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Overview of Different Nutraceuticals used in Fisheries and Aquaculture

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Nutraceuticals are bioactive compounds or substances that have potential health benefits when administered as part of the diet in animals, including fish and other aquatic organisms. In fisheries and aquaculture, nutraceuticals are used to improve the growth, health, and overall performance of the cultured species. In addition to their health benefits, nutraceuticals from fisheries and aquaculture can also be used in aquaculture to improve the growth and health of fish. For example, omega-3 fatty acids can be added to fish feed to improve the fatty acid composition of the fish flesh. This can make the fish more appealing to consumers and have health benefits for the people who eat the fish. They can help to improve cognitive function and memory. Nutraceuticals help to boost the immune system and fight off infection. The use of nutraceuticals in aquaculture is a growing field. As more research is conducted on these compounds' health benefits, their use will likely become more widespread.

Keywords

Probiotics, Prebiotics, Immunostimulants, PUFAs, Organic acids

Introduction.

The relationship between the uses of suitable foods for health and therapeutic benefit was first conceptualized by Hippocrates around 2500 years ago. However, the term “nutraceuticals” came into existence only when Dr. Stephen D. Felice defined it in 1989 as “a food or food product that produces health and medicinal benefits, including prevention and treatment of disease” (Kalra, 2003). A whole, nutrient-rich food like Spirulina, garlic, or specific compounds like vitamins, lycopene or omega-3 fatty acids can be a nutraceutical. It is often difficult to distinguish the terms food, nutraceuticals, dietary supplements functional foods and drugs (Gupta et al., 2010). According to (Zeisel, 1999), nutraceuticals are not dietary supplements but rather “are consumed as part of a normal diet and deliver one or more active ingredients (that have physiologic effects and may enhance health) within the food matrix.” The potential nutritional and therapeutic benefits and their presumed safety made them more popular than drugs and dietary supplements. Though this concept was initially recognized for human health improvement, in recent years, it also gets more importance in animal nutrition. These are food products of natural origin from terrestrial and marine sources that have healthcare importance. The word nutraceuticals comprise various products derived from terrestrial and marine sources (isolated nutrients, dietary supplements, genetically engineered designer foods, herbal products, processed foods, and Beverages). Nutraceutical is a term used to describe any product derived from food sources with extra health benefits in addition to the essential nutritional value found in foods. In other terms, a nutraceutical, sometimes known as a “bioceutical,” is a pharmaceutical substitute that asserts to offer physiological advantages for organisms. These ingredients of nutraceuticals are not identified as essential nutrients but are considered as bioactive substances with one or more health benefits.

Types of Nutraceuticals

Based on bio-functional properties of bioactive compounds from terrestrial and marine sources are classified into the following –

Dietary Supplements

According to the (Food and Administration, 1995) in the USA, dietary supplements are defined as products comprised of —dietary constituents that are orally administered to supplement the nutritional requirement of diet. The Dietary constituents mainly refer to bioactive components comprising amino acids, vitamins, minerals, fibers, important metabolites, and certain enzymes. The dietary supplements also include extracts available in tablets, capsules, powders, liquids, and in any other dosage form (Priyadarshani & Rath, 2012).

Functional Food

Functional foods that are naturally obtained that are rich in nutrients and are fortified with essential nutrients (Jones & Jew, 2007). As per Health Canada, functional food is a regular food with an ingredient having specific therapeutic effect and nutritional value (Jalili et al., 2001). Whereas in Japan, functional foods are assessed on based onee important essential (1) functional foods must be derived from natural sources and consumed in their native state instead of processed in different dosage forms like tablet, capsule, or powder; (2) consumed regularly as a part of the daily diet; and (3) exert a dual role in prevention and management of disease and contribute in biological processes (Arai, 1996)

Medicinal food

Medical foods are specially formulated and are to be consumed under the supervision of a physician, which is intended for the dietary management of a particular disease that has specified nutritional needs that cannot be met by a normal diet alone. Dietary supplements and functional foods do not meet these criteria, and therefore they are not classified as medical food (Radhika et al., 2011)

