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Review

Pivotal Roles of Fish Nutrition and Feeding: Recent Advances and Future Outlook for Brazilian Fish Farming

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Abstract: The aquafeed industry evolved alongside fish farming, utilizing scientific and technological advancements to incorporate a variety of feed additives, supplements, and alternative ingredients in the nutrition and feeding of fish in aquaculture. These advances played a significant role in improving the production, health, and welfare of farmed fish. Recent research in Brazil highlighted the importance of using fish feed additives, such as vitamins, minerals, and amino acids, to ensure that farmed fish receive all the necessary nutrients for growth and health. Functional additives can enhance the immune system, boosting disease resistance and promoting the overall health of fish. Antimicrobial and antiparasitic additives help prevent and treat infections and infestations, reducing the occurrence of disease outbreaks. Additionally, some additives improve feed digestibility, leading to better nutrient absorption and reduced feed requirements. Overall, nutritional strategies are essential for optimizing fish farming practices in Brazil and globally, promoting fish health and sustainability in the industry. This review emphasizes the significance of certain additives, supplements, and ingredients strategically incorporated into experimental feeds for research in Brazilian fish farming. It also underscores the necessity for ongoing research. There is a noticeable trend towards developing more sustainable and efficient feeds, which is essential for the future of sustainable aquaculture. The goal is to minimize environmental impacts while maintaining economic viability in aquaculture operations.

Keywords: aquaculture; fish; functional feed; sustainability; Brazil

Key Contribution: Research in Brazil emphasizes the importance of additives such as vitamins, minerals, and amino acids for fish growth and health. Functional additives boost immunity and prevent diseases, while antimicrobial additives help treat infections. Some additives enhance feed digestibility, leading to better nutrient absorption. These additives are crucial for optimizing fish farming practices in Brazil and globally; promoting sustainability. Ongoing research is essential for creating more sustainable and effective feeds to minimize environmental impacts and maintain economic viability in aquaculture.

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1. Introduction

Fish farming plays a pivotal role in global aquaculture, generating jobs, income, diversifying livelihoods, and boosting the economies of several countries [1]. Simultaneously with the expansion of fish farming, scientific and technological advances have driven the evolutionary ascension of the aquafeed industry and the use of feed additives, supplements, and alternative ingredients, which play a pivotal and complex role in this growth scenario, allowing significant improvements in the production, health, and welfare of aquacultured fish [2–9].

Recent breakthroughs have shown that fish feed additives such as vitamins, minerals, and amino acids are used to ensure that the feed provides all the essential nutrients for the growth and health of farmed fish [2,10–12], whereas certain additives are considered growth promoters [13–17], as they provided significant improvements in growth performance and feed conversion, allowing fish to reach commercial size more quickly. Feed additives such as prebiotics, probiotics [18–22], plant extracts (phytobiotics) [22–27], or algae extracts (phycobiotics) [28–31] can strengthen the immune system of fish, making them more resistant to diseases and infections.

Furthermore, some additives can reduce stress and improve the welfare of aquatic organisms [5,18,21]. Additives with antimicrobial and antiparasitic potential improve symptoms (control, alleviate or restore health) resulting from infections and infestations caused by pathogens or parasites, reducing the incidence of disease outbreaks [6,8], while some additives are extensively regarded as adjuvants to improve feed digestibility, increasing the efficiency of nutrient absorption, and consequently reducing the amount of feed required [7,8,10,32]. At present, feeding strategies have become essential to optimize Brazilian and global fish farming, render them promising candidates to promote fish health, and ensure greater sustainability and efficiency in fish farming.

Bioactive compounds derived from animals, plants, algae, or microorganisms are among the most investigated feed additives to improve the health of aquacultured fish [11]. For example, the use of digestive enzymes (amylases, lipases, proteases, cellulases, and hemicellulases) and non-digestive enzymes (phytases, glucose oxidase, and lysozyme) in dietary supplementation for fish could improve the digestibility and absorption of ingredients, with positive effects on growth performance [12].

The use of microalgae as an aquafeed ingredient could replace fishmeal or fish oil due to their rich content of ω-3 polyunsaturated fatty acids, carotenoids, vitamins, and β-glucan, which can improve the growth rates, skin pigmentation, immunity, intestinal morphophysiology, and survival of aquatic animals [10,13,31,33–36], whereas macroalgae offer a functional dietary ingredient for aquafeed, since in addition to their nutritional value, marine macroalgae contain proteins that encompass all essential amino acids, taurine, lipids, and carotenoids, bioactive compounds that could have beneficial effects on the growth, physiology, resistance to stress, immune system, and fillet quality of farmed fish [28,29,37,38].

Plant-derived active compounds are an alternative to synthetic chemicals for improving growth and disease resistance in aquaculture. Dietary supplementation with essential oils (0.5% ginger) was useful for improving growth, immune responses, and disease resistance (streptococcosis) of Nile tilapia, *Oreochromis niloticus* [23], and *Lippia sidoides* essential oil (0.25%) improved inflammatory response and histological condition in zebrafish, *Danio rerio* [25]. The milk thistle, *Silybum marianum* (0.1% with a commercial product that contained 16% silymarin phosphatide), provided a hepatoprotective and immunomodulatory effect on Nile tilapia [24], while *L. origanoides*, *L. sidoides*, and *Mentha piperita* essential oils were effective for treatment of *Neobenedenia melleni* infecting farmed Lebranche mullet

Mugil liza [26]. Thus, plant-derived compounds can improve overall fish health, promote a healthier environment, and reduce the incidence of disease in fish farming.

On the other hand, probiotics, prebiotics, and postbiotics play a crucial role in aquaculture, offering a number of health benefits for fish, improving the efficiency of production systems. Dietary *Saccharomyces cerevisiae* (200 g metric ton^{-1}) improves survival after thermal and osmotic challenge during sexual reversal of postlarval Nile tilapia [18]. Similarly, *S. cerevisiae* or *Bacillus amyloliquefaciens* plus *B. subtilis* improved the intestinal microbiome community and survival of Nile tilapia challenged with *Aeromonas hydrophila* [15], whereas a feed additive composed of multi-strain *Bacillus* showed modulation of the intestinal microbiome of tilapia, leading to positive changes in the composition of the microbiota at the phylum and genus levels. This promotes the growth of beneficial bacteria and reduces the presence of harmful pathogens in treated fish [19].

