



Bioactive Feed Ingredients used in Aquaculture: A Review

**Rana Rushirajsinh Jitendrasinh ^{a*}, A. S. Kotiya ^b
and Jungivala Mansi Dipakbhai ^c**

^a Department of Aquaculture, College of Fisheries Science, Kamdhenu University, Veraval, Gujarat, 362265, India.

^b Fisheries Research and Training Center, Kamdhenu University, Mahuva, Gujarat, India.

^c Department of Fish Processing Technology, College of Fisheries Science, Kamdhenu University, Veraval, Gujarat, 362265, India.

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ABSTRACT

Food security is a critical concern for nations like India, where poverty affects access to nutritious food for a significant portion of the population. While India has made strides in addressing this issue through agricultural revolutions, evolving demands necessitate a reformation in aquaculture practices. With a global surge in demand for fish and fisheries products due to their nutritional benefits, aquaculture has become pivotal. However, the intensification of aquaculture brings risks such as disease outbreaks and rising costs of essential feed ingredients like fish meal, particularly impacting the shrimp industry. To mitigate these challenges, exploring alternatives like bioactive feed additives sourced from marine and agricultural origins emerges as a promising solution. Marine derivatives such as algae offer nutritional benefits and bioactive compounds, while agri-industrial wastes provide versatile applications, including medicinal plant extracts and plant-based ingredients. Additionally, complex bioactive feed ingredients like probiotics, prebiotics, metabiotics,

*Corresponding author: E-mail: rrushirajsinh19@gmail.com;

and phytobiotics show promise for enhancing the health and productivity of cultivated aquatic organisms. Integration of these alternatives into aquaculture practices presents a sustainable approach to improving food security, feeding efficiency, animal health and economic sustainability in India and beyond.

Keywords: Bioactive feed; marine derivatives; agri-industrial derivatives; prebiotic; probiotic; phytobiotic.

1. INTRODUCTION

In the year 2023, a surprising 811 million people worldwide are still suffering from the scourge of hunger [1]. Almost three-quarters of a billion people are unable to exercise their right to adequate food as 2030 approaches and there are only seven years left to accomplish the Sustainable Development Goals [2]. In the face of these challenges, aquaculture, one of the fastest-growing businesses, emerges as a beacon of hope for tackling global food security issues [1]. Hunger and food insecurity are significant obstacles that young people must overcome during this crucial period in their lives [2].

Food security is described as having a constant supply of secure and enough food for everyone [3]. Food security is the primary approach for any country in the globe to improve its socioeconomic level and combat malnutrition. For developing nations like India, where the majority of the population lives in poverty and a portion of total family spending falls towards food, food security issues are of the utmost importance. India is being driven to provide food for its fast-increasing population through the green and blue revolutions [4].

The increasing demand for global food production needs a fundamental restructuring of the aquaculture sector, as well as more efficient use of available resources and space [5]. Furthermore, global demand for fish and fisheries products continues to increase due to several health benefits [6, 3]. Fish and fishery products are recognized as excellent sources of protein and minerals [7]. Aquaculture is one of the most resource-efficient and sustainable methods of producing animal protein. By 2030, the Food and Agriculture Organization estimates that 53% of the world's seafood supply will come from cultured aquatic species [8].

Traditional intensive forms of aquaculture often contribute positively [4]. To meet current and future demand, the cultural sector accepted

innovative intensive and super-intensive farming methods. Although fish production and productivity have increased due to enhanced farming, there is also a greater risk of disease outbreaks in the culture system, which can result in production and financial losses. As the sector has intensified, so has the demand for high-quality feed ingredients for feed formulation. Fish meal is a traditional aqua-feed ingredient, as well as the primary element in aqua feed, and its price has risen due to a lack of available fish for the manufacturing of the fish meal [7].

