ANNALS OF ANIMAL SCIENCE
ISSN: 2300-8733, https://sciendo.com/journal/AOAS

## ACCEPTED AUTHOR VERSION OF THE MANUSCRIPT:

# Biogenic dietary promoters in aquaculture: nature-based solutions for enhancing growth, health, and sustainability

DOI: 10.2478/aoas-2024-0115

Srirengaraj Vijayaram[1♦], Karthikeyan Mahendran[2], Einar Ringø[3], Hary Razafindralambo[4,5], Suruli Kannan[6] , Yun Zhang Sun[1♦]

[1]Xiamen Key Laboratory for Feed Quality Testing and Safety Evaluation, Fisheries College, Jimei University, Xiamen361021, China
[2]Department of Microbiology, PSG College of Arts and Science, Coimbatore, Tamil Nadu, India
[3]Norwegian College of Fishery Science, Faculty of Bioscience, Fisheries, and Economics, UiT the Arctic University of Norway, Tromsø, 9037, Norway
[4]ProBioLab, Campus Universitaire de la Faculté de Gembloux Agro-Bio Tech/Université de Liège, B-5030 Gembloux, Belgium
[5]BioEcoAgro Joint Research Unit, TERRA Teaching and Research Centre, Microbial Processes and Interactions, Gembloux Agro-Bio Tech/Université de Liège, B-5030 Gembloux, Belgium
[6]Department of Environmental Studies, School of Energy Environment and Natural Resources, Madurai Kamaraj University, Madurai, India

♦Corresponding author: vijayarambiotech@gmail.com; jmusunyunzhang@163.com

Received date: 23 July 2024
Accepted date: 21 October 2024

**To cite this article**: (2024). Vijayaram S., Mahendran K., Ringø E., Razafindralambo H., Kannan S., Sun Y.Z. (2024). Biogenic dietary promoters in aquaculture: nature-based solutions for enhancing growth, health, and sustainability, Annals of Animal Science, DOI: 10.2478/aoas-2024-0115

**Biogenic dietary promoters in aquaculture: nature-based solutions for enhancing growth, health, and sustainability**

Srirengaraj Vijayaram[1♦], Karthikeyan Mahendran[2], Einar Ringø[3], Hary Razafindralambo[4,5], Suruli Kannan[6], Yun Zhang Sun[1♦]

[1]Xiamen Key Laboratory for Feed Quality Testing and Safety Evaluation, Fisheries College, Jimei University, Xiamen361021, China

[2]Department of Microbiology, PSG College of Arts and Science, Coimbatore, Tamil Nadu, India

[3]Norwegian College of Fishery Science, Faculty of Bioscience, Fisheries, and Economics, UiT the Arctic University of Norway, Tromsø, 9037, Norway

[4]ProBioLab, Campus Universitaire de la Faculté de Gembloux Agro-Bio Tech/Université de Liège, B-5030 Gembloux, Belgium

[5]BioEcoAgro Joint Research Unit, TERRA Teaching and Research Centre, Microbial Processes and Interactions, Gembloux Agro-Bio Tech/Université de Liège, B-5030 Gembloux, Belgium

[6]Department of Environmental Studies, School of Energy Environment and Natural Resources, Madurai Kamaraj University, Madurai, India

♦**Corresponding author:** vijayarambiotech@gmail.com; jmusunyunzhang@163.com

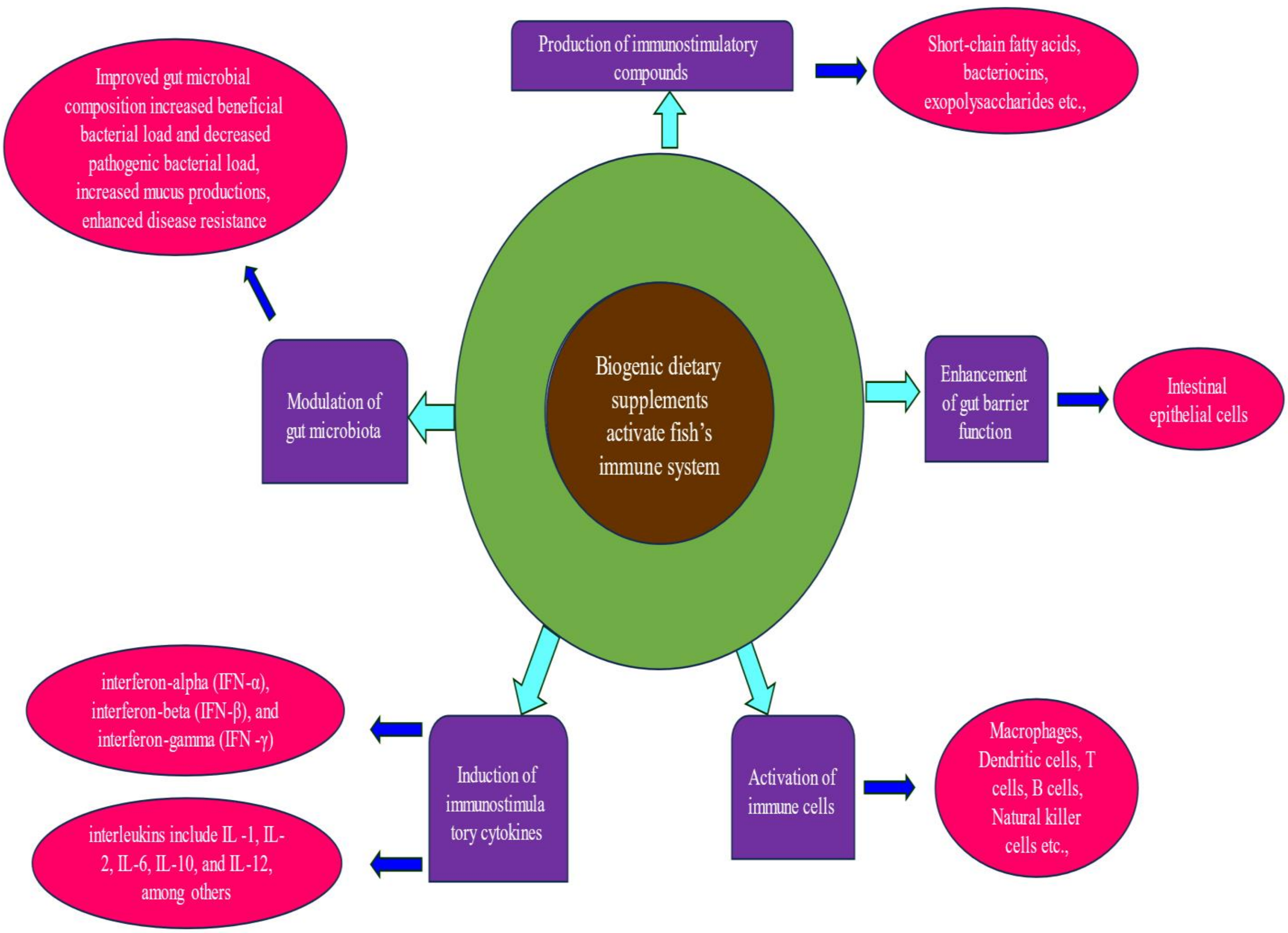
**DOI: 10.2478/aoas-2024-0115**

## Abstract

Aquaculture, as a rapidly expanding global industry, is increasingly challenged by both infectious and non-infectious diseases, posing significant threats to fish health and production. Traditional interventions, such as antibiotics and vaccines, though effective, raise concerns regarding environmental impact and the potential for resistance development. This review explores the promising role of dietary biogenic promoter supplements as an innovative, sustainable alternative for aquaculture. By analysing emerging literature, we highlight the significance of these nature-based solutions, which offer cost-effective, non-toxic, and eco-friendly options to enhance aquaculture productivity. Biogenic supplements, derived from herbs, beneficial microbes, insects, nutrients, bioactive molecules, and nanoparticles, have shown potential in improving feed quality, promoting growth, boosting disease resistance, enhancing immune system function, and supporting overall health in aquatic species. This comprehensive review demonstrates the efficacy of biogenic-mediated supplements in fostering aquaculture sustainability by minimizing the need for traditional chemical interventions. Furthermore, the analysis identifies critical research gaps, particularly in determining optimal supplement concentrations and their species-specific effects. Additionally, large-scale field trials are recommended to validate laboratory findings and assess their practical applications in real-world settings. By synthesizing current research, this review

provides valuable insights into the future trajectory of aquaculture practices, positioning biogenic dietary supplements as key contributors to sustainable and efficient aquaculture development.

**Key words:** aquaculture, algae, bioactive molecules, herbs, probiotics, nutrients, nanoparticles




The projected increase in the global population to 9.7 billion by 2050, coupled with a corresponding rise in food demand by 60-100%, presents substantial challenges for food production, agriculture, and environmental sustainability (Yarnold et al., 2019). As population growth accelerates, the need for nutrient-rich protein sources becomes increasingly urgent, with aquaculture emerging as a critical sector to address this demand (Sattanathan et al., 2020a, b). Aquaculture, or aquafarming, plays a pivotal role in global food production, contributing significantly to human nutrition by providing a steady supply of fish and other aquatic products (Prem & Tewari, 2020). The anticipated expansion of the global animal feed market, projected to reach around 110.29 billion USD by 2025 at a 4% annual growth rate, reflects the growing demand for protein-rich meat and animal-derived products (Technavio, 2021). This market growth is driven by the increasing needs of both livestock and aquaculture industries, which are key players in addressing the protein requirements of a burgeoning global population. Moreover, advancements in animal nutrition and feed technology are enhancing feed production efficiency, further supporting the growth of these sectors. Dietary supplementation is widely adopted in aquaculture to enhance various aspects of fish farming, including improving feed efficiency, promoting growth, and bolstering non-specific immune system responses. A range of supplements, including vitamins, minerals, amino acids, probiotics, prebiotics, and enzymes, are incorporated into fish diets to ensure nutritional balance and optimize health outcomes (Abdel-Tawwab, 2016; Hoseini et al., 2017, 2018). Sustainable practices in agriculture and aquaculture are essential for overcoming challenges posed by emerging diseases, climate change, and socio-economic pressures while maintaining food security (Calicioglu et al., 2019). Disease outbreaks represent a major concern in aquaculture, as they can lead to significant economic losses and threaten the sector's sustainability. Diseases in aquaculture can be categorized into communicable and non-communicable types. Communicable diseases, caused by pathogens such as bacteria (e.g., *Aeromonas hydrophila*, *Pseudomonas* spp., *Streptococcus* spp., and *Vibrio* spp.), fungi, viruses, parasites, and protozoa, pose a direct threat to fish health. Non-communicable diseases, on the other hand, often result from factors like poor water quality, pollution, and malnutrition (El-Sayed Ali et al., 2014a, b; El-Sayed Ali et al., 2018; Idowu et al., 2017). Biogenic nutritional supplements offer a promising solution to these challenges, playing a crucial role in enhancing growth, improving disease resistance, strengthening immune function, and promoting the overall well-being of aquatic species (Vijayaram et al., 2024; Vijayaram et al., 2023; Vijayaram et al., 2022). These supplements, classified by their origin—whether animal-derived, plant-derived, or microbial-derived—or by their function as vitamins, minerals, enzymes, antioxidants, and others, are gaining attention as natural alternatives to synthetic feed additives. Biogenic supplements not only support the growth and productivity of aquaculture species but also contribute to the sustainability of the aquatic ecosystem. They do so by optimizing nutrient recycling, minimizing waste, and promoting efficient use of resources during feed consumption and reproduction (Dawson et al., 2018). In intensive aquaculture, approximately 16% of wild-caught fish species are used as feed, which raises concerns about overfishing and its effects on marine ecosystems (Dineshbabu et al., 2019). Feed conversion ratios further underscore the resource efficiency of aquaculture compared to other livestock systems. For example, producing 1 kg of edible meat requires approximately 1.4–1.8 kg of feed for poultry, 2.6–4.4 kg for pork, 3.5–9 kg for beef, and only 1.1–1.6 kg for seafood, making aquaculture one of the most efficient methods of protein production (Jones et al., 2020). Thus, biogenic dietary supplements not only address the nutritional needs of aquaculture species but also offer a sustainable path forward for meeting global protein demands while minimizing environmental impact.

**Biogenic products and medicinal herbs in aquaculture**

Biogenic products such as probiotics, antimicrobial peptides, prebiotics, Chinese herbs, and medical nutritional factors are increasingly utilized in aquaculture to bolster the immune systems of aquatic animals and combat diseases (Mohan et al., 2019). These products play a crucial role in enhancing the overall health and disease resistance of fish and other aquatic organisms.

*Biogenic Immunostimulators*

Various biogenic immunostimulators, including seaweed, probiotics, and beneficial fungi, have gained recognition for their antimicrobial properties and their capacity to enhance the immune system and feed quality in aquaculture (Efianda et al., 2018; Ramadhani et al., 2019; Rudi et al., 2019).

