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APPLICATION OF HERBAL DIETARY SUPPLEMENTS IN AQUACULTURE – A REVIEW

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Abstract

Aquaculture is a crucial food manufacturing sector in the world and it is also of economic importance in many countries. Disease outbreaks reduce aquatic production, prior chemotherapeutics and antibiotics treatments are supportive to manage the infections. In this method, residues cause side effects on humans and aquatic animals. Researchers find out pro- and pre-synbiotics methods used to enhance the feed quality and aquatic production. Herbal dietary feed supplementation development is eco-friendly, non-toxic, cost-effective, and easily handled for the preparation of feeds for aquatic animals in aquaculture. This review provides some information regarding herbal dietary feed supplements that help to improve aquatic animals' health and also the quality of aquatic feed in the aquatic sector. This review reports on the upcoming investigations and progress of novel applications in aquaculture.

Key words: medicinal plants, feed additives, immunostimulants, disease resistance, aquaculture

Aquaculture is an alternative significant food-producing sector in the world. China has shaped various types of aquatic products compared to other countries since 1991, and also China has well developed in the aquatic sector since 2000 (FAO, 2020). China is the largest fish-producing country in the world (FAO, 2020). China's aquaculture production targeted 62.2 million tonnes (14.6 million tonnes from capture fisheries and 47.6 million tonnes from aquaculture) in 2018 (FAO, 2020). China produced more aquatic products compared to other countries like India, Vietnam, Bangladesh, Indonesia, Norway, and Egypt, with an additional 60% of fish production being produced in China (Coates et al., 2023). The aquaculture sector is the main source of minerals, protein, and vitamins in different developing countries (Karim et al., 2022). The aquatic sector produced diverse types of aquatic products including aquatic plants, algae, fish, molluscs, crustaceans, and other aquatic fauna (Asche et al., 2022). Fish is the major and most inexpensive dietary protein source and half of the world's population turns to dietary protein sources in fish (Ghafoor et al., 2020).

Nutrition is the key to maintaining the growth and reproduction of fish, providing significance for fish production and nutrition, and functional foods are excellent feed for fish to support and enhance natural healthy fish production (Abdel-Tawwab et al., 2022). In addition, the fish products ratio is noticeably raising day by day driven by consumers' demands around the globe. Some new techniques are used to enhance the fish growth ratio and fish production in farms (Hu et al., 2022; Tibbetts et al., 2023). To prevent or protect the infection outbreaks, maintain fish growth activity, and improve feed intake, diverse types of antibiotics and chemicals are incorporated into the aquatic feed supplements to manage the diseases. This method causes various complexity, drug tolerance, and ecological contamination in aquaculture (Ye et al., 2020). Several studies described that antibiotics, disinfectants, and chemotherapeutics are used to manage fish infections (Lieke et al., 2020). Natural methods like immunostimulants, probiotics, prebiotics, synbiotics, and medicinal herbs are another approach to controlling antibiotic use in the aquatic sector (Ghafarifarsani et al., 2021 a, b, c; Rufchaei et al., 2021; Ajdari et al., 2022; Elabd et al., 2022; Ahmadifar et al., 2023; Ghafarifarsani et al., 2023; Malekpourzadeh et al., 2023; Nedaei et al., 2023). Medicinal plants are essential to dietary feed supplements and chemotherapeutics in aquaculture (Chavda et al., 2022). Feed supplement is the major significant diet, also evaluating the appropriate amount and standard is crucial. Accepted dietary feed supplement system is inexpensive and available for aquatic organisms, aquaculture expenses are about 40–50% of the overall production expenditure (Hussein et al., 2022).

Herbals are another essential dietary feed supplement in the aquaculture sector and they provide an affirmative reaction in fish like growth maintenance and health development effects. Herbal extracts of diverse plants like lamb's ears (*Stachys lavandulifolia*), lemon balm (*Melissa officinalis*), and small water pepper (*Polygonum minus*) provide better growth specification in different fish species like rainbow trout (*Oncorhynchus mykiss*) and pirarucu (*Arapaima gigas*) (Adel et al., 2020; Bilen et al., 2020; Dias et al., 2023). Herbals exhibit a potentially curative approach in fish, this approach is inexpensive and offers better accuracy without toxicity (Techaoei, 2022). In addition, medicinal herbs incorporated into the feed are a novel way to maintain growth and health development and protect or prevent diseases in aquatic organisms (He et al., 2022; Wangkahart et al., 2022). Herbal dietary feed additives are an optional way to the chemical treatment used to control diseases. The herbal dietary management progression has helpful possessions on functional feed factors in the aquatic sector (e.g. Gupta et al., 2021; Van Doan et al., 2021; Alemán-Ramirez et al., 2022; Vijayaram et al., 2024). Dietary management (oral or injection) of herbal complement is considerably better for growth response, immune system, and infection confrontation in opposition to bacterial, viral, and parasitic infections. An elevated quantity of herbal dietary feed supplements may provoke immunosuppression without negative impacts but assist to decrease the depletion effect of aquatic animal diseases (Sharma et al., 2021). Dissimilar plants and their by-products have different types of bioactive combinations like alkaloids, phenols, polyphenols, quinone, terpenoids, lectine, and polypeptides; these components are efficient alternatives for chemicals, vaccines, antibiotics, and other artificial combinations in the aquatic sector (Harikrishnan et al., 2020; Rufchaei et al., 2022). Herbs contain different kinds of successful dietary feed additives including alkaloids, flavonoids, tannins, organic acids, polysaccharides, volatile oils, and nutrients (vitamins, minerals, carbohydrates, and amino acids) (Zhu, 2020). A previous study pointed out that dietary supplementation of Chinese herbs significantly promotes growth, enhancing immunity, better meat condition and flavour of fish, and maintaining gut microflora formation in hybrid grouper (*Epinephelus lanceolatus*♂ × *Epinephelus fuscoguttatus*♀) (Sun et al., 2022).

