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Immune System and Nutrition in Fish

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Özet

Fish have a complex immune system consisting of various defense mechanisms to protect their bodies from disease-causing organisms and external threats. While fish's immune system shares some similarities with that of humans, it also has some differences. Understanding and researching the immune system of fish in recent years has become crucial for combating infections in both natural habitats and fish farms. The health of fish depends not only on environmental factors but also on the strength of their immune systems. In fish farms, the risk of infectious diseases spreading increases due to high fish density and limited living spaces. Therefore, fish producers employ various methods to strengthen the immune system of fish. Immunostimulants play a significant role in this context. These compounds, which stimulate both specific and non-specific immune systems in fish, can enhance resistance to infectious diseases. The immune system of fish can vary depending on species and environmental conditions. Factors such as nutrition, stress, water temperature, and water quality can affect the immune system of fish. Thus, in situations like fish farming or aquarium maintenance, measures such as maintaining proper water conditions, providing balanced nutrition, practicing hygiene, and implementing disease prevention strategies should be taken into account to support the health of fish.

Keywords: Fish, İmmune system, Nutrients, Immunonutrition

INTRODUCTION

Immune system in fish

Knowledge of immune defenses is remarkably advanced in mammals, and this knowledge is generally taken as a basis for comparative studies in other vertebrates. This is mainly due to the similarity in the anatomical and functional organization of the immune system among vertebrate species. However, in recent years some difficulties have emerged in transferring the experimental knowledge in immunology acquired in mammals to ectothermic vertebrates, particularly in fish. These difficulties originated from the increasing number of fish species investigated, each one living in a unique environment and thus requiring unique handling conditions, from the use of outbred species with high genetic variability in immune responses and, mainly, from the lack of markers for cellular and molecular components of the immune system (Randelli et al., 2008). Since fish are cold-blooded animals, their immune properties are quite different from mammals. Cold-blooded animals change their body temperature depending on their external environment. This requires them to adjust their metabolism and behavior according to temperature changes. The mammalian immune system includes specialized organs such as bone marrow and lymph nodes. Bone marrow is a place where white blood cells are produced and matured. Lymph nodes, on the other hand, are regions where immune cells interact and pathogens are recognized. In fish, these organs are either absent or very limited. Therefore, the immune system of fish relies on different mechanisms than that of mammals (Press and Evensen, 1999). Among the factors that significantly affect the immune system of fish are the physical and

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chemical characteristics of the aquatic environment. Careful management of these factors in fish farming or natural habitats is of critical importance for maintaining the health and immune system of fish (Altınterim, 2011).

The immune system of vertebrate animals encompasses both acquired immunity and innate immunity responses. The first line of defense against infection occurs through innate immunity and this process occurs independently of antibodies. Unlike acquired immunity, innate immunity is faster and does not necessitate prior exposure to pathogens. Various proteins that serve as opsonins to neutralize pathogens have direct antibacterial activity (Epstein et al., 1996; Sumyia and Summerfield, 1997). The immune system in fish includes a range of factors that prevent infections and enable the body to respond to infections. Among these factors are natural immune cells, the complement system, interferons, antiviral proteins, and many other molecules and mechanisms. The natural immune system of fish plays a crucial role in defending the body against infections and combating diseases. The combination of these factors is critical in providing fish with resistance to infections (Aoki and Neurosci, 1992).

Like other vertebrates, fish also divide their immune system into two main categories: non-specific (innate) and specific (adaptive) immunity. The primary defense mechanism of fish relies on the non-specific immune system. This system cansubpart respond rapidly without the need for the recognition of antigens (foreign substances). This means that infections can be quickly controlled. The non-specific immune system protects the body against pathogens (microorganisms such as bacteria, viruses, and fungi) while showing relatively less variation depending on body temperature. This contributes to the ability of fish to tolerate different water temperatures. Despite these advantages, the non-specific immune system may be inadequate against some infections that require a more specific and customized response. Therefore, in some fish species, the specific immune system has also developed, and they can generate acquired immune responses. The immune systems of fish are formed through a combination of specific and non-specific immune mechanisms, allowing them to mount highly effective defenses against various infections (Ellis, 2001).

