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Functional feed additives used in fish feeds

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Abstract
Global aquaculture production (including aquatic plants) stands at 110.2 million tonnes, with the first-sale value estimated at USD 243.5 billion. The total production included 80.0 million tonnes of food fish and 30.1 million tonnes of aquatic plants. Since 2000, world aquaculture no longer enjoys the high annual growth rates of the 1980s and 1990s. Nevertheless, aquaculture continues to grow faster than other major food production sectors. Annual growth declined to a moderate 5.8 percent during the period 2001–2016, growth is still. Presently aquaculture contributes to 46.8 percent of total global fish production. This increase in growth of aquaculture has been primarily attributed to development in good quality feeds. Any good quality feed is prepared from proper and essential feed additives. Recent developments in functional feed additives are showing promising yields to aqua farmers. Functional feed additives not only improve the growth performance of the fishes but also improve the health performance of the fishes. These functional feed additives are derived from different sources. These are organic and eco-friendly to fishes and environment. These functional feed additives include prebiotics, probiotics, seaweeds, mushrooms, microalgae, enzymes, organic acids, mycotoxin binders, photogenic or phytobiotic compounds and yeasts.

Keywords: Aquaculture, functional feed additives, eco-friendly, health performance, growth performance

1. Introduction

Feed represents around 50 – 80% production cost in aquaculture. Proper nutrition is one of the critical factors in aquaculture. Successful aquaculture depends on a nutritionally balanced diet and low cost of production. The nutritional quality and cost of the feed depending on the price and quality of the feed ingredients and additives which is used for feed formulation. Feed ingredients are a mixture of both organic and inorganic components. These components are varied based on the raw material and their extraction process. Feed additives are added during feed preparation to improve the quality of the feed and health performance, feeding efficiency of the fishes. Most of the feed additives are non – nutritious and include antioxidants, immunostimulants, probiotics, antibiotics are added in the culture system to improve the growth as well as water quality. These components in aquaculture feed also increase the cost of production. To overcome escalating costs, feed companies have turned to the application of functional feed additives. These functional feed additives have become an alternative for antibiotics and chemotherapeutics [99]. The functional feed additives improve growth, immune response; induce the physiological functions and health performance of the fishes over the normal feed additives. Functional feed additives include phytogenic compounds, mycotoxin binders, organic acids, immune – stimulants, yeast products, probiotics, prebiotics, enzymes [3].

2. Phytogenic or phytobiotic compounds

Phytobiotic or phytogenic compounds are plant derivatives, added in the feed to improve the growth and health performance of the fishes. These plant products have different properties like antioxidant, antimicrobial, anticarcinogenic, analgesic, insecticidal, antiparasitic, anti coccidial, growth promoter's appetite enhancement, stimulant of secretion of bile and digestive enzyme activity etc. [6]. These phytobiotic components are heterogeneous feed additives originating from different part of the plants, viz., leaves, roots, tubers, fruits and spices. These components are used in different forms (oil, powder or extract [3]. Various phytogenic compounds used in aquaculture are detailed in Table 1.

Table 1: Effects of different phyotogenic compounds and their effects in various fish species

Phytogenic compounds	Effects	References
Allicin - Garlic (*Allium sativum*)	It controls & increases immunostimulation against bacterial diseases in cultured fishes	[65]
Rosemary (*Rosmarinus officinalis*)	It reduces mortality against *Streptococcus inae* in Nile Tilapia	[103]
Oregano- Carvacrol	0.025% & 0.05% of carvacrol provides an appreciable resistance to *Listonella anguillarum* in European seabass	[94]
Moringa oleifera	It gives better results against *Aeromonas hydrophila* infection and transportation – induced stress in Nile tilapia	[27]
Psidium guajava	Dry leaf powder and ethanol extract of *Psidium guajava* controls *A. hydrophila* infection in Tilapia	[68]
Astragalus radix	*Astragalus radix* root extract increased the leucocytic phagocytosis and Lysozyme activity in Nile tilapia	[97]
Withania somnifer	Root extract of *Withania somnifer* increased Nitro blue tetrazolium level, Phagocytic cell activity, Lysozyme activity and Total immunoglobulin level in *Labeo rohita*	[78]
Ipomoea batatas	The peel of sweet potato in the diet improved the growth performance and feeding efficiency in Nile tilapia	[66]
Allium sativum	Garlic peel improved the haematological parameters and developed the resistance against *Aeromonas hydrophila* infection in African catfish fingerlings	[85]
Astragalus sp.	The root and stem extract of these chinese herbs showed humoral and cellular immune response in Common carp	[100]