*Medicinal Herbs*

The utilization of medicinal herbs and traditional remedies in animal husbandry dates back to ancient times, serving to promote animal health, treat diseases, and enhance overall well-being. In recent decades, there has been a resurgence of interest in employing medicinal herbs and traditional remedies within the aquatic division, particularly in aquaculture (Das et al., 2018; Vijayaram et al., 2023). Different kinds of herbal dietary supplements have shown significant efficacy in improving immune system activity across diverse fish species. Rosemary (*Rosmarinus officinalis*) leaf and ginger (*Zingiber officinale*) for common carp (*Cyprinus carpio*) (Yousefi et al., 2019; Mohammadi et al., 2020). Garlic (*Allium sativum*), wood betony (*Stachys lavandulifolia*), and kesum (*Polygonum minus*) leaf for rainbow trout (*Oncorhynchus mykiss*) (Esmaeili et al., 2017; Moghanlou et al., 2018; Adel et al., 2020; Ghafarifarsani et al.2022). Purple coneflower (*Echinacea purpurea*), thyme (*Thymus vulgaris*) essential oil, and Mexican daisy (*Tridax procumbens*) for Nile tilapia (*Oreochromis niloticus*) (Abdel Rahman et al., 2018; Valladão et al., 2019; Adeshina et al., 2021). Common mallow (*Malvae sylvestris*) for rainbow trout (*Oncorhynchus mykiss*) fingerlings and mentha piperita for Siberian sturgeon (*Acipenser baerii*) (Rashidian et al., 2019; Adel et al., 2024; Ghafarifarsani et al.2021). Lavender (*Lavandula angustifolia*) for goldfish (*Carassius auratus*) (Pastaki et al., 2023). (Table 1 provides a summary of these medicinal herbs and their effects.)

Table 1. Herbals used as a supplement for aquatic animals

| Herbals local name and scientific name | Aquatic animals local name and | Administration/ dosages | Response | Duration of treatment | References |
|---|---|---|---|---|---|

| | scientific name | | | | |
|---|---|---|---|---|---|
| Ginger (*zingiber officinale*) | Grass carp (*ctenopharyngodon idella*) | 4 mg/l | Preventing *ichthyophthirius multifiliis* infections | - | Fu et al. (2019) |
| Wood betony (*stachys lavandulifolia*) | African cichlid (*sciaenochromis fryeri*) | 8% | Enhancing liver function and resilience to acute stress | 10 weeks | Mohammadi et al. (2019) |
| Thyme (*zataria multiflora*) | Rainbow trout (*oncorhynchus mykiss*) | Oral, 0, 1, 2.5, and 5 g/kg of ginger extract | Increased weight gain (wg), feed conversion ratio (FCR), lymphocytes (Ly), alkaline phosphatase (Alp), and acid phosphatase (ACP) | Ethanolic ginger, 45 days | Mirghaed et al. (2020) |
| Garlic (*a. Sativum*) | Catfish (*heteroclitas*) | 2.5% | Enhanced growth performance | - | Ayanwale et al. (2021) |
| Coriander (*Coriandrum sativum*) | Rainbow trout (*o. Mykiss*) | Seed extract 2% | Enhanced hematocrit value, white blood cell count, hemoglobin content, and red blood cell count | 8 weeks | Farsani et al. (2019) |
| Black cumin oil (*nigella sativa*) | Rainbow trout (*o. Mykiss*) | 1% | Enhanced growth performance, body composition, and lipid profile | 144 days | Öz et al. (2018) |
| Elephant's foot (*elephantus scaber*) | Nile tilapia (*o. Niloticus*) | 5 g/kg | Enhanced disease resistance | 8 weeks | Doan et al. (2019) |

against
*streptococcus agalactiae*
infections

---

## 2.1 **Microalgae in Aquaculture**

Microalgae represent a promising and sustainable feed ingredient for aquaculture, offering various benefits such as improved feed intake, growth performance, and overall health. As the aquaculture sector continues to expand and address sustainability challenges, microalgae-based feeds are positioned to play a significant role in its future development (Kupchinsky et al., 2015).

### 2.1.1 Nutritional Value and Safety

Numerous microalgae species, including *Arthrospira, Chlorella, Chaetoceros, Haematococcus Isochrysis, , Nannochloropsis,Pavlova , Phaeodactylum Skeletonema, Tetraselmis, Thalassiosira, and*, are Generally Recognized as Safe (GRAS) and widely used in aquaculture due to their safety for both human and animal consumption. These microalgae species have a long history of safe use and are renowned for their nutritional value and potential health benefits (Madeira et al., 2017).

### 2.1.2 Importance as Nutrient Sources

Microalgae and their by-products serve as valuable nutrient sources in aquaculture, particularly for zooplankton. As primary producers in aquatic ecosystems, microalgae provide essential nutrients and energy at the base of the food chain. Zooplankton, including various copepods, rotifers, and other small organisms, rely on microalgae as a primary food source (Tibaldi et al., 2015).

### 2.1.3 Protein and Amino Acid Profiles

Microalgal biomass is recognized for its rich protein and amino acid profiles, making it an excellent source of high-quality protein for aquaculture and animal feed production. The protein content of microalgae differs depending on the species and cultivation conditions, but many microalgae species offer highly nutritious protein sources (Becker, 2007; Sarker et al., 2018; Carneiro et al., 2020).

### 2.1.4 Bioactive molecules

Microalgae contain various bioactive molecules such as proteins, lipids, carbohydrates, and pigments, which can have specific health and growth-promoting effects in aquaculture species. These components make microalgae valuable for formulating nutritious and health-promoting feeds for various aquatic animals (Apandi et al., 2018).

### 2.1.5 Carotenoids and Astaxanthin

Microalgae produce diverse carotenoids, including α-carotene, β-carotene, astaxanthin, lutein, and zeaxanthin, which are important antioxidants and pigments. Astaxanthin, in particular, is a valuable nutrient with numerous benefits for various aquatic animals, enhancing pigmentation, acting as an antioxidant, promoting growth, and improving immune and inflammatory responses (Lu et al., 2021).

### 2.1.6 Lipid Content and Functional Properties

Microalgae, such as *Chlorella vulgaris* and *Bortryococcus braunii*, exhibit varying lipid yields, with implications for their functional properties. Additionally, microalgae pigments possess important biological functions such as antioxidants, anti-obesity agents, anti-inflammatory agents, and neuroprotective properties (D'Alessandro and Filho, 2016).

### 2.1.7 *Spirulina* and *Dunaliella*

Certain microalgae strains, like *Spirulina* and *Dunaliella*, are particularly notable for their high protein content. Spirulina, for instance, contains 50–70% proteins, making it valuable for both human and animal nutrition. It is widely used in aquaculture to provide essential protein and nutrients to farmed fish and other aquatic species (Ejike et al., 2017).

Table 2. The use of algae as a dietary feed supplement in aquaculture and their impact on aquatic animals

| Algae | Algae (Family) | Aquatic Organisms | Replaced Ingredients | DietaryInclusion Level(g/kgor%) | BeneficialEffects | References |
|---|---|---|---|---|---|---|
| *Arthrospira platensis* | *Micrococleaceae* | Giantriverprawn (*Macrobrachium*) | FM | 50% | Improved Growth Performance and Feed Conversion Efficiency | Radhakrishnan et al. (2016) |
| *Chlorella vulgaris* | *Chlorellaceae* | Carp (*Carassius auratus gibelio*) | FM | 0.4–2.0% | Augmented Immunoglobulin (Ig)M and igd Levels, Interleukin-22 (IL-22) Expression, and Chemokine (C-C motif) Ligand 5 (CCL-5) Production | Khani et al. (2017) |
| *Gracilariafisheri* | *Gracilariaceae* | Gianttigerprawn(*P.monodon*) | FM | 100–200µg/ml | Improved immune system function and Enhanced Resistance Against White Spot Syndrome Virus | Wongprasert et al. (2014) |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Spirulina sp.* | *Spirulinaceae* | Common carp (*Cyprinus carpio*) | FM | 5g/kg | Increased Growth Rate and Improved Feed Conversion Ratio | Nandeesha et al. (1998) |
| *S.platensis* | *Micrococcaceae* | Silverfish (*Trachinotus ovatus*) | FM | 5% | Enhanced Composition and Feed Utilization | Lin et al. (2016) |

### 2.2 Probiotics in Aquaculture

Probiotics offer numerous benefits in aquaculture, spanning enhanced water quality, disease resistance, growth rate, feed conversion ratio, and regulation of the immune system. They also positively impact the host, reducing reliance on broad-spectrum antibiotics (Lin et al., 2017; Vijayaram & Kannan, 2018; Mirbakhsh et al., 2023; Morshedi et al., 2021; Van Doan et al., 2020; Guardiola et al., 2016). Probiotic feed supplements have been shown to improve fish feed conversion, and growth, reduce mortality, and boost immune system responses, making them ideal for fish feeding (Kumar et al., 2016).

Table 3. Commonly applied probiotic supplements used as feed additives for fish

(Vijayaram et al., 2023, Biology)

| Genus | Probiotics | Example of target fish species |
|---|---|---|
| *Bacillus* | *Bacillus coagulans* | *Cyprinus carpio* (Common carp), *Scophthalmus Maximus* (turbot) |
| | *Bacillus subtilis* | *O. niloticus* (Nile tilapia) |
| | *Bacillus licheniformis* | *Ctenopharyngodon idella* (Grass carp) |
| | *Bacillus cereus* | *Heteropneustes fossilis* (Catfish) |
| *Bifidobacterium* | *Bifidobacterium bifidus* | *Cyprinus rubrofuscus* (Koi fish) |
| *Carnobacterium* | *Carnobacterium divergens* | Gadus morhua (Atlantic cod) |
| *Enterococcus* | *Enterococcus faecium* | *O. niloticus* (Nile tilapia) |
| *Lactobacillus* | *Lactobacillus casei* | *Cyprinus carpio* (Common carp) |
| | *L. plantarum* | *Acanthopagrus schlegelii* Black sea bream () |
| | *L. rhamnosus* | *O. niloticus* (Nile tilapia ) |
| *Lactococcus* | *L. lactis* | *Siniperca chuatsi* (Mandarin fish) |
| *Pediococcus* | *Pediococcus acidilactici* | *Oncorhynchus mykiss* (Rainbow trout) |

| | | |
|---|---|---|
| *Streptomyces* | *Streptomyces sp.* | *Danio rerio* (Zebrafish) |
| *Saccharomyces* | *Saccharomyces cerevisiae* | Striped catfish (*Pangasianodon hypophthalmus*) |
| *Weissella* | *Weissella cibaria* | Common carp (*Cyprinus carpio*) |

## 2.3 Prebiotics, Postbiotics, Minerals and Synbiotics in Aquaculture

Different categories of organic and inorganic compounds, such as prebiotics, postbiotics, and minerals, serve as valuable feed additives in aquaculture, contributing to the health well-being, and growth of aquatic species.

### 2.3.1 Prebiotics

Prebiotics, primarily composed of carbohydrates, especially oligosaccharides, polyphenols, and long fatty acids, support the growth of host microorganisms (Gibson et al., 2017). These compounds, including fructooligosaccharides (FOS), chitosan, polyphenols, butyric acid, propionic acid, lentinan, lipoteichoic acid, fucoidan, and isoflavones, offer benefits such as enhancing the growth, immune system, survival, and disease resistance in aquatic species against pathogens. Prebiotics represent innovative feed additives in aquaculture, contributing to the overall health and performance of cultured organisms (Yang et al., 2020; Magrone et al., 2018; Vijayaram et al., 2022).

### 2.3.2 Postbiotics

Postbiotics are bioactive molecules or structural components derived from probiotics (Salminen et al., 2021). These compounds play a crucial role in supporting host health and performance. Postbiotics, derived from the fermentation processes of probiotics, offer similar benefits to prebiotics, contributing to growth promotion, immune system enhancement, and disease resistance in aquatic species.

### 2.3.3 Minerals

Minerals are essential components of aquafeeds, playing critical roles in regulating various physiological processes in fish. Magnesium, for example, is crucial for fish growth, particularly in controlling myotube formation and muscle cell proliferation (Maradze et al., 2019). Adequate mineral supplementation in aquafeeds ensures optimal growth, development, and overall health of cultured aquatic organisms.

**Nutrient Absorption and Intestinal Health**

In addition to prebiotics, postbiotics, and minerals, certain feed additives containing fatty acids, essential amino acids, vitamins, and other nutrients are employed to enhance intestinal health and promote nutrient absorption through intestinal barriers (Martin & Krol, 2017). Nutrients are absorbed in the intestinal region, where enzymes, microorganisms, and genes are regulated and activated. Studies utilizing microbiome and transcriptome tools provide insights into these processes (Martin et al., 2016; Dawood et al., 2020b).