Abarike et al. (2022) investigated that dietary inclusion of feed supplements in different herbs such as guava (*Psidium guajava*), bitter melon (*Momordica charantia*), and neem (*Azadirachta indica*) is supportive of improved growth and body formations (i.e., elevated crude protein, and lower moisture and crude lipids) in Nile tilapia (*Oreochromis niloticus*) differentiated to the test group. In the past two decades, medicinal herb dietary feed additives had considerably eradicated the use of chemicals, drugs, and antibiotics in aquaculture and they provide several biological mechanisms with various optimistic reactions (optimal level) such as modulating the immune system, attractive growth, antioxidant, appetite stimulation, digestive function, antidepressant and hepatoprotective response in aquaculture (Yilmaz, 2019; Araby and Abbass, 2022; Mahboub et al., 2022; Sönmez et al. 2022; Tadese et al., 2022; Wang et al., 2022; Yilmaz et al., 2022; Quintino-Rivera et al., 2023). Many types of medicinal herbs and dietary feed supplements are examined to provide some positive responses challenging a broad spectrum of pathogens' action and turn-on reactions on immunopoietic cells (Effendi et al., 2022). Different types of medicinal herb feed additives as dietary supplements showed antimicrobial activity, supported growth, and development of rohu (*Labeo rohita*) (Harikrishnan et al., 2020). As regards herbal dietary feed additives as possible immunostimulants in aquatic organisms, several studies investigated the response at the molecular mechanism level on Indian lotus (*Nelumbo nucifera*) and astragalus (*Astragalus membranaceus*) (An et al., 2022; Zhao et al., 2023). Medicinal herb feed additive used as a dietary supplement had considerably increased the function of bactericidal activities, natural killer cells, phagocytic cells, complement, lysozyme activity, and antibody reactions in walking catfish (*Clarias batrachus*) fry (Sharma et al., 2021). The small bowel plays a vital responsibility in nutrient absorption for fish growth (Dawood et al., 2020). Nutritional oregano essential oil used as a dietary administration process was shown to alter gut microbiota composition and to have negative effects on intestinal pro-inflammatory genes (TNF-a and TGF-b) in common carp (*Cyprinus carpio*) (Abdel-Latif et al., 2020). The role of immunostimulants is to trigger the immune system of the host against harmful microbes. This process is quite different depending upon the classification of immune reaction, quantity, and way of management, instance, and stage of exposure (Ang et al., 2020). This review provides some information on herbal dietary feed supplement types, dosages, and administration methods utilized to enhance aquatic animals' health and get better quality aquatic feed supplements in the aquaculture sector.

Applications of herbal dietary feed supplements in aquatic animals

Dietary additives of different medicinal plants such as turmeric (*C. longa*), lemongrass (*Cymbopogon citratus*), drumstick tree (*Moringa oleifera*), rosemary (*S. rosmarinus*), rucola (*Eruca sativa*), thyme (*Thymus vulgaris*) have numerous valuable properties like growth enrichment, immunostimulation, bactericidal activity, anti-stress and antioxidant in diverse fish species such as *C. carpio*, *O. mykiss*, and Caspian roach (*Rutilus caspicus*) fry (Abd El-Naby et al., 2020; Ghafarifarsani et al., 2022 a, b, c, d; Yousefi et al., 2022). Dietary inclusion of feed additive gokshur (*Tribulus terrestris*) extract at 400 mg/kg for 88 day trial periods in *O. niloticus* showed enhanced growth performance, nutrient utilization, and some immunological and biochemical traits (El-Kady et al., 2022). Dietary incorporation of feed supplements in *S. rosmarinus* leaf powder (RLP) (10 g/kg) for 60 day trial period showed growth development, improved feed utilization, antioxi-

dant, infection resistance, and immune system activity in *O. niloticus* (Naiel et al., 2020). Dietary incorporation of feed additives in *T. terrestris* extract (500–750 mg/kg) showed improved health condition, growth performance, testicular function, semen quality, and reproductive efficiency without adverse impacts on water quality in 45 day trial periods in male *O. niloticus* (Hassona et al., 2020). Dietary feed supplementation of coriander seed extract (*Coriandrum sativum*) 2% notably improved growth response, immune system activity, and infection confrontation challenge *Yersinia ruckeri* in *O. mykiss* for 8 week trial period (Farsani et al., 2019). In addition, dietary feed additives of *P. minus (Polygonaceae)* extract 15 mg/kg in *O. mykiss* showed significantly enhanced growth performance, immune system response, and infection tolerance against *Y. ruckeri* in 8 week trial period (Adel et al., 2020). Dietary feed supplementation of medicinal plant common mallow (*Malvae sylvestris*) flower extract 3% and 5% of *O. mykiss* diet resulted in notably better growth activity, immune system, and infection tolerance against *Y. ruckeri* for 8 week trial period (Rashidian et al., 2020). Dietary feed additive administration of medicinal plant oak acorn (*Quercus brantii*) extracts (OAE) (600 mg/kg) had significantly improved innate and mucosal immune system reaction and bactericidal activity of *Y. ruckeri* and *Streptococcus iniae* of *O. mykiss* fingerlings for 8 week trial period (Ghafarifarsani et al., 2021 b).

Dietary feed administration of twelve Chinese medicinal plants at 8–12 g/kg in European eel (*Anguilla anguilla*) in a 4-week feeding trial demonstrated better growth activity, immune response, and digestive enzymes in fish (Huang et al., 2020). Dietary inclusion of feed additive in Chinese medicinal herbs combination (CHMM; *Medicago falcata*, *Allium sativum* and asafoetida (*Ferula sinkiangensis*) aqueous extract 20 g/kg) notably improved growth activity, innate immunity, gut digestion of Japanese sea bass (*Lateolabrax japonicus*) for 28 day experiment (Xu et al., 2020). Dietary inclusion of feed additives in fermented Chinese medicinal herbs (FCMH) 1% had notably improved growth activity, immune system, liver antioxidant, and expression of the gut inflammatory gene in juvenile largemouth bass (*Micropterus salmoides*) for 8 week experimental period (Zhou et al., 2022). Dietary incorporation of feed supplement in fermented ginkgo (*Ginkgo biloba*) leaves (0.125%~0.25%) for *O. niloticus* for a 60 day trial period showed noticeably improved antioxidant activity, immune system response, lipid metabolism, and infection resistance against harmful microbes in fish (Abdel-Latif et al., 2021). Dietary inclusion of feed additive in lemon verbena (*Aloysia citrodora*) extracts 10–20 mg/kg showed significantly improved feed utilization, growth performance, and immune system defense challenge against *Aeromonas hydrophila* disease in Siberian sturgeon (*Acipenser baerii*) for 8 weeks of experimental analysis (Adel et al., 2021). Dietary feed supplement investigation of Chinese herbal medicine mixture (CHMM) at 9 g/kg showed enhanced growth activity, body protein components, enteric trypsin response, non-specific immune system activity, and antioxidant capability of *A. anguilla* for 42 day trial period (Huang et al., 2020). Dietary administration of feed additive in medicinal plants bhumi amla (*Phyllanthus amarus*) and *P. guajava* L (0.08% and 0.5%) for 6 week trial study showed improved growth performance, immune gene expression, and infection tolerance of striped catfish (*Plotosus lineatus*) (Nhu et al., 2020). Dietary feed supplementation of ashwagandha (*Withania somnifera*) root extract at 0.05% shows a noticeable improvement in growth percentage, feed intake, survival level, and digestive function of white leg shrimp (*Litopenaeus vannamei*) (Rao et al., 2020). Dietary feed incorporation of medicinal herbs chamber bitter (*Phyllanthus urinaria*) and Indian almond (*Terminalia catappa*) extract at 1% shows beneficial effects in *L. vannamei* like improving growth performance, immunity disease resistance against white spot syndrome virus (WSSV) for 4 week trial period respectively (Isnani et al., 2021). Dietary feed supplementation of combined allicin 0.5%, astragalus polysaccharides (APS) 0.1%, and chlorogenic acid (CGA) 0.1% showed enhanced immunity, antioxidant, and protection against *Vibrio harveyi* disease in *L. vannamei* without biomolecule damage in 21 day trial period (Pu and Wu, 2022).