Digestion improvements related to pre- and probiotics have been reported after observations of increased efficiency in nutrient absorption. The use of protected forms of sodium butyrate (0.25% or 0.5% pure, 0.25% or 0.5% palm oil-protected Na-butyrate, and 0.25% or 0.5% protected Na-butyrate buffer) were beneficial for the development and intestinal health of Nile tilapia during the sexual reversion period [39]. Furthermore, strengthening the immune system (e.g., boosting blood parameters and plasma proteins) as well as pathogen control (such as bacterial resistance) have also been extensively investigated in recent years in native Brazilian fish such as hybrid Surubim (*Pseudoplatystoma corruscans* x *P. reticulatum*) [14], dourado *Salminus brasiliensis* [20], tambaqui *Colossoma macropomum* [40], and hybrid catfish (*P. reticulatum*♀ x *Leiarius marmoratus*♂) [21].

This scenario depicts the importance of strategically formulated feeds in aquaculture, raising the need for ongoing research, as there is a growing trend toward developing increasingly sustainable and efficient aquafeeds. Recent studies concentrated on plant-based ingredients or natural compounds that could potentially substitute traditional ingredients without affecting the growth and quality of farmed fish. These advancements are crucial for the future of sustainable aquaculture, which aims to reduce environmental impacts while ensuring the economic sustainability of its operations.

Brazilian aquaculture is expanding rapidly and has potential for further growth, particularly with advancements in technology for cultivating and feeding native species. Research in nutrition can greatly improve fish farming in Brazil. While this review focuses on Brazilian aquaculture, the scientific evidence discussed in the following sections is not limited to Brazil and is applicable to aquaculture practices worldwide.

2. Pivotal Roles of Feed Additives in Fish Farming

Fish feed additives are added to feed to enhance feed quality, support fish health and well-being, and optimize productive and nutritional performance (Figure 1). These additives can be categorized based on their specific functions and modes of action [2].

2.1. Improved Digestibility and Nutrient Absorption

Research demonstrated that feed additives such as proteolytic, lipolytic, and carbohydrase enzymes aid in breaking down hard-to-digest food components such as proteins, fats, and carbohydrates. Additionally, exogenous enzymes could assist in compensating for the insufficient levels of endogenous enzymes, particularly in young fish. This enhances fish digestion and nutrient absorption, leading to better feed efficiency and growth [41–45]. For example, Cavero et al. [42] found that adding exogenous digestive enzymes protease and lipase to pirarucu (*Arapaima gigas*) feed at levels of 0.1%, 0.2%, or 0.4% can enhance the growth of this carnivorous species. Similarly, the inclusion of an enzyme complex derived from the fungus *Aspergillus niger* (0.0, 0.25, 0.50, 0.75, and 1.0 g kg^{-1}) containing pectinase

(4000 IU kg^{-1}), protease (700 IU kg^{-1}), phytase (300 IU kg^{-1}), beta-glucanase (200 IU kg^{-1}), xylanase (100 IU kg^{-1}), cellulase (40 IU kg^{-1}), and amylase (30 IU kg^{-1}) enhanced nutrient digestibility and productive performance of pirarucu. The researchers noted that the specific activities of the digestive enzymes alkaline protease, amylase, and lipase decreased linearly as the levels of the enzyme complex increased in the treatments [43]. Phytase is an enzyme that can have a significant impact on fish diets, especially those made up of plant ingredients such as soy or corn, and mainly for wheat. Lipase is responsible for breaking down fats, leading to improved lipid digestion and absorption when added to fish feed. Protease aids in breaking down proteins more efficiently, ensuring better absorption of essential amino acids and reducing undigested proteins [41,44]. As the aquafeed industry seeks sustainable alternatives to fishmeal, incorporating enzymes into diets shows promise for improving fish nutrition and feed efficiency.

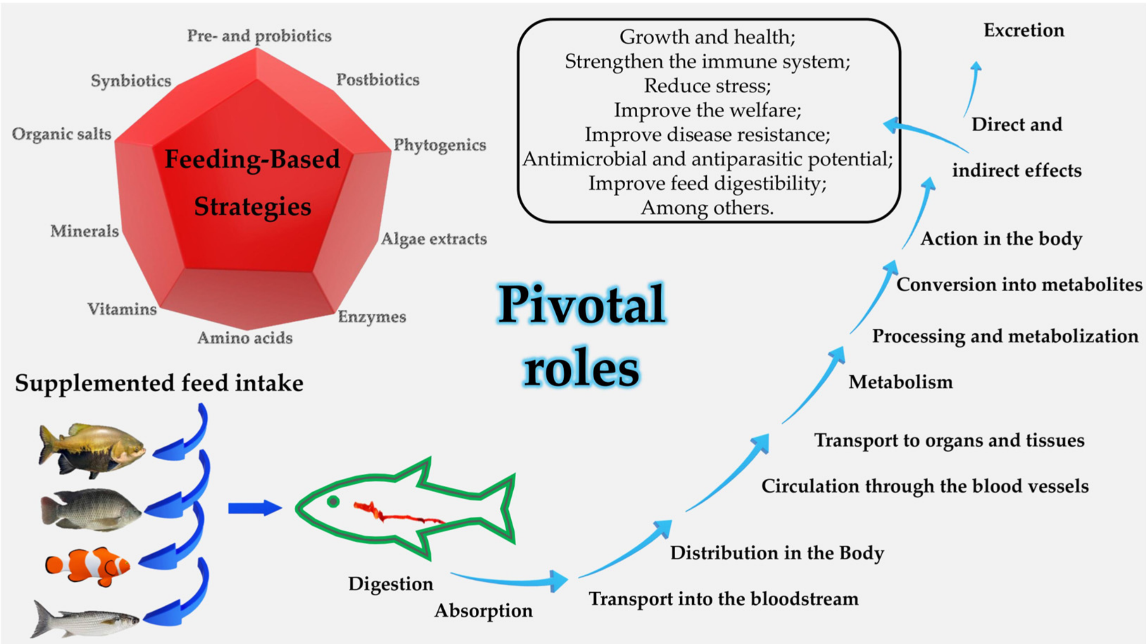

Figure 1. Diagram illustrating the essential functions of feeding-based strategies for aquacultured fish.

Additionally, studies indicated that Nile tilapia benefited from diets containing poultry liver protein hydrolysate at levels of 0, 10, 20, and 40 g kg^{-1} [45]. Similarly, South American catfish (*Rhamdia quelen*) showed improved productive performance and nutritional efficiency when fed diets supplemented with sardine (*Sardinella* spp.) protein hydrolysate at levels of 0, 2, 5, and 10% [46]. Enhancing nutrient digestibility and absorption in fish farming offers numerous advantages, such as enhanced feed efficiency, optimized growth, better fish health, reduced environmental footprint, cost savings, and improved sustainability. This not only boosts productivity in fish farming, but also promotes a healthier environment and more efficient food production.

