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A Review of the Effects of Dietary Fatty Acids on the Growth of Large Yellow Croaker (Larimichthys crocea)

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Abstract. Large yellow croaker (Larimichthys crocea) is one of the most important marine farmed fish in China, and its growth condition directly affects the economic returns of aquaculture. Dietary fatty acids, as essential nutrients in formulated feed, play an irreplaceable role in regulating the growth and development of this fish species. When the fish can take in sufficient amounts of n-3 highly unsaturated fatty acids (HUFAs), especially DHA and EPA, the weight gain effect, feed utilization efficiency and survival rate of the fish can be obviously improved, while excessive intake or unbalanced supply of fatty acids will lead to oxidative stress and immune function depression in the fish body, and then slow down the normal growth of the fish. Different kinds of lipid sources including fish oil, vegetable oil and mixed oil can cause obvious differences in lipid metabolism, digestive enzyme activities and the expression levels of growth-related genes such as GH and IGF1 in large yellow croaker. In addition to providing the basic nutritional needs for the fish, fatty acids can also participate in immune regulation and inflammatory response processes through related pathways such as eicosanoid synthesis and nuclear receptor regulation. This paper summarizes the existing research results of the effects of dietary fatty acid levels, sources and types on the growth of large yellow croaker, and sorts out the related physiological and molecular regulation mechanisms, so as to provide a solid theoretical basis for the formulation of efficient and sustainable feeding strategies in the large-scale culture process.

Keywords: Dietary fatty acids, Larimichthys crocea, growth performance, regulatory mechanisms, unsaturated fatty acids, saturated fatty acids

1. Introduction

Large yellow croaker (Larimichthys crocea) is among the most economically valuable marine fish species farmed in China, with steady growth in production and market demand [1,2]. However, its sustainable cultivation is restricted by nutritional issues, particularly over-reliance on fish oil in traditional aquafeeds. Fish oil is rich in LC-PUFAs, primarily EPA and DHA, which are vital for fish growth, reproduction and physiological balance [3,4]. With the global scarcity and rising price of fish oil, there is an urgent need to find alternative lipid sources, which makes it more important to clarify how fatty acids regulate the growth of large yellow croaker [1]. Under such a research background, this review sorts out and summarizes the existing research results about the effects of

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dietary fatty acids on the growth performance of large yellow croaker, and analyzes the main sources, physiological functions and corresponding molecular regulation mechanisms of saturated fatty acids, monounsaturated fatty acids and polyunsaturated fatty acids in a detailed way [1]. Fatty acids are key components in the daily diet of fish, they can not only provide sufficient energy for the normal life activities of fish, but also participate in the construction process of cell membranes and serve as important synthetic precursors of a variety of bioactive substances in the body [5,6]. Appropriate dietary lipid levels can effectively improve the utilization efficiency of dietary protein and promote the healthy growth; however, insufficient or excessive intake of fatty acids will disturb the normal metabolic process of fish and further reduce the growth speed of individuals [5,7].

In recent years, scholars from different countries and regions have carried out a large number of experimental studies and theoretical analyses on the effects of dietary fatty acids on the growth of large yellow croaker [8,9]. Current research has clarified the suitable fatty acid demand levels for larval and juvenile large yellow croaker, and has fully proved that n-3 HUFAs and phospholipids have obvious positive effects in promoting the growth of this fish [2]. When it comes to replacing fish oil with vegetable oils, relevant evidence shows that completely replacing fish oil with vegetable oils such as linseed oil or soybean oil will lead to a significant decrease in the fish's weight gain rate and feed efficiency [1]. This phenomenon is closely related to the reduced content of LCPUFAs in the fish body, as well as the insufficient compensatory response of fatty acid synthesis-related genes such as Δ6Fad [3,8].

In addition to direct effects, dietary fatty acids can also indirectly affect the growth of large yellow croaker by regulating key transcription factors such as ChREBP, as well as autophagy and inflammatory responses [10], forming a relatively complex regulatory network. Even so, there are still some unsolved problems in this field: for example, the molecular mechanisms behind the growth inhibition caused by vegetable oil substitution have not been fully clarified [11,12], and the way different fatty acids cooperate to regulate the fish's growth also needs further research [4,8]. This paper combs the published research results on the effects of dietary fatty acids on the growth of large yellow croaker [1], discusses the sources, growth regulation effects, and molecular mechanisms of saturated, monounsaturated, and polyunsaturated fatty acids separately, aiming to identify key regulatory factors and signaling pathways, so as to provide theoretical support for improving feed formulations, developing sustainable lipid substitutes, and improving aquaculture efficiency and product quality [1].