The immune system, due to this complexity, is divided into subparts. These subparts are referred to as specific/non-specific immunity, acquired immunity/innate immunity, or even mucosal/systemic immunity (Timothy, 2008). In recent years, immunological research in fish has been primarily divided into two main areas. Firstly, developmental and comparative studies have led to a better understanding of the functional and structural evolution of the immune system from fish to invertebrates and then to mammals. Fish provide an interesting model to study the interaction between the innate and adaptive components of the immune system, and a significant delay often occurs between the onset of infection and the emergence of adaptive responses. The second significant aspect encompasses the financial requirements of the aquaculture industry. The growth of the aquaculture sector worldwide over the past decade has made it necessary to obtain comprehensive information about the immune systems of commercially important fish species. There are two reasons for this demand: to optimize the natural immune defense system of fish under culture conditions and to advance fish stock selection, as well as to develop and proliferate protective measures such as probiotics and vaccines (Magnadottir, 2010).

Immunity in fish comes in two forms: 1) Innate immunity and 2) Adaptive immunity. Innate immunity is known as the body's ability to naturally recognize signals from substances that are inherently foreign and dangerous. This system recognizes the protein structures of bacteria, fungi, and disease-causing compounds using a limited number of patterns. These patterns are specific to compounds found on the surface of

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microorganisms, such as glycoproteins and lipopolysaccharides (Arda et al., 2002). Adaptive immunity: Unlike the response mechanisms of innate immunity, adaptive immunity is a component of the immune system in which cells like lymphocytes carry specific receptors. These receptors can recognize various substances produced by microorganisms and even non-infectious molecules. Adaptive immunity is characterized by the ability to develop a specific response to the body and its ability to create specific mechanisms to combat different types of microorganisms (Abbas and Lichtman, 2007).

It emphasizes the complexity and adaptability of the immune system. Innate immunity is based on the organism's genetic traits and the evolutionary history of the species and is shaped over time by interactions with environmental factors and pathogens. This illustrates how versatile and dynamic the body's self-defense capability is. Thanks to its ability to adapt to environmental changes, the immune system can develop more effective defenses against infections and can adapt evolutionarily appropriate responses. Therefore, the immune system provides an important evolutionary advantage in supporting the survival and resistance of animals to various infections (Janeway and Medzhitov, 1998; Carroll and Janeway, 1999; Du Pasquier, 2001, 2004; Alvarez-Pellitero, 2008). During the processes of development and growth, various systems within the bodywork to ensure the organism's healthy and balanced growth. At the same time, even when external or internal stress factors such as inflammatory reactions or tissue damage occur, the organism strives to maintain this balance (Magnadottir, 2010). Innate immunity encompasses the natural defense mechanisms of an organism and forms the first line of defense against infections with rapid responses. Macrophages and monocytes are essential cell types that recognize foreign substances entering the body and act to destroy them. Granulocytes are directed to sites of inflammation and infection, aiding in the destruction of pathogens in infected areas. Additionally, humoral elements like lysozyme and the complement system are significant components of the innate immune system. Lysozyme is an enzyme used to eliminate bacteria, while the complement system consists of a series of proteins and protein complexes that initiate natural killing mechanisms against pathogens. When these components come together, they assist the organism in developing rapid defenses against infections and help cope with diseases. The innate immune system is a crucial defense line that regulates the immune responses of the organism and provides protection against pathogens (Secombes and Fletcher, 1992; Magnadottir, 2006). Phagocytosis is an important component of innate immunity, especially in organisms like fish, against pathogens such as bacteria, viruses, and parasites, and it is used in the fight against these pathogens. Phagocytosis works by engulfing and destroying pathogens. Additionally, different pathways like the alternative, lectin, and classical pathways can lead to various outcomes, including the formation of the membrane attack complex and cell lysis, or they can involve the activation of the adaptive immune response through the opsonization of the pathogen. These processes can help diversify the organism's defense strategies against pathogens and facilitate adaptation. Furthermore, enhancing phagocytosis through the classical pathway can trigger the activation of the adaptive immune response. In conclusion, phagocytosis and these different immune pathways are essential components of the organism's defense mechanisms against pathogens and are intricately regulated by the immune system (Nonaka and Smith, 2000; Boshra et al., 2006).