2.2. Increased Immunity and Health

Over the years, functional diets have become increasingly popular in Brazilian aquaculture for enhancing immunity and supporting fish health. These feeds can enhance disease resistance by strengthening the immune system and promoting overall well-being. Recent research conducted by Brazilian scientists aims to benefit Brazilian aquaculture specifically, while also offering potential insights for global aquaculture practices (Table 1).

Table 1. Recent advances and future outlook for nutrition and feeding in Brazilian fish farming. The studies listed focus on fish feeding and were carried out on fish species that are native to Brazil but can also be found in other countries, such as those of the genera *Pseudoplatystoma*, *Mugil*, *Centropomus*, *Colossoma*, *Sardinella*, *Arapaima*, *Seriola*, *Elacatinus*, and *Rhamdia*.

Common Name (In Brazil)	Species	Feeding-Based Strategies	Trial Period	Dosage	Main Breakthroughs	Key References
Tilapia	*O. niloticus*	Clove basil (*Ocimum gratissimum*) essential oil	55 days	0.5%, 1.0%, or 1.5%	Clove basil at 0.5% significantly improved feed conversion ratio.	Brum et al. [23]
Tilapia	*O. niloticus*	Ginger (*Zingiber officinale*) essential oil	55 days	0.5%, 1.0%, or 1.5%	All supplemented diets resulted in higher phagocytic activity. Following the challenge with *S. agalactiae*, the group that received 0.5% supplementation exhibited a relative survival rate of 100%.	Brum et al. [23]
Paulistinha	*Danio rerio*	Rosemary-pepper (*Lippia sidoides*) essential oil	15 days	(0.25%)	Essential oil at 0.25% improved inflammatory response and histological condition and appears to be beneficial to the health of *D. rerio* subjected to intraperitoneal injection with Ehrlich ascitic carcinoma.	Cardoso et al. [25]
Pirarucu	*Arapaima gigas*	Protease and lipase	37 days	0.1%, 0.2%, or 0.4%	Enhanced the weight gain, growth rate, and feed conversion efficiency of *A. gigas*.	Cavero et al. [42]
Palhaço	*Amphiprion clarkii*	Triiodothyronine	13 days	0, 0.01, or 0.1 mg L^{-1}.	The treatment with 0.01 mg L^{-1} resulted in improved survival rates and accelerated larval metamorphosis.	Contrera et al. [47]
Nile tilapia	*O. niloticus*	Sodium butyrate, dehydrated hydrolyzed yeast, and zinc proteinate	60 days	0, 0.60, 1.20, 2.40, or 4.80 g kg^{-1}	Beneficial effects for gut health.	De Oliveira et al. [48]
Neon goby	*Elacatinus figaro*	Triiodothyronine	14 days	0, 0.01, 0.025, or 0.05 mg L^{-1}.	The 0.025 and 0.05 mg L^{-1} treatment anticipated metamorphosis.	Eugênio et al. [49]
Tilapia	*O. niloticus*	*Saccharomyces cerevisiae*	20 days	200 g metric ton^{-1}	Yeast improves final weight, resistance to cold heat stress, and increases resistance to osmotic challenge.	Faust et al. [18]
Tilapia	*O. niloticus*	Multi-strain Bacillus probiotic *Bacillus subtilis* and *B. licheniformis*	50 days	100 mL kg $feed^{-1}$	A beneficial change in the intestinal microbiome was observed following the in vivo experiment.	Ferrarezi et al. [19]
Tilapia	*O. niloticus*	Poultry liver protein hydrolysate	45 days	10, 20, or 40 g kg^{-1}	Reduced gill's carbonylated protein levels and enhanced gill's antioxidant enzymes activity.	Gomes et al. [45]
Jundiá	*Rhamdia quelen*	Sardine protein hydrolysate	56 days	2%, 5%, or 10%	The inclusion level of 5% increased digestive enzymatic activity and intestinal lactic acid bacteria.	Ha et al. [46]

Table 1. *Cont.*

Common Name (In Brazil)	Species	Feeding-Based Strategies	Trial Period	Dosage	Main Breakthroughs	Key References
Tilapia	*O. niloticus*	Blending Curcuma longa (CL) Hydrolate and *Lactobacillus plantarum* (*LP*)	70 days	LP = 100 mL kg $feed^{-1}$ CL = 2.5%	The additives combination enhances the overall health and survival of fish.	Jatobá et al. [22]
Tilapia	*O. niloticus*	Sodium butyrate	28 days	0.25% or 0.5%	Na-butyrate reduced alkaline protease activity and contributed to the intestinal development and health of the animals.	Jesus et al. [39]
Seriola	*Seriola dorsalis*	*Ulva fasciata*	48 days	(0, 5, 10, or 20 g kg^{-1})	Improved the fish muscle tissue quality.	Legarda et al. [50]
Tilapia	*O. niloticus*	Benzoic acid	54 days	0.1%, 0.2%, or 0.3%	Fish that were given diets with 0.1% organic benzoic acid exhibited higher weight gain. Incorporating benzoic acid into the fish diet resulted in reduced mortality rates and enhanced the fish's immune response.	Libanori et al. [51]
Pirarucu	*Arapaima gigas*	Enzyme complex (pectinase, protease, phytase, β-glucanase, xylanase, cellulase, amylase)	30 days	0.25, 0.50, 0.75, or 1 g kg^{-1}	In total, 1 g kg^{-1} enzyme complex improved digestibility and productive performance.	Lima et al. [43]
Sardinha	*Sardinella brasiliensis*	Citral (α-citral = 60.15%, β-citral = 39.85%)	20 days	0.5, 1.0, or 2.0 mLkg $feed^{-1}$	Improved survival, increased lipase and amylase activity, and enhanced intestinal morphology at 2 mL kg $feed^{-1.}$	Michelotti et al. [52]
Tilapia	*O. niloticus*	Microencapsulated probiotic *Saccharomyces cerevisiae*, *Bacillus amyloliquefaciens* and *B. subtilis*	45 days	0.02%	Both probiotics enhanced the health and survival of Nile tilapia following exposure to *A. hydrophila*.	Moraes et al. [15]
Tambaqui	*Colossoma macropomum*	Grape extract	60 days	20, 40, 60, or 80 g kg^{-1}	In total, 80 g kg^{-1} of the supplement led to enhanced growth performance and immunity, as evidenced by increased levels of plasma albumin and lysozyme activity.	Morante et al. [4]
Robalo	*Centropomus undecimalis*	Citral-supplemented diet	45 days	0, 0.44, 0.88, or 1.76 g kg $feed^{-1}$	Citral modulated negatively the oxidative stress parameters. The authors do not recommend using citral as diet additive for common snook.	Mori et al. [53]
Tainha	*Mugil liza*	Citral-supplemented diet	45 days	0.5, 1.0, or 2.0 mL kg $feed^{-1}$	Enhanced growth, digestive enzyme function, and overall health. Dietary citral at a dosage of 2.0 mL kg $feed^{-1}$ is recommended for *M. liza*.	Mori et al. [17]
Dourado	*Salminus brasiliensis*	*Lactobacillus rhamnosus* (probiotic + prebiotic)	45 days	0.02% or 2.0%	The addition of 0.02% probiotic and 2.0% paraprobiotic enhanced intestinal immune functions and promoted weight gain comparable to that of fish in the control group, while also reducing feed consumption.	Oliveira et al. [20]