Role of nutraceuticals in aquaculture

The use of nutraceuticals has been much advocated for production performance, growth enhancement, boosting immunity, and enhancement of feed utilization ((Sinha et al., 2007); (Tejpal et al., 2021). Various groups of nutraceuticals that are being used in the aqua feed industry and on farms include enzymes, methyl donors, nucleotides, Levans and other immunostimulant chitin, chitosan, polychaete and tunicates extract, vitamins, antioxidant minerals, amino acids, anabolic growth promoters, organic acids, carotenoids, etc. There is no apprehension that nutraceuticals in the aquafeed industry have a better impact on feed utilization, immunity, flesh quality, stress tolerance, reproductive and productive performance, and better water quality during the culture due to less feed waste and efficient feed utilization. The stagnation in marine production, concurrent with the increased consumer demand put pressure on aquaculture to enhance the production. The constraints of land and water make the inland culture system more intensive, which is more prone to disease attack as the immunity of the fishes is suppressed due to stress. Plenty of pathogens exist in the aquatic environment, waiting for an opportunity to attack the fish. Several disease outbreaks in aqua farms have been witnessed in recent years. In order to control disease outbreaks in aquaculture farms, the use of antibiotics and drugs has become a common practice. The unregulated usage of these chemicals results in antibiotic resistance, residue accumulation in aquatic systems, and many other side effects. The use of nutraceuticals as an alternative to these drugs or chemicals is an ideal approach to avoid such problems. Nutraceuticals have been reported to have immune-boosting and growth-enhancing ability in fish. The research reports indicate that they support increased feed intake, enhance the anti-stress and antimicrobial ability of the fish and shellfish and induce maturation without any detrimental effects. In aquaculture, some feed additives are also included in the list of nutraceuticals (Brower, 1998).

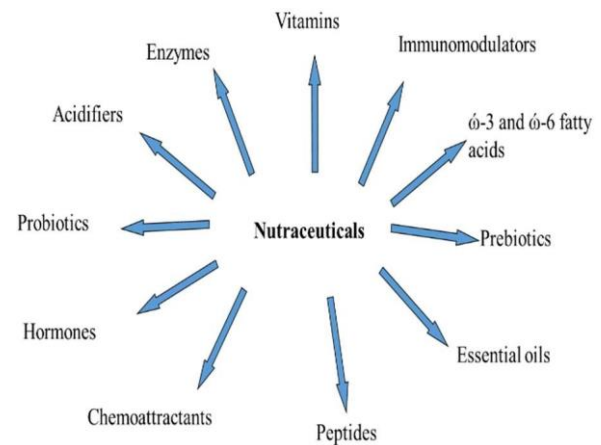


Figure 1. Classification of nutraceuticals

Stress in aquatic systems is caused due to several factors. The high stocking density, variation in climatic conditions, exposure to pesticide or insecticide, malnutrition, use of plant-based ingredients containing anti-nutritional factors can cause stress to fish. Today, researchers are come up with several compounds which can mitigate the effect of stress in fish. The classification of these compounds can be done according to their function and chemical nature. The commonly used nutraceuticals in aquaculture can be classified as

Traditional

Ancient civilizations like Indian, Chinese, Egyptian, and Sumerian are very well aware of the importance of food as a medicine, and it was mentioned in their epics and other similar documents. For example, Ancient Indian medical science Ayurveda clearly mentioned the importance of food for therapeutic purposes. The traditionally used simple, natural food are classified as traditional nutraceuticals whereas the commercial products enriched with nutrients or new technologies like breeding and hybridization enhance the specific nutrients in it are classified under nontraditional nutraceuticals.