Different types of dietary fatty acids have distinct sources and growth-regulating effects on large yellow croaker, and their specific differences are summarized in Table 1, which clearly shows the core components of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), as well as their respective main sources and effects on the growth of large yellow croaker.

Table 1. Main sources and growth effects of different dietary fatty acids for large yellow croaker

Fatty Acid Type	Main Sources	Key Components	Core Effects
Saturated Fatty Acids (SFA)	Palm oil, lard	Palmitic acid (C16:0), Stearic acid (C18:0)	Inhibit growth, induce metabolic disorders and inflammation
Monounsaturated Fatty Acids (MUFA)	Olive oil, rapeseed oil	Oleic acid (C18:1n-9)	Moderate amount promotes growth; excessive intake inhibits growth and causes liver damage
Polyunsaturated Fatty Acids (PUFA)	Fish oil, linseed oil, soybean oil, sunflower oil	EPA, DHA, ALA, LA, CLA	n-3 PUFA and CLA promote growth; excessive n-6 PUFA inhibits growth

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2. Effects and mechanisms of Saturated Fatty Acids (SFA) on the growth performance of large yellow croaker

2.1. Main sources and key types

Saturated fatty acids in large yellow croaker feeds are derived from a wide range of sources, with palm oil being one of the core sources. Palm oil is rich in palmitic acid (PA, C16:0), the dominant saturated fatty acid in this species [1]. Additionally, stearic acid (C18:0) contained in animal fats (e.g., lard) is another common saturated fatty acid in large yellow croaker feeds. These saturated fatty acids participate in energy metabolism and body construction after being ingested through feeds, and then participate in the body's energy metabolism and somatic tissue construction, and their dietary content and relative amounts directly influence both the growth outcomes and the physiological metabolic condition of large yellow croaker.

2.2. Effects on growth performance

A marked growth-inhibiting effect is observed in large yellow croaker when saturated fatty acids constitute the main lipid component of the diet. Studies have demonstrated that completely replacing fish oil with palm oil (the main source of saturated fatty acids) in the diet of large yellow croaker significantly lowers weight gain rate and specific growth rate, while also markedly elevating hepatic lipid deposition and hepatosomatic index (HSI) [1]. The core reason for this growth inhibition is the low digestion and absorption efficiency of saturated fatty acids in large yellow croaker; excessive intake will reduce the absorption and utilization efficiency of other functional fatty acids such as n-3 HUFAs [13-15]. At the same time, the metabolic disorders and inflammatory responses induced by excessive saturated fatty acids will further inhibit the growth-related physiological processes of the fish, and ultimately lead to the decline of aquaculture performance [1].

The saturated fatty acid composition of large yellow croaker varies greatly with different sources, which is closely related to the dietary supply of saturated fatty acids. Studies have found that the muscle C16:0 content (448.00 mg/100g) of farmed large yellow croaker from Ningde, Fujian Province is significantly higher than that of wild individuals caught in the Zhoushan sea area (80.30 mg/100g), and the total saturated fatty acid content (ΣSFA) (563.51 mg/100g) is also significantly higher than that of the wild group (97.30 mg/100g). This difference is mainly due to the addition of palm oil and other raw materials rich in saturated fatty acids in aquafeeds [16].

2.3. Regulatory mechanisms

2.3.1. Disruption of intestinal homeostasis

As the most representative saturated fatty acid in the feed, palmitic acid can be regarded as a key factor that causes intestinal lipid metabolism disorders in large yellow croaker, related research results have shown that palmitic acid can effectively promote the uptake of fatty acids and the synthesis of lipid in intestinal cells of this fish, and then make triglycerides accumulate continuously in the cells, at the same time, it can also significantly reduce the content of phosphatidylethanolamine (PE) in the body, and further induce the occurrence of endoplasmic reticulum stress [1]. It is worth noting that adding a proper amount of PE to the daily feed can relieve these adverse effects brought by palmitic acid, PE can inhibit the expression of genes related to fatty acid uptake, reduce the synthesis of triglycerides in cells, so as to alleviate the abnormal

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lipid metabolism caused by palmitic acid, and help to keep the metabolic state of the intestine of large yellow croaker in a stable and balanced level [1].

