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Aquaculture Advancements Through Bioactive Molecules

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Abstract

A wide range of seafood species – including fish, shellfish, squid, and bivalves – generate by-products that are often discarded as waste. However, these by-products hold great potential for developing innovative functional food products. Because there is limited opportunity to recycle natural resources, the loss of profit may be accompanied by the loss of ecological sustainability, given that the "wastes" of industrial processing can account for up to 75% of entire organisms. Depending on the species and taxa under consideration, fish heads, viscera, skin, bones, scales, exoskeletons, pens, ink, and clam shells can all be regarded as valuable wastes in varying weight percentages. Beyond a few underutilized sources of protein, the most promising and innovative applications of by-products from fisheries and aquaculture are emerging in the field of biotechnology. These by-products, often considered waste, are now recognized for their potential to serve as valuable raw materials in various high-value industries. Specifically, marine-derived by-products, such as fish skins, bones, scales, viscera, and shells, are being explored for the extraction of bioactive compounds, enzymes, collagen, gelatin, and other functional ingredients. These compounds have shown great promise in pharmaceuticals, nutraceuticals, cosmetics, agriculture, and environmental sustainability. As research advances, the biotechnological exploitation of marine by-products is expected to play a crucial role in promoting a circular economy and reducing waste in the seafood industry.

Keywords: Bioactive, chitin, aquaculture, seaweed, byproducts

INTRODUCTION

Owing to their rich nutritional profile and numerous health benefits – such as being high in essential omega-3 fatty acids, quality protein, vitamins, and minerals – fish and fishery products are consistently sought after across the globe. This growing awareness of their role in promoting heart health, brain function, and overall well-being has significantly contributed to their sustained global demand [1]. Fish and seafood products are well-known for being high-protein sources that include all the necessary micronutrients. They are rich in high-quality protein and omega-3 fatty acids, including eicosapentaenoic acid (EPA), which is good for cardiovascular health, and docosahexaenoic acid (DHA), which is crucial for optimal brain and neurodevelopment [2]. The cultural sector has embraced cutting-edge intensive and super-intense farming practices to meet demand both now and in the future. For developing countries, like India, where a sizable fraction of the population lives in poverty and where a big amount of the family budget is spent on food, food security is a critical issue [3]. Even though India has addressed this issue through agricultural revolutions, changing demands

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require for changes to aquaculture techniques. The rapid expansion of aquaculture can also be attributed to advancements in fish farming technologies [4].

Risks associated with aquaculture intensification include disease outbreaks and growing prices for vital feed materials, like fish meal, which will especially affect the prawn industry. Investigating substitutes, such as bioactive feed additives obtained from agricultural and marine sources, appears to be a viable way to lessen these difficulties. The goal of employing these bioactive substances as food additives in aquaculture is to help the organisms not only grow but also maintain their health and develop resistance to disease. Utilizing agricultural and industrial waste as a source of bioactive chemicals for aquaculture adds value to supply chains, lowers pollution, and enhances organism health through diet. To create functional foods, the scientific community and the agriculture sector have worked to develop suitable processes for the extraction and purification of bioactive chemicals from trash [5]. This work offers fresh perspective on how to manage hatcheries more efficiently and productively while also enhancing the immune system's ability to fight against diseases and ensure the survival of marine life [6–10].

SOURCES OF BIOACTIVE FEED INGREDIENTS

Most bioactive feed components are extracted from agro-industrial waste and marine derivatives. The marine ecosystem is a valuable source of diverse biomolecules, many of which possess powerful bioactive properties like anti-inflammatory, antioxidant, antiviral, anti-tumor, and anti-parasitic effects. The production and handling of agricultural products produce enormous amounts of waste. Husk, seeds, leaves, roots, and stems are among the waste materials produced by the source and are a potential source of bioactive chemicals [11–15]. Bioactive substances include terpenes (essential oils and carotenoids), phenolic complexes (flavonoids, coumarins, xanthones, chalcones, stilbenes, lignins), dietary fibre (β-glucans, fructooligosaccharides, galactooligosaccharides), glucosinolates, etc.

Bioactive Compounds from Marine Source

- Seaweed and its derivatives.
- Fish protein hydrolysate.