This explanation emphasizes that adaptive immunity is an immune mechanism used by the organism to develop a more effective response against specific pathogens. Adaptive immunity initiates a response when the organism encounters a specific pathogen for the first time and provides a stronger response upon re-encountering the same pathogen. This allows the immune system to develop a more effective defense mechanism against pathogens.

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Additionally, it mentions that the activation of the adaptive immune system involves processes such as the selection of specific receptors, cellular proliferation, and protein synthesis. These processes may take time but have long-lasting effects in regulating the immune response. In conclusion, adaptive immunity is a crucial component of the immune system, enhancing the complexity and effectiveness of the organism's immune response (Dixon et al., 1995; Du Pasquier, 2000; Harding and Neefjes, 2005; Huttenhuis et al., 2005; Randelli et al., 2008).

Immunonutrition

Fish health is closely related to what they eat, or more specifically, how they are fed in the context of aquaculture. Proper feed and feeding regimes are of utmost importance for the health of fish. While fish nutrition and fish immunity have existed as separate fields since the early 1960s, it was only in the late 1980s that the scientific community began to merge these two areas. The past decade has witnessed a rapid increase in research in this field, driven not only by interdisciplinary efforts and the availability of modern genomic tools but also by a better understanding of preventive health measures and the central role of feeds in maintaining the health of fish. Current knowledge about the immune responses of fish to nutrients, feed ingredients, or additives is based on a limited number of selected substances (Kiron 2012).

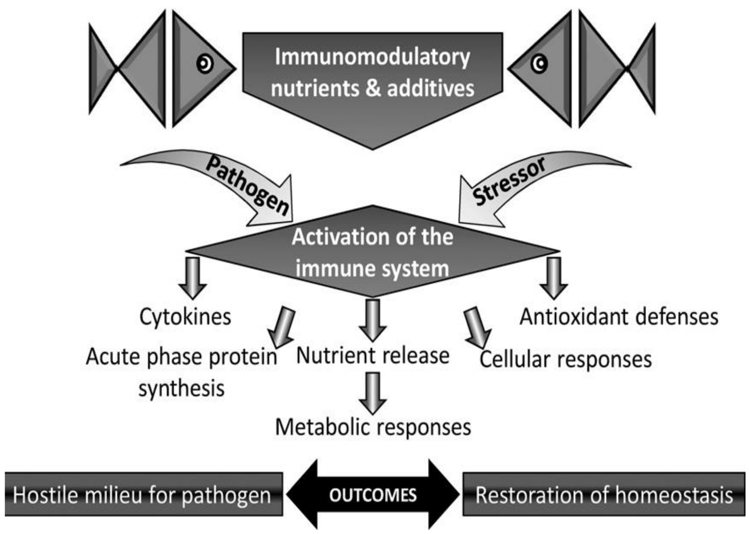

Figure 1*. The concept of immunonutrition in preventive health (Kiron 2012).*

Nutrients

Nutrients can influence fish health and their immune systems in ways that can enhance their resistance to infections. Specific nutrients like vitamin C, vitamin E, and lipids are known to have positive contributions to fish health. A deficiency in these nutrients can have adverse effects on fish health and weaken their immune systems. Therefore, the aquaculture and seafood industries should focus on carefully managing fish nutrition and ensuring the provision of these essential nutrients. In conclusion, nutrients play a critical role in maintaining fish health and their immune systems, making this a matter of significant importance. According to Hardy (2001), This description emphasizes that vitamin C plays a role in various processes by

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affecting biological metabolism, particularly regulating steroid and collagen formation. Vitamin C is an important vitamin for the organism and contributes to many vital functions.