**Benefits and Sustainability**

Bioactive molecules added to aquafeeds offer numerous benefits, including antimicrobial, immunostimulant, antioxidant, growth-promoting, and anti-inflammatory properties. These techniques are not only economically viable and environmentally sustainable but also devoid of adverse effects, contributing to the sustainability and efficiency of aquaculture operations (Wang et al., 2017; Ragunath et al., 2022; Firmino et al., 2021).

### 2.3.4 **Synbiotics**

The utilization of synbiotics in aquaculture, a combination of probiotics and prebiotics, presents a promising and relatively recent approach. Synbiotics offer several potential benefits, including enhancing growth, health, and disease resistance in cultured aquatic organisms. This approach has garnered attention for its potential to contribute to the long-term success and sustainability of aquaculture operations (Ringø & Song, 2016; Hoseinifar et al., 2016; Vijayaram, 2023). Synbiotics are crucial in enhancing intestinal health, growth, and overall performance in aquatic organisms. They represent a potential alternative to antibiotics in aquaculture, addressing concerns related to antibiotic resistance and ensuring health and food safety (Okey et al., 2018; Ghafarifarsani et al.2021). Studies have shown notable improvements in various aspects of aquaculture, particularly in Pacific white shrimp, with the use of dietary synbiotics at a concentration of 3 g/kg for 56 days. These improvements include enhanced growth, feed utilization, intestinal health, and non-specific immunity. Interestingly, applying synbiotics by spraying onto the diet has demonstrated better performance compared to simply adding them during the pelleting process (Yao et al., 2021). As research in this field progresses, it is expected that more probiotic strains and prebiotic compounds will be tested, leading to a better understanding of their specific benefits for different aquaculture species. This continuous exploration and refinement of synbiotic applications hold promise to further enhance aquaculture practices' efficiency and sustainability.

## 3. Application of biogenic supplements in aquaculture

### 3.1 Herbals

Incorporating various botanical extracts into aquafeed supplements has shown promising results in enhancing antioxidant levels growth performance gene expression, immune response, and disease resistance in various cultured aquatic species.

Black Mulberry (2%) in Nile Tilapia: Inclusion of black mulberry (*Morus nigra*) at 2% in aquafeed supplements during a 60-day feeding trial resulted in enhanced immune response, growth performance, related gene expression, antioxidant levels, and disease resistance against *Aeromonas veronii* in Nile tilapia (Yilmaz et al., 2020c).

Olive Leaf Extract (1%) in Common Carp: Adding 1 g/kg of olive (*Olea europaea*) leaf extract to aquafeed supplements during a 60-day trial improved the immune system and increased survival against *E. tarda* in common carp (Zemheri-Navruz et al., 2019).

Turmeric (1%) in African Sharp Tooth Catfish: Incorporating 1% turmeric (*Curcuma longa*) powder into aquatic feed enhanced hematological parameters, reduced liver enzyme activity, and boosted the immune response in African sharp tooth catfish (*Clarias gariepinus*) with no adverse effects (Anene et al., 2021).

Turmeric Rhizomes, Tuhau Stems, and Betel Leaves (0.5%) in Hybrid Grouper: Inclusion of turmeric rhizomes, tuhau stems, and betel leaves at a concentration of 0.5% in aquafeed supplements significantly improved growth, feed consumption, apparent digestibility coefficient of body protein, and lipid contents of hybrid grouper compared to the control diet (Abang Zamhari et al., 2021).

Chinese Yam (0.4%) in Rainbow Trout: *Chinese yam* (Cinnamon vine) extract at a 0.4% concentration in aquafeed supplements during an 8-week trial improved gut microbial composition, digestive enzymes, and immunomodulatory effects in Rainbow trout (*Oncorhynchus mykiss*) (Wang et al., 2020).

Herbal Cassava (15 mL) in Common Carp: Supplementing aquafeed with 15 mL of herbal *Manihot esculenta Crantz* (cassava) extract significantly enhanced the growth rate and decreased the feed conversion ratio in common carp (*Cyprinus carpio*) (Efianda et al., 2020).

Mojave Yucca (0.75 mg/L) in European Seabass: Administering 0.75 mg/L of *Yucca schidigera* (Mojave yucca) liquid extract with aquafeed supplements improved growth, survival, hematological and immunological parameters in European seabass (*Dicentrarchus labrax*) juveniles, while also reducing ammonium concentration in the water (Fayed et al., 2019).

Jujube (1%) in Rainbow Trout: Feeding rainbow trout (*Oncorhynchus mykiss*) with aquafeed supplements containing 1% jujube (*Ziziphus jujuba*) water extracts for 8 weeks improved immunity, digestive function, and gut microbial composition (Liu et al., 2021).

Citrus Lemon Peel By-Product (50 g/kg) in Juvenile Abalone: Dietary inclusion of 50 g/kg of citrus lemon peel by-product into aquafeed supplements increased growth performance and acted as a stress reducer for juvenile abalone (*Haliotis*) during a 16-week feeding trial (Dai & Cho, 2022).

Ginkgo Biloba Extract (4 g/kg) in Nile Tilapia: Adding *Ginkgo biloba* (Maidenhair trees) extract at a concentration of 4 g/kg to aquafeed supplements during a 60-day feeding trial improved antioxidative status, immune system, and reduced inflammation in Nile tilapia (Zheng et al., 2022).(Table 4)

Table 4. Summary of herbal feed supplements and their effects on aquatic animals

| Herbals local name and scientific name | Aquatic animals local name and scientific name | Administration/ Dosages | Response | Duration of Treatment | References |
|---|---|---|---|---|---|
| Turmeric (*Curcuma longa* | African sharp-tooth catfish (*Clarias gariepinus*) | 1% | enhances hematological parameters, reduces the activity of liver enzymes (ALT, AST, ALP), and boosts the immune response | 8 weeks | Anene et al. (2021) |
| Turmeric rhizomes (TR), Tuhau stems (TS), and betel leaves (BL) | Hybrid grouper (*Epinephelus fuscoguttatus* ♀ × | 0.5% | improved the growth, feed consumption, apparent digestibility co-efficiency | 8-weeks | Abang Zamhari et al. (2021) |

| | | | | | |
|---|---|---|---|---|---|
| | *Epinephelus lanceolatus* ♂) | | of body protein, and lipid contents | | |
| Mojave yucca (*Yucca schidigera*) | European seabass (*Dicentrarchus labrax*) | 0.75 $mg/L^{-1}$ | improved the growth, survival, and hematological parameter | 8-weeks | Fayed et al. (2019) |
| Citrus lemon peel by-product | juvenile abalone (*Haliotis discus*) | 50 g/kg | significantly increased the growth performance and acted as a stress reducer | 16-week | Dai, & Cho (2022) |

### 3.2 Biogenic supplements from different sources

Section 1: Animal-Derived Biogenic Supplements

The utilization of animal-derived supplements in aquaculture is gaining attention due to their nutritional benefits and potential to improve fish health and performance. Taurine and selenium yeast are examples of such supplements that have been thoroughly researched (Sampath et al., 2020; Wang et al., 2019).

Section 2: Plant-Derived Biogenic Supplements

Plant-derived supplements, particularly microalgae and seaweed, are widely used in aquaculture diets. Microalgae species like *Chlorella* sp. and *Nannochloropsis* sp. are rich sources of nutrients and have demonstrated improvements in growth, immunity, and nutrient utilization in aquatic animals (Becker, 2013; Adissin et al., 2019).

Section 3: Microbial-Derived Biogenic Supplements

Microbial-derived supplements, including probiotics, play an important role in promoting gut health and disease resistance in aquaculture species. *Tetraselmis suecica* and *Gracilaria arcuata* are examples of microbial supplements that have been studied for their efficacy in enhancing fish health and performance (Sharawy et al., 2020; Younis et al., 2018).

Section 4: Cultivation and Application of Microalgae in Aquaculture

**Microalgae cultivation is essential for sustainable aquaculture practices. Studies have demonstrated the application of microalgae in wastewater treatment and nutrient management in aquaculture systems (Guldhe et al., 2017; Tejido-Nuñez et al., 2020).**

### 3.3 Probiotics

**Probiotics derived from various sources like the gut, water, soil, food, and primary/secondary hosts have a crucial role in the aquatic industry. They offer several advantages to the host, including enhancing gut microbiota composition, promoting growth, boosting immune gene expression, improving immune system responses, increasing disease resistance, and enhancing water quality in aquaculture (Tang et al., 2018;90 Balasubramanian et al., 2018; Makridis et al., 2021; Sharifuzzaman & Austin 2017).**Probiotics exhibit essential characteristics such as acid tolerance, bile salt tolerance, auto-aggregation, antimicrobial activity, susceptibility to antibiotics, and the ability to bind to the mucosal surface. These traits are significant factors when identifying potential probiotic candidates (Hosain & Liangyi 2020). Probiotics employ various mechanisms of action, including antimicrobial activity against harmful pathogens, the production of beneficial metabolites, the synthesis of vitamins, the ability to adhere to the gut lining, and the enhancement of the immune system (Pushparaj et al., 2022). Various types of probiotics are isolated from salmon and black tiger shrimp hatcheries, encompassing species such as *Aeromonas* sp., *Vibrio* sp., *Pseudomonas* sp., and groups of Coryneforms. These probiotics exhibit potential antiviral activity against the Infectious Hematopoietic Necrosis Virus (IHNV) in *Oncorhynchus masou* (masu salmon). (Loh 2017).Dietary supplementation of probiotics stimulates the immune response to help control diseases in cultured aquatic species. Probiotics like *Aeromonas veronii*, *Vibrio lentus*, and *Flavobacterium* activate both cellular and humoral-mediated immunity by increasing the production of immune factors such as TNF, IL-1b, and lysozymes in carp species (Dawood et al., 2018). Hlordzi et al., (2020) reported that *Bacillus* species significantly improved water quality parameters such as pH, DO, conductivity, BOD, COD, and more. They also found that *Bacillus* species influenced the microbial composition in fish culture.

**However, the effectiveness of these improvements depends on the method of application, the selection of the specific *Bacillus* strain, and the availability of nutrients in the aquatic environment. Supplementing the diet of shrimp (*P. vannamei*) with probiotics CDM8 and CDA22 for 21 days significantly decreased pathogenic *Vibrio* counts in the hindgut and increased survival rates, attributed to the secretion of catalase. The study concluded that these probiotics when used in 21-day feeding trials, enhance disease resistance against Acute Hepatopancreatic Necrosis Disease (AHPND) caused by *Vibrio parahaemolyticus* in shrimp aquaculture (Wang et al., 2018).**According to FAO (2020), probiotics exhibit strong inhibitory activity against pathogens and enhance disease resistance in various fish species, including Atlantic cod (*Gadus morhua*), Nile tilapia (*Oreochromis niloticus*), rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), and sea bass (*Lates calcarifer*) juveniles. It is worth noting that Nile tilapia (*Oreochromis niloticus*) holds significant importance as a major contributor to global aquaculture production. Corynebacterium ammonia genes (at a level of 10-20%) and Methylobacterium extorquens protein have the potential to serve as substitutes for fishmeal in shrimp diets. These alternative protein sources can help reduce the reliance on fishmeal in aquaculture feeds (Chumpol et al., 2018). Incorporating *Enterococcus faecium* into the diet for 7- and 14 days results in significantly enhanced final weight, final biomass, weight gain, and respiratory burst activity in tilapia (*Oreochromis niloticus*). Furthermore, it helps maintain the defense mechanisms of the immune system in these fish (Changpasert et al., 2022). Incorporating plant-based protein into the diet along with *Bacillus pumilus* (at a concentration of 1.85 x $10^5$ cfu/kg) and protease (at 0.5 g/kg) during an 84-day feeding trial significantly improves the growth and feed intake in tilapia (*Oreochromis niloticus*). The combination of *B. pumilus* and exogenous protease offers synergistic effects that benefit the fish (Hassaan et al., 2021; Yang et al.,2021). Oral administration of probiotic *Lactobacillus plantarum* at a concentration of $2 \times 10^7$ cfu/g in the diet for 72 days, following yersiniosis vaccination, significantly enhances the growth performance of rainbow trout (*Oncorhynchus mykiss*). It also helps maintain gut microbiota, and digestive enzyme activity and improves nutrient digestibility and utilization (Soltani et al., 2019).