2.3.2. Activation of inflammatory responses

Saturated fatty acids are able to induce inflammatory responses in large yellow croaker through a variety of intracellular signaling routes, and the Toll-like receptor (TLR)-mitogen-activated protein kinase (MAPK) pathway has been shown to take on a core regulatory function in this process, palmitic acid can selectively raise the expression of TLR22 and other genes that are closely related to inflammatory reactions, promote the phosphorylation of key proteins in the MAPK family, and further promote the massive generation and secretion of pro-inflammatory cytokines including IL1β and TNFα through the p38 MAPK-p65 signaling axis, so that the inflammatory response inside the fish can be fully activated [1]. In addition, palmitic acid can also activate the inflammatory process by regulating the activity of the NLRP3 inflammasome, and this regulatory process mainly includes two aspects, the first aspect is to activate the NF-κB pathway so as to improve the transcription level of the nlrp3 gene, the second aspect is to inhibit the phosphorylation of AMPK and lower the content of mitophagy-related proteins such as PINK and Parkin, which will further cause mitochondrial damage and excessive accumulation of reactive oxygen species (ROS) in cells [1]. These two kinds of regulatory effects can act together to activate the NLRP3 inflammasome, aggravate the body's inflammatory response, break the original immune balance state, and finally bring obvious interference to the normal growth and development process of large yellow croaker.

2.3.3. Metabolic and antioxidant disorders

When large yellow croaker intakes an excessive amount of saturated fatty acids, it will easily induce endoplasmic reticulum stress inside the body, and this stress response can further disturb the normal process of cholesterol metabolism, for instance, palmitic acid can activate the ER stress pathway and up-regulate the expression level of SREBP2, so as to promote the synthesis of cholesterol in muscle tissue, and eventually lead to the abnormal accumulation of cholesterol and heavier metabolic pressure for the fish [1]. In the meantime, a diet rich in palmitic acid can significantly reduce the serum TAOC and CAT activity of large yellow croaker, which means that the antioxidant system of the body has been weakened to a certain extent [1], and it will also increase the content of malondialdehyde (MDA) that represents the degree of lipid peroxidation, so that the oxidative damage of cells can be further aggravated [1]. Such an unbalanced state between oxidation and antioxidant defense systems will damage the complete structure of cells, lower the efficiency of various normal physiological processes in the body, and indirectly slow down the normal growth speed of large yellow croaker individuals.

3. Growth modulation by Monounsaturated Fatty Acids (MUFA) in large yellow croaker: effects and mechanistic pathways

3.1. Main sources and key types

In feeds for large yellow croaker, the primary sources of monounsaturated fatty acids are olive oil and rapeseed oil, with olive oil serving as the main contributor. Olive oil contains abundant oleic acid (OA, C18:1n-9), a crucial MUFA that regulates the growth and development of this species. After being ingested through the diet, these fatty acids will participate in a variety of physiological functions of the fish, such as cell membrane formation and energy metabolism support; at the same

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time, their content in the feed and the balance between each other will have a significant impact on the growth performance of large yellow croaker.

3.2. Dual effects on growth performance

At an appropriate dose, oleic acid can promote the growth of large yellow croaker. Relevant studies have shown that oleic acid can regulate the triglyceride metabolism of the fish's body by activating PPARγ and up-regulating the expression of ANGPTL4, preventing abnormal fat accumulation in tissues such as the liver, and thus creating a better physiological environment for the fish's growth. In addition, as an important component of membrane lipids, oleic acid plays a key role in maintaining the fluidity of cell membranes—normal cell function relies on appropriate membrane fluidity—and by adjusting the saturation of membrane lipids, oleic acid can ensure the smooth progress of material exchange, signal transduction and other processes, thereby supporting the normal growth and development of large yellow croaker. In feeds with appropriate fat levels, the presence of moderate amounts of oleic acid can synergize with other fatty acids to optimize nutrient supply efficiency.

When 100% olive oil (high in oleic acid) is used as the feed lipid source instead of fish oil, it significantly impairs large yellow croaker growth. A high-oleic acid diet has been demonstrated to reduce weight gain rate and specific growth rate markedly [1], accompanied by an elevation in hepatosomatic index (HSI) and a substantial increase in liver lipid content. Serum biochemical indicators show that the activity of alanine aminotransferase (ALT) in the high-oleic acid group is significantly increased, indicating liver damage, which is closely related to the metabolic pressure caused by hepatic lipid deposition.

