Feed Additives in Aquaculture Enhancing Efficiency and Sustainability

Noor Fatima[1], Abdul Mateen[1]*, Andleeb Zahra[1], Ghazanfa Tariq[1], Laraib Ghulam Abbas[1], Kashuf[1], Mahnoor Imtiaz[1], Affifa Gulzar[1], Mutaiyyba Akhtar[1] and Laraib Ahmad[2]

[1]Department of Zoology, Wildlife and Fisheries, University of Agriculture Faisalabad, Pakistan
[2]Department of Molecular Biology and Biotechnology, University of Lahore, Pakistan
*Corresponding author: mateen117@yahoo.com

Abstract

Nutrition is the major crucial factor determining the potential of cultured fish to exhibit its genetic capability for growth and reproduction. The increased costs and short quantity of fish feed have given reason to the need to increase research for alternatives. Therefore, the fish feeds are required to be enriched with additives. Functional feed additives are a potential innovative way to enhance aquaculture production, sustainability, and profitability. Consumers are concerned that antibiotics may harm water quality and growth, while natural feed additives increase aquaculture productivity. Feed additives regulate harmful microorganisms, promoting host growth, boosting the immune system, and maintaining water quality. The aquaculture industry utilizes various nutritional feed additives, including essential fatty acids, probiotics, prebiotics, and synbiotics. The most pertinent uses of phytogenic and exogenous enzymes are crucial for boosting the immune system, binding site competition, antipathogenic compounds production, and enhancing growth performance. These additives are beneficial for their therapeutic characteristics and eco-friendly metabolism in the digestive system. This chapter reviews the use of considerably significant and promising additives in aquafeed.

Keywords: Feed additives, Probiotics, Prebiotics, Synbiotics, Sustainability, Antibiotics, Aquaculture productivity.

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Introduction

Aquaculture is renowned as the most rapidly expanding sector in the global food production. It is responsible for supplying more than half of the worldwide consumption of fish (Eissa et al., 2022). The rapidly increasing population and the rising demand for aquaculture products are the major reasons behind the expansion of the aquaculture sector (Naylor et al., 2021). Aqua-feed constitutes 60-80 percent of production expenses in aquaculture. Aqua-feed directly influences pricing, potential health benefits, and quality of fish produced. So, researchers are looking for ways to make aqua-feed components that lower fish feed costs and promote sustainable aquaculture. To improve the overall performance of fish feed, various feed supplements and feed additives are used and they have recently gained popularity for meeting fish requirements for suitable and rapid growth performance. Functional feed additives are an innovative way to improve aquaculture output, sustainability, and profitability (Ansari et al., 2021). These additives offer several physiological benefits, including higher rates of growth, greater resistance to disease tolerance to stress, and improved animal health and well-being. Aquatic animal feed contains functional ingredients such as probiotics, prebiotics, organic acids, phytogenic, nucleotides and synbiotics that enhance overall aquaculture performance and productivity (Aragao et al., 2022).

Types of Natural Feed Additives and Their Functions in Aquaculture

The application of functional feed additives (FFA) in aquaculture seems a favorable way to resolve several sustainability issues associated with aquaculture. FFA are dietary substances added in feed to utilize it not only for providing basic nutritional requirements, serve as conventional feed, while also promoting development, enhancing health, and providing economic advantages. There are many useful FFA which are described as follows:

i. Probiotics

Probiotics are a beneficial feed addition for aquaculture that is gaining worldwide recognition. "Probiotics" are defined as a live microbial feed additive that improves the intestinal microbial balance and has a positive impact on the host (Eissa et al., 2022). Probiotics can be given through the diet or in the rearing water. Probiotics have several advantages as feed additions, including increased immunological response, growth, and pathogen suppression and they help in enhancing food digestibility. Probiotics also increase the production of nutrients such as biotin and vitamin B_{12} (Salih & Mustafa, 2017). Allochthonous probiotics are the type of probiotics obtained from bacteria that are usually not found in the digestive tract, such as yeasts, whereas autochthonous probiotics are microorganisms that live in the digestive system. Probiotics commonly used in aquaculture include yeast, both gram-negative and gram-positive bacteria, and algae (Bozkurt et al., 2014).