Based on the chemical nature

Amino acids and peptides

Amino acids are considered essential nutrients and anti-stress agents while some peptides are known for their antimicrobial properties. Amino acids like tryptophan, pyridoxine, tyrosine, glycine, and arginine have already been reported to have stress-reducing ability. Tryptophan is an essential amino acid necessary for the production of serotonin (5-HT), which plays a significant role in the mitigation of stress response in fish (Hoseini et al., 2019) There are several studies showed that the dietary tryptophan alleviates the stress effect in rainbow trout (Lepage et al., 2002), rohu (Akhtar & Abdullah, 2021);(Kumar et al., 2014), mrigal (Tejpal et al., 2009)and in juvenile grouper (Höglund et al., 2007). FNBP lab of ICAR-CIFE has reported that dietary supplementation of L-tryptophan at 1.36% levels reduces stress (Akhtar et al., 2013). Tyrosine is an amino acid precursor of catecholamine which appears to work precisely in the same manner of nor-adrenalins and reduce the stress in fish. Glycine and arginine are other important amino acids which supports the immunity and antioxidant defence in fish. Glycine has a critical role in osmoregulation and is reported that survival of oysters were enhanced on transfer from freshwater to seawater after supplementation of glycine (Takeuchi, 2007).

Fatty acids

Poly unsaturated fatty acids (PUFA) belongs to the n-3 and n-6 family are precursors of biologically active eicosanoids (Bakhle, 1983) and are essential for inflammatory responses in fish. (JOLLY, 1999) showed n3 PUFA increased immunity in rohu fingerlings. There is a report that the dietary inclusion of 3% PUFA causes immune-suppression in juveniles (Fontana et al., 1999).

Nucleotides

The dietary nucleotide inclusion in fish enhances the immunity (Beale et al., 1999) (Snyderman et al., 1999)A study in salmon showed that the overall health of the fish was improved by the dietary nucleotide supplementation (JOLLY,

1999) (Sukumar et al., 1999). Moreover, (Pepin et al., 1999) reported that dietary RNA improved survival in fish. (Jha et al., 2007) reported that 0.8% inclusion of nucleotide can enhance the immune response in catla fingerlings.

Vitamins

Vitamins are micronutrients which are essentially required in smaller quantity to perform vital functions of the animal. Vitamins like A, C and E are important antioxidants, which enhance the immunity in fish. High levels (3000mg/kg diet) of ascorbic acid enhance the antibody production and complementary activity (Soliman, 1985). According to (Chen et al., 2004) the dietary inclusion of more than 100mg/Kg vitamin C showed an enhanced immune protection in fish. Vitamin E supplementation reduced nitrite stress in rohu (Ciji et al., 2012) and showed immune-boosting activity in channel catfish (Zhu et al., 2012). Vitamin A and beta carotenes are strong antioxidants in biological system and the supplementation of astaxanthin showed an immunomodulatory effect in rainbow trout (Thompson et al., 1995). Pyridoxine or Vitamin B6 is reported to have anti-stress effect because it can boost the production of serotonin and GABA. A dose standardization study in our lab reported that the dietary supplementation of pyridoxine at 100mg/Kg diet is optimum for stress reduction and growth enhancement (Akhtar et al., 2013). Similarly, Pantothenic acid can down regulate the hyper-secretion of cortisol and hence a control in stress.

Minerals

Minerals are the inorganic nutrients which can also act as anti-stress agents. The supplementation of minerals in both organic and inorganic forms is found to be effective for stress mitigation in fish. Supplementation of zinc picolinate decreased the oxidative stress in rainbow trout (Kucukbay et al., 2006). Dietary selenium in organic forms also reduced oxidative stress in groupers (Rider et al., 2009).

Polysaccharides

Polysaccharides are mostly targeting the non-specific immune system of the aquatic animals. In recent years, a large number of polysaccharides are used as immunostimulants like, microbial levan, beta glucan, chitin, lactoferrin, inulin etc. β -glucans are glucose polymers with a backbone of β -(1-3) linked β -Dglucopyranosyl units. It can be bind with a variety of cellular receptors, hence can activate these receptors. β -glucan showed enhanced resistance against bacterial and viral infections in fish (Zhang et al., 2014).

Herbal extracts

Herbal extracts are those compounds which has the capacity to scavenge reactive oxygen species and enhance the immune system of the animal. There are several plant extracts, which show immune boosting and stress mitigation effect in fish (Harikrishnan et al., 2011) (Serradell et al., 2020). The bioactive compounds like Rutin (Toonasinensis) are found to be strong antioxidant and anti-stress bioflavonoids and reported as effective for crustaceans. A study in our lab on guava and mango leaf extract showed that 0.5% inclusion of guava and or mango leaf extract in diet enhances immunity in *Labeo rohita* fingerlings (Fawole et al., 2016). There was another study reported from our lab report that feeding of ethanolic leaf extract of *Moringa olifera* at 0.25% in diet for 20 consecutive days enhances immunity in Nile tilapia (Tekle and Sahu, 2015).

