gastrointestinal tract, which acts as a physical and biochemical barrier. This mucosal layer not only prevents direct contact of pathogens with the epithelial cells but also plays a critical role in the maturation and functioning of the fish's immune system. Banerjee & Ray (2017) highlighted the gut microbiota's ability to produce enzymes, outcompete pathogens for binding sites, and secrete bacteriocins—antimicrobial compounds that inhibit the growth of harmful bacteria. The interaction between external microorganisms, antigens, and the host's gut microbiome takes place at the mucosal layer. In response to these interactions, the mucosal layer, along with epithelial cells, releases an array of antimicrobial substances. These include complement proteins, mucins, and antimicrobial peptides such as piscidins and defensins (Silphaduang et al., 2006; Zou et al., 2007). Piscidins and defensins are particularly potent against a broad spectrum of pathogens, enhancing the fish's ability to fend off infections. Probiotics have been demonstrated to play a crucial role in enhancing the immune response in fish. Perez et al. (2007) observed that the presence of Lactobacillus in the gastrointestinal tract reduced the occurrence of furunculosis in rainbow trout. This suggests that beneficial bacteria can actively suppress disease-causing pathogens. Furthermore, Yee et al. (2013) observed that establishing probiotic bacteria like Paenibacillus, Bacillus, and Staphylococcus in the fish intestine not only suppressed harmful bacteria such as Aeromonas hydrophila, A. salmonicida, and Vibrio alginolyticus but also improved nutrient absorption and overall health.

Gut Immunity

The gut-associated lymphoid tissues (GALT) play a central role in regulating the immune system within the gastrointestinal tract. These tissues form part of the broader mucosal immune system and are crucial for maintaining the balance between immune tolerance and defense against pathogens. Research has shown that the gut microbiota significantly influences this immune regulation. For instance, Rekecki et al. (2009) demonstrated that the production of glycoproteins in the gastrointestinal tract of European sea bass (Dicentrarchus labrax) is shaped by the resident microbial community. These glycoproteins are essential for various functions, including mucosal barrier integrity and immune signaling.

Further highlighting the importance of the microbiota, Rawls et al. (2007) reported that the gut microbial community modulates the expression of genes related to innate immunity. These genes include those involved in the complement system, which aids in pathogen clearance, as well as genes encoding C-reactive proteins, myeloperoxidase, and glutathione peroxidase. These molecules collectively enhance the fish's ability to neutralize harmful microbes and mitigate oxidative stress. Additionally, Actinobacteria, a group of bacteria, play a role in regulating the secretion of interleukin-10, which is important for controlling inflammation (Lee & Mazmanian, 2010). Ibrahem (2015) noted that feeding fish with probiotics offer a practical approach to improving gut health in fish. Feeding fish with probiotics enhances the composition of their gut microbiota, leading to better immune function, growth, and overall health. Commonly recommended probiotics for fish diet include Bacillus subtilis, Bacillus cereus, Lactobacillus casei, Lactobacillus acidophilus, Bacillus megaterium, and Arthrobacter sp. (Dahiya et al., 2012; Bhatnagar & Lamba, 2014; Efendi & Yusra, 2014; Vand et al., 2014). These probiotics not only boost immunity but also enhance nutrient absorption and provide resistance against various pathogens, making them a valuable component of aquaculture diets.

The transition from fish meal-based feeds to plant-based alternatives in aquaculture has brought about significant changes in the intestinal structure of fish, which could have far-reaching implications for gut health and overall well-being. One notable consequence is damage to the lamina propria and mucosal folds, both of which are integral to the gut's structural integrity and function.

These alterations may compromise the intestinal barrier and impact the attachment sites for beneficial bacteria, potentially disrupting the delicate microbial balance within the gut. Such disruptions can hinder the fish's ability to maintain an effective immune response and nutrient absorption. In this context, understanding the intricate interactions between gut microbes, the host organism, and environmental factors becomes crucial for advancing sustainable aquaculture practices. Beneficial microbes, particularly species of Bacillus and Lactobacillus, have demonstrated positive effects on fish immunity and overall health. These probiotics can enhance immune function, protect against pathogens, and improve gut integrity, providing an effective, sustainable alternative to conventional methods of disease control in aquaculture systems. Another critical aspect of gut health is the identification of microbial imbalances, or dysbiosis, within the intestinal microbiome. Dysbiosis can serve as an early warning sign of stress-related issues, such as poor water quality, inadequate nutrition, or overcrowding, which may predispose fish to disease and increase mortality rates. Monitoring and addressing dysbiosis could therefore play a pivotal role in maintaining fish health and preventing outbreaks of disease. The gut microbiome of teleost fish has emerged as a key area of research for the future of aquaculture. While significant progress has been made in understanding its composition and function, there remain many unexplored aspects. Further research into microbial diversity, host-microbe interactions, and the development of targeted probiotics could pave the way for more resilient and sustainable aquaculture practices.

Conclusion

As aquaculture shifts towards plant-based feeds, the role of microbial biomass in fish will become increasingly important for adapting to these new diets. Therefore, a thorough understanding of the fish gut microbiome is crucial for sustainable aquaculture. Both biotic and abiotic factors significantly influence gut microbiota, making it essential to research and develop a microbiota that is well-suited to each species and its environment. Some researchers have already started studying the gut microbiota of trout fed with plant-based diets. Additionally, feeding fish specific diets can help develop a beneficial microbiota, which may enhance their growth and immunity.

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