ii. Prebiotics

Prebiotics are non-digestible feed additives that promote host good health by activating beneficial microbes in the digestive tract (Bozkurt et al., 2014). Probiotics, for example, provide both energy and food for healthy intestinal flora (Kim et al., 2011). The benefit of using prebiotics as feed additives is, that they help in bacteria regulation in the stomach (Anadon et al., 2019). Prebiotics stimulate the host's immune system or enhance the proliferation of gut bacteria to activate the host's innate immune system (Song et al., 2014). Prebiotics naturally occur in animal dairy products like microalgae, vegetables, fruits, and sea-weeds (Balakrishnan et al., 2021). The types of prebiotics that are mostly used in aquaculture are monosaccharides, oligofructose, galactooligosaccharides, inulin, and β-glucan (Mohammadi et al., 2020).

iii. Synbiotics

Synbiotics are feed additives that mix probiotics and prebiotics to maximize their potential benefits. The use of synbiotics improves immune response, their usage in farmed fish has been studied, and the results suggest that they should be used regularly in aqua feed. By encouraging the metabolism of several beneficial bacteria in the gut, synbiotics enhance its survival and level of living microorganisms in the gastrointestinal system (Szychowski et al., 2018). Numerous research has looked into how "prebiotics," "probiotics" and "synbiotics" affect fish species' physiology and growth performance. According to the investigation, adding synbiotics to Rainbow trout diets together with probiotics and prebiotics boosted immunological response and growth rate. Additionally, it examined how a mixture of prebiotics and probiotics affected Common carp immunity to Saprolegnia and hematological indicators (Salih & Mustafa, 2017). They discovered that when fish affected by Saprolegnia were treated with synbiotics, their leucocyte counts and survival rates were much greater than those of the control group. This demonstrates that the output of aquaculture is significantly impacted by synbiotic feed additives (Zheng et al., 2020).

iv. Enzyme as a Feed Additives

Enzymes are biological catalysts, also known as biocatalysts, that accelerate metabolic reactions in living organisms. In aquaculture, enzymes are used as a secure and efficient bio-additive to help regulate the immune system, whole-body composition, feed utilization, growth, and digestibility of fish (Figure 1). Anti-nutritional elements have a negative influence on the digestion of dietary components as well as the growth performance of fish (Zhang et al., 2016). These issues can be addressed by using exogenous enzymes in aquafeed. In aquaculture, exogenous enzymes like protease, lipase, carbohydrase, and phytase are frequently used as feed supplements (Zheng et al., 2020). During their early growth or throughout their lives, aquatic animals are deficient in specific digestive enzymes. When larvae lack certain enzymes, giving them these enzymes increases the likelihood that the animals will thrive on feed. Enzymes, mostly phytase, reduce the amount of undigested phosphorus excreted into water bodies, decreasing pollution rates and protecting aquatic ecosystems (Szychowski et al., 2018).