The shrimp industry uses 31% of all fish meal used in aquaculture and accounts for 16% of total aqua-feed production worldwide. The need for fish meal in the shrimp industry is expected to keep rising further until shrimp production doubles by 2030, resulting in a 90% increase in fish meal costs and a 70% increase in fish oil costs [9]. Furthermore, India's aquaculture sector is experiencing a significant crisis due to a sudden increase in the cost of shrimp and fish feed due to the unexpected increase in the costs of the most important essential feed ingredients such as fish meal, soya meal, fish oil, and so on. As the cost of important feed materials such as fish meal rises, and expecting the negative effects of intensification in the culture system, look for alternatives such as bioactive feed additives. These bioactive substances contain functional qualities such as antioxidants, antimicrobials, growth promoters, and immune system modulators and are obtained from marine and agricultural sources [7]. Bioactive compounds are compounds added to aqua- feeds that have the potential to improve feeding efficiency and reduce environmental impacts by improving animal health and lowering economic losses.

2. SOURCES OF BIOACTIVE FEED INGREDIENTS

Most bioactive feed ingredients are isolated from marine derivatives and from agri-industrial wastes.

2.1 Marine Derivative Bioactive Feed Ingredients

One of the richest reservoirs of biomolecules is the marine environment, and these biomolecules have bioactive qualities like antioxidant, antimicrobial, antiviral, anti-parasitic, anti-inflammatory, anti-fibrotic, and anti cancer activity [7]. Marine derivative bioactive feed ingredients are given below:

1. Seaweed and its derivatives
2. Fish protein hydrolysate
3. Chitin & Chitosan

2.2 Agri-Industrial Waste Based Bioactive Feed Ingredients

Agricultural enterprises produce a lot of waste during the collection, storing, transferring, and processing of raw materials and can pollute the environment mostly because of organic matter; however, this organic matter is a source of bioactive compounds that are helpful for the aqua-feed industry [10]. There are several bioactive substances present in agricultural residue. Bioactive substances can be found in any part of the plant, including the husk, seeds, leaves, roots, and stems [11]. Agri-industrial waste contains following types of bioactive feed ingredients:

1. Plant-based bioactive feed ingredients
2. Herbal-based bioactive feed ingredients

2.3 Other Bioactive Feed Ingredients

Other than marine and agriculture waste, there are other sources that contains bioactive feed ingredients which given as follows:

1. Insect meal- based bioactive feed ingredients
2. Complex bioactive feed ingredients
3. Commercially available bioactive feed ingredients

3. MARINE DERIVATIVE BIOACTIVE FEED INGREDIENTS

The marine environment is recognized as a goldmine of bioactive compounds that have good potential as a source of food components [12]. Marine bioactive compounds include seaweeds, fish protein hydrolysate, chitin, and chitosan contain an excellent resource of bioactive ingredients.

3.1 Seaweed and its Derivative-Based Bioactive Feed Ingredients

Algae are aquatic photosynthetic species that form the building blocks of the food chain. According to their size, it is divided into two major groups: microalgae and macroalgae (seaweeds). Many macro algal species have been used as ingredients in both medicinal and food preparations [13]. *Rhodophyta* (red), *Chlorophyta* (green), and *Phaeophyta* (brown) are the three taxonomic groups of seaweeds. They are used in nutritional studies as a primary feed ingredient and are regarded as boosting "standard" feed formulations rather than being a necessary source of fish feed [14]. As a source of essential amino acids, advantageous polysaccharides, fatty acids, antioxidants, vitamins, and minerals, marine macroalgae have been utilized as a nutritious feed supplement [15,16]. In addition to being rich in nutrition, seaweed has bioactive chemicals that are antimicrobial, antiviral, antioxidative, anti-inflammatory, and neuro protective. These properties have been shown to enhance immune response, increase stress tolerance, and scavenge reactive oxygen species, or "ROS" [17].

Seaweeds are distributed in supratidal, intertidal and subtidal horizontally [18]. In intertidal zone green seaweeds are found viz. *Ulva* (sea lettuce), *Enteromorpha* (green string lettuce), *Chaetomorpha*, *Codium*, and *Caulerpa*. In the tidal or upper subtidal zone, brown seaweed inhibits for example *Sargassum*, *Laminaria*, *Turbinaria*, and *Dictyota*. In subtidal water red seaweeds grow viz. *Gracilaria*, *Gelidiella*, *Euclerium*, *Ceramium*, and *Acanthophora*. Blue-green algae grow in a supra-tidal zone as colonies [19-22]. The complex polysaccharides known as phycocolloids are a highly interesting category found in the cell walls of several seaweeds, also the three most significant phycocolloids are carrageenan, algin and agar [22].