Table 1. *Cont.*

Common Name (In Brazil)	Species	Feeding-Based Strategies	Trial Period	Dosage	Main Breakthroughs	Key References
Tambaqui	*C. macropomum*	Quebra-faca (*Croton conduplicatus*) essential oil	60 days	0, 0.25, 0.50, 1.00, or 1.50 mL kg diet^{-1}	Improved growth performance and hemato-biochemical responses.	Pereira et al. [54]
Tilapia	*O. niloticus*	β-glucan-enriched complex and vitamin premix	30 days	Vitamin Premix at 1.5 or 2.0 kg ton feed^{-1} with or without the β-glucan at 5.0 kg ton feed^{-1}	Improve zootechnical parameters. However, pathological conditions were observed in the liver and spleen.	Pereira et al. [55]
Tambaqui	*C. macropomum*	Orange (*Citrus sinensis*) essential oil	40 days	200, 400, and 800 mg L^{-1}	Promoted growth, improved health, and enhanced resistance to *A. hydrophila*.	Pereira Júnior et al. [56]
Tainha	*Mugil liza*	Exogenous enzyme (xylanases, β-glucanases, pectinases, mannanases, phytase, α-galactosidase, aspartate protease, metalloprotease)	75 days	50, 100, 150, or 200 g ton^{-1}	Prevents intestinal soybean meal-induced enteritis.	Ramos et al. [57]
Tilapia	*O. niloticus*	Mixture of immunomodulators β-glucans, nucleotides, ascorbic acid, and alpha-tocopherol	50 days	40 kg t^{-1}	Increase in final weight, weight gain, daily gain, and decrease in feed conversion rate.	Sá et al. [58]
Tilapia	*O. niloticus*	*Bacillus* spp. and benzoic acid	54 days	Organic acid 0.1%	In total, 0.1% benzoic acid showed greater weight gain.	Santos et al. [59]
Tilapia	*O. niloticus*	Zinc-based products nanoparticles or bulk, inorganic zinc and organic zinc (chelated with methionine)	60 days	15 mg kg^{-1}	Organic zinc in nanoparticles or bulk size increased Nile innate defense.	Silva et al. [60]
Tambaqui	*C. macropomum*	Multi-strain probiotic na prebiotic *L. acidophilus*, *B. cereus*, *B. subtilis*, *Bifidobacterium bifidum*, *Enterococcus faecium*/mannan oligosaccharide, lysine, methionine, choline, vitamin C, vitamin E, and dextrose	45 days	0, 2, 4, 6, or 8 g kg feed^{-1}	In stress situations, the 2 g concentration was more favorable for the fish.	Souza et al. [40]
Hybrid surubim	*Pseudoplatystoma* spp.	*B. subtilis* C-3102	10 days	10, 20 30, or 40 g kg feed^{-1}	In total, 30 g kg feed^{-1} caused beneficial changes in productive performance. Additionally, the hematological parameters were improved in all treated groups.	Veiga et al. [14]

Probiotics are live microorganisms, typically beneficial bacteria such as those of the genus *Lactobacillus* and *Bacillus* [19,20], that are intentionally given to fish through their diet. They help balance the intestinal microbiota, leading to better digestive health, nutrient absorption, growth performance, and increased resistance to infections. Probiotics directly compete with harmful microorganisms for adhesion sites in the gastrointestinal tract, limiting the growth of pathogens. They also produce antimicrobial substances such as bacteriocins and organic acids that inhibit the growth of pathogens. Probiotics can also boost the fish's immune system by stimulating the production of immune cells and reducing oxidative stress, protecting the fish from cellular damage [15,18,40]. On the other hand, prebiotics are non-digestible compounds such as plant fibers, mannan oligosaccharides (MOS), and fructooligosaccharides (FOS) that are intentionally added to the diet to support the growth and activity of probiotic bacteria in the intestine of fish. This creates a favorable environment for probiotics, enhancing the health and growth of aquacultured fish [2,40].

Immunomodulators, including fatty acids such as arachidonic acid (ARA; 20:4n-6), eicosapentaenoic acid (EPA, C20:5), and docosahexaenoic acid (DHA, C22:6, ω-3), nucleotides, and plant extracts, can influence the immune response of fish by stimulating or regulating the production of immune cells such as lymphocytes and macrophages [23–25]. These substances help enhance fish resistance to pathogens and diseases and can also improve their ability to combat bacterial infections [21,51]. Essential fatty acids, such as omega-3 (EPA and DHA) and omega-6 fatty acids (ARA), are crucial for building and maintaining cell membranes and regulating the inflammatory response [61]. Additionally, they play a key role in modulating immune function by promoting the production of prostaglandins and leukotrienes that help regulate inflammation and the immune response.

Organic acids, including butyric acid, citric acid, lactic acid, propionic acid, and formic acid, among others, possess antimicrobial and acidifying properties that enhance the intestinal environment of fish. These acids aid in reducing the presence of pathogens, such as harmful bacteria and fungi, in both the gastrointestinal tract and water, while also promoting better digestion and nutrient uptake [2,39,51].

Antioxidants, including vitamins (A, D, and E), minerals (zinc, selenium, and copper), and beta-carotene, play a vital role in reducing oxidative stress in fish [2]. They work by neutralizing free radicals that can cause cellular damage and weaken the immune system. By increasing the fish's resistance to adverse conditions such as temperature fluctuations, environmental stress, and infections, antioxidants help maintain the overall health of the fish [18]. These vitamins and minerals are essential for immune function, growth, and development in fish [2,60]. Additionally, they prevent the peroxidation of lipids in fish muscle tissue, ensuring the quality of the meat is preserved [61]. Nutrient deficiencies can compromise the immune system and make fish more susceptible to diseases. Antioxidant vitamins such as C and E, along with minerals such as zinc, selenium, and iron, are crucial for reducing oxidative stress and supporting immune responses in fish [11,12,60].

Bioactive peptides, derived from proteins, demonstrated the ability to enhance fish immunity by stimulating the activation of immune cells such as macrophages and lymphocytes. Certain peptides also possess antimicrobial properties, aiding in the prevention of infections by targeting pathogens. Incorporating digestive enzymes into fish feed can enhance digestion and nutrient uptake, lessening the strain on the fish's digestive system and promoting gut health. Improved digestion can lead to healthier fish with stronger immune systems [6,8,12,46].