Based on the functions

Anti-stress& antioxidant nutraceuticals

Most of the vitamins, minerals and herbal extracts fall under this category. Dietary supplementation of bovine lactoferrin at a dose of 1200mg/kg diet showed a reduction in salinity stress in groupers (Saichiro et al., 2006). The herbs, *Astragalus membranaceus* and *Astragalus paniculata* are found to be effective antistress agent in *Cyprinus carpio* and tilapia (Wu et al., 2007).

Immunostimulants

The immune system of fish and shell fish are not very well developed like terrestrial animals and the major target in many cases are the non-specific immune system. Many of the polysaccharides and the oligosaccharides enhance the non-specific immune system in fish and shellfish. The studies show that feeding 5mg/kg levamisole in carp diet enhanced the phagocytic activity. (Boonyaratpalin and New, 1995) showed a high dissolved oxygen tolerance and immune stimulation in black tiger shrimp when fed with peptidoglycan. Beta glucan also showed enhanced resistance to bacterial and viral infections in crustacean (Misra et al., 2006). Microbial Levan at 1% concentration enhanced the immunological parameters in rohu fingerlings and similarly, the inulin also enhances the immune response in fish. A number of plant materials like saponin, tannin, glycyrrhizin, azadirachtin etc are also found to be immune enhancers in fish and shell fish.

Antimicrobial and viral nutraceuticals

Most of the sulphur containing nutraceuticals (Onion, garlic, thioles and sulphides), terpenes based compounds (Oregano, turmeric and ginger), phenolic compounds (cloves, nutmeg, cinnamic acid, tannin), Glycosides (sugar, aldehyde like citral and citronello), esters and alcohols are having antimicrobial properties. Many of its application in aquaculture are in experimental stage only. Several plant extracts and many of the immunostimulants like glucan, chitin, lactoferrin, levamisole also have antimicrobial and anti-viral agents.

Growth promoters

There are various natural compounds and micronutrients showing growth enhancing property in fish. The inclusion of spirulina has found to have growth promotive effect in tilapia, (Abdel-Tawwab et al., 2008). Spirulina is rich in carotenoids and phenolic compounds and dietary supplementation of it enhanced the growth and phosphatase activity in rohu exposed to metallic

stress (James, 2010). Yeast and seaweed extracts are also found to be growth and immune booster in fish. The herbal growth promoters are found to be supporting the transcription rate to promote growth. Enrichment of artemia nauplii with herbal products like stressol I and stressol II were found to be growth promoting in *Penaeus indicus* (Chitra, 1995). According to (Francis et al., 2005) the inclusion of quillaja saponins enhances the metabolic rate and overall growth in tilapia.

Acidifiers

Organic acids in isolation or in combination can improve the digestion, intestinal micro flora and intestinal health status which are commonly called as acidifiers. Additions of acidifiers in feed improves the shelf life of the feed, support digestion by providing suitable pH for enzyme action and even act as intermediates in TCA cycle. A study from our lab showed that the application of citric acid (3%) along with exogenous phytase enhance the action of phytase and promote mineral availability in rohu (Baruah et al., 2007). Formic acid and acetic acid are other important acidifier studied in animal diets. The mode of action of organic acid is given below:

Prebiotics, probiotics and synbiotics

Probiotics can be defined as “a viable mono or mixed culture of microorganism which, when applied to and animals or man beneficially affects the host by improving the properties of indigenous flora” (Havenaar, 1992) while prebiotics are the non-digestible food ingredients which promote the growth and colony formation of gut microflora. When both prebiotics and probiotics together supplied to the system it has synergistic effect and is called as synbiotics. The probiotics suppresses the bacterial pathogens, and helps in production of special metabolites, which enhance the immune system. The most commonly used probiotic organisms in aquaculture are *Lactobacillus sp.*, *Enterococcus spp*, *Bifidobacterium spp*, *Bacillus sp.* and *Streptococcus spp*. The major prebiotics studied

in aquaculture systems include Mannan oligosaccharides (MOS), Xylan oligosaccharides (XOS), Fructan oligosaccharides (FOS) etc., which supports the establishment of favourable microbes, helps in absorption of nutrients and immune modulation of species. Reports on utilization of MOS in fish showed that the survival, immunity and growth were improved in rainbow trout (Staykov et al., 2007), channel catfish (Welker et al., 2007) and common carp (Staykov et al., 2007).