Agar is a vital phycocolloid derived from red seaweeds [22]. The species that used to produce agar are *Gelidium*, *Gracilaria*, *Gelidiell aacerosa*, *Pterocladia capillaca*, *Pterocladia lucida*, *Ahenpeltia plicata*, *Acanthopheltis japonica*, *Ceramium hypnoides*, and *Ceramium boydenii* [21,23]. Due to its structure, rheological behavior, stability and interactions, the algal polysaccharide agar has been employed for long time as a food binder. These features enable to making of firm, round, disk-shaped

pellets that can be utilized in recirculating sea urchin rearing systems [24].

Another highly significant polysaccharide that is isolated from brown seaweeds, such as *Laminaria*, *Macrocystis*, *Sargassum* and *Ascophyllum*, is alginate [22]. Alginate-producing seaweeds in India include *Sargassum*, *Turbinaria*, *Dictyota*, *Padina*, *Cystoseira*, *Hormophysa*, *Colpomenia*, *Spatoglossum*, and *Stoecospermum*, with *Sargassum* and *Turbinaria* serving as raw materials for the commercial synthesis of alginate [25,26]. The linear polysaccharide sodium alginate ($\text{NaC}_6\text{H}_7\text{O}_6$) is derived from alginic acid and contains the amino acids 1,4-d-mannuronic (M) and l-guluronic (G). Alginate is a structural element of the cell wall of marine brown algae and the cell wall of brown algae contains approximately 30 to 60% alginic acid [27]. It also contains antibacterial, antiviral, antimicrobial, and antifungal properties [28,29]. Sodium alginate is a common feed additive in aquaculture, especially for herbivorous and omnivorous fish species. It has been established that fish LMWSA diets can enhance growth performance, innate immunity, and disease resistance in tilapia against *S. agalactiae* [30]. The immune stimulatory effect of sodium alginate on the white shrimp *Litopenaeus vannamei* and its resistance against *Vibrio alginolyticus* was carried out by [31].

Carrageenan is a high molecular weight sulfated polysaccharide found in the cell wall of red seaweed. Carrageenan is primarily produced through aquaculture-based seaweed farming, with *Eucheuma* and *Kappaphycus* species accounting for more than 90% of global carrageenan production [32]. Carrageenan has many bioactive applications such as an antioxidant, antibacterial, antiviral, antitumor, anticoagulant, anti hyper lipidemic and immune modulatory agent [33,34]. Carrageenan supplementation of shrimp feed can improve innate immunity as well as the expression of immune-related genes in *Litopenaeus vannamei* [35].

3.2 Fish Protein Hydrolysate

Fish protein hydrolysate (FPH) is the enzymatic hydrolysis of protein into smaller peptides and free amino acids, which has recently captured considerable attention as a supplementary ingredient in the aqua-feed industry sector [36]. Fish protein hydrolysate contains a very rich amount of soluble protein, making it more

digestible and absorbable in comparison with whole protein [37,38]. Short-chain peptides improve feed palatability, resulting in high feed utilization. Moreover, FPH contain high antioxidant peptides, which may protect fatty acid from peroxidation, enhancing the growth and health of cultured animals [39,40].

Fish protein hydrolysates are used as a supplement or as a component in fish feed to replace fishmeal. Functional characteristics of fish protein hydrolysate include antihypertensive, antithrombotic, immunological modulatory, and antioxidative effects. The results of a study on the use of two types of fish protein hydrolysate (FPH) in place of fish meal in feed for post-larval shrimp, *Litopenaeus vannamei*, showed that FPH may be used to replace fish meal and also promote the shrimp's growth [41]. In another study into the use of fish protein hydrolysate as a feed component for silver pompano (*Trachinotus blochii*) fingerlings, researchers discovered that the dietary supplement of FPH showed promising results in terms of enhancing growth, metabolism, immune response and resistance to bacterial infection [41].