Applications of herbal dietary feed supplements in the growth response of aquatic animals

Padala et al. (2021) pointed out that dietary inclusion of peppermint (*Mentha piperita*) at various concentrations (2 g/kg) significantly improved growth activity, feed consumption, survival, weight gain, leucocytes, erythrocytes, hematocrit, hemoglobin, lysozyme, respiratory burst, phagocytic activity, anti-protease and bactericidal activities and also a depletion in serum glucose, triglycerides, cholesterol, and lipids level in treated *L. rohita* for 4 weeks trial period respectively. Dietary feed supplementation of coneflowers (*Echinacea purpurea*) at 1000 mg/kg and garlic (*A. sativum*) at 1000 mg/kg showed significantly improved body weight gain, survival rate, cold stress resistance during the winter season, and protection against *Aeromonas hydrophila* disease in beluga sturgeon (*Huso huso*) for 2 month experimental period (Bazari Moghaddam et al., 2022). Dietary incorporation of sugar apple (*Annona squamosa*) at 20 g/kg diet in fish fed for 60 day period, revealed improved weight gain, survival rate, specific growth percentage, feed efficiency, proximate composition and hematological parameters of *O. niloticus* fingerlings (Almarri et al., 2023). Dietary feed additives of *Astragalus caudiculosus* at 2.5–5% for 90 day study report showed enhanced growth performance, antioxidant and survival in *O. mykiss* (Sönmez et al., 2022). Dietary feed supplementation of roselle (*Hibiscus sabdariffa*) at 0.5% for 60 day experimental analysis showed improved growth performance, survival, blood erythrocyte, catalase (CAT) hematocrit (Hct), hemoglobin (Hb), plasma and hepatic superoxide dismutase (SOD), and also lower plasma cortisol, glucose, hepatic malondialdehyde (MDA) content, and hemolysis rate for *O. mykiss* (Hoseini et al., 2021).

Table 1. Herbal feed supplements in aquatic animal health.

Herbals Local name	Herbals Scientific name	Aquatic animals Local name	Aquatic animals Scientific name	Administration/Dosages	Duration of treatment	Response	References
1	2	3	4	5	6	7	8
Turmeric and clove	*Curcuma longa* and *Syzygium aromaticum*	Nile tilapia	*Oreochromis niloticus*	Oral, 0, 2, 4, and 8 g/kg	Dietary turmeric, 8 weeks	NO, leukocytes, Ly, IL-4, lymphocyte proliferation index	Abdel Rahman et al. (2020)
Thyme	*Zataria multiflora*	Rainbow trout	*Oncorhynchus mykiss*	Oral, 0, 1, 2.5, and 5 g/kg of ginger extract	Ethanolic ginger, 45 days	WG, FCR, Ly, ALP, ACP	Mirghaed et al. (2020)
Pumpkin seed meal	*Cucurbita mixta*	Mozambique tilapia	*Oreochromis mossambicus*	Oral, 0, 2, 4 and 6 g/kg	*C. mixta* seed meal diet, 4 weeks	WG, FCR, SGR, Co, Ly, RBA, Pa	Musthafa et al. (2017)
Velvet bean	*Mucuna pruriens*	Mozambique tilapia	*O. mossambicus*	Oral, 0, 2, 4, and 6 g/kg	*M. pruriens* seed meal diet, 4 weeks	WG, SGR, FCR, Ly, RBA, Co, Pa	Saiyad Musthafa et al. (2018)
Ashwagandha	*Withania somnifera*	Nile tilapia	*O. niloticus*	Oral, 0, 2.5%, and 5%	Dietary *W. somnifera* root powder, 6 weeks	CAT, GST, GSH, SOD, TAC	Zahran et al. (2018)
Aloe vera	-	Pacu	*Piaractusmesopotamicus*	Oral, 0, 0.5%, 1%, and 2%	Dietary *Aloe vera* extract, 10 days	Ly, Co, RBA	Zanuzzo et al. (2017)
Lemon verbena	*Aloysia citrodora*	Siberian sturgeon	*Acipenser baerii*	Oral, 0, 300, 500, and 800 mg/kg	Leaf extract, 90 days	WBC, HCT, HIS, VSI	Adel et al. (2020)
Lemon peel	*Citrus limon*	Rainbow trout	*O. mykiss*	1.5%	Lemon peel powder, 45 days	Immunostimulant, cytotoxic, bactericidal and antioxidant	Chekani et al. (2021)
Spade flower	*Hybanthus enneaspermus*	Rohu	*Labeo rohita*	Oral, 0, 1, 2, 3, and 4 g/kg	Aqueous extract, 6 weeks	Ly, Pa, RBA, RBC, WBC, SOD, neutrophil, protein, ALP, amylase, lipase, protease	Giri et al. (2017)
Chaff flower	*Achyranthes aspera*	Rohu	*L. rohita*	Oral, control diet, 0.5% seeds (D1) and leaves (D2)	Dietary seeds and leaves, 80 days	Me, nitric oxide synthase, lysozyme C and G, TNF-A, IL-10 and IL-1b	Kumar et al. (2019)
Ginseng	*Araliaceae*	Nile tilapia	O. niloticus	200 mg/kg	17 weeks	Enhanced growth performance, diet utilization efficiency, and hematological indices	Mansour et al. (2022)
Wood betony	*Stachys lavandulifolia*	African cichlid	*Sciaenochromis fryeri*	8%	10 weeks	Improved liver function and response to acute stress	Mohammadi et al. (2019)
Garlic	*Allium sativum*	Nile tilapia	O. niloticus	0.5%	5 weeks	Improved growth performance	Mekawey (2019)
Garlic	*A. sativum*	Cat fish	*Heteroclarias*	2.5%	-	Improved growth performance	Ayanwale et al. (2021)
Black cumin oil	*Nigella sativa*	Rainbow trout	*O. mykiss*	1%	144 days	Growth performance, body composition and lipid profile	Öz et al. (2018)
Sabah snake grass	*Clinacanthus nutans*	Giant tiger prawn	*Penaeus monodon*	1 g/kg leaf extract	-	Prevented yellow head virus disease	Tan et al. (2020)
Gallnut (myrobalan)	*Terminalia chebula*	Common carp	*C. carpio*	0.5% and 1%	-	Prevention of *A. Hydrophila* infections	Zhu (2020)