Chitin & Chitosan

The wide range of habitats in which marine species exist has led to the development of unique traits and bioactive substances. It has long been recognized that functional food ingredients are valuable for promoting health and lowering the risk of disease. The fundamental organisms of the food chain are watery photosynthetic algae. It is separated into two main types based on size: macroalgae (seaweeds) and microalgae. Numerous macroalgal species have been employed as food and medicinal substances. Red seaweed contains carrageenan, a high molecular weight sulfated polymer, in its cell wall. The main method of producing carrageenan is seaweed farming based on aquaculture, with Eucheuma and Kappaphycus species producing more than 90% of the material produced worldwide [16].

Bioactive Feed Ingredients from Seaweeds

Seaweeds are generally divided into three main categories based on their taxonomy: red seaweeds (Rhodophyta), green seaweeds (Chlorophyta), and brown seaweeds (Phaeophyta). They are used and studied as a major feed element and are thought to enhance "standard" feed formulations instead than being an essential source of fish feed [17]. Agar is a valuable phycocolloids obtained from red seaweeds. It is commonly extracted from a variety of species, including *Gelidium*, *Gracilaria*, *Gelidiella acerosa*, *Pterocladia capillacea*, *Pterocladia lucida*, *Ahenpeltia plicata*, *Acanthopeltis japonica*, *Ceramium hypnoides*, and *Ceramium boydenii*. Alginate is another significant polysaccharide that is extracted from brown seaweeds, such as *Laminaria*, *Macrocystis*, *Sargassum*, and *Ascophyllum*. Moreover, including carrageenan in the diet has been found to enhance innate immunity and stimulate the expression of immune-related genes in *Litopenaeus vannamei* (Pacific white shrimp) [18–20].

Bioactive Feed Ingredients from Fish Protein Hydrolysate

Fish protein hydrolysate (FPH) is produced through the enzymatic breakdown of fish proteins into smaller peptides and individual amino acids, making them easier to digest and absorb. In recent years, FPH has attracted considerable attention as a valuable additive in the aquafeed industry. It is commonly used either as a supplement to traditional fishmeal or as a key ingredient in fish feed formulations. It has been discovered that fish protein hydrolysate has advantageous biofunctional characteristics, such as antihypertensive, antithrombotic, immunological modulatory, and antioxidative qualities. Several studies have demonstrated that adding fish protein hydrolysate to fish and shellfish diets improved their growth and immune parameters [21–25].

Bioactive Feed Ingredients from Chitin and Chitosan

Chitin, a cationic amino polysaccharide made of N-acetyl-d-glucosamine with β (1 → 4) glycosidic linkages connecting each monomer, is a naturally occurring biopolymer. Chitosan, like chitin, is a biopolymer made up of d-glucosamine units that are produced when chitin is heated to a high temperature to deacetylate it [26]. The carbohydrate polymers chitin and chitosan, which are present in the waste products of crustaceans, have a variety of uses, such as being added to fish and prawn meals. Furthermore, rich carotenoids found in crab waste can be isolated from chitosan and added to aquaculture and ornamental fish meals to intensify colour. Chitin and chitosan can be produced using bio-waste derived from both terrestrial and marine sources.

Adding chitin and chitosan to fish diets has proven effective in enhancing growth rates, improving feed utilization, and boosting disease resistance in several fish species. These positive effects have been noted in species like rainbow trout (*Oncorhynchus mykiss*), Nile tilapia (*Oreochromis niloticus*), grey mullet (*Liza ramada*), red sea bream (*Pagrus major*), Japanese eel (*Anguilla japonica*), and yellowtail (*Seriola quinqueradiata*).

CONCLUSIONS

Marine resources are a rich source of bioactives and nutraceuticals. Food items, supplements, and natural health products containing marine bioactives are expected to command a sizable market due to their many potential health advantages. Since three fatty acids have been shown to be the most helpful in addressing a range of health issues, their inclusion in food has been the subject of extensive research and development. To sum up, the obstacles encountered by the aquaculture industry in India, specifically the escalating expenses of vital feed components demand a transition toward economical and sustainable substitutes. A potential remedy is the use of bioactive feed additives made from agricultural and marine sources, such as insect proteins and extracts from medicinal plants. These alternative feed ingredients offer more than just nutritional value – they can significantly enhance the overall health and resilience of farmed aquatic species. Rich in essential nutrients, they also possess beneficial properties, such as immunomodulatory, antioxidant, and antibacterial effects. By boosting the immune system, protecting cells from oxidative damage, and helping to fight off harmful pathogens, these substitutes contribute to better growth performance, improved survival rates, and reduced reliance on antibiotics in aquaculture. As a result, they play a key role in promoting sustainable and healthier farming practices.

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