Bio-encapsulated *Planococcus* at a 1% concentration in live food culture (rotifers and Artemia) during a 40-day feeding trial significantly improved the growth, survival, digestibility, and biochemical indices of gilthead sea bream (*Sparus aurata*) (Ghoname et al., 2020). Adding the probiotic *Paenibacillus ehimensis* NPUST1 to the diet during a 2-month feeding trial significantly enhances the growth performance, immunity, and infection resistance in Nile tilapia (*Oreochromis niloticus*) (Chen et al., 2019).Probiotics *B. thuringiensis* QQ1 and *B. cereus* QQ2 at a concentration of $10^9$ CFU/g in the diet during an 8-week feeding trial significantly enhances immunity and antioxidant levels, helping to suppress *Vibrio alginolyticus* infections in Asian seabass (*Lates calcarifer*). However, further research is needed to clarify the precise mechanisms associated with the QQ system and its role in protecting fish from infections caused by *Vibrio* pathogens. (Ghanei-Motlagh et al., 2021). Supplementing the diet with probiotic *Pediococcus pentosaceus* MR001 at a concentration of 109 cfu/g significantly increases feed utilization, growth, digestive enzyme activity, and disease resistance against vibriosis in shrimp (*Litopenaeus vannamei*). The study concludes that *P. pentosaceus* MR001 is an effective and valuable feed additive for aquaculture (Wanna et al., 2021).In a 45-day feeding trial, the dietary administration of the probiotics *Streptomyces* antibiotics EW1 (MH301104) demonstrated better activity compared to a diet incorporating *B. cereus*. The probiotics *Streptomyces* antibiotics EW1 (MH301104) significantly improved growth performance, digestibility, and nutrient intake, and reduced the mortality rate of juvenile catfish (*Heteropneustes fossils*) (Das et al., 2021). Probiotics such as *Lactococcus lactis* L19 and *Enterococcus faecalis* W24 at a concentration of $1.0 \times 10^8$ cfu/g in the diet during a 56-day feeding trial significantly increase digestive enzyme activity. improve intestinal microbiota, enhance the intestinal morphology antioxidant capacity of Northern snakehead (*Channa argus*). Dietary supplementation of the probiotic *L. lactis* L19 is more efficient in providing protection compared to W24. Probiotic dietary additives demonstrate a more beneficial response in cultured fish species (Kong et al., 2021). In a study by Siddik et al., (2022), a dietary combination of probiotics, specifically *Lactobacillus casei* and *Saccharomyces cerevisiae* at a 1% concentration, was administered to juvenile barramundi during a 56-day feeding trial. This combination significantly enhanced growth, and feed utilization, maintained microbiota composition, and improved the immune response in the juvenile fish.

Further research is required to fully comprehend the exact mechanisms of action in the gut region of fish. However, dietary inclusion of two *Bacillus* strains, *B. cereus* KAF124, and *B. thuringiensis* KAF135, has shown significant improvements in growth, immunity, antioxidant activity, digestive enzymes, disease resistance, antimicrobial activity, and the regulation of gut microbiota composition in marine fish *Moolgarda seheli* (Husain et al., 2022). Probiotic *B. velezensis* GY65 in the diet significantly improves growth performance, immunity, and amylase activity, and reduces the pathogenic load in mandarin fish (*Siniperca chuatsi*) (Wang et al., 2021)

### 3.4 **Essential oils and plant oils**

**Incorporating lemon peel essential oil (LPEO) into the diet at a concentration of 400 mg/kg significantly reduced the negative effects of deltamethrin (DMN) pesticide exposure and enhanced growth indices and carcass composition in juvenile rainbow trout (*Oncorhynchus mykiss*) (Amiri Resketi et al., 2021). Dietary supplementation of microencapsulated carvacrol, garlic, and thymol enhanced the activation of the protein biosynthetic process in the gills of gilthead sea bream (*Sparus aurata*), utilizing plant-derived supplements (Firmino et al., 2020).** Including Greek oregano (*O. onites*) essential oil at a concentration of 3.0 mL/kg in the diet during a 90-day trial significantly improved the survival rate of rainbow trout (*Oncorhynchus mykiss*) against *L. garvieae*, a pathogenic bacterium, which is also a plant-derived supplement (Diler et al., 2017b). In a study conducted by Baba et al., (2017), dietary incorporation of argan oil derived from the argan tree (*Argania spinosa*) at various concentrations (0%, 0.5%, 1%, or 2%) significantly increased immuno-hematological and biochemical responses. Additionally, this dietary supplementation improved disease resistance against *L. garvieae* in Nile tilapia (*Oreochromis niloticus*), which is another example of plant-derived supplements. Including olive pomace (Olea europaea) oil in the diet has been shown to significantly improve the antioxidant capacity and infection tolerance in Rainbow trout (*Oncorhynchus mykiss*), also categorized under plant-derived supplements (Yilmaz et al., 2020b). In a study by Baba et al., (2016), it was found that including 0.5% citrus lemon peel essential oil in the diet significantly increased the antioxidant capacity and disease resistance against *E. tarda* in Nile tilapia (*Oreochromis niloticus*), representing plant-derived supplements.

Incorporating essential oil from sweet basil (*Ocimum basilicum*) at a concentration of 2.0 mL per kilogram of diet for 48 days of feeding trials resulted in improved growth performance in pirarucu juveniles (*Arapaima gigas*), which is another example of plant-derived supplements (Chung et al., 2020). Including the essential oil of Ginger (*Zingiber officinale*) (EOZO) at a concentration of 0.5 mL in the diet during a 60-day feeding trial enhanced the growth activity, increased intestinal villi size, and improved hematological variables in Nile tilapia (*Oreochromis niloticus*), which falls under plant-derived supplements.

### 3.5 Nutrients

3.5.1 Animal-Derived Supplements:

Methionine (MET) in the diet at concentrations ranging from 0.6% to 1.2% during weeks of a feeding trial resulted in improved serum lipid profiles and a reduction in the size and number of liver lipid droplets in juvenile large yellow croaker (*Larimichthys crocea*), representing a functional supplement (Li et al., 2021).

Glutamine and glutamate at a concentration of 3% in the diet significantly increased growth performance, specific and non-specific immune responses, and skeletal muscle growth in fish, classified as functional supplements (Li et al., 2021).

Lysine supplement at a concentration of 14.18 g/kg in the diet for a 60-day feeding trial significantly increased lysozyme, acid phosphatase (ACP), and complement C3 activities in the gut region of grass carp (*Ctenopharyngodon idella*), representing a functional supplement (Hu et al., 2021).

Tryptophan at concentrations of 1.28% and 2.56% for a 7-day feeding trial under stress conditions significantly increased growth response and improved thermal and salinity stress resistance in Nile tilapia (*Oreochromis niloticus*), categorized as a functional supplement (Vieira et al., 2021).

Histidine at a concentration of 7.9 g/kg in the diet for an 8-week feeding trial significantly enhanced growth activity and digestive enzyme activity in grass carp (*Ctenopharyngodon idella*), classified as a functional supplement (Wu et al., 2020).

Taurine was included at a concentration of 1% in the feed; however, there were no significant changes observed in various growth and body composition parameters in striped bass (*Morone chrysops x M. saxatilis*), indicating that taurine supplementation at this level did not have a significant impact on the measured parameters in this particular study (Suehs, & Gatlin III, 2021).In a 70-day feeding trial, taurine at a concentration of 30 g/kg considerably enhanced hepatic, digestive, and antioxidant enzyme activity in A. ruthenus, classified as a functional supplement (Bavi et al., 2022).

3.5.2 Plant-Derived Supplements:

Konjac glucomannan at a concentration of 1% in the diet for 60 days in aqua feed supplements significantly increased growth performance, antioxidant levels, lipid metabolism, and immune response in juvenile golden pompano (*Trachinotus ovatus*), categorized as a functional supplement (Li et al., 2021).

3.5.3 Microbial-Derived Supplements:

Incorporating sulfate-based alginate polysaccharide (SAP) at a concentration of 1.91% in the diet during a 56-day feeding trial significantly improved growth, serum antioxidant levels, nonspecific immunity, intestinal health, and disease tolerance in Pacific white shrimp (*Litopenaeus vannamei*), representing a functional supplement (Chen et al., 2022).

## 3.6 Bioactive molecules

3.6.1 Animal-Derived Supplements:

Pepsin at a concentration of 0.50 g/kg had a positive influence on the growth, feed consumption, blood physiology, and potentially water quality in the culture of striped catfish, representing a functional supplement (Islam et al., 2021).

Hydroxyproline (Hyp) at a concentration of 1% had multiple positive effects on Chinese perch (*Siniperca chuatsi*), including increased growth, improved muscle quality, higher collagen content, enhanced nutritional value, and improved digestive system activity, classified as a functional supplement (Feng et al., 2022).

Lactoferrin at a concentration of 100 mg/kg in fish feed for a one-week feeding trial had a positive impact on the immune system in diverse fish species such as goldfish (Carassius auratus), rainbow trout (*Oncorhynchus mykiss*), Atlantic salmon (Salmo salar), red sea bream (*Pagrus major*), and Asian catfish (*Pangasius hypophthalmus*), categorized as a functional supplement (Roy et al., 2020).

The oral dietary administration of peptidoglycan at a concentration of 0.2 mg/kg had a significant positive effect on the health and disease resistance of kuruma shrimps (*Marsupenaeus japonicas*), functioning as a dietary supplement (Kondo et al., 2021).

3.6.2 Plant-Derived Supplements:

Polyphenols at a concentration of 400 mg/kg had multiple positive effects on common carp (*Cyprinus carpio*) fingerlings, including increased growth, improved feed conversion ratio, enhanced antioxidant status, and strengthened immunological parameters, classified as a functional supplement (Hussain et al., 2021).

Quercetin at concentrations of 0.5 or 1.0 g/kg notably reduced excess fat deposition in *Lateolabrax maculates*(Asian sea bass) tissues stimulated by the intake of a high-fat diet (HFD), representing a functional supplement (Dong et al., 2021).

3.6.3 Microbial-Derived Supplements:

β-glucans at a concentration of 10 mg/kg in aquafeed supplements for 56 days of feeding trials increased expression level to control the immune function and also blood neutrophils, oxidative radical production, and superoxide anion production in activated macrophages of White leg shrimp (*Litopenaeus vannamei*) juveniles, categorized as a functional supplement (Ayiku et al., 2020).

Microbial levan at 25 g/kg in aqua feed supplement significantly enhanced innate immune response, growth, survival, disease resistance, and thermal stress tolerance and also reduced loads of total viable aerobic bacteria and *Vibrio* spp. in the gut region of orange-spotted grouper (*Epinephelus coioides* H.), representing a functional supplement (Mohan et al., 2020).

*Clostridium* autoethanogenum protein (CAP) at 200 g/kg in fish feed significantly improved growth performance, serum chemical parameters, antioxidant status, and histopathological examination of the liver and midgut in juvenile Jian carp (*Cyprinus carpio*), functioning as a dietary supplement (Li et al., 2021).

## 3.7 Nanoparticles

Incorporating nanoparticle supplements into aquatic feed is an innovative approach that has shown significant potential in enhancing the quality of aquaculture. These nanoparticles have been demonstrated to improve survival rates, antioxidant levels, growth performance, and immune responses in aquatic species. However, it's crucial to note that excessive nanoparticle supplementation can potentially lead to side effects in aquatic organisms (Muralisankar et al., 2014; Ashouri et al., 2015; El Basuini et al., 2016; Faiz et al., 2015; Vijayakumar et al., 2019; Rashidian et al., 2021; Prema et al., 2023; Elabd et al., 2022).

3.7.1 **Selenium Nanoparticles**:

Selenium nanoparticles (1–2 mg/kg diet) for a 45-day feeding trial notably improved the immune system, total protein content, and antioxidant activities in red sea bream (*Pagrus major*), indicating their potential as a valuable dietary supplement in promoting fish health (Dawood et al., 2019).

Qin et al. (2016) demonstrated that selenium nanoparticles at 0.2 mg/kg for 60 days of feeding trials significantly increased the immune system, disease resistance, and resistance against hypoxia stress in Chinese mitten crab (*Eriocheir sinensis*), highlighting their role in enhancing the resilience of aquatic species.

3.7.2 **Gold Nanoparticles**:

Oral dietary administration of Au-NPs (2 μg/g) increased the immune system, antioxidant levels, survival, and disease resistance against *V. parahaemolyticus* in shrimp (*Litopenaeus vannamei*), suggesting the potential of gold nanoparticles as a beneficial dietary supplement aimed at promoting shrimp health (Na-Phatthalung et al., 2018).

3.7.3 **Copper Nanoparticles**:

Copper nanoparticles at 20 mg/kg in a 90-day feeding trial significantly enhanced growth, survival, and immune response in postlarval stages of the freshwater prawn (*Macrobrachium rosenbergii*). However, elevated doses (40–80 mg/kg) may lead to toxic effects, emphasizing the importance of proper dosage management (Muralisankar et al., 2016).

3.7.4 **Silver Nanoparticles**:

Silver nanoparticles considerably enhanced growth response, protease, and metalloprotease activity in zebrafish (*Danio rerio*) and rainbow trout (*Oncorhynchus mykiss*) , suggesting their potential to optimize growth and nutrient utilization in aquaculture practices (Sarkar et al., 2015b;Mirghaed et al.2018).

3.7.5 **Zinc Nanoparticles**:

Zinc nanoparticles at 20 mg/kg enhanced growth and immune system response against abiotic and biotic stress conditions in shark catfish (*Pangasius hypophthalmus*), highlighting their potential benefits in promoting fish health and resilience (Kumar et al., 2018).