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1	2	3	4	5	6	7	8
Elephant's foot	*Elephantopus scaber*	Nile tilapia	*O. niloticus*	5 g/kg	8 weeks	Disease resistance against *Streptococcus agalactiae* infections	Doan et al. (2019)
Sweet wormwood	*Artemisia annua*	Goldfish	*Carassius auratus*	20 g/kg	45 days	Prevention of *Ichthyophthirius multifiliis* and *A. hydrophila* infections	Wu et al. (2017)
Ginger	*Zingiber officinale*	Grass carp	*Ctenopharyngodon idella*	4 mg/L	–	Prevention of *Ichthyophthirius multifiliis*	Fu et al. (2019)
Coriander	*Coriandrum sativum*	Rainbow trout	*O. mykiss*	Seed extract 2%	8 weeks	Improved hematocrit value, hemoglobin content, white blood cells, red blood cells	Farsani et al. (2019)
Mistletoe	*Viscum album*	Rainbow trout	*O. mykiss*	1.78 to 1.94%	8 weeks	Growth performance, innate immune antioxidant systems, promoted bactericidal activity	Yousefi et al. (2021)
Common mallow	*Malva sylvestris*	Common carp	*C. carpio*	0.5 and 1 g/kg	45 days	Non specific immune response, growth promoter disease resistance against *A. hydrophila*	Bilen et al. (2020)
Coriander Common mallow Oak acorn	*C. sativum* *M. sylvestris* *Quercus brantii*	Common carp	*C. carpio*	3%	60 days	Growth immune system, antioxidant, and disease resistance	Raissy et al. (2022)
Tarragon	*Artemisia dracunculus*	Rainbow trout	*O. mykiss*	2%	8 weeks	Growth performance, haemato-immunological, biochemical parameters, and mucosal immunity	Gholamhosseini et al. (2021)
Garlic	*A. sativum*	Nile tilapia	*O. niloticus*	1.0 g	–	Upregulation of intestinal gene expression il-10 and IL×17F and prevention of *Streptococcus i*nfection	Foysal et al. (2019)
Pyrola Common verbena	*Pyrola calliantha* *Verbena officinalis*	Giant grouper	*Epinephelus fuscoguttatus* × *Epinephelus lanceolatu*	60 g/kg	60 days	Growth response and immune system	He et al. (2021)
Roth	*Ulva clathrata*	Nile tilapia	*O. niloticus*	0.1, 0.5, 1%/kg	60 days	No changes in weight gain, specific growth rate, weight gain and feed conversion ratio	Pratiwi and Pratiwy (2022)
Moshkoorak	*Oliveria decumbens*	Mozambique tilapia	*O. mossambicus*	0.01, 0.1 and 1%	90 days	Specific growth rate, weight gain and feed conversion ratio	Vazirzadeh et al. (2019)
Shallots	*Allium hirtifolium*	Common carp	*C. carpio*	1.5 %/kg	30 days	WBC, phagocytic action, globulin, phagocytic index	Mahboub et al. (2022)
A. vera	–	Golden mullet	*Liza aurata*	6%	91 days	Growth promoter	Quirós-Pozo et al. (2021)

ALP: alkaline phosphatase activity; An: antibody; AP: antiprotease; CAT: catalase; Co: complement; FCR: feed conversion ratio; GPx: glutathione peroxidase; GST: glutathione-S-transferase; Hb: hemoglobin; HCT: hematocrit; Ig: immunoglobulin; IL-10: interleukin 10; IL-1 b: interleukin 1 beta; Ly: lysozyme; Lyz c and g: lysozyme c and g gene; Me: myeloperoxidase; NBT: nitroblue tetrazolium; NO: nitric oxide; Pa: phagocytosis; PL: protein level; PO: phenoloxidase; RBA: respiratory burst activity; RBC: red blood cells; ROS: reactive oxygen species; RNS: reactive nitrogen species; SOD: superoxide dismutase; SGR: specific growth rate; TNF-a: tumor necrosis factor alpha; VSI: viscerosomatic index; WBC: white blood cells; WG: weight gain.

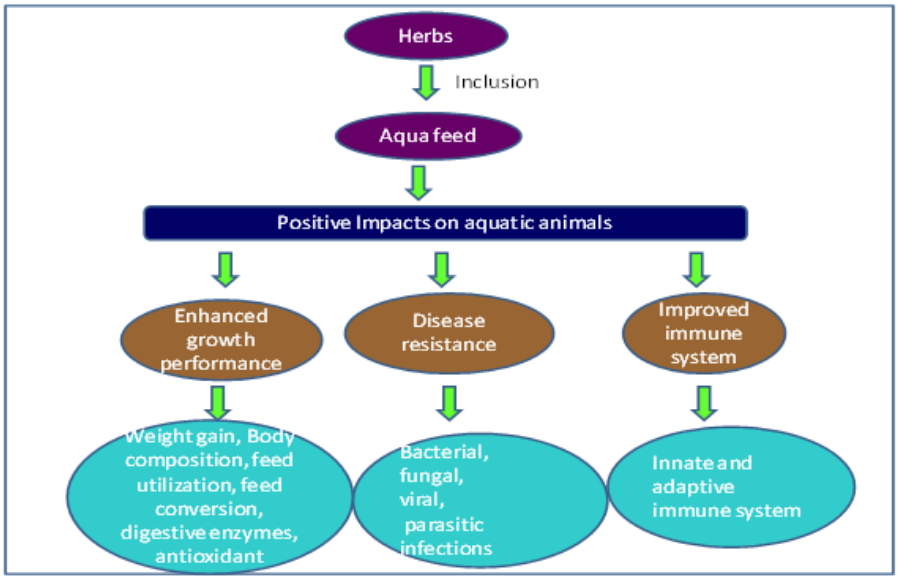


Figure 1. Applications of herbal supplements in aquaculture

Kate et al. (2023) reported that dietary inclusion of 1% katuk ethanolic extract (*Sauropus androgynous*) stimulated appetite, improved growth performance, and increased food utilization (inferior feed conversion percentage) in orange spotted grouper (*Ephinephelus coioides*) for 70 day experimental period, respectively. Sutthi et al. (2020) examined the dietary supplementation of *P. minus* leaf extract at 70 ml/kg for 60 days in fingerling climbing perch (*Anabas testudineus*) and the study results demonstrated that feed efficiency (FE), weight gain (WG), specific growth rate (SGR), average daily growth ratio (ADG), and protein efficiency ratio (PER) values, Hct, red blood cells (RBC) and total white blood cell count (WBC) concentrations were considerably higher and lowest feed conversion value differentiated to the test group. Dietary feed additives of herbal medicine mixture of 5–12.5 g/kg notably improved the growth activity of eels (*Anguilla japonica*) (Abarike et al., 2019; Shadrack et al., 2021).