3.3 Chitin and Chitosan

Chitin and chitosan, carbohydrate polymers found in crustacean waste, offer diverse applications, including their use as additives in fish and shrimp feeds. Additionally, crustacean waste contains valuable carotenoids, which can be extracted from chitosan and utilized as additives in aquaculture and ornamental fish feeds, enhancing color intensity. The inclusion in fish feed formulations improves digestibility, growth, and nutrient absorption. Chitosan would be a good immune stimulant/ growth promoter in shrimp diets [42].

It has been demonstrated that chitin and the deacetylated derivative of chitin, chitosan, have positive effects on the performance of cultured fish and are therefore regarded as functional components or bioactive substances [43,44]. Chitin and chitosan supplementation in the diet increases growth rates, feed efficiencies and disease resistance in several fish species, including rainbow trout (*Oncorhynchus mykiss*), Nile tilapia (*Oreochromis niloticus*), grey mullet (*Lizaramada*) red sea bream (*Pagrus major*), Japanese eel (*Anguilla japonica*), and yellowtail (*Seriola quinqueradiata*) [45- 50].

4. AGRI-INDUSTRIAL WASTE-BASED BIOACTIVE FEED INGREDIENTS

4.1 Plant-Based Bioactive Feed Ingredients

Plant active substances can be broadly divided into alkaloids, terpenoids (including triterpenes and steroid saponins), phenolic compounds, glycosides, flavonoids, tannins, and polysaccharides based on their chemical structures [51]. The use of plants as bioactive feed in aquaculture shows antimicrobial/ immunomodulatory properties due to secondary metabolites of the above-mentioned classes of compounds [52]. Various types of plant-based bioactive feed ingredients are used in aquaculture such as corn silk, banana peel, orange peel, mango peel, mushroom, grape seed extract, and olive waste cake.

Corn silk has traditionally been employed to treat cystitis, edema, gout, kidney stones, nephritis, and urological problems [53]. Corn silk is a good source of essential nutrients, including fibers, proteins, carbs, vitamins, and minerals [54]. It also contains a variety of bioactive substances, including steroids, volatile oils, and other naturally occurring antioxidants including polyphenols and flavonoids [55-57]. The immunostimulatory and antioxidative properties of corn silk from *Zea mays L.* in the Nile tilapia (*Oreochromis niloticus*) show that the dietary supplementation of corn silk extract lowered the level of lipid peroxidation in the liver of Nile tilapia under paracetamol-induced oxidative stress [58].

Banana peel is a food waste produced by households and businesses that can make up to 35% of the mature fruit [59]. The bioactive substances flavonoids, tannins, phlobatannins, alkaloids, glycosides, anthocyanins, and terpenoids present in banana peels have been discovered to have a variety of biological and pharmacological effects, including antibacterial, antihypertensive, antidiabetic, and anti-inflammatory effects [60]. The dietary administration of banana peel powder can modulate the growth parameters, antioxidant status, immune responses, and expression of cytokine genes in *L. rohita*. Also, banana peel can be used as a feed additive in aquaculture to improve fish growth and disease resistance [61].

One of the most popular tropical fruits, *Citrus sinensis* is an excellent source of antioxidants, vitamins and minerals [62]. Orange peel contains

bioactive substances such as limonoids, enzymes, dietary fibers, carotenoids, and phenolic compounds [63-65]. These important components are also high in antioxidants, which have a wide range of health advantages, including the prevention of chronic diseases, the reduction of cancer incidence, and anti-inflammatory actions [66-68]. The dietary orange peels can act as a growth promoter and can improve the nutrient-absorptive ability of the intestine in Nile tilapia fingerlings [69].

Mango peel is a rich source of bioactive compounds that have potential health benefits. Mango peel includes antibacterial, anti-diabetic, anti-inflammatory, and anti-carcinogenic compounds such as protocatechuic acids, mangiferin, and -carotene [70]. Mango peel is rich in beneficial substances such as polyphenols, carotenoids, enzymes, and dietary fiber [71].