3. Nutritional Approaches in Brazilian Marine Fish Farming

Although marine fish farming is incipient in Brazil [62], the use of specially formulated and enriched diets for marine fish has become increasingly important in Brazilian aquaculture, with the goal of enhancing the performance, health, and welfare of farmed animals. Research in this field increased in recent years, aiming to find sustainable and efficient alternatives to enhance the production of economically significant marine species such as mullet, common snook, and sardines.

For example, a study investigated the impact of adding guar gum (galactomannan), a non-starch polysaccharide obtained from *Cyamopsis tetragonolobus*, to the diets of juvenile lebranche mullet (*M. liza*). Results show that diets with guar gum levels above 4% were not recommended for *M. liza*. Fish fed diets with 8% and 12% gum had lower final weight, weight gain, growth rate, feed intake, and protein intake compared to the control group. Additionally, diets with gum had reduced levels of dry matter, crude protein, and carcass fat. Liver glycogen levels increased with gum supplementation, while cholesterol levels decreased in fish fed 4% and 8% gum levels [63]. Similarly, Ramos et al. [64] warned against the use of citrus pectin at levels of 4%, 8%, or 12% in the diet of juvenile *M. liza*. Fish fed pectin exhibited lower percentages of body dry matter, crude protein, and ash. Liver glycogen levels were elevated in the group fed 12% pectin, with no significant effects on cholesterol and triglyceride levels. Citrus pectin did not have any discernible impact on the microbial community.

In contrast, Mori et al. [17] found that adding citral to the diet had positive effects on juvenile *M. liza*. Fish that received citral (2.0 mL kg feed^{-1}) showed improved weight gain and protein retention efficiency, along with higher pepsin and amylase activities in the stomach and intestine compared to the control group. Additionally, citral supplementation reduced hepatic lipoperoxidation and increased the activities of glutathione peroxidase, glutathione-S-transferase, and superoxide dismutase in the gills, liver, and brain. Citral also showed beneficial effects and enhanced the survival rate of Brazilian sardines (*S. brasiliensis*). Adding citral to the diet at a rate of 2.0 mL kg feed^{-1} increased the specific activity of digestive enzymes lipase and amylase. Furthermore, it had a positive impact on the number of villi and the depth of the intestinal crypt, while the inclusion of citral at a dose of 0.5 mL kg feed^{-1} increased the diameter of the intestine of the fish [27]. On the other hand, Mori et al. [53] and Michelotti et al. [52] both advise against using citral as a dietary additive for juvenile common snook (*Centropomus undecimalis*).

Noffs et al. [65] studied the impact of adding *B. subtilis* probiotic (5.0×10^9 CFU kg feed^{-1}) to the diet of common snook (*C. undecimalis*) fingerlings. While the addition of *B. subtilis* did not result in higher growth rates for the common snook fingerlings, it did exhibit immunostimulant effects when administered on an alternate schedule.

Including organic salts in the diet of Brazilian marine fish has been proven to be advantageous for juvenile fat snook (*C. parallelus*). In a study by Silva et al. [66], it was found that including organic salts in the diet of fat snook can be beneficial for juvenile fish. The researchers added 3% sodium acetate and sodium citrate to the diets of fat snook fingerlings and the fish that received sodium acetate showed higher final weight, length, and yield compared to the control group. Furthermore, the fish that received acetate and citrate had lower levels of total heterotrophic marine bacteria compared to the control group. This suggests that using organic salts in fish diets could be a promising area for future research.

The effects of supplementing different levels of ascorbic acid in the diet of the lebranche mullet *M. liza* were reported. Ascorbic acid had no effect on growth parameters, but treatments with 107 and 216 mg kg^{-1} demonstrated the most favorable outcomes for sperm quality in male lebranche mullet [67]. Sperm quality is crucial for the successful reproduction of any fish species in aquaculture, as it plays a key role in maintaining the robustness and health of fish stocks.

Furthermore, supplementing the diet with exogenous enzymes has been shown to be an effective approach for mullet. A complex of exogenous enzymes, such as xylanases, β-glucanases, pectinases, mannanases, phytase, and other non-starch polysaccharidases, helps prevent soybean meal-induced intestinal enteritis in juvenile *M. liza* [57].

Unlike freshwater fish, marine species face distinct challenges due to the saline environment and their unique digestive physiology. As a result, specialized additives must be developed and evaluated to meet the nutritional and physiological requirements of marine fish.

Nutritional Strategies for Aquacultured Marine Ornamental Fish in Brazil

The trade of ornamental aquatic organisms experienced significant growth in recent decades, evolving into a multibillion-dollar international industry [68–70]. Fish are the most traded and popular group within this industry. With millions of fish traded annually for aquarium purposes, freshwater fish continue to be the dominant species in the ornamental fish market, representing a significant portion of the global fish trade. While saltwater fish make up less than 10% of the volume traded, their higher prices result in a greater overall value compared to freshwater fish [69].

The aquarium industry heavily relies on wild-caught marine ornamental fish, with estimates suggesting that 90 to 99% of these fish are sourced from the wild [69]. This reliance raises concerns about sustainability and environmental impact, including overfishing, destructive collection methods, habitat destruction, and the exploitation of endangered species. Efforts are being made to promote sustainable practices through regulations and certification in the trade of marine ornamental fish. To address these concerns and reduce pressure on wild populations, there is a growing focus on breeding marine ornamental fish in captivity.

However, breeding ornamental marine species presents unique challenges due to the complexity of the marine environment, low success rates in breeding certain species, disease management, stress in captivity, specific dietary requirements, water quality management, color maintenance, and feeding costs [5,71,72]. It is crucial to note that numerous studies documented the presence of additives in freshwater that do not qualify as feed additives or supplements. Nevertheless, for marine fish that require seawater intake for osmoregulation, adding additives to the water may be classified as a form of feed additive.

Experimental diets have been tested in Brazilian ornamental fish production to ameliorate some of the problems mentioned above, playing a pivotal role in boosting the growth, health, color, and overall welfare of the fish. Research is currently concentrated on the advancement of technology for the production of native marine ornamental fish species, particularly those that are vulnerable or near threatened, such as seahorses (*Hippocampus reidi*). The focus is on increasing survival rates and enhancing technology for farming exotic species, such as clownfish, with efforts to shorten the larviculture duration and improve body coloration.

For instance, thyroid hormones (THs), including T3 (triiodothyronine) and T4 (thyroxine), play a crucial role in fish physiology and are crucial for early development [73], and studies have shown that administering THs to fish can have positive effects on growth, survival, skeletal muscle development, swim bladder inflation in larvae, reduction in cannibalism, and acceleration of metamorphosis [74,75]. Research also documented the impact of THs on tissue differentiation, including the digestive system, in fish larvae [76,77].