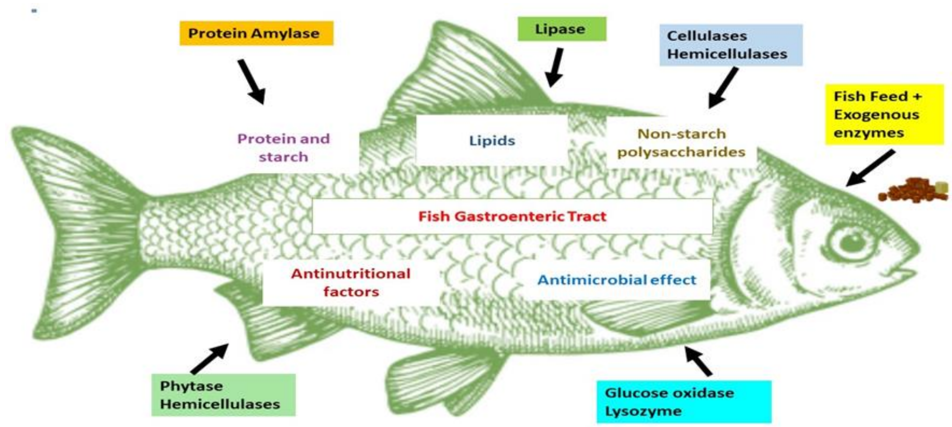

Fig. 1: Schematic Diagram of Different Enzymes Used in Aquaculture

v. Phytogenic

A very diverse class of feed additives known as phytogenic feed additives arise from the leaves, roots, tuber, and sand. Based on the part of the plant (e.g., seeds, leaves, roots, and bark), harvesting season, and place of origin, the amount of active ingredients in products might vary greatly (Reverter et al., 2014). Phytogenic feed additives include components like neem, moringa, oregano, thyme, and garlic. Bioactive substances like ajoene, allicin, phenol, polysaccharides, and saponin are found in garlic (He et al., 2020). Garlic has antibacterial, antiparasitic, and antioxidant qualities in addition to promoting growth (Szychowski et al., 2018). The bitter taste and distinct scent of neem have been attributed to meliacine and tignic acid, respectively. Neem also has anti-oxidative and anti-inflammatory properties, as well as hepatoprotective, and has the potential to prevent cancer with chemotherapy. It also has anti-diabetic properties (Md-Noor & Harun, 2022). One possible plant protein source for aquaculture diets is the moringa plant. High-profile nutrients can be found in the leaves and pods of moringa plants (Majhi, 2013). Studies have demonstrated the impact of *Moringa oleifera* a dietary additive, on the growth performance in term in many fish species, including weight gain, length increase, specific rate of development, food conversion ratio, and rate of survival (Elabd et al., 2019)

vi. Organic Acids

The major functional feed additives that are used widely in aquaculture enhancement include many elements like probiotics, prebiotics, synbiotics and many others such as organic acid (Figure 2). Animal nutrition has made extensive use of dietary acidification with the addition of organic acids has emerged as a promising feed additive to improve gut function and health. Alternatives acetic, formic, fumaric, lactic, propionic, and citric acids are frequently derived from environmentally acceptable sources of organic acids, they are very effective growth promoters (Balasubramanian et al., 2016). Acetic and peracetic acids are notably used as anesthetics in fish to immobilize them to reduce handling stress and physical harm and to enhance immune suppression of internal activity (Pedersen & Lazado, 2020). The organic acid that is most closely examined for weight increase and growth in aquaculture is citric acid (Zhang et al., 2016). Two distinct processes are involved in how organic acids function in the digestive tract, Improved activity of digestive enzymes is a result of organic acids in the stomach and small intestine lowering pH makes the environment less conducive to infections and stops Gram-negative bacteria from growing by causing the acids to dissociate and the bacterial cells to produce anions (Davies et al., 2020). Acidifiers can be a useful tool for achieving safe, affordable, and sustainable fish production (Omosowone et al., 2015).

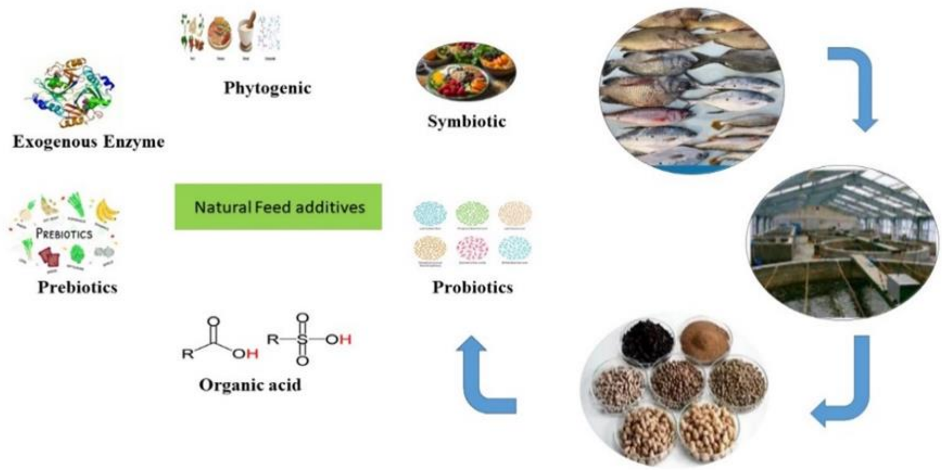

Fig. 2: Schematic Diagram of Natural Feed Additives Used in Aquaculture

Aquaculture and Sustainability Issues

Environmental deterioration, disease outbreaks and unsustainable methods are among the issues connected with increased aquaculture output (Pedersen & Lazado, 2020). Moreover, there are growing concerns regarding its viability. Institutional, financial, technological, environmental, and social resources are all systematically managed to ensure "sustainability"(Valenti et al., 2018). There are three categories of sustainability in aquaculture: social, environmental, and economic sustainability. The capability of aquaculture to continue to sustain the livelihoods of its practitioners is a key factor of economic sustainability. Environmental sustainability is the capacity to carry out aquaculture operations without endangering the environment (Boyd et al., 2020). Economic sustainability challenges include animal development in confinement which causes disease outbursts. The usage of antibiotics and chemotherapeutics to treat infections in aquaculture is one issue with environmental sustainability as well as the release of nutrient-rich effluents into aquatic habitats (Md-Noor et al., 2022). The issues of social sustainability involve the destruction of ecosystems and competition for land with other commercial operations due to aquatic farming through the destruction of terrestrial environments, such as shrimp farming in mangroves (Sampantamit et al., 2020).