Vitamin C deficiency can lead to a range of negative health effects. These effects include growth problems, loss of appetite, and poor feed utilization, among nutrition-related issues. Additionally, it can cause more serious health problems such as pigment deficiency, anemia, spine deformities, and organ hemorrhages. Therefore, it is important to ensure an adequate intake of vitamin C within a balanced diet (Blazer and Wolke, 1984a).

Vitamin E emphasizes its importance for both marine and freshwater fish. This importance is particularly associated with its antioxidant properties because these properties can prevent the oxidation of unsaturated fatty acids. Furthermore, it can promote cell proliferation in immunogenetic organs, increase the number of antibody-producing plasma cells, stimulate helper T lymphocytes, and enhance phagocytic activity. This can, in turn, affect both humoral (related to body fluids) and cellular immune responses.

The various effects of Vitamin E point to its positive contributions to the immune system of fish, underscoring the importance of having an adequate amount of vitamin E in their diets. This is a vital factor in maintaining fish health and making them more resilient against infections (Tacon, 1985).

Proteins, amino acids

Proteins provide the essential amino acids required for the proper functioning of animals' bodies. They also serve as the source of nitrogen needed for the synthesis of these amino acids and contribute to the formation of nitrogen-containing compounds used in important biochemical processes in the body. Therefore, dietary proteins are considered a critical component for the growth, energy production, and overall health of animals (Young, 2000). The deficiency of protein and amino acids can adversely affect the normal protein production capability of cells and ultimately render these cells non-functional. Fish, in particular, require approximately ten essential amino acids for the proper functioning of their bodies. This highlights how critical it is for their healthy growth and functionality to obtain these essential nutrients. Additionally, this sentence alludes to a general biological principle by indicating that other living organisms also have a similar need for amino acids and proteins (Hardy, 2001). Feeds based on high-quality fish meal are effective in providing the amino acids that fish require. However, when the amino acid content from alternative sources replacing fish meal in feeds is insufficient, the health and growth of fish can be jeopardized.

This is particularly important in the field of fish farming and aquaculture because the quality of fish feeds directly impacts the productivity and health of the cultivated fish. Therefore, fish feed producers and fish farmers should be cautious in developing and using suitable feeds that meet the nutritional requirements of fish (Tacon, 1995).

Amino acids play a significant role in the synthesis of various important proteins, including components of the immune system such as antibodies. While certain amino acids, particularly arginine, glutamine, and cysteine, may have received more attention in terms of nutrition and immunity, other amino acids also play a crucial role in maintaining immune competence and preserving resistance to diseases. Imbalances or antagonisms among amino acids can hinder the effective utilization of nutrients and have a negative impact on immune organs and responses. Therefore, proper nutrition and maintaining the balance of amino acids are of critical importance for a healthy immune system (Li et al., 2007).

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Lipids, fatty acids

Lipids serve as both an energy source and fulfill the requirements of essential fatty acids (EFA). Vertebrates like fish require precursor fatty acids or their highly unsaturated metabolic derivatives in their diets. When we examine the effects of various polyunsaturated or monounsaturated fatty acids on immune functions in mammals, these fatty acids can influence the immune system through various mechanisms. The increased use of alternative lipid sources, especially vegetable oils, in response to the decrease in marine resources, has led to a reduction in natural essential fatty acid sources in fish feeds. These changes can challenge the physiological mechanisms of fish, especially in carnivorous fish species, and may impact immune functions (Kiron et al., 1995, 2011; Bell et al., 1996; Montero et al., 2008).

Antioksidan micro nutrients

The content of antioxidant micronutrients, including vitamins A, C, and E, carotenoids, and various minerals, especially selenium, zinc, copper, manganese, and iron, is emphasized. These nutrients possess important antioxidant properties that are crucial for the health of fish.