The inclusion of triiodothyronine (T3) in the larval development of the barber goby (*Elacatinus figaro*), a vulnerable and endemic to Brazil fish with high risk of extinction in the wild, was tested from 14- to 40-days after hatching (when all larvae completed metamorphosis). Larvae immersed in the concentration of 0.025 mg L^{-1} of T3 and 0.05 mg L^{-1}

predicted their metamorphosis in up to 11 days in relation to control group (no T3 addition) and to 0.01 mg L^{-1} treatment [49], therefore reducing the larviculture period for this species.

Contrera et al. [47] found a similar outcome in their study on the larviculture of the yellowtail clownfish *Amphiprion clarkii*. They observed that adding different concentrations of T3 (0.01 mg L^{-1} and 0.1 mg L^{-1}) to the rearing water had an impact. The treatment with 0.01 mg L^{-1} resulted in improved survival rates and accelerated larval metamorphosis by 4 days, with 81% of the larvae undergoing metamorphosis by day 13, compared to fish without hormone supplementation in the rearing water. However, the highest T3 dosage led to lower growth rates and incomplete metamorphosis, with larvae exhibiting abnormalities such as skeletal deformities, fin malformations, altered coloration, and erratic swimming behavior.

Probiotics are among those functional feed additives showing strong effects on growth, health, and well-being. In a study conducted by Ferreira [78], a commercial live feed enrichment product containing microalgae, microencapsulated fish oil, and arachidonic acid oil was tested on *Artemia* sp. offered as exclusive food for *H. reidi* juveniles at 30 days after hatching (DAH). The microalgae *Nannochloropsis oculata* was also tested alone or in combination with a commercial probiotic containing *B. subtilis*, *Enterococcus faecium*, *Pediococcus acidilactici*, and *Lactobacillus reuteri* at a concentration of 3×10^9 CFU g^{-1}. The findings indicate that at 45 days after hatching (DAH), growth performance was enhanced in treatments where *Artemia* sp. was enriched with the commercial enrichment product, irrespective of the inclusion of probiotics. Additionally, during the early phases of *H. reidi* larviculture, incorporating copepods into a diet of rotifers and artemia along with the use of the same commercial probiotics in the rearing water led to successful larval growth and development [79].

Carotenoids play a crucial role in enhancing and preserving the vivid colors of ornamental fish. Fish and other aquatic animals cannot produce carotenoids on their own, so they are added to the diet of farmed fish and crustaceans to enhance their coloration and boost their immune system. Astaxanthin and other carotenoids are sourced from synthetic sources as well as natural sources such as yeasts, algae, maize, and bacteria for inclusion in aquatic feed formulations. In a study by Hoffmann [80], the effectiveness of commercial products containing synthetic (3, 3′-dihydroxy-β, β-carotene-4, 4′-dione) and natural astaxanthin from *Haematococcus pluvialis* was compared in terms of color, growth, and survival of juvenile clownfish *A. ocellaris*. Dietary astaxanthin was found to be beneficial for fish pigmentation. The diet supplemented with natural astaxanthin was the most effective in enhancing fish coloration, providing the species with a characteristic red hue.

Other approaches, such as supplementing the diet with exogenous enzymes, have shown positive effects on marine ornamental fish. Supplementing fish feed with exogenous enzymes can enhance feed efficiency, leading to increased growth of animals in aquaculture. Feeding seahorse *H. reidi* exclusively with *Artemia* sp. supplemented with 75 mg L^{-1} of porcine pancreatin (enzyme complex of pancreatic enzymes consisting of trypsin, amylase, lipase, ribonuclease and protease) from birth to 30 days of age resulted in significant changes in the intestinal mucosa, leading to improved survival and growth of the fish. This suggests that supplementing with digestive enzymes is a valuable advancement in establishing a more efficient and practical feeding protocol (solely using artemia) for juvenile seahorses [81]. Similarly, when feeding *A. ocellaris* with *Artemia* sp. enriched with porcine pancreatin, a concentration of 75 mg L^{-1} enhanced the zootechnical performance (length and daily growth) of larvae [82].

Organic acids have shown promise for marine ornamental species, similar to their effectiveness in freshwater fish farming. A commercial blend of organic acids (126.5 g kg^{-1} of ammonium formate, 115.5 g kg^{-1} of formic acid, 82.5 g kg^{-1} of plants fatty acids, 66.0 g kg^{-1}

of propionic acid, and 55.0 g kg^{-1} of acetic acid) was tested in the diet of juvenile clownfish *A. ocellaris* at 21 DAH. After 77 days, the zootechnical performance and the activity of digestive enzymes (trypsin, chymotrypsin, and amylase) were not affected by the addition of the mixture to the diet. However, the group receiving 15 g kg^{-1} of the mixture showed positive changes in intestinal morphology, suggesting improved nutrient absorption and indicating that a longer period of supplementation may enhance the growth performance and health of *A. ocellaris* [83].

Organic acids have proven to be highly advantageous for aquacultured fish, enhancing fish digestion and intestinal health due to their antimicrobial properties that hinder the proliferation of harmful microorganisms. Nevertheless, in Brazil, additional research is required in the marine ornamental fish industry to promote the utilization of this supplement.

Microalgae play a vital role as a feed source for the larvae of different aquatic organisms such as bivalves, fish, and shrimp due to their high nutritional value and suitable cell size. They are also crucial as feed sources or nutrient supplements for secondary live prey such as rotifers, artemia, and copepods. Mélo et al. [84] observed that including microalgae *N. oculata* in the rearing water (green water) increased the survival rates of newborn *H. reidi*.

Sousa et al. [85] conducted a study to assess the impact of different live microalgae (*Tisochrysis lutea*-ISO and *Chaetoceros muelleri*-CHO), used either individually (TISO and TCHO) or combined (TIC 1:1) in the rearing water, as well as a treatment without microalgae (TWM), during the initial 15 days of *H. reidi* rearing. The inclusion of microalgae, particularly *T. lutea*, offered numerous advantages for seahorse aquaculture. Its presence in the rearing water positively influenced the surface area of the larvae's intestinal villi, leading to improved weight performance and higher concentrations of PUFA, DHA, $\sum n{-}3$, and $n{-}3/n{-}6$ ratio in the larvae compared to the treatment without microalgae. Sales et al. [86] noted that *H. reidi* seahorses (15 DAH) fed a flocculated paste and fresh microalgae culture of *N. oculata* exhibited greater height and length compared to those fed a commercial paste, which is likely due to the presence of live cells and high levels of highly unsaturated fatty acids.