Munglue et al. (2019) reported that dietary supplementation of rice paddy (*Limnophila aromatica*) extract (LAE) at 1% significantly improved growth activity, feed efficiency, and gut morphology of catfish (Siluriformes) for 8 week trial period. A dietary feed supplement combination of *Aloe vera* polysaccharides (0.66% and 0.8%) and *A. sativum* shows significantly improved growth activity, feed intake, survival, and hematological index of African catfish (*Clarias gariepinus*) juveniles (Gabriel et al., 2021). Dietary incorporation of *C. sativum* seed extract at 2% considerably enhanced immunological parameters, growth performance, and infection confrontation against *Y. ruckeri* disease of *O. mykiss* for 8 week trial period (Farsani et al., 2019). Dietary incorporation of clove (*Eugenia caryophyllata*), buds extract (ECBE) at 15 g ECBE/kg appreciably improved growth action, feed intake, intestinal villi/absorption, and disease confrontation in opposition to *A. hydrophila* of *C. gariepinus* for 12 week trial period (Dawood et al., 2020). Dietary incorporation of velvet bean (*Mucuna pruriens*) and pumpkin (*Cucurbita mixta*) extracts at 4 g/kg and 6 g/kg diet showed noticeable development in growth activity, survival percentage, feed conversion ratio (FCR), WG, PER, SGR, and FE, innate immunity, phagocytic activity, respiratory burst activity, complement activity, and lysozyme activity and also infection confrontation against *A. hydrophila* disease in tilapia (*Oreochromis mossambicus*) for 4 week experimental analysis (Abd El-Gawad et al., 2020; Kurian et al., 2020).

Dietary incorporation of oregano essential oil at 20 g/kg diet for 2 months shows significantly enhanced growth performance (feed intake, weight gain, weight gain percentage, specific growth rate, and final body weight,) and intestinal histomorphology (villus width, villus height, and crypt depth) with no inflammatory action, and with the possible hepato-protective consequence on *C. carpio* fingerlings (Abdel-Latif et al., 2020). Dietary incorporation of chestnut (*Castanea sativa*) and olive mill wastewater extracted polyphenol at 0.2% for 8 weeks shows significantly better growth activity, immune parameters, and antioxidant defence of *C. carpio* and diminished feed conversion ratio in fish (Jahazi et al., 2020). Dietary supplementation of almond oilcake (*T. catappa*) (FTC), water fern (*Salvania molesta*) (FSM), and duckweed (*Lemna minor*) (FLM) at 300 g/kg significantly improved final body weight, digestive enzyme action, specific growth rate, and decreased feed conversion ratio of rohu (*L. rohita*) (Goswami et al., 2020). Dietary incorporation of the chameleon plant (*Houttuynia cordata*) leaf extract at 10 g/kg for 60 day trial period showed better weight gain

%, specific growth rate, expression of higher insulin-like growth factor-I (IGF-I), muscle alanine aminotransferase and aspartate aminotransferase, protease activities, no changes in amylase and lipase activity and decreased feed conversion rate in *L. rohita* (Rosmin et al., 2023).

Dietary inclusion of medicinal plants and their by-products shows significantly enhanced growth and stimulated appetite, immunostimulation as well as antimicrobial and anti-parasitic (virus, monogeneans, and protozoans) effects in fish and shellfish aquaculture (Chang et al., 2023). Dietary inclusion of medicinal plant *P. urinaria* crude extract (10000 ppm) appreciably enhanced growth percentage and feed utilization with no improvement to increased survival ratio of *L. vannamei* boone (Charoendat and Koedprang, 2019). Dietary incorporation of bei chaihu (*Bupleurum chinense*) and *A. membranaceus* (0.25% and 0.5%) for an 8-week trial period had shown beneficial effects on growth improvement, feed conversion ratio, immune-associated enzymes including lysozyme in serum, alkaline phosphatase (AKP), superoxide dismutase (SOD), and hepatopancreas in *L. vannamei* (Angela et al., 2020). Dietary feed additives of green tea (*Camellia sinensis*) 0.5% for 12 week trial period shows improved growth response, feed utilization, survival, and infection tolerance against *A. hydrophila* infection in *O. niloticus* (Adeniyi et al., 2021). Dietary inclusion in feed supplements of blackberry syrup at 15 g/kg for 90 days improves fish growth performance, immune specification, antioxidant status, and increased survival ratio against *Plesimonas shigelloides* of *O. niloticus* diets (Yilmaz, 2019). Dietary incorporation of feed supplements in *A. vera* powder at various concentrations (0.5% 1%, 2%, and 4%/kg feed) for 8 weeks showed that 0.5%, 1%, and 2% *A. vera* incorporated diet considerably improved absolute growth rate, weight gain, and specific growth ratio. Feed utilization was notably improved in fish fed with an *A. vera* diet at 1% and 2%/kg feed. The feed competence percentage, feed conversion rate, and somatic indicator were considerably improved in 4% *A. vera*-supplemented fish over unsupplemented ones, and also infection tolerance against *S. iniae* disease in *O. niloticus* as well as improving antioxidant, hepatoprotective enzyme activities, plasma lipid formation level, reduced serum aspartate and alanine aminotransferase (AST and ALT) activities before and after the challenge (Kannan et al., 2022; Xu et al., 2022).

Dietary incorporation of milk thistle (*Silybum marianum*) seeds at 7.5 and 10 g/kg for 10 weeks shows improved growth response (specific growth rate (SGR), weight gain (WG), protein efficiency ratio (PER), and apparent protein utilization (APU)), increased immune system activity, antioxidant activity (SOD and CAT) and gene expression and also lowest level of aspartate and alanine aminotransferase in *O. niloticus* fingerlings (Hassaan et al., 2019). Dietary feed supplementation of caraway seed meal (*Carum carvi* L.; CSM) at 12.5 g/kg for 12 week study shows significantly improved growth action, feed consumption, and no changes in survival condition in *O. niloticus* (Hamed et al., 2022). Dietary feed additives of 1% cinnamon showed significantly improved feed conversion ratio (FCR), feed efficiency ratio (FER), protein efficiency ratio (PER), apparent protein utilization (APU), specific growth rate (SGR), and energy utilization (EU) and infection tolerance against *A. hydrophila* disease in *O. niloticus* (Abdulrahman and Sadeeq, 2023). Dietary feed incorporation of *A. citrodora* 2% shows significantly enhanced immune-associated genes (TNF- α IL-1β, and IL-8), improved quantity of skin mucus, lysozyme, and total immunoglobulin in serum, and also increased antioxidant enzymes level (GPx, GST, and SOD), but no effect on growth performance in *O. mykiss* (Hoseinifar et al., 2020).