It is mentioned that fish feeds typically contain these vitamins and minerals, aiding in meeting the nutritional requirements of fish. However, in aquaculture, it is noted that there may be deficiencies in these nutrients, necessitating supplementary feeding. This is particularly important in situations where fish cannot obtain these nutrients directly, such as in aquarium environments or natural habitats (Hardy, 2001). It is known that incorrect feeding practices, feed production errors, and storage conditions can lead to nutrient deficiencies. Furthermore, research has shown that the stability of micronutrient substances such as vitamins and carotenoids can be affected by the extrusion process used during feed production. This information emphasizes the importance of proper feed production, storage, and feeding practices in fish farming and aquaculture. Incorrect feed production or storage conditions can prevent fish from obtaining essential nutrients and may lead to health issues, underscoring the need for careful attention to these aspects. Additionally, studies have highlighted how crucial feed production processes are in preserving the stability of the nutrients they contain (Riaz, 2000; Anderson and Sunderland, 2002).

Supplements

Additives are substances intentionally added to feeds and have various functions such as regulating the immune system, alleviating stress, or preventing pathogens. These substances have been evaluated and approved by the European Food Safety Authority (EFSA). These additives have the potential to influence the natural defense mechanisms of fish, and it is noted that this can occur through their direct effects on cell receptors or their effects on genes associated with the immune system. Therefore, these additives are typically incorporated into feeds, especially during stressful aquaculture processes such as sorting, transfer, vaccinations, or critical life stages. This practice helps animals become more resistant to pathogens and maintain good health (Bricknell and Dalmo, 2005).

Protectıve nutrıtıon

The feeding habits and immune system of fish involve a complex array of different physiological processes occurring in various organs at different regulatory levels. These processes encompass various aspects such as the intake, absorption, metabolism of nutrients, and the regulation of immune responses. Additionally, feeds are complex mixtures containing different nutrients, which elicit various physiological responses to

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support processes like growth, energy production, immune function, and overall health in fish. Therefore, the interaction between nutrition and the immune system entails a multitude of physiological processes and has a significant impact on fish health (Panserat and Kaushik, 2010).

Dietary immunomodulation has significant potential in aquacultural production for preventing or treating diseases. It involves optimizing immune function and resistance to diseases by adding nutrients and non-nutritive immunostimulatory compounds to diets. If consistent reductions in mortality rates can be demonstrated, this approach can be cost-effective. However, further research is needed in this field. Particularly, questions regarding the diversity of fish and pathogen species, the amount of nutrients and non-nutritive immunostimulatory compounds needed for protection, and the duration of different treatments need to be addressed using standardized protocols. This way, we can better understand how to effectively utilize dietary immunomodulation in aquacultural production (Delbert, 2003).

The effects of nutrition on disease resistance mechanisms and the potential effects of these effects on the incidence and severity of infectious diseases are quite important. Various nutrients, such as vitamins, minerals, and fatty acids, are mentioned to play a role in increasing disease resistance. It is stated that there is potential for the diet to enhance disease resistance, but there are still many questions to be answered in this area. An important point emphasized is that feeds that promote high growth may not necessarily guarantee the optimal immune response. In other words, using feeds that only stimulate growth may not be sufficient to enhance fish resistance to diseases. Therefore, nutrition strategies need to be carefully planned to increase disease resistance (Blazer, 1982; Blazer and Wolke, 1984b; Blazer et al., 1989). In such cases of "marginal deficiencies," fish may continue to grow, appear healthy, and show no apparent signs of histopathological problems. However, a significant decrease in disease resistance mechanisms is observed. In many instances, while the effects on mortality may be evident, the exact mechanism(s) of these effects have not yet been fully understood. To effectively utilize feeds for enhancing disease resistance, we need more information about the pathogenesis of significant infectious diseases, the protective responses involved in resistance to individual diseases, and the interactions among various dietary components (Blazer, 1992).