3. Microalgae

Microalgae are a large group of unicellular photosynthetic microorganisms, ranging from 2 to 20 µm in size. Microalgae are a source of protein (Spirulina – 60 to 90%), fat (polyunsaturated fatty acids, HUFA), polysaccharides, vitamins, antioxidants, pigments, trace elements, etc [46]. Microalgae are presently used as a live feed for fish and shellfish larvae [60]. Commonly used microalgal species are *Chlorella*, *Tetraselmis*, *Isochrysis*, *Pavlova*, *Phaeodactylum*, *Chaetoceros*, *Nannochloropsis*, *Skeletonema* and *Thalassiosira*. Combination of different algal species provides better growth performance and nutrition to fishes [81]. For a hit utility in aquaculture, a microalgal strain has to satisfy various criteria, inclusive of ease of culture, lack of toxicity, high nutritional value with correct cell size and shape and a digestible cell wall to make nutrients available [73, 69]. Protein and vitamin content is a major factor determining the nutritional value of microalgae. As a feed additive, the microalgae powder contained diets gave better results in fishes [46]. Microalgae studies related to fish nutrition is given in table 2

Table 2: Effects of different microalgae and their effects in various fish species

Microalgae	Effects	Reference
Spirulina	*Spirulina* incorporated diets showed better growth performance and feed efficiency in pengze carp	[46]
	5% and 10% of spirulina in diet showed better growth and bright colouration in (*Regalecus glesne*), Koi and Gold fish	
	It increased Superoxide dismutase and lysozyme serum activity in Silver carp	
Haematococcus Pluvialis	It enhances the antioxidant system and certain biochemical parameters in Rainbow trout.	[79]
Crypthecodinium cohnii	It improved the growth performance and shows good survival in juvenile Seabream	[105]

4. Yeast

Yeast contains a high amount of enzymes, fatty acids, amino acids, vitamin B – complex and number of unknown growth factors. Yeasts are used in both terrestrial and aquatic animal nutrition [24]. Only a few species are used in aquaculture, among which *Saccharomyces cerevisiae* is the most common. It is Generally Recognized As Safe (GRAS) status by the US Food and Drug Administration (FDA) and is appropriate for use in animal feeds [13]. The Bakers yeast cell wall contains a high amount of mannan oligosaccharides and brewer's yeast contains more amounts of trace minerals such as selenium and chromium [84]. It has been proved that yeasts can enhance growth, survival, maturation; improve the immune and antioxidant systems in finfish and crustaceans. β-glucan, mannoproteins, chitin (as a minor component), and nucleic acids are the main components for yeasts immune-stimulatory properties [54]. Mannan - Oligosaccharide removes the bacteria from the gut, enhances growth performance, improves feeding efficiency, and also increases guts absorption efficiency [22]. Effect of yeast in different fish feeds are given in table 3.

Table 3: Effects of different yeast and yeast products and their effects in various fish species

Yeast and Yeast products	Effects	Reference
Saccharomyces cerevisiae	It increased the growth performance and feeding efficiency of Tilapia	[45]
	It improved disease and bacterial resistance against infections in hybrid Striped bass	[47]
	It enhanced the cellular innate immune response in gilthead sea bream	[67]
	It enhanced the fish growth and expression of antioxidative key enzymes (catalase, glutathione peroxidase, and superoxide dismutase) in European sea bass larvae (*Dicentrarchus labrax*)	[88]
Saccharomyces cerevisiae and *Saccharomyces boulardii,*	It enhanced the intestinal microbiota and brush border enzyme activities.	[24]
Debaryomyces hansenii HF1	It secrets amylase and trypsin which aidimproves digestion in sea bass larvae	[87]

5. Enzymes

The negative effect of anti-nutritional factors, affect the digestion of dietary components and growth performance of the fishes. These problems can be overcome by exogenous enzymes [51, 23]. Commonly used enzymes in aquaculture feeds are phytase, carbohydrase, protease, lipase, alpha - amylase, papain, pepsin. Eighty percent of the phosphorus in the plant seeds is present in the form of phytate. For the fishes, the phytate phosphorus digestibility and bioavailability is very low. Hence, phytase in fish feed increases the phytate phosphorus digestion and reduces phosphorus excretion and it also increases the protein and phosphorus utilization [10]. The digestible efficiency of the Non-starch polysaccharides is increased by the addition of non-starch polysaccharides degrading enzymes in the feeds [80]. Application of enzymes in different fish feeds is detailed in table 4