Liu et al. (2022) reported that dietary feed inclusion of 1,8-cineole (cineole) (30 µg/L) and ginger extract (*Zingiber officinale* Rosc) (20 µg/L) considerably enhanced the survival ratio, growth activity, and increased serum CAT and SOD performance in *M. salmoides* L. Dietary feed inclusion of *H. sabdariffa* extract (100, 200, and 400 µg/mL) notably improved levels of glutamate oxalate transaminase (GOT), glutamate pyruvate transaminase (GPT), lactate dehydrogenase (LDH), and malondialdehyde (MDA) and also considerably decreased the levels of superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) of red tilapia (*Oreochromis* spp.) (Diab et al., 2023). Dietary feed incorporation of date palm fruit (*Phoenix dactylifera* L. Arecaceae) at 200 ml/kg DPE for 8 week study showed increased growth activity, antioxidant level, and immune system response in *C. carpio* fingerlings (Kari et al., 2022). Dietary feed additives of herbal supplements wormwood (*Artemisia annua*) leaf extract, common water hyacinth (*Eichhornia crassipes*) leaf extract, and flavonoids from *Allium mongolicum* in various concentrations in different periods improved CAT and SOD activities, as well as dormant oxidative stress in *O. niloticus*, *C. carpio*, *O. mykiss*, and snakehead (*Channa argus*) (Li et al., 2019; Mirghaed et al., 2020; Rufchaei et al., 2020; Ghafarifarsani et al., 2022 e). Dietary feed inclusion of milky mushroom (*Calocybe indica*) extracts at 6% for 90 days significantly improved spiral babylon (*Babylonia spirata*) growth (shell length and body weight and antioxidant levels (CAT and SOD)) and reduced mortality compared to the control group (Chelladuraia and Maran, 2019). Dietary inclusion of *A. vera* at 1.76 and 1.79%/kg diet resulted in notably enhanced growth specifications (i.e., specific growth ratio, absolute growth rate, final weight, and weight gain), protein efficiency, hemato-biochemical indices, and inferior feed conversion percentage of *C. gariepinus* fingerlings (Gabriel et al., 2019). Dietary incorporation of barberry root (*Berberis vulgaris*) extracts at 250 mg/kg significantly enhanced the growth activity, digestive enzymes, whole-body composition, and muscle fatty acids form of *O. mykiss* for 56 day trial period (Ramezanzadeh et al., 2020).

Applications of herbal dietary feed supplements in aquatic animal diseases

Dietary inclusion of feed supplement ashwagandha (*Withania somnifera*) root powder at 5% for 6 weeks of feeding showed notable improvement in the antioxidant and immune system activity against *A. hydrophila* infection in *O. niloticus* (Zahran et al., 2018). A dietary combination of feed supplements in spatholobus stem (*Spatholobus suberectus*), birthwort (*Aristolochia debilis*) and Asian ginseng (*Panax ginseng*) is helpful to improve infection confrontation against *Streptococcus agalactiae* infection in *O. niloticus* with good antibacterial effects in *in vitro* method (Guo et al., 2019). Dietary feed additives of *M. piperita* essential oil (0.25%) for 50 days of feeding showed improved survival and infection tolerance against *Streptococcus agalactiae* infection in *O. niloticus* (de Souza Silva et al., 2019). Dietary feed supplementation of *S. rosmarinus* at 16% notably reduced mortalities following infections of *S. agalactiae* and *S. iniae* bacterial disease in tilapia (*Oreochromis sp.*) (Van Doan et al., 2022). Dietary inclusion of 0.75% *Z. officinale* extract for 8-week feeding in juvenile black rockfish (*Sebastes schlegelii*) resulted in significantly higher survival in the *S. iniae* challenge test, finally, and *Z. officinale* extract improved the survival ratio in juvenile *S. schlegelii* (Oh et al., 2022).

Dietary incorporation of combined herbal supplements in arjun tree (*Terminalia arjuna*) at 12.3 g/kg for 90 days of feeding showed enhanced growth and disease confrontation against *A. hydrophila* disease in *L. rohita* (Meena et al., 2022). Dietary incorporation of cape jasmine (*Gardenia jasminoides*) extract showed improved survival and reduced mortalities against WSSV infection in crayfish (*Procambarus clarkii*) (Huang et al., 2019). Dietary incorporation of various plants' methanolic extract like Indian acalypha (*Acalypha indica*), bermuda grass (*Cynodon dactylon*), katuka (*Picrorrhiza kurrooa*), *W. somnifera,* and *Z. officinale* in diet fed to shrimp for 60 days, showed improved immune response against white spot syndrome virus (WSSV) disease in tiger shrimp (*Penaeus monodon*) (Ghosh et al., 2023). Dietary inclusion of polyvinylpyrrolidone from snake grass (*Clinacanthus*) beans showed significantly improved infection resistance against yellow head virus (YHV) infection in *P. monodon* (Effendi et al., 2022). Dietary inclusion of essential oil and organic acids combinations at 0.3 g/kg for 8 weeks of ruminating significantly improved immune activity, intestinal environment, and infection resistance against *Vibrio parahaemolyticus* in *L. vannamei* (Sivakumar et al., 2022; Vijayaram et al., 2022). Dietary feed additives of epigallocatechin-3-gallate (EGCG) at 1% had significantly improved the innate immune activity against *A. hydrophila* and cyprinid herpesvirus 2 disease in gibel carp (*Carassius auratus gibelio*) (Shen et al., 2022). Dietary inclusion of chaga mushroom (*Inonotus obliquus*) ethanolic extract at 1% and 2% significantly enhanced anti-protease, respiratory burst, and phagocytic activity, lysozyme activity and serum antibacterial activity reduced mortalities against *V. harveyi* disease in kelp grouper (*Epinephelus bruneus*) (Varalakshmi et al., 2022).