Functional Feed Additives and Their Sustainability Roles

In aquaculture, functional feed additives (FFA) contribute to eco-friendly cultivation through boosting disease immunity, enhance growth, promoting sustainable resource use and improving feed efficiency (Table 1). They also contain antiparasitic qualities, which help to improve water quality. The roles of FFA are discussed in detail as follows

i. Feed Efficiency Improvement

The efficiency with which feed that is consumed is transformed into biomass is known as feed efficiency. Feeds that are highly efficient are those that promote greater growth rates when consumed in small amounts (Young et al., 2023). The feed conversion ratio (FCR), determined by dividing the amount of feed consumed by the weight of the animal over a certain time period, is a measure of feed efficiency; a low diet ratio indicates more efficient growth. Aquaculture relies largely on growth performance indicators to calculate output yield. Growth performance measures are affected by genetics, the environment, and diet as a result, they are commonly used in determining the efficiency of feeding (He et al., 2020). Because cultured animals grow faster, the production cycle is shorter, permitting farmers to gather their harvest and refresh their cultivation systems promptly while improving yield efficiency. Enhanced growth produces larger-sized animals, which frequently fetch greater prices when sold. Animal growth plays a vital role in aquaculture because it affects financial gain; any advancements that would result in increased growth while ensuring the health, welfare and safety of cultured aquatic animals for food is widely supported by aqua farmers (Puvanasundram et al., 2021).

ii. Sustainable Resource Utilization

The significant output in aquaculture is feed since it influences the survival and growth of aquatic animals, which boosts aquaculture's profitability. Aquaculture is primarily based on feed formulations for aquatic animals. To satisfy the dietary needs of animals, formulated feeds are made using a variety of feed ingredients. For aquatic animals, fishmeal continues to be the most effective source of protein among these feed ingredients. Omega-3 fatty acids are mostly found in fishmeal and essential oils. Aquaculture promotes wild stock sustainability, has emerged as the primary user of fishmeal and fish oil among the various users, including the animal production industries and people. More fish oil and fishmeal will be required as a result of the anticipated rise in production, which also suggests an increase in feed composition. This has led to the partial or whole substitution of fishmeal with plant-based protein. When fishmeal is partially or completely replaced in aqua diet with another source of protein after a specific amount of time, for financial or environmental reasons it effects aquatic organisms (Dawood et al., 2015). The use of substitute proteins can be improved in aquafeed by adding functional feed additives (He et al., 2020).

iii. Enhanced Disease Resistance

In aquatic environments, organisms are always at risk of getting a disease. Because aquatic animals can consume waterborne pathogens through feeding, the likelihood of illness occurrence is greater in aquatic environments than in any other environment (Stentiford et al., 2017). A significant obstacle in aquaculture is disease outbreaks, which cause between 40 and 60 percent of output losses in fish and crab farms (Raman et al., 2017). Diseases are more likely to emerge and spread when aquaculture is intensified through high stocking rate, which serves such as breeding environment for pathogens and parasites (Reverter et al., 2020). Aquatic feed contains antibiotics to cure bacterial illnesses. Intestinal bacteria can also be eliminated by antibiotics, which improves aquatic animals' growth and feed efficiency. Prebiotics, probiotics, and phytogenic have been utilized to prevent disease and increase the immunity of host (Lieke et al., 2021).

iv. Antiparasitic

Aquaculture is also limited by parasite infection. Ectoparasites cause skin lesions by feeding on the host's blood, mucus, and tissue. The host's growth is impacted by parasite infestation, leaving it susceptible to a secondary bacterial or fungal infection that could be fatal (Lieke et al., 2021). Additionally, parasite infestation lowers aquaculture products' value and profitability. In addition to being efficient antiparasitic, functional feed additives such as phytogenics, which help prevent parasite infections. The application of phytogenic substances to lessen the effects of parasites like ichthyopthirius, multifiliis, trichiniasis and monogeneans (Rosny et al., 2014). It has been reported that neem oil's azadrichtin extract successfully reduces salmon sea lice infection (Kim et al., 2022). Adding garlic to fish diet resulted in reduction of infection prevalence (92-100%) in compare to the control group. Because phytogenics are safe, environmentally friendly, derived from natural sources, and consistent with sustainable production methods, they are ideal substitutes for controlling parasites in aquaculture (Aragao et al., 2022).