Numerous bioactive substances with anti-inflammatory, anti-acne, and anti-dermatitis effects have been found in grape seed extract. Additionally, grape seed oil has several bioactive substances, such as carotenoids, phytosterols, phenolic acids, tocotrienols, and tocopherols [72]. The application of GSE as a dietary supplement in aquaculture can improve growth performance, antioxidant status, and disease resistance in cultured organisms [73-76]. According to Mehrinakhi et al. [77], an extract of GS can enhance growth performance, humoral and mucosal immunity, and resistance against *Aeromonas hydrophilla* in Common carp.

Olive waste cake is the main by-product of the olive oil industry [78]. Olive waste cake contains various types of bioactive compounds such as polyphenols which provide antioxidant and anti-inflammatory properties [79]. Phenolic compounds include flavanols and flavonoids [80]. Hoseinifar et al. (2020) investigated the effects of dietary olive waste cake on performance, antioxidant condition, immune responses of rainbow trout (*Oncorhynchus mykiss*) and it can improve growth rate, oxidative stress status, humoral and skin mucosal immune responses.

Mushrooms are widely recognized for their bioactive components such as lectins, polysaccharides (β -glucans), polysaccharide-peptides, polysaccharide-protein complexes, lanostanoids, other terpenoids, alkaloids, sterols, phenolic structured compounds, which possess

many biological and therapeutic qualities such as antibacterial, antioxidant, anti-inflammatory, anti-diabetic, anti-tumorous, antiviral, and anti-immuno-modulatory effects [81-83].

The diverse range of bioactive substances present in plant-based ingredients demonstrates their potential as effective and sustainable additions to aquaculture feeds, promoting the health, growth, and disease resistance of cultured organisms.

4.2 Herbal-Based Bioactive Feed Ingredients

The use of medicinal plant extracts in aquaculture for illness prevention, growth promotion and production is a unique development that has the potential to eliminate the need for antibiotics [84, 85]. Bioactive compounds that are present in herbal plants can enhance the growth, innate immune response and disease resistance against harmful microorganisms in fish [86]. Aquaculture uses a variety of herbal-based bioactive feed components, including ashwagandha, neem, tulsi, bitter weed, thyme seed, and aloe vera.

Aloe vera is a succulent, stemless herb that is extensively spread in tropical and subtropical regions [86]. A. vera is thought to be the most popular and bioactive, containing over 70 biologically active chemicals [87,88]. Aloe gel is rich in a variety of polysaccharides, vitamins, minerals, enzymes, salicylic acid, lignin, saponins, fatty acids, hormones, and around 20 of the 22 essential amino acids that the human body needs [89;90]. Other than these, Aloe vera also contains bioactive characteristics such as antibacterial, antiseptic, anti-inflammatory, immune-modulatory effects, anti-oxidant, anti-cancerous properties, anti-mutagenic and anti-hypersensitivity, growth and gastro-intestinal promoting effects [91-94,87]. To improve common carp growth, aloe vera extract can be used in the diet as a growth promoter, appetite stimulator, tonic, and immune stimulant [87].

Thymus vulgaris, a medicinal herb, may have the capacity to reduce the adverse effects of aflatoxins in feed [95]. *T. vulgaris* contains phenolic compounds that possess antioxidant activities [95]. El-Nekeety et al. (2011) showed that *Thymus vulgaris* oil promotes innate and acquired immunity, hence increasing

resistance to AFT- induced immunological suppression.

Indian medicinal plant Ashwagandha, *Withania somnifera* a time-honored Ayurvedic herbal immune booster, that is effective as an immune-modulatory agent in fish [97-100]. Ashwagandha contains various bioactive characteristics such as anti-stress, anti-oxidant, rejuvenating, and immune modulatory [101-103;99]. Sharma et al. (2017) suggested that the dietary supplement of Ashwagandha can improve the growth, haemato-biochemical response and disease resistance against *A. hydrophila* for *L. rohita* fingerlings.

Neem is utilized for a variety of purposes due to its immunological, anti-inflammation, and anti-ulcer characteristics [104-106]. Neem tree has a variety of pharmacological qualities that strengthen antioxidant qualities and protect against several bacterial, viral, and fungal illnesses. The dietary leaf extract has improved the growth and health of rainbow trout in hatchery settings, making it a great nutritional supplement [107].