Applications of herbal dietary feed supplements in the immune system of aquatic animals

Dietary incorporation of various medicinal plants such as astragalus (*Radix astragalin*), astragalus (*Astragalus radix*), *A. membranaceus*, Baikal skullcap root (*Scutellaria radix*), common nettle (*Urtica dioica*), chaff-flower (*Achyranthes aspera*), duhuo (*Radix angelicae*), European mistletoe (*Viscum album*), false daisy (*Eclipta alba*), *Z. officinale*, ganoderma (*Ganoderma lucidum*), Indian rhubarb (*Rheum officinale*), and Japanese honeysuckle (*Lonicera japonica*) at 0.1% to 1% notably improved immune system and immune gene expression in diverse fish species (Zoral, 2022; Hu et al., 2022; Ren et al., 2022; Sattanathan et al., 2022; Kumar et al., 2023; Mohanasundari et al., 2022; Gabr et al., 2023; Ridwanudin et al., 2022). Dietary medicinal herb supplements play a main function in the fish immune system by way of phagocytosis, respiratory burst activity, complement, reactive nitrogen species, reactive oxygen species, total hemocytes, lysozyme, antiprotease, myeloperoxidase, nitric oxide, glutathione peroxidase, and phenoloxidase challenged with fungal, viral, and parasitic diseases in *C. batrachus* fry (Sharma et al., 2021). Phagocytic cells are the crucial cellular mechanism in the fish immune system; phagocytic action is the main protection mechanism and significant feature of the fish immune system, as well as phagocytes, fabricating toxic oxygen formation through the development of respiratory bursts (Das and Salinas, 2020). Dietary inclusion of *Origanum* essential oil (1 g/kg) for 15 day trial period demonstrated notably improved natural immune system activity and plasma bactericidal activity against *Vibrio anguillarum* infection in red belly tilapia (*Tilapia zillii*) (Mabrok and Wahdan, 2018). Dietary feed additives of 1% *P. guajava* leaf extract (PGE) for 84 days of experimental analysis demonstrated enhanced growth response, antioxidant, nutrient utilization, immune system reaction, and infection resistance against *A. hydrophila* infection in *O. niloticus* fingerlings (Omitoyin et al., 2019). Dietary feed supplementation of 2 g/kg *C. sinensis* extract for 8 weeks of feeding showed significantly enhanced humoral (phagocytosis, respiratory burst activities, alternative complement (ACH50), peroxidase, and serum lysozyme) and mucosal immunity (peroxidase activities and lysozyme), growth, infection resistance against *S. agalactiae* infection in *O. niloticus* (Van Doan et al., 2019). Dietary incorporation of 5 g/kg elephant foot (*Elephantopus scaber*) extract for 8 weeks of feeding showed improved humoral (phagocytosis (PI), respiratory burst (RB), alternative complement (ACH50), serum peroxidase (SP), and serum lysozyme (SL)) and mucosal immunity (skin peroxidase (SMPA) and mucus lysozyme (SMLA)), growth and infection tolerance against *S. agalactiae* infection in *O. niloticus* (Van Doan et al., 2019). Dietary additives of

herbs and spices at 15 g/kg for 60 days of feeding trial notably improved some immunological and serum biochemical status (albumin, globulin, and total protein) and plasma lysozyme action of *O. mossambicus* (Garnier and Shahidi, 2021).

Dietary incorporation of feed supplements in Thai ginseng (TG) (*Kaempferia parviflora*), Chinese ginger (*Boesenbergia rotunda*) powder at 10 g/kg for 8 weeks of feeding trial showed notably improved peroxidase and lysozyme activities in tilapia skin mucus, as well as phagocytosis index (PI), respiratory burst activities (RB) serum lysozyme (SL), alternative complement (ACH50), and serum peroxidase (SP), and disease resistance against *S. agalactiae* in *O. niloticus* (Van Doan et al., 2019). Dietary feed supplementation of wolfberry (*Lycium barbarum*) polysaccharides powder notably improved complement 3 (C3) action, stimulated interleukin IL-1β gene expression in spleen tissue, considering turning down apoptosis in spleen tissue, and no changes in malondialdehyde (MDA), serum alkaline phosphatase (AKP), and superoxide dismutase (SOD), apoptosis, blood constituents or gene expression of IL-1β in liver tissue in *O. niloticus* (Zhang et al., 2020). Dietary supplementation of 1.5% borage (*Borago officinalis*) powder for 2 weeks of feeding trial showed significantly improved white blood cells and no changes in hemoglobin, hematocrit, and red blood cells and also increased leucocyte count before and after *A. hydrophila* disease in *C. carpio* fingerlings (Cheraghi, et al., 2022). Dietary feed additives of 2 g/kg turmeric powder (TP) (*C. longa*) for 10 weeks of feeding period showed significantly improved fish performance, innate immunity, and challenge against *A. hydrophila* infection in grass carp (*Ctenopharyngodon idella*) (Ming et al., 2020). Dietary feed supplementation of 1% loquat (*Eriobotrya japonica*) leaf extract (LLE) for 7 week feeding period significantly improved immune-associated gene (TNF-alpha, IL1B, IL8, and LYZ) and downregulated gene (TGF-β) in the bowel and also improved innate immune activation in the early stage of *C. carpio* culture (Hoseinifar et al., 2018). Dietary incorporation of *Z. officinale* extract (6 or 10 g/kg) for 56 days of feeding trial showed a notable improvement in phagocytic activity, antibacterial, antioxidant enzymes activity, together with lysozyme activity, total serum protein, and total serum immunoglobulin and caused no changes in lactate dehydrogenase, alanine aminotransferase, and aspartate aminotransferase activities and infection resistance against *Y. ruckeri* disease in *O. mykiss* (Soltanian et al., 2019). Dietary feed supplementation of garlic peel (0.5%) for 20 day feeding trial showed significantly improved hematological parameters (white blood cells and red blood cells), biochemical parameters (albumin, globulin, and serum total protein), and more resistance against *A. hydrophila* disease in *C. gariepinus* fingerlings (Hamza et al., 2021).

Anene et al. (2021) reported that the dietary inclusion of turmeric powder at 4% notably improved glucose, serum glutamic pyruvic transaminase, serum glutamic oxaloacetic transaminase, and cholesterol levels without any adverse effect on physiological response in *C. gariepinus*. Singh et al. (2020) reported that 0.5% *A. aspera* feed additives showed notably increased nitric oxide synthase, myeloperoxidase, and serum lysozyme levels and also reduced carbonyl protein and malondialdehyde content as well as stimulation of IL-1b and TLR 4 in *L. rohita* challenged with *A. hydrophila*. Jomeh et al. (2021) demonstrated that 1% *H. sabdariffa* extract (RE) supplemented for 8 weeks of feeding trial resulted in notably improved RBC, WBC hemoglobin, hematocrit, complement, lysozyme, and up-regulated hepatic tumor necrosis factor-alpha gene expression, as well as 1.5% RE down-regulated interleukin-10 gene expression in *O. mykiss*. Dietary additives of five herbal extracts at 0.2% and 1.0%, or shame plant (*Mimosa pudica*) at 2.0% for 8 week feeding period showed notable improvement of the immune system and infection resistance against *Edwardsiella ictaluri* challenge in *C. gariepinus* (Nhu et al., 2019). Dietary inclusion of 5% *C. dactylon* for 60 days of feeding period showed improved biochemical and hematological criteria including red blood cell counts, white blood cell counts, hemoglobin substance, protein, albumin, globulin, albumin/globulin ratio, serum glucose and cholesterol against *A. hydrophila* disease in giant water prawn (*Macrobrachium rosenbergii*) (Banerjee et al., 2023).