v. Improved Water Quality

Aquafeeds provide a variety of nutrients, including protein, carbs, minerals, and vitamins. Carbon, nitrogen, phosphorus, and a few other elements are all components of protein, which makes up the majority of the nutrients found in aquafeed (Aragao et al., 2022). Approximately 20-50% of the phosphorus and nitrogen that enter the cultural framework (by using fertilizer and feed) are retained in the animals. Excretory products of aquatic animals, as well as nitrogenous components together with organic waste such as ammonia and nitrite originating through un-consumed feeds, are characteristics of the aquaculture culture unit (Yousaf et al,2024). The quality of water is important in aquaculture because aquatic animals, including all their physiological activities, including breathing, eating, evacuation and reproduction, take place inside the aqueous medium. There is a considerable correlation between water quality and animal health in land-based culture systems (Boyd et al., 2017; He et al., 2020).

Table 1: Effect of Functional Feed Additives on Growth and Feed Utilization.

Natural feed additives	Instance	Mode of actions	References
Probiotics	*Bacillus pumilis* B16, B. *mojavensis* J7, *Streptomyces panacagri*, and *Streptomyces flocculus*, *Lactobacillus salivarius*, and *Lactobacillus spp*.	Enhances the bacitracin level of biomolecules, protects against food poisoning, and can be used in place of antibiotics.	(Aragao et al. 2022)
Prebiotics	Mannanoligosaccharide, fructooligosaccharide, and galactooligosaccharide	Encourage innate immune response, boost fish development, and promote health.	(Chakraborty et al. 2014).
Synbiotic	*B. subtillus* and Mannanoligosaccharide	Regulate gut's lysozyme activity during ingestion.	(He et al. 2020).
Organic acids	Acetic acid, formic acid, fumaric, lactic, propionic and citric acid	Serve as fish anesthetics, inhibit the immune system, encourage development, and lead to a rise in body weight.	(Davies et al. 2020)
Exogenous enzymes	Protease, phytase, lipase, amylase, and carbohydrase enzymes	Capacity to develop and boost nutritional content.	(Sampantamit et al. 2020)
Phytogenic	Protein-based such as essential oils, phenolic, flavonoids, alkaloids, *Moringa oleifera*, Garlic and Neem	Acts as an antioxidant and boosts digestive enzymes.	(Reverter et al. 2014)

Determining Ideal Inclusion Rate

Chinese seabass (*Lateolabrax maculatus*) growth performance was unaffected by dietary inclusion levels below 1gkg^{-1}, numerous studies suggested the significance, of maximizing the amount of feed additives added and focusing on maintaining a balance between their positive and negative nutritional effects at varied dosage amounts. However, larger supplementation doses greater than 2gkg^{-1} affected feed intake and development, suggesting that optimal inclusion levels are required to provide the preferred advantages while reducing antinutritional components (Davies et al., 2020). Additionally, the significance of determining the ideal hydrolysate concentrations to optimize growth advantages, with a concentration on determining the importance of arginine inclusion as an additive to feed, and promote the health and growth of fish. Generally, these findings show that specific functional feed additives can increase growth in a variety of species, highlighting the discovery of functional component ratios and synergistic combinations (Table 2). Further investigation may increase the additive's inclusion rates, examine multiple synergies, and explain physiological pathways (Chakraborty et al., 2014).

Table 2: Effect of Functional Feed Additives on Different Fish Species.