Intestinal immunity

Aquaculture is a sector that includes the cultivation of fish, shellfish, and other aquatic products, offering consumers high-protein and nutritious seafood. It is considered a critical resource for meeting the nutritional needs of the global population and plays a significant role in food security. Moreover, with the increasing demand for natural seafood products, aquaculture is becoming even more crucial in fulfilling this requirement (Dawood, 2016). Protein, fat, fiber, energy, as well as mineral and vitamin contents, are fundamental factors that can influence the balance between gut microbiota and intestinal health. Therefore, a balanced diet is important to support gut health and help the body maintain the balance between these two crucial components (Francis et al., 2001). This statement highlights that the formulation of aquaculture feeds is based on plant and animal protein sources that have been investigated locally for their contribution to intestinal health. The composition of these feeds can impact intestinal health through various mechanisms, including intestinal morphology, microbial diversity, intestinal barriers, oxidative status, and digestive enzyme activity.

As a result, the components of aquaculture feeds can have a significant influence on the intestinal health of fish. Careful examination of these factors and the formulation of feeds to support these health aspects are

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critical in fish farming. Intestinal health plays a vital role in the growth and overall health of fish (Oliva-Teles, 2012).

The statement emphasizes the importance of the relationship between the gastrointestinal system (GIS) and the microbial diversity in the intestine in regulating the local intestinal immunity and overall immunity of fish. The intestines form the first line of contact between the organism and the external world, and the microbial diversity in the intestines can have a significant impact on the immune system.

Microorganisms in the intestines play a critical role in regulating the immune system and developing defense mechanisms against pathogens. Therefore, the interaction between the gastrointestinal system and microbial diversity is important for maintaining the health and immunity of the organism. This concept is a crucial factor that should be focused on to improve intestinal health and immunity in fish farming and aquaculture (Montalban-Arques et al., 2015). This statement emphasizes that specific food additives, particularly essential amino acids, fatty acids, vitamins, and minerals, can positively impact intestinal health. These additives enhance the absorption of nutrients through the intestinal barriers, thereby improving intestinal health. Intestinal barriers play a crucial role in preventing pathogens and harmful substances from entering the body from the external environment. Therefore, strengthening intestinal barriers can help the immune system function better and provide better protection against pathogens. In conclusion, the use of these food additives can be considered as a strategy to support the intestinal health of fish and enhance their overall health. Good intestinal health is a critical factor for the growth and resilience of fish (Martin & Krol, 2017).

The intestinal health of fish is positively influenced by suitable conditions and nutrition established in the early stages of their life. This emphasizes the importance, in fish farming and aquaculture, of creating the right environment and dietary regimen during the early stages of life for healthy growth and development. Good intestinal health can help fish become more resistant to diseases and grow better, which is a critical factor for the feed industry (Dawood and Koshio, 2018). The nutrition of fried fish has a significant impact on the intestinal health and immunity of fish. Feeds with insufficient nutritional value for fried fish can negatively affect the abundance of beneficial microorganisms and intestinal health. This, in turn, can weaken the fish's immune system, making them more vulnerable to infectious diseases. Therefore, proper nutrition for fried fish is crucial for healthy growth and immune system development. Fish farmers should pay special attention to the nutrition of fried fish (Ringø & Birkbeck,1999).

General condition of the fish ımmune system

Innate immunity refers to the defense mechanisms that an organism possesses from birth, while adaptive immunity denotes a more complex immune system where the organism develops specialized responses against infections and pathogens. It is stated that fish have both innate and adaptive immunity, with the latter being less elaborate. This suggests that the immune system of fish is an evolutionary precursor and has become more complex in higher vertebrates (Warr, 1995). The immune system of fish operates at the intersection of innate and adaptive responses, meaning it includes both their inherent defense mechanisms and the ability to develop specialized responses against pathogens. This implies that fish can develop a more flexible immune system against various infections. It emphasizes that fish have adapted to their aquatic environment and their poikilothermic nature. Since fish are aquatic organisms, their immune systems have evolved to be compatible with the aquatic environment and work in harmony with these environmental factors. The body temperature of fish can vary depending on the environmental temperature, which can affect the functioning of their immune systems. This kind of adaptation enhances fish's ability to survive

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and develop resistance against infections (Tort et al., 2003). Fish live in various types of aquatic environments, which can lead them to develop different defense mechanisms against various conditions and threats.