Table 4: Effects of different enzymes and their effects in various fish species

Enzymes	Effects	Reference
Phytase	It increases growth, feed conversion ratio, protein efficiency ratio, and specific growth rate in Nile tilapia	[48]
	500 U/kg of Phytase in the diet gave weight gain, apparent net protein utilization and energy retention value in *Pangasius pangasius* fingerlings	[20]
Pepsin, papain, amylase	Enhanced the growth and feed utilization efficiency in Nile tilapia fingerlings	[3]
Microbial phytase	500 U/kg of Microbial Phytase supplementation in the diet improved the availability of energy and phosphorus in Rainbow trout	[16]
Alpha - amylase	It improved the starch digestibility in juvenile Silver perch	[82]
	50 mg/kg of Alpha – amylase in diet enhanced the growth and protein sparing effect in rohu fingerlings	[44]
Non starch polysaccharides (cellulose, Xylans, mannans, arabinans)	Improved the digestibility of the aquatic animals	[80]
Glucanase, pentosanase, cellulase, xylanase	Enhanced feed Conversion Ratio, Feeding Efficiency Ratio, nitrogen retention and reduced ammonia excretion in Japanese seabass	[2]

6. Organic acids

Organic acids are weak carboxylic short-chain fatty acids. Because they partially dissociate in water to form a hydrogen ion (H+) and a carboxylate ion (-COO-) [50]. Examples of organic acids are formic acid, citric acid, benzoic acid, lactic acid, acetic acids propionic, malic, and sorbic acids and their salts [64]. Organic acids enhanced growth, nutrient utilization and disease resistance of fishes [62]. It decreases pH in stomach and intestine, at the same time increasing digestive enzyme activity. The organic acids penetrate into the cell wall of bacteria, disrupt the normal action and inhibits their growth [61]. Its actions depend on various factors like fish species, size, age, types and level of organic acids, feed management and water quality [25]. Effect of organic acids and its salts in different fish feeds are given in table 5

Table 5: Effects of different organic acids and their effects in various fish species

Organic acids and Salts	Effect	Reference
Formic acid	Rainbow trout fed with formic acid contained diet, had apparent improvement in digestibility of phosphorus	[93]
Citric acid	Citric acid aids in retention of nitrogen and phosphorus in Sea bream	[37]
	It increases calcium and phosphorus bioavailability in sturgeon fish	[41]
Sodium diformate	1% supplementation in Rainbow trout diet increased the digestibility of protein, lipid and amino acids.	[58]
	0.3% in the diet improved the protein efficiency ratio and protein retention in tilapia fingerlings	[49]
	Increased the growth performance and feed utilization of hybrid tilapia (*O. niloticus* × *O. aureus*) fingerlings	[42]
Potassium diformate	It reduced the faecal and adherent gut bacteria in Red hybrid tilapia	[62]
	It improved the digestibility of amino acids in Atlantic salmon	[83]
Propionic + Formic + acetic acid + Phytochemical (Cinnamaldehyde)	It actively inhibit the *A. hrdrophila and Yersinia rucker*i, improved the FCR & growth performance of Tilapia	[74, 75]
Lactate	Increased the growth and feeding efficiency in Arctic Char	[76]

7. Mycotoxin Binders

Secondary metabolites produced from different species of the fungi are called mycotoxins [9]. These are mainly grown in agricultural products [44]. Plant-based feed ingredients are easily affected by these mycotoxins when used in formulated feed, it reduces weight gain and feeding efficiency, causing liver and kidney damage to the fishes [5]. In the 1960s the first mycotoxin – Aflatoxin was discovered in turkey feed prepared from peanut meal. In the UK. 10,000,00 turkeys and other animals were lost due to this contamination. Later rainbow trout were lost in government and commercial hatcheries in the USA due to aflatoxicosis contamination in feed pellets prepared with cottonseed meal [72]. Aflatoxins are mainly prepared from following fungal species *Aspergillus flavus*, *A. parasitcus*, and *A. nomius.* Fusarium mycotoxins are also a major threat in aquaculture feeds [52]. There are several binders to overcome the negative impacts of these mycotoxins. Aluminium silicates, bentonite, montmorillonite, hydrated sodium calcium alumina silicates, Zeolitic materials are commonly used at the range of 1 to 10g/kg in the feeds [9]. Effect of mycotoxin binders in different fish feeds are given in table 6