Additionally, incorporating fatty acid and carotenoid extracts from the microalgae *N. gaditana* into the diet of juvenile clownfish *A. ocellaris* resulted in higher weight at 30 days with the fatty acid extract, and greater length values with both the fatty acid and carotenoid extracts. However, by 60 days, growth performance was comparable across all treatments, indicating that substituting fish oil with microalgae extracts does not lead to reduced production [87]. The aquaculture industry is constantly seeking more profitable and sustainable ingredients [88,89]. Microalgae have been shown to be a great choice as feed supplements for ornamental fish, providing numerous advantages. Furthermore, microalgae are packed with vital nutrients such as proteins, vitamins, minerals, and fatty acids that are essential for the well-being and development of fish.

Certain micronutrients, such as iodine, can be crucial for the health and overall well-being of fish as they serve vital functions in various biological processes. Araújo-Silva et al. [90] recommended supplementing iodine in the water or feed to treat thyroid goiter in the Brazilian basslet (*Gramma brasiliensis*) when kept in captivity. Although the specific cause of this condition in the species is not fully understood, the authors advised keeping nitrate levels low and regularly monitoring iodine levels in the water. According to Araújo-Silva [91] (personal communication), fish of this species showed a notable reduction in goiter size when treated with iodine added to their feed.

The search for sustainable methods in breeding ornamental marine species in captivity is vital to alleviate pressure on wild populations. Research in nutrition, including feed additives, made significant progress, which is key for enhancing aquaculture efficiency while minimizing environmental harm.

4. Using Seaweed as a Feeding Strategy in Brazilian Fish Farming Research

In recent years, there has been a growing interest in using macroalgae as a feeding strategy because of the nutritional, immunostimulant, antiviral, antibacterial, and growth-promoting properties. The dietary inclusion of the macroalgae *Ulva ohnoi* [92], *Sargassum filipendula* [93], *Undaria pinnatifida* [94], *Chaetomorpha clavata* [95], and *Kappaphycus alvarezii* [96] demonstrated significant effects on the growth and immunity of Pacific white shrimp (*Penaeus vannamei*). Seaweed-derived bioproducts could significantly benefit other aquatic organisms, such as fish. Despite this, research on the use of macroalgae in fish diets remains limited in Brazil.

Costa and Miranda-Filho [97] emphasized the importance of investigating the properties of pigment sources from marine macroalgae for the future of Brazilian aquaculture. They highlighted that carotenoids have significant impacts on the growth, reproduction, and health of these animals, going beyond coloration. Pontes et al. [98] studied the impact of incorporating marine macroalgae *U. fasciata* in the diet of juvenile tilapia (*O. niloticus*). The researchers found that including 10% *Ulva* meal in the diet did not affect the gastrointestinal transit time of juvenile tilapia compared to the control group. This suggests that incorporating 10% Ulva meal in the diet of tilapia is safe and does not have any negative nutritional effects. Similarly, Costa et al. [99] also found that including 20 g kg^{-1} of the brown seaweed *Ascophyllum nodosum* in the diet could be advantageous for Nile tilapia. They observed a linear improvement in apparent feed conversion rate values and carcass yield values with increasing levels of inclusion in the diets.

In a study by Mendonça et al. [100] it was found that incorporating different levels of macroalgae *Gracilaria domingensis* (0%, 5%, 10%, 15%, and 20%) into the diet of juvenile mullet (*M. liza*) enhanced the immune response. However, growth of the fish was significantly hindered when the macroalgae levels exceeded 10%. Additionally, mullet that were fed diets containing marine macroalgae exhibited higher levels of anti-CD3 and anti-CD4 antibodies compared to the control group. The inclusion of 5% macroalgae in the diet led to improved immune competence without negatively impacting fish growth.

Indeed, seaweed has significant biotechnology potential in fish farming, as it can serve as a regulator of growth, immune and antioxidant responses, and gut microbiota in fish [101]. In a study conducted by Cian et al. [102], the antioxidant properties of the red algae *Pyropia columbina* were examined in juvenile Pacu (*Piaractus mesopotamicus*). The researchers found that there were no significant differences in final body weight, specific growth rate, condition factor, and hepatic somatic index among the fish. However, those fed with *P. columbina* exhibited lower levels of lipid peroxidation, superoxide dismutase, and a reduced SOD/CAT ratio in the intestine, liver, and white muscle, suggesting a systemic impact of the algae. In contrast, *U. fasciata* was included in the diet of *Seriola dorsalis* at various levels (0, 5, 10, and 20 g kg^{-1}) and did not impact growth performance or somatic parameters. However, at an inclusion level of 20 g k^{-1}, there were significant changes in hematological parameters compared to the control group. Additionally, supplementation with *U. fasciata* led to a reduction of approximately 20% in linoleic acid and an increase in DHA levels in muscle tissue, ultimately enhancing the quality of fish fillets [50].

Calheiros et al. [103] suggest that the genus *Ulva* can serve as a natural source of phenylalanine and tryptophan for use as anxiolytics in fish farming. They propose that *Ulva* spp., being rich in tryptophan and phenylalanine, could help alleviate stress in fish farming. Furthermore, products derived from *Ulva* spp. could enhance fish health in integrated multitrophic aquaculture.

Research has shown that macroalgae can be beneficial as feed additives in aquaculture, improving fish growth, immunity, and overall health. Although studies on the use of macroalgae in Brazilian fish farming are limited, the results suggest promising biotechnological potential. The antioxidant and anti-stress properties of macroalgae could enhance fish health and the quality of fish products.

5. Recent Advances for Feeding in Brazilian Fish Farming

Brazilian aquaculture is currently experiencing rapid and promising growth. In 2024, fish farming, particularly tilapia production, solidified its position as a key sector in Brazilian agribusiness, establishing Brazil as a leading global producer of tilapia. Nevertheless, there is significant potential for further expansion, driven by advancements in technology for cultivating and feeding native species such as tambaqui and pirarucu. Furthermore, exports are increasing, with key markets such as the United States and the European Union emerging as important destinations for Brazilian fish products [1,104]. Therefore, research in the nutrition field can have a significant impact on enhancing fish farming in Brazil.

The advancement of highly effective and improved feeds using alternative ingredients or additives could enhance nutrient absorption and the well-being of aquacultured fish, leading to decreased production costs. Recent studies concentrated on formulating feeds that have minimal environmental impact, decreasing pollution and utilizing sustainable resources, while others focused on utilizing by-products from agroindustry to promote more efficient resource utilization. Romaneli et al. [105] discovered that a diet with a well-balanced amino acid profile, even with a lower protein content, did not hinder the growth of juvenile Nile tilapia and reduced digestible protein from 32% to 29%, resulting in a 12% decrease in nitrogenous waste excretion. Gandolpho et al. [106] examined the nutritional composition, phenolic profile, and antioxidant properties of trub, a beer industry byproduct, for potential use in aquafeed formulation and found that it could serve as a natural antioxidant source with significant potential for fish dietary supplementation, such as tilapia.

