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Editorial: Functional feed additives: current trends

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Editorial on the Research Topic
Functional feed additives: current trends

Introduction

Functional feed additives are a potential innovative way to enhance aquaculture production, sustainability, and profitability. These additives have many physiological benefits, like increased growth rates, enhanced disease resistance, stress tolerance, and improved animal health and welfare. Probiotics, prebiotics, paraprobiotics, phytochemicals, unique proteins, nucleotides, and pigments are functional additives in the feed of aquatic animals (Herrera et al., 2019; Idenyi et al., 2022; Amir et al., 2024). In the context of functional feed additives for aquaculture, the most important thing is nutritional programming, which indicates the ability of dietary additives, when administrated during a certain development period to exert long-lasting effects on the physiology, growth, and health of aquatic species. Nutritional programming can be influenced by the source and origin of the additives, their inclusion doses, feeding period, and the fish's development stage during administration (Encarnação, 2016). However, it is always essential to focus on appropriate formulations and the rate at which they are added to increase practical benefits while reducing anti-nutritional effects. For example, some protease inhibitors harm nutrient digestibility and mineral absorption. Identifying synergistic additive combinations, developing efficient and cost-effective production techniques, and understanding the mechanisms by which bioactive compounds work are critical challenges in aquaculture. This Research Topic, "Functional feed additives: current trends," aimed to fill the most critical knowledge gaps and key issues in feed additive formulation, production, and application. The findings from this Research Topic provide new insight into the use and consequences of available feed in diverse aquatic animals. Together, they demonstrate the enormous potential of tailored functional additives to improve growth performance, enhance immune and gut health, reduce disease incidence, and ultimately increase production and profitability. Thus, this Research Topic covers the most recent studies on the applications, results, and future directions of functional feed additives for various farmed fish species.

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Revolutionizing aquaculture: enhancing growth with functional feeds

Several studies in this Research Topic discussed how feed additives may be used to improve the growth performance of aquaculture species. Velasco et al. showed that the gene expression of *Dicentrarchus labrax* (European seabass) changed after the administration of swine blood hydrolysate to their feed. Moreover, their research demonstrated that dietary hydrolysates enhance myosin heavy-chain expression and promote muscle development protein accretion. The bioactive properties of hydrolysates are correlated with their peptide components since low medium-weight peptides have been found to produce a functional balance in protein accretion. These findings suggest that blood hydrolysates can increase the gene expression levels necessary for muscular growth. They added 3% swine blood hydrolysate in a plant-based diet and found that muscle fiber hyperplasia occurred noticeably sooner before the lesions developed when comparing fishmeal-based diets to plant-based ones. This implies, particularly in plant-based aquaculture, the bioengineering of functional meals for optimal hyperplastic muscle formation.

Apart from muscle impacts, Mueller et al. described that functional feeds have promising potential to improve conversion efficiency. Administration of microalgae like *Tetraselmis chuii* and *Schizochytrium limacinum* enhanced feed conversion rate and protein digestibility in Atlantic salmon (*Salmo salar*). The expression of different genes like alpha-linolenic acids (*ALA*) and docosahexaenoic acid (*DHA*) were high after microalgae administration. Overall, the administrated microalgae in the Atlantic salmon feed enhances the different health aspects without compromising the growth performance when cultured in a recirculatory aquaculture system (RAS). The beneficial results are due to the composition of microalgae, as they are rich in high protein and bioactive compounds, making them potential functional ingredients to improve feed utilization. Thus, it promises to enhance Atlantic salmon's nutritional quality and health (Ampofo and Abbey, 2022). Moreover, Jiang et al. also described that administering fermented Chinese herbs increased juvenile largemouth bass' (*Micropterus salmoides*) weight gain and specific growth rate. Similarly, Ding et al. showed that graded levels of arginine significantly induced the expression of genes involved in energy and signaling pathways.

Enhancing intestinal morphology, immunity, and health

A significant area of research investigated how functional feeds affect immunity, gut health, and disease resistance. Several studies have shown that functional additives with an optimized formulation can modulate intestinal morphology, gut microflora antioxidant capacity, and immunity markers.

Marmelo et al. demonstrated a significant increase in antioxidant enzymes, immunity markers, and intestinal villi length when *Laminaria digitata* was included in the feed of *Sparus aurata* (gilthead seabass). The study suggests that *L. digitata* can be used as an effective feed additive for aquatic animals. The biofortification method helps improve the absorption capacity and function of the intestine by increasing the size of the villi. In the case of spotted seabass, Zhou et al. also observed an increase in intestinal villi length with mulberry leaf (*Morus* spp.) extract. The study shows that Mulberry leaf extract supplementation enhances growth, enteric antioxidant capacity, microbial composition like *Lactobacillus* sp., and the intestine morphology of sea bass. These results highlight the capacity of marine and plant functional ingredients to improve intestinal morphology and functions.