Table 6: Effects of different mycotoxin binders and their effects in various fish species

Mycotoxin binders	Effects	References
Hydrated sodium calcium alumina silicates	It effectively reduced the alfatoxin B1 toxicity in Nile tilapia.	[77]
Bentonite	1% bentonite reduced the inhibitory effect and Bioaccumulation of AFB1 in the muscle of Nile tilapia	[59]
	Showed better performance in fish growth and AFB1 reduction in Pangasius catfish	[89]
Montmorillonite + Bentonite (Clay adsorbents)	5g / kg of clay adsorbents in fish feed reduced the Improved the biochemical, histochemical parameters against AFB1 in Tilapia	[35]

8. Probiotics

Fish intestinal microbial balance can be improved by the use of probiotics. Probiotics are live microbes supplemented to the fish gut through feeds [24]. It has an antimicrobial effect thru editing the intestinal microbial stability, secreting antibacterial substances (bacteriocins and organic acids), competing with pathogens to prevent their adhesion to the intestine, competing for nutrients vital for pathogen survival, and producing an antitoxin effect. Probiotics are also capable of modulating the immune system, regulating the allergic response of the body, and lowering the proliferation of cancer in mammals. So it is commonly described as friendly bacteria or healthy bacteria [95]. It also improves the water quality of the aquaculture systems [4]. Usage of probiotics in different fish feeds and its effects are given in table 7

Table 7: Effects of different probiotics and their effects in various fish species

Probiotics	Effects	References
Streptococcus faecium	Improved the growth and protein and lipid content of the Nile tilapia	[45]
Bacillus subtilis and *Streptomyces*	Improved the ornamental fishes (sword tail, guppy) growth and survival	[21]
Bacillus cereus	0.5g/kg supplementation in the diet improved the growth performance of the juvenile common dentex	[36]
B. subtilis, B. licheniformis, and *Enterococcus Faecium*	Supplemented diet improved the growth performance of rainbow trout	[55]
Lactobacillus delbrueckii ssp. Delbrueckii	It improved the growth and reduce the stress in European sea bass	[11]
Bacillus coagulans and Rhodopseudomonas palustris	Concentration of 1 X 9107 CFU/ml increased the Specific Growth Rate and weight gain in Nile tilapia	[102]
Pseudomonas fluorescens	Reduced mortality of 40 g rainbow trout infected with pathogenic *V. anguillarum*	[29]
Lactobacillus rhamnosus	Showed immune enhancement in Rainbow trout	[63]
Enteroccus faecium	Enhances the growth performance and immune response of the tilapia	[96]

9. Prebiotics

Prebiotics are non-digestible feed ingredients that beneficially affect the host by selectively stimulating the growth or activity of one or a limited number of bacterial species, already resident in the gut and thus attempt to improve host health [28]. Commonly used prebiotics in aquaculture is inulin, oligofructose, Xylo oligosaccharide, fructooligosaccharide, mannan oligosaccharide, galactooligosaccharide, b-glucan. The following criteria should be a must for prebiotics, which is used in feed, i) resistance to the upper gut tract of the fishes. ii). it should be easily fermentable by intestinal microbiota. iii). It should be beneficial to host health. iv). It should selectively stimulate the probiotics [19].

Table 8: Effects of prebiotics in different fish feeds

Prebiotics	Effects	References
Inulin	It increased RBC, magnesium, calcium, iron content, increased the length of intestinal villi and lysozyme activity in juvenile Nile tilapia	[86]
Mannan oligosaccharides	0.4% of prebiotic in the diet increases intestinal fold height and intestine muscular layer thickness	[101]
Fructo oligosaccharides	10g/kg of feed in FOS increased the feed intake and digestibility of Atlantic salmon	[30]
Fermacto prebiotic	3g/kg of Fermacto prebiotic contained diet improved the growth and feed conversion ratio of carp fry	[53]

10. Seaweeds

Seaweeds are macroalgae and its derivatives have been used in animal and human nutrition as well. Nutritional quality of seaweeds depends on the species and seasonal. In Europe the brown seaweeds are used for the production of additives for animal nutrition, owing to their mineral content and polysaccharides [26]. The mineral content and polysaccharides present in seaweeds and its derivatives are used as functional feed additives in fish nutrition.