Fish Species	Types of Additives	Name of Strain	Concentration	Duration (Days)	Feed Conversion Ratio (FCR)	Specific Growth Rate (%d−1)	Protein Efficiency Ratio	Reference
Rohu (*Labeo rohita*)	Probiotics	The oligosaccharide fructose *Methylotrophicus* *Bacillus licheniformis* *Bacillus* The combination of FOS with *Bacillus licheniformis* and *Bacillus Methylotrophicus*	Control 10^7cfu/g	90	$2.22±0.01^{d}$ $2.0±0.01^{c}$ $2.02±0.02^{c}$ $1.74±0.01^{a}$ $1.94±0.01^{b}$ $2.4±0.01^{e}$	$1.26±0.1^{a*}$ $1.34±0.2^{b*}$ $1.34±0.1^{b*}$ $1.42±0.2^{c*}$ $1.37±0.1^{bc*}$ $1.19±0.2^{a*}$	$1.29±0.02^{b}$ $1.43±0.01^{c*}$ $1.41±0.01^{c*}$ $1.64±0.02^{e*}$ $1.55±0.02^{d*}$ $1.19±0.02^{a*}$	(Sukul et al. 2023)
Tilapia (*Oreochromis niloticus*)	Probiotics	*C. cerevisiae Saccharomyces*	Control group 1g kg diet 2g 4g	60	$1.68±0.1^{b}$ $1.39±0.1^{b}$ $1.28±0.1^{ab}$ $1.18±0.1^{a}$	$1.49±0.25^{a}$ $157±0.40^{ab}$ $1.60±0.25^{ab}$ $2.0±0.19^{b}$	$2.10±0.01^{a}$ $2.27±0.01^{ab}$ $2.23±0.01^{ab}$ $2.81±0.01^{b}$	(Islam et al. 2021)
White shrimp (Litopenaeus vannamei)	Probiotics	*Bacillus subtillus* *Lactobacillus pentose* *Lactobacillus fermentum* *S. cerevisiae*	10^9cfu kg^{-1} 10^9 10^9 10^9 10^7 10^8 10^9 Control	56	$1.64 ± 0.0^{ab}$ $1.67 ± 0.0^{ab}$ $1.75 ± 0.0^{bc}$ $1.82 ± 0.0^{c}$ $1.82 ± 0.0^{c}$ $1.67 ± 0.0^{ab}$ $1.53 ± 0.0^{a}$ $1.82 ± 0.01^{c}$	NP	NP	
Catfish (*Clarias gariepinus*)	Probiotics	*NP5 Bacillus*	Control 1 × 10^9 1 × 10^{10}	30	$2.14 ± 0.13^{a}$ $1.0 ±1.42^{b}$ $1.09 ± 0.07^{C}$ $1.4± 0.14^{B}$	$2.56 ± 0.0^{a}$ $2.44 ± 0.1^{a}$	NP	
Pacific white shrimp (*Litopenaeus vannamei*)	Prebiotics	Mannan oligosaccharides	1 g kg feed 2g 4 g 6 g Control	56	$1.54±0.03^{bc}$ $1.43±0.02^{c}$ $1.60±0.07^{b}$ $1.68±0.33^{b}$ $1.71±0.04^{b}$ $1.78±0.05^{a}$	$2.26±0.03^{ab}$ $2.49±0.02^{c}$ $2.41±05^{c}$ $2.41±4^{bc}$ $2.41±0.5^{c}$ $2.29±0.5^{a}$		(Zhang et al. 2012)
Thinlip grey mullet (*Liza ramada*)	Prebiotics	Oligosaccharide of Mannan	0.5% 1% 2% Control	56	$1.22±0.02^{b}$ $1.21±0.03^{b}$ $1.24±0.01^{b}$ $1.43±0.10^{a}$	$2.57±0.2^{a}$ $2.54±0.3^{a}$ $2.47±0.2^{b}$ $2.34±0.4^{c}$	$2.71±0.05^{a}$ $2.75±0.09^{a}$ $2.66±0.03^{b}$ 2.32±0.15	(Sukul et al. 2023)
Rohu (*Labeo rohita*)	Prebiotics	*Fructose* and *oligosaccharides* *Bacillus* species include *licheniformis* and *Methylotrophicus* *FOS* + *Bacillus licheniformis* or *FOS* + *Bacillus*	10^7 cfu/g Control	90	$2.22±0.01^{d*}$ $2.0 ±0.01^{c*}$ $2.02±0.02^{c*}$ $1.74±0.01^{a*}$ $1.84±0.01^{b*}$ $2.4 ±0.01^{e*}$	$1.26±0.1^{a*}$ $1.34±0.2^{b*}$ $1.34±0.1^{b*}$ $1.42±0.2^{c*}$ $1.37±0.1b^{c*}$ $1.09 ±1.02^{a*}$	$1.29 ±0.02^{b}$ $1.43±0.01^{c*}$ $1.41±0.01^{c*}$ $1.64±0.02^{e*}$ $1.55±0.02^{d*}$ $1.19±0.02^{a*}$	(Sukul et al. 2023)