One of the most valued and comprehensive medicinal plants, tulsi (*Ocimum sanctum*), has long been utilized in India to prepare traditional medicines due to its medicinal significance [108]. The Tulsi leaf extract contains eugenol, urosolic acid, carvacrol, rosmarinic acid, α & β -caryophyllene, linalool, euginal, β -elemene, geraneol and oc-imene as its main active ingredients [109]. Other than these active ingredients, it also has antimicrobial, antibacterial, antifungal, antiviral, and antioxidant properties [108]. Tulsi leaf extract can stimulate immunity and make *L. rohita* more resistant to bacterial infection of *A. hydrophila* [110].

The incorporation of medicinal plant extracts, such as Aloe vera, *Thymus vulgaris*, Ashwagandha, Neem, and Tulsi, into aquaculture practices represents a promising and sustainable approach to promoting fish health and growth. These herbal extracts offer a diverse range of bioactive compounds with proven immunomodulatory, antioxidant, and antibacterial properties. As alternatives to antibiotics, these plant-based supplements have the potential to enhance disease resistance, stimulate immune responses, and improve overall well-being in aquaculture, paving the way for a healthier and more environmentally friendly approach to fish farming.

5. OTHER BIOACTIVE FEED INGREDIENTS

5.1 Insect Meal-Based Bioactive Feed Ingredients

Insect protein has received considerable scientific attention due to its high energy conversion efficiency, good nutritional quality and benefits in growth and health enhancement in fish and shellfish [111-113]. Due to its richness in lipids, vitamins, minerals, and amino acids (AAs), insect meal (IM) is becoming a more popular energy source for the agricultural industry (Premalatha et al. 2012). Insect-based diets that have immunomodulatory and physiological effects include four major groups, black soldier fly (*Hermetia illucens*), yellow mealworm (*Tenebrio molitor*), housefly (*Musca domestica*), silkworm (*Bombyx mori*), and a minor group of insect species such as locusts, grasshoppers, termites, crickets, and beetles [114].

Black soldier fly (*Hermetia illucens* L.) Is one of the most attractive sources for its sustainability as an unusual protein source for fish feeding due to its ability to transform organic waste material into biomass-containing proteins (40-45%) with high biological value [115]. Also, there was a wide range of antibacterial activity in the BSF larval extract [116]. Dietary addition of BSF extract could stimulate immune competence hematological measures in common carp (*C. carpio*) challenged with *A. hydrophila* [117].

The yellow mealworm (*Tenebrio molitor* (TM)) is one of the few unique options for potential FM replacement in aqua feeds [118]. *T. molitor* larvae and pupae have a high protein and lipid content because they contain many essential amino acids (EAAs)(particularly methionine), lipids and essential fatty acids (EFAs), which vary depending on the worm's developmental stage [119,120]. According to Ido et al. (2019), Yellow mealworm (*Tenebrio molitor*) larvae are a promising alternative animal protein source that improves red seabream growth performance.

Insect meal, particularly silkworm meal, has been demonstrated to have immune-modulatory and physiological effects in aquatic species, making it a functional element capable of increasing immune-stimulatory effects in a variety of aquatic animals (The protein of silkworm pupae is high in phenylalanine, methionine, and valine, three important amino acids [122]. Silk worm meal, an

insect-based diet, can be used in place of fish meal to enhance the biochemical composition and growth performance of Catla-rohu hybrids [123].

The utilization of insect protein, particularly from sources such as black soldier fly, yellow mealworm, and silkworm, represents a promising and sustainable alternative in aquaculture nutrition. These insect-based diets offer high energy conversion efficiency, nutritional richness in lipids, vitamins, minerals and essential amino acids, contributing to the growth and health enhancement of fish and shellfish. Moreover, the immune-modulatory properties observed in certain insect meals such as black soldier fly larval extract and silkworm meal, highlight their potential to positively impact the immune response and physiological well-being of aquatic species, making them valuable components in the development of innovative and environmentally friendly aquafeeds.

5.2 Complex Bioactive Feed Ingredients

The use of novel and effective probiotic-based immunostimulating preparations, prebiotics, metabiotics, and phytobiotics is thought to be a promising direction for the development of new complex feed additives for aquaculture enterprises to improve the health and productivity of cultivated hydrobionts [124].