3.3. Regulatory mechanisms

3.3.1. Activation of inflammatory responses and oxidative stress

A high-oleic acid diet induces inflammatory responses and oxidative stress in large yellow croaker. Oxidative index detection shows that the serum superoxide dismutase (SOD) activity in the high-oleic acid group is significantly reduced, and the content of malondialdehyde (MDA), a product of lipid peroxidation, is increased, resulting in decreased antioxidant capacity of the organism. In addition, it has been demonstrated that high concentrations of oleic acid promote the activation of p38 MAPK and JNK signaling, upregulate the expression of pro-inflammatory genes such as COX-2 and TNFα, and ultimately enhance inflammation in large yellow croaker [1].

3.3.2. Mitochondrial dysfunction

Mitochondrial dysfunction is an important way for high levels of oleic acid to cause physiological damage to large yellow croaker. When the fish are fed with olive oil, it will change the methylation pattern of the liver mitochondrial DNA (mtDNA) of the fish—specifically, the methylation level of the coding regions of arginine tRNA and NAD(H) dehydrogenase 4L will increase. This epigenetic change will reduce the activity of mitochondrial complex I and the expression levels of ND3 and ND4L, further leading to a decrease in energy metabolism efficiency and ultimately inhibiting the growth of the fish.

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3.3.3. Regulation of gene expression

Much like saturated fatty acids, a diet high in oleic acid also lowers the expression of the ChREBP gene. Studies have found that fish fed olive oil have noticeably lower levels of hepatic ChREBP compared to those given fish oil. This kind of gene regulation ends up affecting the growth performance of large yellow croaker indirectly, by disturbing the normal balance of glycolipid metabolism.

4. Impacts and functional mechanisms of Polyunsaturated Fatty Acids (PUFA) on the growth performance of large yellow croaker

4.1. Regulatory roles of n-3 Polyunsaturated Fatty Acids (n-3 PUFA)

4.1.1. Main sources and key types

The n-3 PUFA in large yellow croaker feeds come mainly from fish oil, linseed oil, perilla oil, and other lipid sources. Fish oil is the traditional premium source, rich in highly bioactive EPA (C20:5n-3) and DHA (C22:6n-3) [1]; linseed and perilla oils are composed largely of ALA (C18:3n-3) [1,2]. All three are essential for the fish's growth and development, with EPA and DHA serving especially critical physiological functions.

4.1.2. Effects on growth performance

n-3 PUFAs can bring about obvious promoting effects on the growth of large yellow croaker, and a great deal of research evidence has shown that keeping the ratio of α-linolenic acid (ALA) to linoleic acid (LNA) within the range of 0.5 to 1.5 is very important for obtaining better growth performance of this fish, in this suitable ratio range, the weight gain rate and specific growth rate of fish can reach levels that are similar to those of fish fed with diets mainly using fish oil as lipid source [1]. For larval and juvenile large yellow croaker, the content of n-3 HUFA in the diet needs to reach about 3.9% to support the best growth state of individuals, in a related research experiment, the specific growth rate of the group fed with 3.9% n-3 HUFA reached 9.5% per day and the survival rate reached 31.5%, these two indicators were both significantly higher than those of the group fed with 1.1% n-3 HUFA, in which the specific growth rate was 8.5% per day and the survival rate was 18.6% [1].

4.1.3. Core regulatory mechanisms

DHA has a significant regulatory effect on the immune cell function of large yellow croaker: as a key component of membrane lipids in immune cells such as head kidney macrophages, DHA can maintain the normal activity of these cells, affect their phagocytosis and cytokine secretion, and thus enhance the fish's resistance to pathogens. This immune-enhancing effect can reduce the negative impact of diseases on the fish's growth, making the growth performance of the fish more stable during the aquaculture process. In addition, keeping the ALA/LNA ratio at an appropriate level can also inhibit the overexpression of COX2, IL1β and other pro-inflammatory mediators that are induced by high linoleic acid levels, so as to avoid excessive inflammatory reactions that may hinder the normal growth of fish.