Tilapia (*Oreochromis niloticus*)	Prebiotics	*Lactobacillus* combined with *xylooligosaccharides*.	10^{8} CFU g-1 10 g kg-1 diet (10^{8} CFU g-1 + 10 g kg-1) Control	84	1.56 ± 0.01^{c} 1.55 ±0.01^{b} 1.50 ± 0.01^{b} 1.62±0.01^{a*}	2.61 ±0.01^{b} 2.59 ±0.01^{b} 2.70 ±0.03^{a} 2.53 ± 0.02^{c}		(Van Doan et al. 2020)
Nile tilapia (*Oreochromis niloticus*)	Phytogenics	Lemon grass (*Cymbopogon citratus*). *Geranium* essential oil.	250 mg kg-1 Lemon grass oil 400 mg kg^{-1} Lemon grass oil 200 mg kg^{-1} geranium oil 400 mg Kg^{-1} geranium oil	84	1.79±.01^{bc*} 1.75±0.04^{bc*} 1.86±0.04^{ab*} 1.77±0.03^{c*} 1.89±0.03^{a*}	3.90±0.1^{a*} 3.88±0.4^{a*} 3.78±0.3^{b*} 3.93±0.3^{a*} 3.75±0.4^{b*}	1.75±0.01^{ab*} 1.78±0.04 ^{a*} 1.68±0.03^{b*} 1.76±0.03^{ab*} 1.65±0.02^{b*}	(Al-Sagheer et al. 2018)
Rainbow trout (*Oncorhynchus mykiss*)	Phytogenics	Garlic (*Allium sativum*)	1% 2% 3% Control	120	0.74±0.02^{a} 0.73±0.04^{a} 0.73±0.03^{a} 0.76±0.01^{b}	2.63±0.00^{b} 2.66±0.03^{bc} 2.68±0.04^{c} 2.60±0.01^{a}		(Buyukdeveci et al. 2018)
Rainbow trout (*Oncorhynchus mykiss*)	Phytogenics	Garlic	5% 7% 10% Control	90	2.90 ± 0.0^{a} 1.90 ± 0.0^{d} 2.60 ± 0.0^{b} 2.10 ± 0.0^{c}	3.62 ± 0.03^{a} 3.68 ± 0.02^{a} 3.65 ± 0.01^{a} 3.50 ± 0.02^{b}		(Buyukdeveci et al. 2018)
Mori (*Cirrhinus mrigala*)	Phytogenic	Moringa (*Moringa oleifera*)	25% Control	60	2.5+0.5^{ab}	2.8±0.3^{a}		(Zhang et al. 2012)
Snakehead fish (*Channa argus*)	Synbiotics	*Enterococcus* *Lactococcus lactis* *Enterococcus* + *Lactococcus lactis*	Control 1.0×10^{8} cfu/g of diet	56	1.29±0.01^{b} 1.23±0.03^{c} 1.27±0.02^{b} 1.34±0.02^{a}	2.38±0.03^{b} 2.51±0.02^{b} 2.42±0.01^{bc} 2.26±0.03^{a}	1.84±0.03^{b} 1.93±0.01^{c} 1.88±0.01^{b} 1.77±0.02^{a}	(Kong et al. 2020)
Tilapia (*Oreochromis niloticus*)	Synbiotics	*Lactobacillus plantarum* CR1T5 Xylooligosaccharides *plantarum* + xylooligosaccharides	108 CFU g^{-1} 10 g kg^{-1} diet (10^{8} CFU g^{-1} + 1g kg^{-1}) Control	84	1.56±0.01^{c} 1.55±0.01^{b} 1.50±0.1^{b} 1.62±0.1^{a}	2.61±0.01^{b} 2.59±0.01^{b} 2.70±0.03^{a} 2.53±0.02^{a}		(Van Doan et al. 2020)

Benefits of Feed Additives on Growth Performance

An important field of study examined the effects of functional feeds on disease resistance, gut health, and immunity. Numerous studies indicate functional feed additives with an ideal formulation can affect intestinal shape, gut microbiota, antioxidant capacity, and immune indicators (Agboola et al., 2021). When Laminaria digitata was added to the diet of Sparusaurata, there was a notable increase in intestinal villi length, antioxidant enzymes, and immunity markers. The biofortification process enhances the intestine's absorption capacity and function by expanding the diameter of the villi. It also observed an increase in the length of intestinal villi in the spotted seabass when Mulberry leaf extract was administered (Shakeel et al., 2023). All of these studies indicate that feed additives promote resistance to disease by lowering oxidative pressure and improving immune function (Figure 3). According to these investigations, adding functional feed additives to aquafeed improves fish production and efficiency (Chakraborty et al., 2014).