3.7.6 Zinc oxide nanoparticle supplements demonstrated better disease resistance activity against multi-drug resistant bacteria that affect fish such as *A. veronii* and *S. maltophilia* in aquaculture, showcasing their potential as effective nano antibiotics (Pati et al., 2021; Ghafarifarsani et al., 2023). The biogenic dietary supplementary role is summarized in **Figure 1**

**Figure 1**. Biogenic Dietary Supplements' role on aquaculture

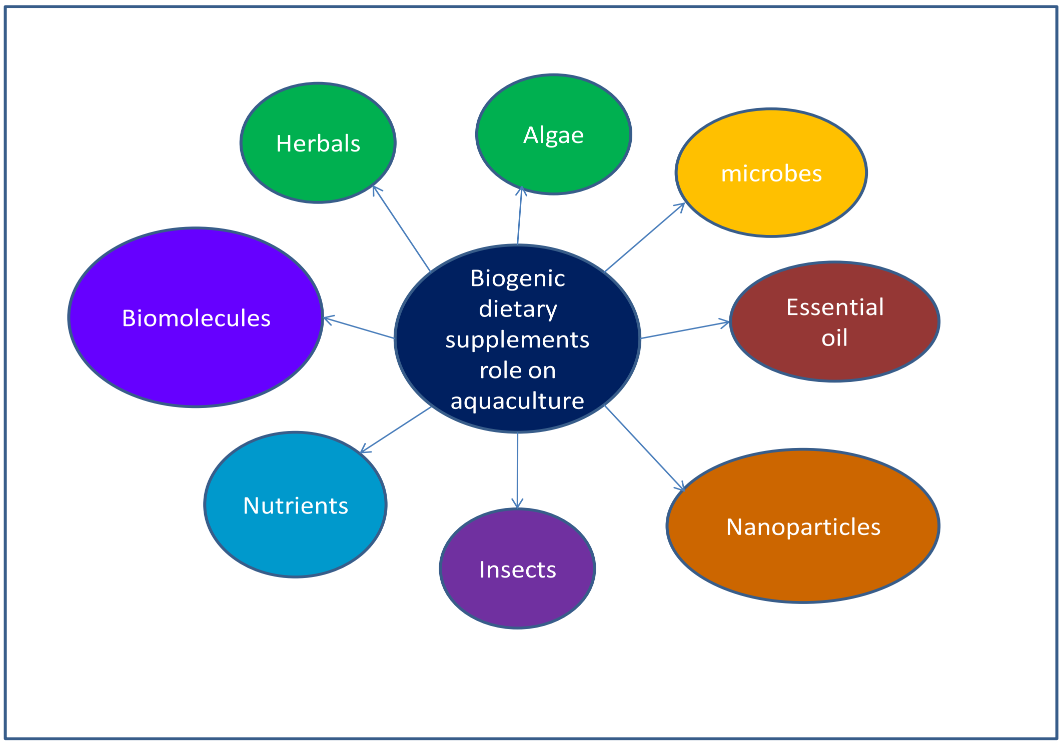



Table 5. Applications of biogenic dietary supplements in aquaculture

| Biogenic substances | Scientific name of Biogenic substances | Aquatic animals Scientific name | Aquatic animals Local name | Administration | Response | References |
|---|---|---|---|---|---|---|
| Black mulberry | *Morus nigra* | *Oreochromis niloticus* | Nile tilapia | 2% for 60 days | Enhanced growth performances, immune responses, antioxidant and related gene | Yilmaz et al. 2020c |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | expression, and disease resistance against *Aeromonas veronii* | |
| Turmeric powder | *Curcuma longa* | *Clarias gariepinus* | African sharptooth catfish | 1% | Improved hematological parameters | Anene et al.2021 |
| Chinese yam | *Dioscorea oppositifolia L.* | *Oncorhynchus mykiss* | Rainbow trout | 0.4% for 8 week | Increased gut microbial composition, digestive enzymes, and immunomodulatory effects | Wang et al.2020 |
| Mojave Yucca | Yucca schidigera | *Dicentrarchus labrax* | European seabass | 0.75 mg /$L^{-1}$ | Increased stress tolerance effect against ammoinia | Fayed et al.2019 |
| Maidenhair trees | *Ginkgo biloba* | *Oreochromis niloticus* | Nile tilapia | 1 and/ or 4 g/kg for 60 days | Improved antioxidative status, immune system, and suppression of inflammation | Zheng et al. 2022 |
| Marine microalgae | Tetraselmis suecica | *Litopenaeus vannamei* | Pacific white shrimp | 7.5 g/kg | Improved growth and nutrient utilization | Sharawy et al. 2020 |
| Microalgae | *Chlorella vulgaris* | *Macrobrachium rosenbergii* | Giant freshwater prawn | 4% and 15% for 50 days trial | better immune response and resistance of *M. rosenbergii* postlarvae against *A. hydrophila* infection | Maliwat et al. 2017 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Microalgae | *Scenedesmus obliquus* | *Anarhichas minor* | Spotted wolffish | 4% for 12 week feeding trials | Increased muscle growth | Knutsena et al. 2019 |
| Microalgae | *Gracilaria arcuata* | *Oreochromis niloticus* | Nile tilapia | 20% for a 12-week feeding trial | Improved growth performance | Younis et al. 2018 |
| Microalgae | *Arthrospira sp.* | *Sparus aurata* | gilthead seabream | 4% for 128 feeding trial trials | Enhanced muscle pigmentation and antioxidant activity | Galafat et al. 2022 |
| Microbes | *Bacillus pumilus* | *Oreochromis niloticus* | Nile tilapia | $1.85 \times 10^5$ for 84 feeding trials | Enhanced the growth performance, intestinal histological morphometric, immune response, hematological, biochemical blood, metabolic gene expression and intestinal bacterial flora | Hassaan et al. 2021 |
| Microbes | *Bacillus sp. R2* and *Planococcus sp. R11* | *Sparus aurata* | sea bream | 1:1 for 40 feeding trials | Improved growth performance and survival | Ghoname et al. 2020 |
| Microbes | *B. thuringiensis QQ1* and *B. cereus QQ 2* | *Lates calcarifer* | Asian seabass | $10^9$ Cfu/g for 8 week | Enhanced immune response, antioxidant and disease resistance | Ghanei-Motlagh et al.2021 |
| Microbes | *Streptomyces antibiotics* | *Heteropneustes fossilis* | freshwater catfish | NM | Improved growth, digestion, nutrient | Das et al.2021 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | *EW1 (MH301104)* | | | | utilization and survival | |
| Microbes | *Saccharomyces cerevisiae coupled with Lactobacillus casei* | *Lates calcarifer* | Barramundi | 1% for a 56-day feeding trial | improved the growth, immune response and gut health | Siddik et al.2022 |
| Yellow mealworm | *Tenebrio molitor* | *Oncorhynchus mykiss* | Rainbow trout | 50 % for 75 days | Improved growth performance | Gasco et al. 2014 |
| Maggot | *Musca domestica* | *Lates calcarifer* | Barramundi | 300 g/kg for 8 weeks | Improved physiological responses | Lin et al.2017 |
| Grasshopper | *Caelifera* | *Clarias gariepinus* | African catfish | 25% | Improved growth performance | Alegbeleye et al.2012 |
| Migratory locust | *Locusta migratoria* | *Oreochromis niloticus* | Nile tilapia | 25% | Improved growth performance | Emehinaiye et al.2012 |
| Lemon peel essential oil | *Citrus limon* | *Oncorhynchus mykiss* | Rainbow trout | 400 mg/kg for 96-h | Decreased the adverse effect of deltamethrin (DMN) pesticide | Amiri Resketi et al.2021 |
| Oregano essential oil | *Origanum onites* L. | *Oncorhynchus mykiss* | Rainbow trout | 3.0 mL/kg for 90 days | Enhanced disease resistance | Diler et al.2017b |
| olive pomace oil | *Olea europaea* | *Oncorhynchus mykiss* | Rainbow trout | 12% for 60 days | increased the immune responses and makes O. mykiss more resistant to infection by L. garvieae | Yilmaz et al.2020b |

| | | | | | | |
|---|---|---|---|---|---|---|
| konjac glucomannan | *Amorphophallus konjac* | *Trachinotus ovatus* | Golden pompano | 1% for 60 days | Improved growth, feed efficiency, antioxidant capacity, hepatic lipid metabolism and inflammatory response | Li et al.2021 |
| Methionine | NA | *Larimichthys crocea* | Large yellow croaker | 0.6-1.2% for 10 weeks | Enhanced antioxidant and lipid metabolism level | Li et al.2021 |
| Lysine | NA | *Ctenopharyngodon idella* | Grass carp | 14.18 g/kg for 60 days feeding trials | Enhanced immune response and molecular mechanism in skin, head kidney and spleen | Hu et al. 2021 |
| Histidine | NA | *Ctenopharyngodon idella* | Grass carp | 7.9 g/kg diet for 8 weeks | Improved growth and flesh quality | Wu et al. 2020 |
| Taurine | NA | *Acipenser ruthenus* | Sterlet | 30 g/kg for 70 days | enhancement of growth performance, hepatic, digestive, and antioxidant enzyme activities | Bavi et al.2022 |
| Pepsin | NA | *Pangasianodon hypophthalmus* | striped catfish | 0.50 g/kg for 90 days | Increased production performance | Islam et al.2021 |
| pyrroloquinoline quinone | NA | *Pelteobagrus fulvidraco* | yellow catfish | 4.92 mg/kg for 56 days | improve the growth performance, serum biochemical parameters, antioxidant status, and growth- | Shi et al.2022 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | related genes expressions | |
| Polyphenol | NA | *Cyprinus carpio* | Common carp | 400 mg/kg kg for 70 days | increased mineral absorption,<br><br>improved body composition and hematology | Hussain et al. 2021 |
| β-glucans | NA | *Litopenaeus vannamei* | pacific white shrimp | 10 mg/ kg | get better growth, intestinal health, immune response, and resistance against *Vibrio harveyi* infections | Ayiku et al.2020 |
| Curcumin | NA | *Channa argus* | Northern snakehead | 400 mg/kg for 28 days trial | Reduced DEL-induced oxidative stress, inflammation, and cell apoptosis in *C. argus* via Nrf2 and NF-κB signaling pathways | Kong et al.2021 |
| selenium nanoparticles | NA | *Pagrus major* | Red sea bream | 1–2 mg/kg for 45-day feeding trial | Maintaining overall growth response | Dawood et al.2019 |
| copper nanoparticles | NA | *Macrobrachium rosenbergii* | freshwater prawn | 20 mg/kg for 90 days | regulating better survival, growth and immune response of *M. rosenbergii* PL. | Muralisankar et al.2016 |
| Zinc nanoparticles | NA | *Pangasius hypophthalmus* | striped catfish | 20 mg/kg | Improved stress tolerance effect against abiotic and biotic condition | Kumar et al.2018 |

## 4. Conclusion

This study provides a comprehensive summary of the benefits of biogenic-mediated dietary supplements in aquaculture, highlighting their potential to improve growth, antioxidant levels, immune response, disease resistance, stress tolerance, and water quality. These supplements, developed from natural sources, offer an eco-friendly, non-toxic, and cost-effective alternative to traditional methods such as antibiotics, chemotherapeutics, and vaccines, which often lead to side effects in both aquatic animals and humans. The manuscript emphasizes that while the optimal concentration of these supplements enhances physiological responses, exceeding this concentration does not further improve outcomes. To strengthen the study, it is recommended that future research be directed toward exploring the optimal dosage of biogenic supplements across different fish species, as variations in species may affect efficacy. Additionally, large-scale field trials are essential to validate the results obtained in laboratory settings and to confirm their real-world applicability. This study sets the foundation for ongoing research aimed at developing new biogenic supplement products, which have the potential to revolutionize sustainable aquaculture practices.

**Conflicts of interest/Competing interests**

There is no conflict of interest to declare.

**Consent for Publication**

All authors give consent for publication.

**Availability of data and material**

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

## References

Abang Zamhari D.N.J. B., Yong A.S.K. (2021). Dietary herbs supplementation improves growth, feed efficiency and apparent digestibility coefficient of hybrid grouper (*Epinephelus fuscoguttatus*× *Epinephelus lanceolatus*) juvenile. Aquacult. Res., 52: 5239–5246.

Abd El-Kader M.F., Shukry M., Dawood M.A., Hassan M.M., Farrag F., Omar A., Moustafa E. M. (2021). Ameliorative effect of dietary lipopolysaccharides on *Oreochromis niloticus* juveniles submitted to aflatoxin B1-induced oxidative stress and bacterial challenge. Aquacult. Res., 52: 3660–3676.

Abdel-Latif H.M., El-Ashram S., Yilmaz S., Naiel M.A., Kari Z.A., Hamid N.K.A., Kucharczyk D. (2022). The effectiveness of *Arthrospira platensis* and microalgae in relieving stressful conditions affecting finfish and shellfish species: An overview. Aquacult. Rep.,24: 101135.

Abdel-Tawwab M. (2016). Feed supplementation to freshwater fish: Experimental approaches. LAP Lambert Academic Publishing.