Among the defense mechanisms of fish are physical features such as camouflage, rapid escape abilities, and poisonous spines or scales. For example, some species can change their color to blend in with their surroundings and hide from predators. Additionally, their ability to swim quickly allows them to escape danger when needed.

These defense mechanisms of fish enhance their chances of survival against natural predators and influence the evolutionary development of their species. These defense strategies in underwater ecosystems help fish both evade predators and capture their prey. Therefore, these types of defense mechanisms in fish contribute to their successful survival in aquatic habitats (Plouffe et al., 2005).

Pathogens are organisms that pose a disease risk to fish. In order to cope with these pathogens and protect themselves from diseases, fish have developed a complex innate defense mechanism. This defense mechanism exists in two fundamental ways. Firstly, there are "constitutive" or "pre-existing" defense mechanisms. These mechanisms include defense components that fish are born with and are continuously active. For example, the mucous layer found on the skin of fish can serve as a type of physical barrier against pathogens. Secondly, there are "inducible" or "regulated" defense mechanisms. These mechanisms include defense components that allow fish to adjust their response to the pathogens they encounter. The fish's immune system can adapt its response based on the type and quantity of pathogens it is exposed to. These innate and regulated defense mechanisms help fish remain healthy and cope with pathogens in their natural environments. These mechanisms play a critical role in the survival and evolutionary processes of fish (Ellis, 2001).

In aquaculture farms, the widespread use of intensive culture practices is a notable concern because it increases the risk of infection. In these farms, fish's defense mechanisms against pathogens are under greater pressure. Specifically, primary defense barriers such as mucus and epidermis, which constitute local immune mechanisms, can weaken or be damaged due to physical injuries or environmental stress. This provides an easier pathway for pathogens to access the fish's body tissues. At this stage, the systemic innate immune responses of the fish may come into play. However, pathogens often have the ability to evade these responses, and as a result, they can infect a fish that is generally weakened. In this context, fish's immune system operates at both local and systemic levels. Local defense mechanisms aim to prevent initial pathogen contact and limit local infections, while systemic innate immune responses provide broader protection against infections throughout the body. Fish rely on cellular and humoral immune responses, similar to higher vertebrates, and have organs dedicated to regulating and coordinating these responses. As a conclusion, in aquaculture farms, considering the risk of infection, appropriate management and treatment measures should be taken to support the immune health of fish and prevent infections (Press and Evensen, 1999).

Assessing immune responses and disease resistance from a nutritional context

The immune system of fish involves various mechanisms regulated by interactions between different cell types and humoral factors. These mechanisms serve both general and local defense functions in the body.

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To understand the immune system of fish and assess the response of animals, simplified approaches and parameters are used. This is important for documenting the functioning and status of the immune system. While live organism responses provide the best results, laboratory experiments based on isolated cells are also commonly employed. Additionally, challenging experiments carefully designed to study immune defenses and the capacity of fish to endure stress or resist diseases are utilized. It is known that genetic and environmental factors, as well as the nutritional status of fish, influence their immune system. Nutrition can modulate immune responses and resistance to infections in fish, much like it does in humans.

In summary, the immune system of fish comprises various mechanisms involving interactions between different cell types and humoral factors. Simplified approaches and parameters are used to understand and evaluate the immune system. Genetic, environmental factors, and nutritional status play significant roles in modulating immune responses in fish, similar to how nutrition affects the immune functions in humans (Albers et al., 2005; Mahmoud et al ., 2021).