On the other hand, Brazilian research primarily focuses on the health and growth of aquacultured fish, utilizing specific additives to achieve these goals. Oliveira et al. [20] discovered that *L. rhamnosus*, used as a probiotic, prebiotic, and in a synbiotic combination, could benefit a Brazilian carnivorous species, the dourado *S. brasiliensis*. The study tested diets with different additives: a control group without additives, 0.02% probiotic (*L. rhamnosus* 10^8 CFU), 2.0% prebiotic (inactive *L. rhamnosus* 10^{10} CFU), and a synbiotic combination. The results show that the use of 0.02% probiotic, 2.0% prebiotic, and synbiotic was promising, as it improved productive performance, allowing for weight gain similar to the control group with lower feed consumption. Additionally, treated fish exposed to *A. hydrophila* showed notable improvements in intestinal immunohistochemical parameters. Specifically, the anatomopathological examination revealed that the specific cells comprising the villus and serosa tissue were more intact, and there was an increased abundance of goblet cells.

Research on the specific nutritional requirements of different fish species can help in creating diets that support optimal health and growth. De Oliveira et al. [48] found that a combination of sodium butyrate, dehydrated hydrolyzed yeast, and zinc proteinate in varying concentrations (0.00, 0.60, 1.20, 2.40, and 4.80 g kg^{-1}) was advantageous for juvenile Nile tilapia. Tilapia fed diets with this blend at 2.40 g kg^{-1} showed increased trypsin activity in the intestine, improved intestinal tissue integrity, reduced fusion of intestinal folds, and enhanced development and height of microvilli, indicating positive effects on intestinal health through modulation of the intestinal microbial community.

Similarly, Ferrarezi et al. [19] discovered that a multi-strain *Bacillus* probiotic was advantageous for Nile tilapia, leading to changes in the tilapia's intestinal microbiome with species increased richness and decreased abundance of *Aeromonas* sp., while Pereira Júnior et al. [56] reported that supplementation with orange essential oil from *Citrus sinensis* (200, 400, and 800 mg L^{-1}) was highly effective for native Brazilian tambaqui (*C. macropomum*). Tambaqui fed diets with 400 and 800 mg L^{-1} of *C. sinensis* essential oil showed improved growth and innate immunity, as well as lower mortality rates after exposure to *A. hydrophila*.

Nutritional research plays a crucial role in identifying dietary compounds that can enhance the immune system of fish, thereby reducing disease incidence and improving survival rates. For instance, a study on juvenile Nile tilapia showed that supplementing their diet with vitamins and immunomodulators (β-glucans + nucleotides) for 60 days led to improved haematoimmunological responses and increased resistance to physical and thermal stress [107].

Furthermore, advancements in technology can lead to the development of more efficient and sustainable fish diets. Sá et al. [58] explored the effects of supplementing the diet of juvenile Nile tilapia with immunomodulators (β-glucans, nucleotides, ascorbic acid, and alpha-tocopherol) along with a diet containing lower levels of animal protein (11.5%) and higher levels of soybean meals (43.5%). This combined supplementation resulted in significant improvements, including a 59.95% increase in final weight, 64% weight gain, 66% daily gain, 21.31% reduction in feed conversion rate, and doubled body protein retention. Additionally, the supplementation enhanced intestinal morphology and modulated the intestinal microbiome, highlighting the potential for reducing the reliance on animal protein in fish diets.

In a recent study, Pereira et al. [54] found that dietary supplementation with *Croton conduplicatus* essential oil (at doses of 0, 0.25, 0.50, 1.00, or 1.50 mL kg diet^{-1}) could have positive effects on tambaqui. Fish fed diets containing 0.85 mL kg diet^{-1} showed improved growth parameters, while the feed conversion rate was lower in the 0.25 mL kg diet^{-1} group. However, the group receiving 1.00 mL kg diet^{-1} experienced hematological and serum disorders. This highlights the dual nature of essential oils in fish diets, as they can provide benefits, but also have the potential to be toxic and cause disorders. Therefore, it is crucial to use essential oils cautiously and in appropriate doses to prevent adverse effects.

The utilization of technologies such as biotechnology and nanotechnology may result in the creation of novel feed varieties that are both more effective and environmentally friendly. Silva et al. [60] studied the impact of various zinc-based supplements on the growth and health of Nile tilapia. The study used zinc in different sizes (nanoparticles or bulk) and forms (inorganic or organic) as a dietary supplement for tilapia at a dosage of 15 mg kg of feed^{-1} for 60 days. The results show that while the different zinc-based products did not influence growth performance, zinc had significant positive effects on haemato-immunological parameters. Additionally, organic zinc in nanoparticle or bulk form enhanced the innate defense of Nile tilapia following exposure to *Streptococcus agalactiae*.

The recent research mentioned above is essential to ensure that Brazilian fish farming continues to grow in a sustainable and competitive manner. Higher-quality and more sustainable products have the potential to open up new markets and entice consumers who are concerned about sustainability and health.

6. Future Outlook for Nutrition and Feeding in Brazilian Fish Farming

The future outlook for nutrition and feeding in Brazilian fish farming looks very promising. With the ongoing expansion of the Brazilian fish farming industry, there is anticipated to be a notable rise in research efforts and the introduction of new products to the market. The fish farming sector in Brazil is experiencing rapid growth, with investments being made in water resource management technologies and the development of specific diets for native species, which will help ensure the sector's sustainability. These prospects indicate a dynamic future with significant growth opportunities for fish farming in Brazil.

Recent highlights of the Brazilian evolution in the search for sustainable alternatives for the aquafeed industry include feed additives such as citral [17,27], β-glucan-enriched complex [55], *Ocimum basilicum* essential oil [108], *Bacillus* spp. and organic benzoic acid [59], propionic acid [109], *Curcuma longa* Hydrolate and *L. plantarum* [22], Inulin [21], *L. sidoides* essential oil [25], and *L. rhamnosus* [20].

Despite the advancements in Brazilian research reported in this study, it is crucial to incorporate these advancements into the aquafeed industry to enhance the growth and sustainability of the sector. Quality ingredients are necessary for formulating fish diets, even though they can be costly. Proper selection of feed ingredients and additives is vital for the health and growth of fish. Nutrition for native species remains a challenge in the Brazilian aquaculture industry. Government support and targeted public policies for the fish feed sector could drive development and innovation. These challenges present obstacles, but also opportunities for innovation and expansion in the Brazilian fish feed industry.

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