On the other hand, DHA can also play an obvious anti-inflammatory role by interfering with the formation process of lipid rafts, lipid rafts are important action platforms for TLR22-mediated

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inflammatory signal transduction, DHA can reduce the content of membrane sphingomyelin (SM) and saturated fatty acid-containing phosphatidylcholine (SFAPC), and also reduce the expression level of caveolin1 which is the marker protein of lipid rafts, these changes will inhibit the binding of TLR22 to its ligands and the signal transduction process in the downstream, prevent the nuclear translocation of NF-κB and the activation of interferon, and finally relieve the inflammatory response in fish.

In the inflammation model that has been induced by palmitic acid, DHA can effectively relieve the inflammatory damage to fish bodies through the regulation of the TLR22-MAPK-PPARγ/Nrf2 signaling pathway, DHA is able to suppress the phosphorylation process of key proteins in the MAPK family, and it can also restore the reduced expression level of PPARγ protein that has been caused by palmitic acid, at the same time, DHA can regulate the activity of Nrf2 and further promote the transcription and expression of a series of antioxidant genes inside the body [1]. Such a complete regulatory network can play a synergistic role in inhibiting inflammatory reactions and enhancing the antioxidant capacity of fish, protect the normal physiological function of macrophages, and provide an indirect support for the stable growth and development of large yellow croaker individuals.The anti-inflammatory effect of EPA is mainly achieved by reducing the production of prostaglandin E2 (PGE2) and secretory phospholipase A2 (sPLA2). PGE2 is an important pro-inflammatory mediator, and sPLA2 is involved in the release of lipid mediators in inflammatory responses, so EPA can reduce the amplification of inflammatory signals by inhibiting the synthesis of these two substances, and maintain the immune homeostasis of the fish's body.

Both ALA and DHA can significantly improve the antioxidant defense system of large yellow croaker. Studies have shown that an appropriate amount of these two fatty acids can increase the total antioxidant capacity, SOD and CAT activities of the fish, while reducing the content of MDA and the damage caused by lipid peroxidation [1]. These antioxidant effects can help maintain the integrity of cell structure and function, and thus create a favorable internal environment for the fish's growth and metabolism.In addition, n3 HUFAs (EPA+DHA) are critical for improving the stress resistance of larval and juvenile large yellow croaker. Adding an appropriate amount of n3 HUFAs to the diet can significantly improve the tolerance of young fish to various stress factors, including low temperature, low salinity, low dissolved oxygen, and air exposure [1]. This effect is closely related to the regulation of cell membrane fluidity, osmotic pressure regulation function and metabolic homeostasis by n-3 HUFAs, which can reduce the inhibitory effect of stress responses on the fish's growth [1].

4.2. Regulatory roles of n-6 series Polyunsaturated Fatty Acids (n-6 PUFA)

4.2.1. Main sources and key types

Soybean oil and sunflower oil are the main sources of n6 PUFAs, with linoleic acid (LA, C18:2n6) as their core component. After entering the body of large yellow croaker, LA can be further converted into arachidonic acid (ARA, C20:4n6). These fatty acids are involved in a variety of physiological functions of the fish, including inflammatory responses and immune regulation, but excessive intake will bring harm to the fish, so it is very important to maintain a proper balance between n6 PUFAs and n3 PUFAs.

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4.2.2. Dual effects on growth performance

The effect of n6 PUFAs on the growth of large yellow croaker is dose-dependent: a moderate amount of linoleic acid can be used as an energy source or a precursor for fatty acid synthesis, helping to support the basic growth of the fish; but when the supply of linoleic acid exceeds the appropriate range, it will start to inhibit the growth of the fish. Studies have shown that a diet high in linoleic acid will significantly reduce the weight gain rate and specific growth rate of the fish, and at the same time trigger inflammatory responses and oxidative stress, which indirectly damage the overall growth performance of the fish.

4.2.3. Core regulatory mechanisms

High linoleic acid intake provokes inflammation in large yellow croaker. According to studies, excess LA increases the expression of pro-inflammatory genes (COX-2, IL-1β, TNFα) in the liver and kidneys, which in turn activates the NF-κB pathway. The resulting inflammatory state undermines immune homeostasis, boosts energy consumption, and hampers growth.

In terms of antioxidant capacity, excessive LA inhibits the nuclear translocation of Nrf2 and its binding ability to antioxidant response elements (ARE), which lowers both the activity and the transcriptional levels of antioxidant enzymes such as SOD and CAT, and exacerbating oxidative damage. This synergistic effect of oxidation and inflammation causes multiple damages to tissues such as the liver and intestines of large yellow croaker, further affecting growth.