The processes of initial resistance to infection and recovery in fish are the result of complex interactions between non-specific and specific defense mechanisms. Acquired immunity is conveyed through specialized white blood cells called lymphocytes, and in this context, antibodies play a significant role. Antibodies can neutralize viruses, facilitate the phagocytosis of pathogens through opsonization, and activate the classical complement pathway. These mechanisms help in the development of a protective response against infectious diseases in the body. The immune system of fish includes a range of defense mechanisms to fight against infections, and the interaction of these mechanisms contributes to the development of resistance against diseases. Therefore, the immune system of fish is of critical importance for them to live healtily manner and to combat infectious diseases (Sakai, 1984).

It is known that the role of antibodies in the recovery process from disease in fish is not fully understood. However, studies have shown that vaccination procedures often generate a high level of antibody activity, leading to complete protection against infections.

In other words, vaccination is a method that stimulates the immune system of fish and triggers the production of a high amount of antibodies in their bodies. These antibodies can protect against infections by neutralizing viruses or pathogens and removing them from the body. Nevertheless, the process of recovery from disease in fish is still considered a subject that requires further research. In conclusion, vaccination can help establish a protective response against infections in fish, but the exact role of antibodies in the recovery process from disease is still uncertain and requires further investigation (Ellis, 1989).

The specific antibodies generated in the body as a result of vaccination exhibit a protective effect against Vibrio spp. bacteria. This can be indicative of the success of vaccination and the reduction of infection risk. Vaccines can be an important tool in combating pathogens like Vibrio spp., helping to maintain the health of fish and fight against diseases (Kumaran et al., 2010). The immune system can sometimes develop a protective response against a pathogen without producing antibodies. This indicates that the immune system can involve different mechanisms and that the immune response is not solely limited to antibodies. Immune responses to disease in fish can be complex and may include other defense mechanisms besides antibody activity (Croy and Amend, 1977). This may be attributed to mucosal antibodies against Vibrio spp. as these antibodies are found in fish where serum antibodies are undetectable or very low (Kumaran et al., 2010). In fish, when they become infected with a pathogen, it takes a longer time for lymphocyte proliferation and an increase in antibody levels to peak. Additionally, during a secondary response (upon re-infection), the

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increase in antibody levels is less compared to mammals. This information highlights the differences in immune responses between fish and mammals, indicating that the processes by which fish cope with infections are unique and complex. Therefore, research on the immune system and responses of fish holds significant importance for fish health and disease management (Ellis, 1989).

While acquired immunity in fish may initially appear to be temporary, it can persist for more than a year after vaccination (Paterson et al., 1981; Johnson et al., 1982) and likely even longer after recovery from an acute disease (Pradipta et al., 2012). This suggests that fish's immune system can develop a long-term response and provide protection against infections for an extended period.

CONCLUSION

Natural immunity is of great importance for fish, and it is known to play a critical role in maintaining the overall health of aquatic organisms. Furthermore, there is an emphasized parallel relationship between nutrition and immunity.

In the context of aquaculture, the development of feeds and the consideration of the health-promoting qualities of their components are crucial. It is emphasized that quality feeds should not only promote growth but also support the health of fish. Therefore, when formulating feeds, the potential health-promoting qualities of each component should be taken into account.

As a result, this text highlights the impact of nutrition on the immune system in aquaculture, emphasizing its significance for sustainable aquaculture. Enhancing the health and disease resistance of fish can be achieved by considering nutritional factors.

The immune system of fish includes various defense mechanisms, and the cooperation of these mechanisms helps create a protective response against infections. Therefore, in aquaculture, factors affecting the fish's immune system, such as nutrition and genetics, should be taken into account, in addition to other factors like environmental conditions. The immune system and health management of fish are crucial for supporting sustainability in aquaculture. Making appropriate dietary adjustments to strengthen the natural immunity of fish and enhance their resistance to diseases plays a critical role in this regard.

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