Adam A.H., Verdegem M., Soliman A.A., Zaki M., Khalil R.H., Nour A.E.M., Khalil H.S. (2023). Effect of dietary bile acids: Growth performance, immune response, genes expression of fatty acid metabolism, intestinal, and liver morphology of striped catfish (*Pangasianodon hypophthalmus*). Aquacult. Rep., 29: 101510.

Adel M., Dawood M.A., Shafiei S., Sakhaie F., Shekarabi S.P.H. (2020). Dietary Polygonum minus extract ameliorated the growth performance, humoral immune parameters, immune-related gene expression and resistance against *Yersinia ruckeri* in rainbow trout (*Oncorhynchus mykiss*). Aquaculture, 519: 734738.

Adel M., Sakhaie F., Shekarabi S.P.H., Gholamhosseini A., Impellitteri F., Faggio C. (2024). Dietary *Mentha piperita* essential oil loaded in chitosan nanoparticles mediated the growth performance and humoral immune responses in Siberian sturgeon (*Acipenser baerii*). Fish Shellfish Immunol., 145: 109321.

Adeshina I., Abdel-Tawwab M., Tijjani Z.A., Tiamiyu L.O., Jahanbakhshi A. (2021). Dietary Tridax procumbens leaves extract stimulated growth, antioxidants, immunity, and resistance of Nile tilapia, *Oreochromis niloticus*, to monogenean parasitic infection. Aquaculture, 532: 736047.

Adissin T.O., Manabu I., Shunsuke K., Saichiro Y., Moss A.S., Dossou S. (2020). Effects of dietary Nannochloropsis sp. powder and lipids on the growth performance and fatty acid composition of larval and postlarval kuruma shrimp, *Marsupenaeus japonicus*. Aquacult. Nutr., 26: 186–200.

Ahmed N.H., Ayyat A.M.N., Abdelrhman A.M., El-Latif A. (2023). The ameliorative effect of nano-selenium supplementation on growth, body composition, lead bioaccumulation, and blood components of Nile tilapia fed lead-contaminated diet. Egypt. J. Nutr. Feed., 26: 109–118.

Amiri Resketi M., Yeganeh S., Jani Khalili K. (2021). Dietary sour lemon (Citrus limon) peel essential oil supplementation for reduction of deltamethrin-induced stress in rainbow trout (*Oncorhynchus mykiss*). J. World Aquac. Soc., 52: 105–123.

Anene A., Okorie E.O., Ajima M.N., Onyemaonwu J. (2021). Dietary supplement of tumeric (*Curcuma longa*) powder: Impact on haematological and biochemical responses in *Clarias gariepinus* (burchell, 1822) fingerlings. Aquacult. Stud., 22.

Apandi N.M., Mohamed R.M.S.R., Al-Gheethi A., Kassim A.H.M. (2019). Microalgal biomass production through phycoremediation of fresh market wastewater and potential applications as aquaculture feeds. Environ. Sci. Pollut. Res., 26: 3226–3242.

Arumugam A., Dineshkumar R., Subramanian J., Gopalsamy J., Ahamed Rasheeq A., Bhothichittaun K., Sampathkumar P. (2020, March). Exploration of microalgal live feed on experimental freshwater fish (*Hypophthalmichthys nobilis*) culture. In Proceedings of the Zoological Society (Vol. 73: pp. 16–24). Springer India.

Ashouri S., Keyvanshokooh S., Salati A.P., Johari S.A., Pasha-Zanoosi H. (2015). Effects of different levels of dietary selenium nanoparticles on growth performance, muscle composition, blood biochemical profiles and antioxidant status of common carp (*Cyprinus carpio*). Aquaculture, 446: 25–29.

Ayanwale A.V., Ikumapayi R.A., Egwim E.C., Keke U.N., Samuel P.O. (2021). Evaluation of Dietary Garlic (*Allium sativum*) extract on Growth, Survival and Stress Biomarkers on Heteroclarias fingerlings under Laboratory conditions in Minna, Nigeria.

Ayiku S., Shen J., Tan B.P., Dong X.H., Liu H. Y. (2020). Effects of reducing dietary fishmeal with yeast supplementations on *Litopenaeus vannamei* growth, immune response and disease resistance against *Vibrio harveyi*. Microbiol. Res., 239: 126554.

Baba E., Acar U., Ontas C., Kesbic O.S., Yilmaz S. (2016b). Evaluation of Citrus limon peels essential oil on growth performance, immune response of Mozambique tilapia *Oreochromis mossambicus* challenged with *Edwardsiella tarda*. Aquaculture, 465: 13–18.

Baba E., Acar U., Yilmaz S., Ontas C., Kesbic OS. (2017). Pre-challenge and post-challenge haemato-immunological changes in *Oreochromis niloticus* (Linnaeus, 1758) fed argan oil against *Lactococcus garvieae*. Aquacult. Res., 48: 4563–4572.

Bae J., Hamidoghli A., Won S., Choi W., Lim S. G., Kim K.W., Bai S.C. (2020). Evaluation of seven different functional feed additives in a low fish meal diet for olive flounder, *Paralichthys olivaceus*. Aquaculture, 525: 735333.

Balasubramanian B., Lee S.I., Kim I.H. (2018). Inclusion of dietary multi-species probiotic on growth performance, nutrient digestibility, meat quality traits, faecal microbiota and diarrhoea score in growing–finishing pigs. Italian J. Animal Sci., 17: 100–106.

Baldissera M.D., Souza C.F., Petrolli T.G., Baldisserotto B., Da Silva A.S. (2019). Caffeine prevents hypoxia-induced dysfunction on branchial bioenergetics of Nile tilapia through phosphoryl transfer network. Aquaculture, 502: 1–7.

Bao S.T., Liu X. C., Huang X.P., Guan J.F., Xie D.Z., Li S.A., Xu C. (2022). Magnesium supplementation in high carbohydrate diets: Implications on growth, muscle fiber development and flesh quality of *Megalobrama amblycephala*. Aquacult. Rep., 23: 101039.

Bavi Z., Zakeri M., Mousavi S. M., Yavari V. (2022). Effects of Dietary Taurine on Growth, Body Composition, Blood Parameters, and Enzyme Activities of Juvenile Sterlet (*Acipenser ruthenus*). Aquacult. Nutri., 1: 1713687.

Becker B. (2013). Snow ball earth and the split of Streptophyta and Chlorophyta. Trends Plant Sci., 18: 180–183.

Becker E.W. (2007). Micro-algae as a source of protein. Biotechnol. Adv., 25: 207–210.

Calicioglu O., Flammini A., Bracco S., Bellù L., Sims R. (2019). The future challenges of food and agriculture: An integrated analysis of trends and solutions. Sustainability, 11: 222.

Carneiro W. F., Castro T.F.D., Orlando T.M., Meurer F., de Jesus Paula D.A., Virote B.D.C R., Murgas L.D.S. (2020). Replacing fish meal by *Chlorella* sp. meal: effects on zebrafish growth, reproductive performance, biochemical parameters and digestive enzymes. Aquaculture, 528: 735612.

Changpasert W., Issara U., Chotiko A., Chouljenko A. (2022). Novel Feed Ingredients for Approaching Aquatic Sustainability. In Aquaculture Science and Engineering (pp. 131–174). Singapore: Springer Nature Singapore.

Changpasert W., Wong S. L., Torpol K. (2019). Effect of microalgal diets and its biochemical composition on growth and survival of Asiatic freshwater clam. Malaysian App. Biol., 48: 61–67.

Chen G., Liu B., Chen J., Liu H., Tan B., Dong X., Yao M. (2022). Supplementing sulfate-based alginate polysaccharide improves pacific white shrimp (*Litopenaeus vannamei*) fed fishmeal replacement with cottonseed protein concentrate: Effects on growth, intestinal health, and disease resistance. Aquacult. Nutr., 2022.

Chen M., Chen X. Q., Tian L. X., Liu Y. J., Niu J. (2020). Beneficial impacts on growth, intestinal health, immune responses and ammonia resistance of pacific white shrimp (*Litopenaeus vannamei*) fed dietary synbiotic (mannan oligosaccharide and *Bacillus licheniformis*). Aquacult. Rep., 17: 100408.

Chen S.W., Liu C. H., Hu S.Y. (2019). Dietary administration of probiotic Paenibacillus ehimensis NPUST1 with bacteriocin-like activity improves growth performance and immunity against *Aeromonas hydrophila* and *Streptococcus iniae* in Nile tilapia (*Oreochromis niloticus*). Fish Shellfish Immunol., 84: 695–703.

Chumpol S., Kantachote D., Nitoda T., Kanzaki H. (2018). Administration of purple nonsulfur bacteria as single cell protein by mixing with shrimp feed to enhance growth, immune response and survival in white shrimp (*Litopenaeus vannamei*) cultivation. Aquaculture, 489: 85–95.

Chung S., Lemos C.H., Teixeira D.V., Fortes-Silva R., Copatti C.E. (2020). Essential oil from Ocimum basilicum improves growth performance and does not alter biochemical variables related to stress in pirarucu (Arapaima gigas). Anais da Academia Brasileira de Ciências, 92.

Chung S., Ribeiro K., Melo J.F.B., Teixeira D. V., Vidal L. V.O., Copatti C.E. (2021). Essential oil from ginger influences the growth, haematological and biochemical variables and histomorphometry of intestine and liver of Nile tilapia juveniles. Aquaculture, 534: 736325.

D'Alessandro E.B., Antoniosi Filho N.R. (2016). Concepts and studies on lipid and pigments of microalgae: A review. Renew. Sust, Energy Rev., 58: 832–841.

Dai Q., Cho S.H. (2022). Dietary inclusion effect of citrus peel by-product as an additive on the growth performance, body composition, and various stress resistance of juvenile abalone (*Haliotis discus*) compared to ethoxyquin. Aquacult. Rep., 24: 101187.

Das S.K., Mondal B., Biswas B., Mandal A. (2018). Herbal piscicides in inland aquaculture-a review. J. Ecol. Nat. Res., 2: 000133.

Das S., Aswani R., Midhun S.J., Radhakrishnan E.K., Mathew J. (2020). Advantage of zinc oxide nanoparticles over silver nanoparticles for the management of Aeromonas veronii infection in *Xiphophorus hellerii*. Microb. Pathogen., 147: 104348.

Das S., Mondal K., Sengupta C. (2021). Evaluation of the probiotic potential of *Streptomyces antibioticus* and *Bacillus cereus* on growth performance of freshwater catfish *Heteropneustes fossilis*. Aquacult. Rep., 20: 100752.

Dawood M.A., Abo-Al-Ela H.G., Hasan M.T. (2020). Modulation of transcriptomic profile in aquatic animals: Probiotics, prebiotics and synbiotics scenarios. Fish Shellfish Immunol., 97: 268–282.

Dawood M.A., Koshio S., Esteban M.Á. (2018). Beneficial roles of feed additives as immunostimulants in aquaculture: a review. Rev. Aquacult., 10: 950–974.

Dawood M.A., Koshio S., Zaineldin A.I., Van Doan H., Moustafa E.M., Abdel-Daim M.M., Hassaan M.S. (2019). Dietary supplementation of selenium nanoparticles modulated systemic and mucosal immune status and stress resistance of red sea bream (*Pagrus major*). Fish Physiol. Biochem., 45: 219–230.

Dawson M.R., Alam M.S., Watanabe W.O., Carroll P.M., Seaton P.J. (2018). Evaluation of poultry by-product meal as an alternative to fish meal in the diet of juvenile Black Sea Bass reared in a recirculating aquaculture system. North Am. J. Aquacult., 80: 74–87.

Diler O., Gormez O., Diler I., Metin S. (2017b). Effect of oregano (*Origanum onites* L.) essential oil on growth, lysozyme and antioxidant activity and resistance against *Lactococcus garvieae* in rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquacult. Nutr., 23: 844–851.

Dineshbabu G., Goswami G., Kumar R., Sinha A., Das D. (2019). Microalgae–nutritious, sustainable aqua-and animal feed source. J. Funct. Foods., 62: 103545.

Dong H., Zheng X., Kumar V., Roy S., Duan Y., Gao H., Zhang J. (2020). Dietary supplementation of teprenone potentiates thermal and hypoxia tolerance as well as cellular stress protection of *Epinephelus coioides* juveniles reared under multiple stressors. Aquaculture, 514: 734413.

Dong Y.Z., Xia T., Lin J. B., Wang, L., Song K., Zhang C. X. (2021). Quercetin attenuates high-fat diet-induced excessive fat deposition of spotted seabass (*Lateolabrax maculatus*) through the regulatory for mitochondria and endoplasmic reticulum. Front. Mar. Sci., 8: 746811.

Duy N.D.Q., Francis D.S., Southgate P. C. (2017). The nutritional value of live and concentrated micro-algae for early juveniles of sandfish, *Holothuria scabra*. Aquaculture, 473: 97–104.