Probiotics have been defined as "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host" [125]. Probiotics have several beneficial effects, including strengthening the immune system, increasing competition for binding sites, producing anti-microbial compounds and increasing competition for nutrients that shield the body from disease [124].The majority of probiotics used for aquatic animals come from the genera *Lacto bacillus* and *Carnobacterium* genus *Vibrio*, genus *Bacillus*, or genus *Pseudomonas*; *Bacillus* is one of these that is most frequently used in aquacultures [126].

A Prebiotic can be defined as "a substrate that is selectively utilized by host micro organisms conferring a health benefit "[127]. Prebiotics are non-microbial compounds that are neither digested nor absorbed in the intestine but generate favorable conditions for the establishment of healthy microbiota in the large intestine [128].

Metabiotics are defined as the structural components and physiologically active metabolites of probiotic microorganisms [129,130]. These may be hormone-like compounds that resemble signalling molecules and are secreted by beneficial bacteria. They may influence metabolic, regulatory and behavioural responses that are directly linked to the activity of the body's microbiota, which may help restore normal physiological functions [130].

Phytobiotics are defined as physiologically active compounds produced by plants [130-132]. Prebiotics derived from plants are an important component of feed that promotes beneficial gut microorganisms [124].

New opportunities are emerging in the application of complex bionics produced by probiotic bacteria by solid-phase fermentation of phyto components. Solid-phase fermentation of plant substrates is utilized to acquire numerous physiologically active compounds, enriching phyto-raw materials with useful products of bacterial substrate destruction and specific probiotic metabolites. Probiotic formulations with phyto components are defined by increased biological activity as a result of the combination of the probiotic effect with the presence of metabolites, as well as the action of biologically active phytobiotic components [124].

ProStor (NTC BIO, LLC) is a probiotic composed of the solid-phase fermentation products of *B.subtilis V-8130*, *B.subtilis V-2984* and *B.subtilis V-4099* cultivated on beet root pulp [134]. The HerbaStor (NTC BIO, LLC) product, which contains the yeast autolysate, is an updated version of the ProStor formulation. Metabolites of the active complex of probiotic species *Bacillus* were obtained through solid-phase fermentation of phytocomponents—beet pulp in combination with medicinal plants—that underwent preliminary biological treatment, ensuring the availability of biologically active components [124].

5.3 Commercially Available Bioactive Feed Ingredients

MOTIV™ is a fermented maize protein concentration (CPC) prepared by enzymatically eliminating non-protein components from maize. CPC has significant quantities of methionine, lysine, and other important amino acids, and it has a small amount of starch or ash [134,135].

The usage of feed containing bioactive protein ingredients (MOTIV™) can enhance the number of *L.vannamei* shrimp hemocytes, which can be utilized to signal the shrimp's immune system and health state [135].

Yelaprosecure which is a specifically designed hydrolyzed yeast that offers highly digestible and functional nutrients that support animal performance, digestive care, and feed palatability while contributing to the feed protein balance [136]. The natural microalgal product NOVASTA®EB15, which is rich in a staxanthin, is made up of crushed and spray-dried aplanospores from the green microalga *Haematococcus pluvialis* [137].

6. CONCLUSION

In conclusion, the challenges faced by India's aquaculture sector, particularly the rising costs of essential feed ingredients, necessitate a shift towards sustainable and cost-effective alternatives. The incorporation of bioactive feed additives derived from marine and agricultural sources, such as medicinal plant extracts and insect proteins, presents a promising solution. These alternatives not only offer nutritional richness but also possess immunomodulatory, antioxidant, and antibacterial properties that can enhance the overall health and disease resistance of cultured organisms. Furthermore, commercially available bioactive feed ingredients like MOTIV™, YELA PROSECURE, and NOVASTA® EB15 demonstrate the potential for innovative solutions in aqua feed formulations, contributing to improved immune responses, digestive care, and feed palatability. Embracing these alternatives not only addresses the economic challenges but also promotes a more sustainable and environmentally friendly approach to aquaculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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