A high n-6 PUFA diet (e.g., feeds with a high proportion of soybean oil) can also induce hepatic pro-inflammatory responses through cytokines secreted by adipose tissue, increasing adipose tissue macrophage infiltration and M1 polarization. This process forms a vicious cycle of "adipose inflammation-metabolic disorders", leading to decreased nutrient utilization efficiency and inhibited growth.

Maintaining the balance between n-3/n-6 PUFA is crucial for exerting their physiological functions. Increasing the ALA/LNA ratio can offset the negative effects of high LA, maintain the immune and antioxidant functions of large yellow croaker, and reduce the expression of pro-inflammatory genes. Practice has shown that an appropriate ratio of n-3/n-6 PUFA in feeds can synergistically promote growth, avoiding metabolic disorders induced by excessive single fatty acids.

The farnesoid X receptor (FXR)-mediated signaling pathway can effectively regulate n-6 PUFA-induced inflammatory responses. FXR agonists (e.g., chenodeoxycholic acid, CDCA) can downregulate the expression of pro-inflammatory genes induced by LA. The mechanism is that FXR activation can regulate the small heterodimer partner (SHP), which then binds to P65 to inhibit the transcriptional activity of NF-κB. This regulatory pathway provides a potential solution for alleviating the negative effects of high n-6 PUFA.

The autophagic pathway is an important target for regulating LA-induced inflammation. Research has shown that induction of autophagy suppresses the expression of LA-induced pro-inflammatory cytokines, whereas blockade of autophagy worsens inflammatory responses. This indicates that autophagy alleviates LA-induced inflammation by clearing damaged organelles and reducing reactive oxygen species accumulation, and the adverse effects of high n-6 PUFA can be improved by regulating the expression of autophagy-related genes.

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4.3. Functional Polyunsaturated Fatty Acids: Conjugated Linoleic Acid (CLA)

4.3.1. Main sources and key types

The main sources of conjugated linoleic acid (CLA) include natural dairy products, meat, and synthetic products, with its core active components being two isomers: cis-9, trans-11 and trans-10, cis-12. As a functional fatty acid, the addition of CLA to feed has a special regulatory effect on the growth and physiological functions of large yellow croaker.

4.3.2. Effects on growth performanc

CLA also has a significant impact on the growth of large yellow croaker: when CLA is added to the diet at 0.42%, it can significantly improve the weight gain rate and specific growth rate of the fish; in addition, when the addition amount is between 0.42% and 0.83%, CLA can enhance the non-specific immunity of the fish, which is reflected in the increase of phagocytic index and respiratory burst activity [1]. The feature that CLA can promote growth and enhance immune function at the same time makes it become a functional feed additive with great application potential in the culture process of large yellow croaker.

4.3.3. Core regulatory mechanisms

In terms of antioxidant capacity and lipid metabolism regulation, adding 0.83% of CLA to the daily diet can bring obvious beneficial effects to large yellow croaker, this kind of addition can effectively improve the total antioxidant capacity and catalase (CAT) activity in the liver of fish, and at the same time reduce the content of malondialdehyde (MDA), so as to relieve the oxidative damage to the body [1]. Meanwhile, CLA can inhibit the expression of genes related to lipid oxidation in liver and kidney tissues, such as carnitine palmitoyl transferase I and acyl CoA oxidase, which helps to better regulate the lipid metabolism process and avoid the occurrence of excessive fat deposition in the body.

CLA can also make the fatty acid composition of fish tissues produce obvious changes, related research results show that CLA can increase the content of saturated fatty acids (SFA) and polyunsaturated fatty acids (PUFA) in muscle and liver, and reduce the proportion of monounsaturated fatty acids (MUFA) at the same time, in addition, the two main isomers of CLA have higher accumulation levels in the liver than in muscle, and this result also indicates that the liver is the main tissue site for CLA metabolism in large yellow croaker.

5. Conclusions and future perspectives

While additional research is required, multiple lines of evidence indicate that dietary supplementation with PUFAs—especially long-chain omega-3 fatty acids—may confer benefits to large yellow croaker aquaculture. Further comprehensive and rigorous experiments are still needed to confirm how MUFAs and the n-3/n-6 PUFA ratio affect the physiological health of this species.

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