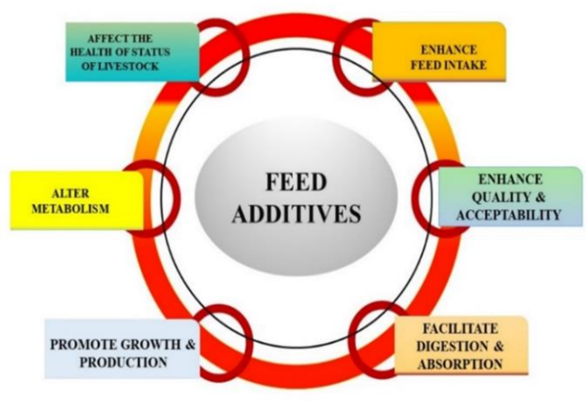

Fig. 3: Enhancing Aquaculture Production Through Feed Additives

Enhancing Aquaculture Production with Feed Additives

Globally, aquaculture is an important sector that provide a significant quantity of animal protein (Fraga-Corral et al., 2022). Aquaculture industries will face difficulties in their future expansion, such as market and regulatory biological problems. To ensure long-term profitability, sustainability will be supported by utilizing natural feed additives. To improve fish farming operations, consider decreasing the danger of loss, reducing the duration of rapid growth, designating a target size, offering access to local markets, and promoting low-cost expenditure. The manufacturing of feed additives in India and Japan has grown steadily. The worldwide aquaculture feed additive market was valued USD 56.27 billion in 2012 and is predicted to exceed USD 186.81 billion by 2022 (Figure 4). In 2020, a global epidemic triggered by a coronavirus spread globally, resulting in lockdowns and also social isolation as new standards. A study was undertaken to analyze the cost of fish productivity by adding specific feed additives including prebiotics, probiotics, antibiotics, vitamins C and E. Public strategy measures, such as limiting economic impact of aquaculture management and utilizing feed additives, have led to cost-effective and also increased aquaculture productivity (Balaji et al., 2013).

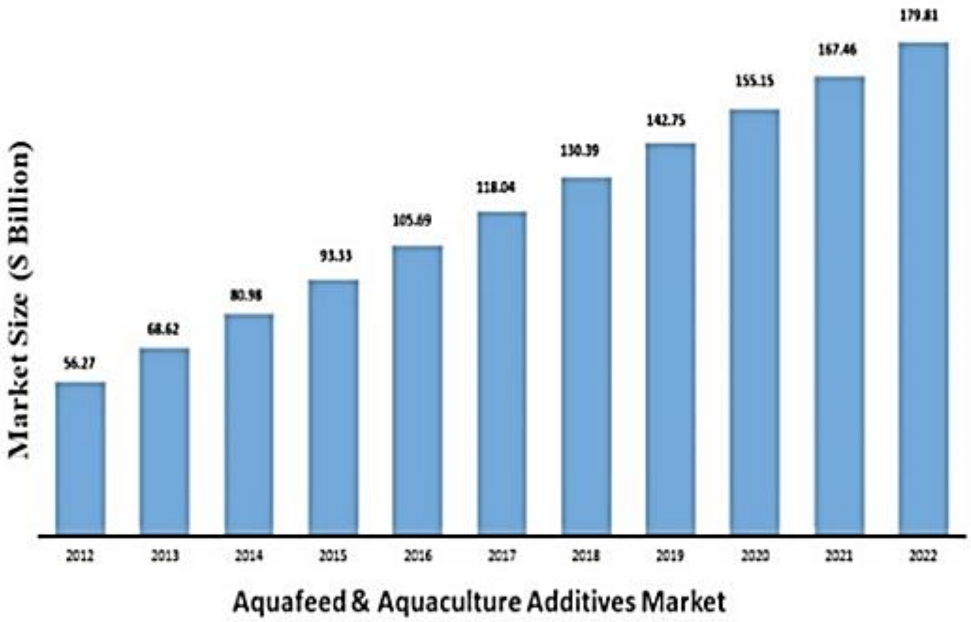

Fig. 4: Improvements in Aquaculture Feeds, 2012-2022

Conclusion

According to the study, feed additives benefit aquaculture in several ways. Previous research has shown that feed additives improve growth performance, making the aquaculture sector profitable. Furthermore, several assessors observed the better impact dietary addition of feed additives is moderately connected with improved feed consumption, which most likely develops immunological action and increases gain weight. This can be ascribed to a various types of feed additives, such as essential oils, probiotics, prebiotics, synbiotics, organic acids, and exogenous enzymes. Some chemicals offer immunostimulant and stress-relieving qualities, in addition to improving aquafeeds and sustaining aquatic animal health. This study suggested that feed additives are beneficial for their therapeutic characteristics and environmentally friendly metabolism in the intestinal system. Probiotic feed additives, are particularly applicable for aquaculture applications due to the best of their ability to strengthen immune response, promote competition for binding sites, produce antibacterial substances and compete for nutrition. As a result, considerable research should be conducted to determine the growth performance, antibacterial activity and activation of the immunological response of existing feed additives.

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