Nutrzymes/exogenous enzymes

The exogenous enzymes which act as nutraceuticals are called as nutrzymes and it supports in enhancing the digestibility of feed and enhance the growth. Plant based feed ingredients naturally contains antinutritional factors and cellulose in it. This creates digestive imbalances in fish and has to be supported by external enzymes to reduce the negative effects. The digestive enzymes like lipase, cellulase, protease, glucanase, phytase and microbial amylase enhance the digestion in fish fed with plant-based ingredients. Studies have shown that gucanase increases the protein digestibility in soybeans from 74-95% and the phytase improved the availability of minerals and protein, which makes complex with makes complex with phytic acid (Coon, 1998). The exogenous chitinase helps to improve the digestion of chitin containing ingredients in the diet. Addition of exogenous carbohydrase improves the utilization of carbohydrate in carnivorous fishes. In a study conducted in our lab we could observe that Non – gelatinised corn supplemented with microbial α – amylase at suboptimal protein in the diet of *L. rohita* fingerlings enhanced the growth and cell size (Kumar et al., 2014).

Mode of delivery

Nutraceuticals can be delivered in different modes like parental, directly oral administration and dietary supplementation. In

a study on nucleotide showed that the yeast RNA supplementation in oral mode enhanced the phagocytic activity in common carp (Sakai et al., 2001), while high dietary RNA supplementation affected the growth and protein accretion European seabass (Peres and Oliva-Teles, 1999). Injection of chitin showed an enhanced immune system in fish. But most of the studies indicate that the supplementation through diet in a protected way is more economical and efficient. Nanodelivery of nutraceuticals is a field yet to be studied in detail. Nano zinc supplementation studies were conducted in our lab and found to be effective in enhancing growth and immunity compared to nascent inorganic zinc supplementation. The targeted tissue delivery, prevention of loss of micronutrients and reduction in cost are added advantages of Nano delivery systems.

Future scope

Recent years have witnessed several types of disease outbreaks in shrimp and fish farms like WSSV, EMS etc, which has taken away a large volume of crops across the world. This happened mainly because of the decreased immune status of the fish. Though several papers are published in this regard, the species- specific dose standardization and efficient mode of delivery are yet to be studied. There are a plenty of scope in this line as it is in infant stage and the control and regulatory measures has to be formulated for the adaptation and inclusion of various nutraceuticals in aquafeed similar to pharmaceutical products. The species-specific dose standardization, and synergistic effect of one or more compounds, nanodelivery systems of nutraceuticals and mechanism of action of some nutraceuticals have to be studied further to establish the inclusion of nutraceuticals in aquafeeds.

Conclusion

There are varieties of nutraceuticals that can be used in fisheries and aquaculture. Nutraceuticals such as antioxidants help to protect fish from the harmful effects of free

radicals, which can damage cells and tissues. They can also help to improve the immune system and prevent disease. Methyl donors are essential nutrients that help to support the production of DNA and RNA. They are also important for the metabolism of fats and amino acids. Immunostimulants help to boost the immune system, making fish more resistant to disease. They can also help to reduce the severity of infections. Probiotics are live microorganisms that are beneficial for the gut health of fish. They can help to improve digestion and absorption of nutrients, and they can also help to protect against disease. Herbal extracts contain a variety of compounds that can have beneficial effects on fish health. For example, some herbal extracts can help to reduce stress, improve growth, and improve the taste of fish. The use of nutraceuticals in aquaculture is still in its early stages, but there is growing evidence that they can be beneficial for fish health and production. More research is needed to determine the optimal doses and combinations of nutraceuticals for different species of fish.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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