Table 9: Application of seaweeds in different fish feeds and its effects

Seaweeds derivatives	Effects	References
sodium alginate	It improved the growth performance, immunological and haematological parameters and disease resistance against *Vibrio alginolyticus, Streptococcus sp*. in grouper	[15]
	At 50g/kg in the diet improved the fat and ash content in the sea bream	[71]
Laminarin	It increased the phagocytic activity and upregulated TNF-a and IL-8 genes in rainbow trout	[57]
	Different concentration of laminarin in grouper diet improved the specific growth rate, feed conversion efficiency, creatinine, alkaline phosphatase, lysozyme, SOD, catalase, and IL-1, IL-8, and TLR2 gene expression	[98]
Low-Molecular-Weight Agar	2g/kg in the diet increases in Specific Growth Rate, Feed Conversion Rrio, serum lysozyme, phagocytosis, Red blood cell count, resistance against *Aeromonas hydrophila* in basa fish (*P.*	[90]

	bocourti)	
	It Improved disease resistance, immune response, and growth in Nile tilapia	[92]
Gracilaria spp., Ulva spp., or Fucus spp	It increased the lipase activity, antioxidant responses, alternative complement activity, and lysozyme activity in European seabass	[70]
k-carrageenan	It increased Leucocyte count, Respiratory burst, Phagocytic activity, Phagocytic index, Alternative complement activity, Lysozyme activity, Resistance to *Vibrio alginolyticus* in Brown marbled grouper	[14]

11. Mushroom

Mushrooms have different polysaccharides like chitin, hemicellulose, b- and a-glucans, mannans, xylans, and galactans [17, 38]. Mushroom-derived polysaccharides also contain antitumor, antimicrobial, antioxidant, antiviral, and immunomodulatory properties. Thus the usage of mushrooms in aquaculture is on the rise due to their properties and awareness among farmers [91].

Table 10: Application of Mushrooms in different fish feeds and their effects

Mushroom and their compounds	Effects	Reference
Pleurotus florida	It stimulated superoxide anion production, respiratory burst (RB), phagocytic, bactericidal, alternative complement, and lysozyme activities in Indian major carp	[39]
Pleurotus sajor-caju	Its stalk in the diet improved the specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER), and survival rates in red tilapia	[91]
Pleurotus ostreatus	Its methanolic extract increased specific growth rate, nitroblue tetrazolium, phagocytic, lysozyme, and myeloperoxidase, as well as resistance to *A. hydrophila* in rainbow trout	[8]
	Different concentration of this mushroom extract shows increased growth rate, higher lysozyme activity and hematocrit contents in amur catfish	[40]
	Its polysaccharide extract increased in specific growth rate, weight gain, and hepatosomatic index (HSI) in Nile tilapia	[1]
Coriolus versicolor (mycelium and b-glucan)	It increased the innate immune response and resistant *against L. anguillarum* and *V. alginolyticus* in groupers	[31, 12]
Coriolus versicolor (polysaccharides)	It increased the red blood cell count (RBC), WBC, haemoglobin (Hb) content, erythrocyte sedimentation rate (ESR), total protein (TP), and blood urea nitrogen (BUN), resistance to *A. hydrophila* in rohu	[56]
Ganoderma lucidum	This mushroom b – glucan in the diet increases survival rate, weight gain, feed intake, specific growth rate in grass carp juveniles	[18]
Hericium erinaceum	It improved the immune response and resistance against *P. dicentrarchi* in kelp grouper	[33]
Phellinus linteus	It improved the growth performance and increased protection against *Vibrio anguillarum* in juvenile flounder	[43]
Agaricus bisporus	It improved the growth performance of common carp	[104]
Innotus obliquus	Its mycelium extract enhance the growth , stimulate appetite in kelp grouper	[34]
	It increased lysozyme, antiprotease, alternative complement, production of reactive oxygen and nitrogen, myeloperoxidase, and resistance against *Uronema marinum* in olive flounder	[32]
Lentinula edodes	It improved total leucocytes, haematocrit levels, phagocytic activity, serum lysozyme, myeloperoxidase activities, and IgM, as well as a resistance to *L. garvieae* in rainbow trout.	[7]

12. Conclusion

Functional feed additives are used for, higher productivity and enhanced resistance to infectious disease, which would ultimately lead to sustainable aquaculture. Understanding the interactions of functional feed additives in the feeds and the biochemical & physiological functions of the animal is key for the further development of functional feeds. Further functional feed additives are eco-friendly and also may not result in negative impact on aquaculture. However sufficient research works in the aspects of functional feed additives is essential for effective application of such functional additives.

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