Efianda T.R., Sari, U.E., Humeira, H., Ananda, K.R. (2020). Enhancing the productivity performance of Cyprinus carpio L. by Manihot utilissima Pohl. leaves supplementation. Biogenesis: J. Ilmiah Biol., 8: 29–34.

Efianda T.R., Wahjuningrum D., Tarman K., Yuhana M., Effendi I., Saputra F. (2018). Effects of feed supplementation of *Nodulisporium* sp. KT29 induced by *Vibrio harv*eyi cells on production performance of pacific white shrimp *Litopenaeus vannamei* cultured under marine culture system. Pak. J. Biotechnol., 15: 59–65.

Ejike C.E., Collins S.A., Balasuriya N., Swanson A.K., Mason B., Udenigwe C.C. (2017). Prospects of microalgae proteins in producing peptide-based functional foods for promoting cardiovascular health. Trend. Food Sci. Technol., 59: 30–36.

El Basuini M.F., El-Hais A.M., Dawood M.A., Abou-Zeid A.E.S., EL-Damrawy S.Z., Khalafalla M.M.E.S., Dossou S. (2016). Effect of different levels of dietary copper nanoparticles and copper sulfate on growth performance, blood biochemical profiles, antioxidant status and immune response of red sea bream (*Pagrus major*). Aquaculture, 455: 32–40.

Elabd H., Youssuf H., Mahboub H.H., Salem S.M., Husseiny W.A., Khalid A., Faggio C. (2022). Growth, hemato-biochemical, immune-antioxidant response, and gene expression in Nile tilapia (*Oreochromis niloticus*) received nano iron oxide-incorporated diets. Fish Shellfish Immunol., 128: 574–581.

El-Habashi N., Fadl S. E., Farag H.F., Gad D.M., Elsadany A.Y., El Gohary M.S. (2019). Effect of using *Spirulina* and *Chlorella* as feed additives for elevating immunity status of Nile tilapia experimentally infected with *Aeromonas hydrophila*. Aquacult. Res., 50: 2769–2781.

El-Sayed Ali T., Abdel-Aziz S.H., El-Sayed A.F.M., Zeid S. (2014). Structural and functional effects of early exposure to 4-nonylphenol on gonadal development of Nile tilapia (*Oreochromis niloticus*): b-histological alterations in testes. Fish Physiol. Biochem., 40: 1495–1507.

El-Sayed Ali T., El-Sayed A.M., Eissa M.A.R., Hanafi H. M. (2018). Effects of dietary Biogen and sodium butyrate on hematological parameters, immune response, and histological characteristics of Nile tilapia (*Oreochromis niloticus*) fingerlings. Aquacult. Int., 26: 139–150.

Esmaeili M., Kenari A.A., Rombenso A. (2017). Immunohematological status under acute ammonia stress of juvenile rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) fed garlic (*Allium sativum*) powder-supplemented meat and bone meal-based feeds. Comp. Clinical Pathol., 26: 853–866.

Faiz H., Zuberi, A., Nazir S., Rauf M., Younus N. (2015). Zinc oxide, zinc sulfate and zinc oxide nanoparticles as source of dietary zinc: comparative effects on growth and hematological indices of juvenile grass carp (*Ctenopharyngodon idella*). Int. J. Agricult. Biol., 17.

FAO (2020) The state of world fisheries and aquaculture 2020. In: Sustainability in action. FAO, Rome

Farsani M.N., Hoseinifar S.H., Rashidian G., Farsani H.G., Ashouri G., Van Doan H. (2019). Dietary effects of Coriandrum sativum extract on growth performance, physiological and innate immune responses and resistance of rainbow trout (*Oncorhynchus mykiss*) against *Yersinia ruckeri*. Fish Shellfish Immunol., 91: 233–240.

Fayed W.M., Khalil R.H., Sallam G.R., Mansour A.T., Elkhayat B.K., Omar E.A. (2019). Estimating the effective level of Yucca schidigera extract for improvement of the survival, haematological parameters, immunological responses and water quality of European seabass juveniles (*Dicentrarchus labrax*). Aquacult. Rep., 15: 100208.

Feng H., Peng D., Liang X.F., Chai F., Tang S., Li J. (2022). Effect of dietary hydroxyproline supplementation on Chinese perch (*Siniperca chuatsi*) fed with fish meal partially replaced by fermented soybean meal. Aquaculture, 547: 737454.

Firmino J.P., Galindo-Villegas J., Reyes-López F.E., Gisbert, E. (2021). Phytogenic bioactive compounds shape fish mucosal immunity. Front. Immunol., 12: 695973.

Firmino J.P., Vallejos-Vidal E., Sarasquete C., Ortiz-Delgado J. B., Balasch J.C., Tort L., Gisbert E. (2020). Unveiling the effect of dietary essential oils supplementation in *Sparus aurata* gills and its efficiency against the infestation by *Sparicotyle chrysophrii*. Sci. Rep., 10: 17764.

Fontagné-Dicharry S., Véron V., Larroquet L., Godin S., Wischhusen P., Aguirre P., Kaushik S. J. (2020). Effect of selenium sources in plant-based diets on antioxidant status and oxidative stress-related parameters in rainbow trout juveniles under chronic stress exposure. Aquaculture, 529: 735684.

Fu Y.W., Wang B., Zhang Q. Z., Xu D.H., Liu Y.M., Hou T.L., Guo S.Q. (2019). Efficacy and antiparasitic mechanism of 10-gingerol isolated from ginger *Zingiber officinale* against *Ichthyophthirius multifiliis* in grass carp. Vet. Parasitol., 265: 74–84.

Galafat A., Vizcaíno A. J., Sáez M.I., Martínez T.F., Jérez-Cepa I., Mancera J.M., Alarcón F.J. (2020). Evaluation of *Arthrospira* sp. enzyme hydrolysate as dietary additive in gilthead seabream (*Sparus aurata*) juveniles. J. Appl. Phycol., 32, 3089–3100.

Galkanda-Arachchige H.S., Roy L.A., Davis D.A. (2021). The effects of magnesium concentration in low-salinity water on growth of Pacific white shrimp (*Litopenaeus vannamei*). Aquacult. Res., 52: 589–597.

Ghafarifarsani H., Hoseinifar S.H., Raeeszadeh M., Vijayaram S., Rohani M.F., Van Doan H., Sun Y.Z. (2023). Comparative Effect of Chemical and Green Zinc Nanoparticles on the Growth, Hematology, Serum Biochemical, Antioxidant Parameters, and Immunity in Serum and Mucus of Goldfish, Carassius auratus (Linnaeus, 1758). Biol. Trace Elem. Res., 1–15.

Ghafarifarsani H., Yousefi M., Hoseinifar S. H., Paolucci M., Lumsangkul C., Jaturasitha S., Van Doan H. (2022). Beneficial effects of Persian shallot (*Allium hirtifolium*) extract on growth performance, biochemical, immunological and antioxidant responses of rainbow trout *Oncorhynchus mykiss* fingerlings. Aquaculture, 555: 738162.

Ghafarifarsani H., Rashidian G., Sheikhlar A., Naderi Farsani M., Hoseinifar S.H., Van Doan H. (2021). The use of dietary oak acorn extract to improve haematological parameters, mucosal and serum immunity, skin mucus bactericidal activity, and disease resistance in rainbow trout (*Oncorhynchus mykiss*). Aquacult. Res., 52: 2518–2527.

Ghafarifarsani H., Hoseinifar S.H., Talebi M., Yousefi M., Van Doan H., Rufchaei R., Paolucci M. (2021). Combined and singular effects of ethanolic extract of persian shallot (*Allium hirtifolium Boiss*) and synbiotic Biomin® IMBO on growth performance, serum-and mucus-immune parameters and antioxidant defense in Zebrafish (*Danio rerio*). Animals, 11: 2995.

Ghanei-Motlagh R., Gharibi D., Mohammadian T., Khosravi M., Mahmoudi E., Zarea M., El-Matbouli M. (2021). Feed supplementation with quorum quenching probiotics with anti-virulence potential improved innate immune responses, antioxidant capacity and disease resistance in Asian seabass (*Lates calcarifer*). Aquaculture, 535: 736345.

Gibson G.R., Hutkins R., Sanders M.E., Prescott S.L., Reimer R.A., Salminen S.J., Scott K., Stanton C., Swanson K.S., Cani, P.D. (2017). The International Scientific Association for Probiotics and Prebiotics (ISAPP) Consensus Statement on the Definition and Scope of Prebiotics. Nat. rev. Gastroenterol. Hepatol., 14: 491–502.

Guardiola F.A., Porcino C., Cerezuela R., Cuesta A., Faggio C., Esteban M. A. (2016). Impact of date palm fruits extracts and probiotic enriched diet on antioxidant status, innate immune response and immune-related gene expression of European seabass (*Dicentrarchus labrax*). Fish Shellfish Immunol., 52: 298–308.

Guldhe A., Ansari F. A., Singh P., Bux F. (2017). Heterotrophic cultivation of microalgae using aquaculture wastewater: a biorefinery concept for biomass production and nutrient remediation. Ecol. Eng., 99: 47–53.

Gunathilaka B.E., Medagoda N., Cha J.H., Yoo B.W., Choi S.I., Shin C.H., Lee K.J. (2022). Effects of a dietary anionic alkali mineral complex in juvenile olive flounder (*Paralichthys olivaceus*) during low water temperature season. Aquacult. Rep., 27: 101420.

Gupta A., Gupta S.K., Priyam M., Siddik M.A., Kumar N., Mishra P.K., Pattanayak A. (2021). Immunomodulation by dietary supplements: A preventive health strategy for sustainable aquaculture of tropical freshwater fish, *Labeo rohita* (Hamilton, 1822). Rev. Aquacult., 13: 2364–2394.

Hahor W., Thongprajukaew K., Suanyuk N. (2019). Effects of dietary supplementation of oligosaccharides on growth performance, gut health and immune response of hybrid catfish (*Pangasianodon gigas*× *Pangasianodon hypophthalmus*). Aquaculture, 507: 97–107.

Hasan M.T., Je Jang W., Lee J.M., Lee B.J., Hur S.W., Gu Lim S., Kong I.S. (2019). Effects of immunostimulants, prebiotics, probiotics, synbiotics, and potentially immunoreactive feed additives on olive flounder (*Paralichthys olivaceus*): a review. Rev. Fish. Sci. Aquacult., 27: 417–437.

Hassaan M.S., Mohammady E.Y., Soaudy M.R., Elashr, M.A., Moustafa M.M., Wassel M.A., Elsaied H.E. (2021). Synergistic effects of *Bacillus pumilus* and exogenous protease on Nile tilapia (*Oreochromis niloticus*) growth, gut microbes, immune response and gene expression fed plant protein diet. Animal Feed Sci. Technol., 275: 114892.

Hlordzi V., Kuebutornye F. K., Afriyie G., Abarike E. D., Lu Y., Chi S., Anokyewaa M.A. (2020). The use of *Bacillus* species in maintenance of water quality in aquaculture: A review. Aquacult. Rep., 18: 100503.

Hosain M. A., Liangyi X. (2020). Impacts of probiotics on feeding technology and its application in aquaculture (2020) Journal of Aquaculture. Fisheries Fish Sci., 3: 174–185.

Hoseini S.M., Hosseini S.A., Eskandari S., Amirahmadi M. (2018). Effect of dietary taurine and methionine supplementation on growth performance, body composition, taurine retention and lipid status of Persian sturgeon, *Acipenser persicus* (Borodin, 1897), fed with plant-based diet. Aquacult. Nutr., 24: 324–331.

Hoseini S.M., Hosseini S. A., Eskandari S., Amirahmadi M., Soudagar M. (2017). The effect of dietary taurine on growth performance and liver histopathology in Persian sturgeon, *Acipenser persicus* (Borodin, 1897) fed plant-based diet. Aquacult. Res., 48: 4184–4196.

Hoseinifar S. H., Ringø E., Shenavar Masouleh A., Esteban M.Á. (2016). Probiotic, prebiotic and synbiotic supplements in sturgeon aquaculture: a review. Rev. Aquacult., 8: 89–102.

Hu Y., Feng L., Jiang W., Wu P., Liu Y., Kuang S., Zhou X. (2021). Lysine deficiency impaired growth performance and immune response and aggravated inflammatory response of the skin, spleen and head kidney in grown-up grass carp (*Ctenopharyngodon idella*). Anim. Nutr., 7: 556–568.

Huang D., Maulu S., Ren M., Liang H., Ge X., Ji K., Yu H. (2021). Dietary lysine levels improved antioxidant capacity and immunity via the TOR and p38 MAPK signaling pathways in grass carp, *Ctenopharyngodon idellus* fry. Front. Immunol., 12: 635015.

Husain F., Duraisamy S., Balakrishnan S., Ranjith S., Chidambaram P., Kumarasamy A. (2022). Phenotypic assessment of safety and probiotic potential of native isolates from marine fish *Moolgarda seheli* towards sustainable aquaculture. Biologia, 77: 775–790.