In the case of largemouth bass, Jiang et al. found that fermented Chinese herbs increase *Lactococcus* and decrease opportunistic pathogens; their study showed an increase in intestinal villus height followed by an increase in the expression of claudin and occludin (the proteins involved in the localization of cell signaling molecules to tight junctions), while decreasing the expression of pro-inflammatory biomarkers such as *TNF-α*. Their study also showed an increase in antioxidant, lysozyme, or immune enzyme activity, evidenced by the reduction in mortality after *Aeromonas hydrophilia* infection. Ding et al. showed that dietary arginine supplantation enhanced the antioxidant capacity and nutritional metabolism as graded arginine enhanced total superoxide dismutase (*TSOD*) and reduced the level of malondialdehyde (*MDA*) and glucose. All these results showed that feed additives improve disease resistance by reducing oxidation stress and increasing immunity. These findings demonstrate a synergistic benefit of optimized feeding additives for boosting gut health, antioxidant status, and immunity. Further research could follow these results to understand the physiological mechanisms that lead to health advantages.

Determining ideal inclusion rates

Several studies discussed the importance of optimizing the inclusion level of feed additives and focused on balancing beneficial and anti-nutritional effects at various supplementation levels. Qiu et al. showed that the dietary hydrolyzable tannin level below 1 g kg^{-1} did not alter growth performance in Chinese seabass (*Lateolabrax maculatus*). However, the higher supplementation levels exceeding 2 g kg^{-1} negatively influenced feed intake and reduced growth, indicating that the optimum inclusion levels are necessary to achieve the desired benefits while minimizing anti-nutritional components. Similarly, Velasco et al. stressed the importance of determining optimum hydrolysate concentrations to maximize growth benefits while Ding et al. focused on the determination of the inclusion level of arginine as a feed additive for the growth and health of *Siniperca cheats*. In general, such results demonstrate the opportunity for optimized functional feed additives to improve growth in various species and emphasize the identification of synergistic combinations and ratios of functional ingredients. Continued research could improve supplement inclusion rates, explore synergistic effects between additives, and clarify physiological mechanisms.

Significance of feed processing techniques

Velasco et al. showed that the bioactive properties of hydrolysates are closely associated with the production process, particularly with a balance between peptides produced. Thus, it could be a beneficial factor as it maintains the stability and bioavailability of active ingredients, which could be further improved by microencapsulation and new processing techniques. Literature also indicates that feed processing techniques significantly affect fish growth, immunity, and disease resistance (Amir et al., 2024). Moreover, the different feed processing techniques such as chemical, enzymatic, and mechanical methods are significant for disrupting yeast cell walls, which ultimately enhances the nutrient digestibility and utilization in aquaculture species, as demonstrated in studies on salmon, shrimp, and Arctic charr (Agboola et al., 2021).

Financial factors and feed appeal

Marmelo et al. have pointed out that expensive processing methods can be necessary to meet the requisite environmental conditions and properties of additives, such as hardness. Enhancing feed palatability and marketability while keeping production costs in check will be imperative for commercial adoption. The aquaculture industry can fully exploit the benefits of functional feed additives by addressing these challenges. Coherent research in nutrition, immunology, genetics, and processing technologies will be needed.

Complexities in functional feed production and formulation

A persistent challenge identified in all studies is the need for time to improve the formulation and develop efficient processing methods. Several technological and economic factors should be considered.

Beyond the horizon: advancing perspectives on functional feeds

In this Research Topic, a valuable insight into the current applications and future potential of functional feed additives has been addressed. The research output has demonstrated that optimized functional feed additives can be beneficial in stimulating growth and enhancing disease resistance, immunity, and fish health. In future research, there should be a critical effort to ensure the development and adaptation of functional feed additives. The critical areas for future studies will include the following:

- ❖ Elucidating the molecular mechanism of functional ingredients.
- ❖ Identification of any synergistic combination and optimal inclusion level.
- ❖ Development of efficient and cost-effective processing methods.
- ❖ Assessing the functional feeds in different aquaculture systems such as semi-intensive culture system and RAS.
- ❖ Evaluating the sensory and market impacts of functional feeds.

The potential benefits are enormous in improving aquaculture's productivity, profitability, sustainability, and animal welfare outcomes. Functional feed additives represent one of the most promising innovation pathways to shape the future of sustainable aquaculture production.

Author contributions

AZ: Writing – review & editing. MK: Writing – original draft. NY: Writing – original draft. MA-T: Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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