Herbal dietary chasteberry (*Vitex agnus-castus*) additives of 15 g/kg for 8 week trial showed notably better hematological parameters (phagocytic activity, respiratory burst and lysozyme) and triggered the natural immune system of goldfish (*C. auratus*) against *A. hydrophila* (Rashmeei et al., 2020). Herbal dietary supplement of 1% *Z. officinale* fed for 12 weeks showed enhancement in white blood cell (WBC), red blood cell (RBC) values, hematocrit (Htc), lysozyme activity, and respiratory burst activity in *C. carpio* (Arshad et al., 2023). Dietary inclusion of feed supplements in fermented Chinese herbal medicines (1%) for 8 weeks of feeding time showed improved respiratory burst activity, superoxide dismutase (SOD) activity, white blood cell count (WBC), myeloperoxidase (MPO) activity, and tumor necrosis factor-α (TNF-α) activity, plasma aspartate aminotransferase (AST) and alanine aminotransferase (ALT) activity in juvenile *M. salmoides*; finally, the study concluded that fermented Chinese herbal medicines supplement is a potential immunostimulant in aquaculture (Zhou et al., 2022). Dietary inclusion of herbal feed supplement aloe-emodin (5 mg/kg) for 3 weeks feeding time significantly increased WBC, biochemical parameters, lysozyme activity, phagocytic action, respiratory burst activity, complement activity, and myeloperoxidase activity and infection resistance against *Aphanomyces invadans* in *L. rohita* (Devi et al., 2019).

Chekani et al. (2021) demonstrated that dietary herbal supplement of dehydrated lemon peel (*Citrus limon*) powder (DLPP) at 1.5 for 45 day feeding trial resulted in notable improvement of cellular immunity,

humoral immunity, and expression of immune-associated genes including interleukin 1B (IL1B), immunoglobulin T heavy chain (IgTH), natural killer enhancing factor A (NKEF-A) and colony-stimulating factor receptor 1 (CSF-AR) and also no elevation of antioxidant enzyme, antioxidant genes, antistress genes activity and expressions after 45 day feeding in *O. mykiss*. Dietary incorporation of herbal *A. membranaceus* and *N. nucifera* leaf powder combinations (1.5%) showed significantly enhanced immune system function of aquatic animals (Hu et al., 2019). Dietary supplementation of herbal butterfly needles (*Bidens alba*) extract (BAE) and Mexican mint (*Plectranthus amboinicus*) extract (PAE) combinations (20 g/kg) for 28 days of feeding trial notably increased natural immune responses, increased total hemocyte count, O^{2-} production ratio, phagocytic activity, PO activity, lysozyme, survival and growth response of *L. vannamei* in aquaculture (Huang et al., 2022).

Applications of herbal dietary feed supplements in the digestive physiology and metabolism of aquatic animals

Dietary feed additives of oregano essential oil caused remarkable changes in colon morphometry (villus width, villus height, and crypt depth) of *C. carpio* fingerlings (Abdel-Latif et al., 2020). Dietary feed additive of thymol significantly increased the height of the villus intestine in *O. niloticus* (Abd El-Naby et al., 2020). Microbial population communities transformed during the earlier development of the fish immune system (Stosik et al., 2023). Microbial populations and their by-products contain numerous favorable impacts on host health through immunomodulatory functions (Salinas et al., 2022). Nutritional feed additives of oregano essential oil showed that it modified the intestinal microbial communities of *Propionibacterium*, *Corynebacterium*, and *Brevinema* in *C. carpio* (Zhang et al., 2020). Dietary feed supplementation of oregano essential oil (50 and 400 mg/kg) showed considerably increased surface area of intestinal villi length and pepsin enzyme level in the intestinal region of Black Sea salmon (*Salmo labrax*) (Özel et al., 2022). Dietary inclusion of oregano essential oil 4500 mg/kg showed significantly improved digestive enzyme activity, antioxidant, immunomodulatory, and alteration of the gut microbial community in koi carp (*C. carpio*) (Zhang et al., 2020). Dietary incorporation of 1% thyme (*T. vulgaris*) essential oil did not alter *Bacillus* sp. in the intestinal region and stimulated the cellular and innate immune system response of *O. niloticus* (Valladão et al., 2019). Dietary inclusion of sweet orange (*Citrus sinensis*) at 2–6 g/kg for 45 days of feeding trial showed considerably enhanced survival rate, growth activity, digestive enzyme activity, muscle biochemical components, and amino acids. Dietary incorporation of 2–6 g kg^{-1} methanolic extract of *C. sinensis* fruit peel caused insignificant alteration in metabolic enzyme activity in catla (*Catla catla*) (Shabana et al., 2019).

Significance of herbal feed supplements in aquaculture

Different types of environmental factors (water quality, salinity, temperature, feed quality, and dissolved oxygen content of water) are mainly involved in improved meat conditions and aquaculture production. Environmental impact threatens to decrease aquatic products like rain, floods, landslides, entry of predatory fish in the culture ponds or reservoirs, excessive temperature, algal bloom, etc. The above factors are mainly caused by anxiety and below consumption of normal feed; disease outbreaks are the main problem to affect health and decrease aquatic production. Chemotherapeutics and antibiotics are applied to manage the infections but these methods affect the organs of aquatic animals and also affect humans; different types of natural methods, probiotics, prebiotics, and synbiotics are applied to improve healthy aquatic productions. The herbal dietary feed supplement method is the best traditional method and is also low-cost, nontoxic, and environmentally friendly. The herbal dietary feed supplement is an alternative way to enhance healthy aquatic production in aquaculture.

Conclusion

Herbals are the most vital traditional medicines for humans and aquatic animals and also the most important nutrient supplements for food and feed. Herbal dietary feed additives appreciably enhance healthy life for humans and aquatic animals. Herbal dietary feed additives are used to develop different types of products like medicines, cosmetics, foods, and feeds. Herbal products are eco-friendly, nontoxic, inexpensive, and easily handled; these products are more effective compared to other biological methods. Herbal dietary feed supplements are more effective and efficient additives in aquaculture as well as these natural feed additives are helpful to improve the aquatic feed quality and reduce toxins levels. This review aimed to provide some information regarding herbal dietary feed supplements. Herbals used as a dietary feed supplement for aquatic animals provide some positive effects like enhanced growth activity, disease resistance against aquatic animal diseases, and stimulating the immune system. This review analyzed how to improve research based on herbal dietary applications in aquaculture. In the future, it is necessary to identify and use novel herbal medicines and their by-products to improve aquatic dietary feed quality and healthy aquatic production to fulfill human protein needs and improve healthy human life.

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Conflict of interest

The authors declare no conflict of interest.

Compliance with ethical standards

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Data availability statements

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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