Hussain S.M., Gohar H., Asrar M., Shahzad M.M., Rasul A., Hussain M., Umair M. (2020). Effects of polyphenols supplemented canola meal based diet on proximate composition, minerals absorption and hematology of *Cyprinus carpio* fingerlings. Pak. J. Zool., 54: 1071–1079.

Idowu T.A., Adedeji H.A., Sogbesan O.A. (2017). Fish disease and health management in aquaculture production. Int. J. Env. Agricult. Sci., 1.

Islam M.M., Ferdous Z., Mamun M.M.U., Akhter F., Zahangir M.M. (2021). Amelioration of growth, blood physiology and water quality by exogenous dietary supplementation of pepsin in striped catfish, *Pangasianodon hypophthalmus*. Aquaculture, 530: 735840.

Jones S.W., Karpol A., Friedman S., Maru B.T., Tracy B.P. (2020). Recent advances in single cell protein use as a feed ingredient in aquaculture. Curr. Opin. Biotechnol., 61: 189–197.

Joy J. M., Joseph A., Anandan R. (2021). The role of carotenoids in enhancing the health of aquatic organisms. Int. J. Fish. Aquat. Stud., 9: 250–254.

Kai Y., Nishikawa J., Yamamoto N (2018) Supplemental effects of Euglena on Japanese quails. J. Poult Sci., 55: 26–31.

Kamalam B.S., Medale F., Panserat S. (2017). Utilisation of dietary carbohydrates in farmed fishes: new insights on influencing factors, biological limitations and future strategies. Aquaculture, 467: 3–27.

Khani M., Soltani M., Mehrjan M.S., Foroudi F., Ghaeni M. (2017). The effect of Chlorella vulgaris (*Chlorophyta*, *Volvocales*) microalga on some hematological and immune system parameters of Koi carp (*Cyprinus carpio*). Iranian J. Ichthyol., 4: 62–68.

Knutsen H.R., Ottesen O.H., Palihawadana A.M., Sandaa W., Sørensen M., Hagen Ø. (2019). Muscle growth and changes in chemical composition of spotted wolffish juveniles (*Anarhichas minor*) fed diets with and without microalgae (*Scenedesmus obliquus*). Aquacult. Rep., 13: 100175.

Kondo H., Kikumoto T., Yoshii K., Murase N., Yamada H., Fukuda Y., Hirono I. (2021). Effects of peptidoglycan and polyinosinic: polycytidylic acid on the recombinant subunit vaccine efficacy against *Edwardsiella tarda* in Japanese flounder (*Paralichthys olivaceus*). Fish Pathol., 56: 149–155.

Kong Y., Li M., Chu G., Liu H., Shan X., Wang G., Han, G. (2021). The positive effects of single or conjoint administration of lactic acid bacteria on *Channa argus*: Digestive enzyme activity, antioxidant capacity, intestinal microbiota and morphology. Aquaculture, 531: 735852.

Kong Y., Li M., Guo G., Yu L., Sun L., Yin Z., Wang G. (2021). Effects of dietary curcumin inhibit deltamethrin-induced oxidative stress, inflammation and cell apoptosis in *Channa argus* via Nrf2 and NF-κB signaling pathways. Aquaculture, 540: 736744.

Kong Y., Li S., Liu M., Yao C., Yang X., Zhao N., Li M. (2019). Effect of dietary organic selenium on survival, growth, antioxidation, immunity and gene expressions of selenoproteins in abalone *Haliotis discus hannai*. Aquacult. Res., 50: 847–855.

Kumar N.P.B., Mahaboobi S., Akhilesh T. (2016). Effect of feed additives on growth performance of fish. J. Fisheries Sci. Com., 10: 84.

Kumar N., Krishnani K.K., Singh N.P. (2018). Effect of dietary zinc-nanoparticles on growth performance, anti-oxidative and immunological status of fish reared under multiple stressors. Biol. Trace Elem. Res., 186: 267–278.

Kupchinsky Z.A., Coyle S.D., Bright L.A., Tidwell J. H. (2015). Evaluation of heterotrophic algae meal as a diet ingredient for channel catfish, *Ictalurus punctatus*. J. World Aquacult. Soc., 46: 445–452.

Lauzon Q.D., Serrano Jr A.E. (2015). Ulvan extract from Enteromorpha intestinalis enhances immune responses in *Litopenaeus vannamei* and *Penaeus monodon* juveniles. Animal Biol. Animal Hus., 7: 1–10.

Li J. M., Zhang Z., Kong A., Lai W., Xu W., Cao X., Ai Q. (2023). Dietary L-carnitine regulates liver lipid metabolism via simultaneously activating fatty acid β-oxidation and suppressing endoplasmic reticulum stress in large yellow croaker fed with high-fat diets. Brit. J. Nutr., 129: 29–40.

Li J., Xu W., Lai W., Kong A., Zhang Z., Pang Y., Ai Q. (2021). Effect of dietary methionine on growth performance, lipid metabolism and antioxidant capacity of large yellow croaker (*Larimichthys crocea*) fed with high lipid diets. Aquaculture, 536: 736388.

Li M. Y., Guo W. Q., Guo G. L., Zhu X. M., Niu X. T., Shan X. F., Zhang D. M. (2020). Effects of dietary astaxanthin on lipopolysaccharide-induced oxidative stress, immune responses and glucocorticoid receptor (GR)-related gene expression in *Channa argus*. Aquaculture, 517: 734816.

Li M., Liang H., Xie J., Chao W., Zou F., Ge X., Ren M. (2021). Diet supplemented with a novel *Clostridium autoethanogenum* protein have a positive effect on the growth performance, antioxidant status and immunity in juvenile Jian carp (*Cyprinus carpio var. Jian*). Aquacult. Rep., 19: 100572.

Li P., Hou D., Zhao H., Peng K., Chen B., Guo H., Cao, J. (2022). Effects of dietary arginine levels on intestinal morphology, digestive enzyme activity, antioxidant capacity and intestinal flora of hybrid snakehead (*Channa maculata*♀× *Channa argus*♂). Aquacult. Rep., 25: 101244.

Li X., Zheng S., Wu G. (2021). Nutrition and functions of amino acids in fish. In *Amino acids in nutrition and health* (pp. 133–168). Cham: Springer. https://pubmed. ncbi.nlm.nih.gov/33770406/.

Li Y., Liang S., Shao Y., Li Y., Chen C., You C., Wang S. (2021). Impacts of dietary konjac glucomannan supplementation on growth, antioxidant capacity, hepatic lipid metabolism and inflammatory response in golden pompano (*Trachinotus ovatus*) fed a high fat diet. Aquaculture, 545: 737113.

Lin H.L., Shiu Y.L., Chiu C.S., Huang S.L., Liu C.H. (2017). Screening probiotic candidates for a mixture of probiotics to enhance the growth performance, immunity, and disease resistance of Asian seabass, *Lates calcarifer* (Bloch), against *Aeromonas hydrophila*. Fish  Shellfish Immunol., 60: 474–482.

Lin H., Chen X., Yang Y., Wang J., Huang X., Huang Z., Qi, C. (2016). Effect of different levels of *Spirulina platensis* dietary supplementation on the growth, body color, digestion, and immunity of *Trachinotus ovatus*. Israeli J. Aquacult.-Bamidgeh., 68.

Liu F., Zhang Y., Wang F. (2021). Effect of jujube (*Ziziphus jujuba*) extract on intestinal flora, digestion, and immunity of rainbow trout (*Oncorhynchus mykiss*). Aquacult. Rep., 21: 100890.

Liu H., Zhou M., Dong X., Tan B., Du T., Zhang S., Liu H. (2021). Liver immune parameters, complement pathway, inflammatory factor and TOR genes expression of silver sillago, Sillago sihama, fed with diets replacing fish meal with low-gossypol cottonseed meal. Aquacult. Nutr., 27: 1934–1945.

Liu W.C., Zhou S. H., Balasubramanian B., Zeng F. Y., Sun C.B., Pang H.Y. (2020). Dietary seaweed (*Enteromorpha*) polysaccharides improves growth performance involved in regulation of immune responses, intestinal morphology and microbial community in banana shrimp *Fenneropenaeus merguiensis*. Fish Shellfish Immunol., 104: 202–212.

Loh J.Y. (2017). The role of probiotics and their mechanisms of action: an aquaculture perspective. World Aquac., 48: 19–23.

Lu Q., Li H., Zou Y., Liu H., Yang L. (2021). Astaxanthin as a microalgal metabolite for aquaculture: A review on the synthetic mechanisms, production techniques, and practical application. Algal Res., 54: 102178.

Luo J., Zhu T., Wang X., Cheng X., Yuan Y., Jin M., Zhou Q. (2020). Toxicological mechanism of excessive copper supplementation: Effects on coloration, copper bioaccumulation and oxidation resistance in mud crab *Scylla paramamosain*. J. Haz. Mat., 395: 122600.

M Ghoname R., S El-sayed H., A Ghozlan H.A., Sabry S. (2020). Application of probiotic bacteria for the improvement of sea bream (*Sparus aurata*) larval production. Egypt. J. Aquatic Biol. Fish., 24: 371–398.

Madeira M.S., Cardoso C., Lopes P. A., Coelho D., Afonso C., Bandarra N.M., Prates J.A. (2017). Microalgae as feed ingredients for livestock production and meat quality: A review. Livest. Sci., 205: 111–121.

Magrone T., Russo M. A., Jirillo E. (2018). Dietary approaches to attain fish health with special reference to their immune system. Current Pharma. Des., 24: 4921–4931.

Makridis P., Kokou F., Bournakas C., Papandroulakis N., Sarropoulou E. (2021). Isolation of *Phaeobacter* sp. from larvae of Atlantic Bonito (*Sarda Sarda*) in a mesocosmos unit, and its use for the rearing of European seabass larvae (*Dicentrarchus labrax* L.). Microorg., 9: 128.

Maliwat G.C., Velasquez S., Robil J.L., Chan M., Traifalgar R.F., Tayamen M., Ragaza J.A. (2017). Growth and immune response of giant freshwater prawn *Macrobrachium rosenbergii* (De Man) postlarvae fed diets containing *Chlorella vulgaris* (Beijerinck). Aquacult. Res., 48: 1666–1676.

Maradze D., Capel A., Martin N., Lewis M.P., Zheng Y., Liu Y. (2019). In vitro investigation of cellular effects of magnesium and magnesium-calcium alloy corrosion products on skeletal muscle regeneration. J. Mat. Sci. Technol., 35: 2503–2512.

Martin S.A., Król E. (2017). Nutrigenomics and immune function in fish: new insights from omics technologies. Dev. Comp. Immunol., 75: 86–98.

Martin S.A., Dehler C.E., Król E. (2016). Transcriptomic responses in the fish intestine. Dev. Comp. Immunol., 64: 103–117.

Miao L., Zhang Y., Lin Y., Liu B., Ge X. (2021). Appropriate leucine supplementation promotes glucose metabolism and enhances energy homeostasis in juvenile crucian carp (*Carassius auratus gibelio* var. CAS III). Comparative Biochem. Physiol. Part D: Genom. Proteom., 40: 100907.

Mirbakhsh M., Ghaednia B., Zorriehzahra M.J., Esmaeili F., Faggio C. (2023). Dietary mixed and sprayed probiotic improves growth performance and digestive enzymes of juvenile whiteleg shrimp (*Litopenaeus vannamei*, Boone, 1931). J. Appl. Aquacult., 35: 823–836.

Mirghaed A.T., Hoseini S.M., Hoseinifar S.H., Van Doan H. (2020). Effects of dietary thyme (*Zataria multiflora*) extract on antioxidant and immunological responses and immune-related gene expression of rainbow trout (*Oncorhynchus mykiss*) juveniles. Fish Shellfish Immunol., 106: 502–509.

Mirghaed A.T., Yarahmadi P., Craig P.M., Farsani H.G., Ghysvandi N., Eagderi S. (2018). Hemato-immunological, serum metabolite and enzymatic stress response alterations in exposed rainbow trout (*Oncorhynchus mykiss*) to nanosilver. Int. J. Aquatic Boil., 6: 221–234.

Moghanlou K.S., Isfahani E.N., Dorafshan S., Tukmechi A., Aramli M.S. (2018). Effects of dietary supplementation with Stachys lavandulifolia Vahl extract on growth performance, hemato-biochemical and innate immunity parameters of rainbow trout (*Oncorhynchus mykiss*). Anim. Feed Sci. Technol., 237: 98–105.

Mohammadi G., Adorian T.J., Rafiee G. (2020). Beneficial effects of *Bacillus subtilis* on water quality, growth, immune responses, endotoxemia and protection against lipopolysaccharide-induced damages in *Oreochromis niloticus* under biofloc technology system. Aquacult. Nutr., 26: 1476–1492.

Mohammadi G., Rashidian G., Hoseinifar S.H., Naserabad S.S., Van Doan H. (2020). Ginger (*Zingiber officinale*) extract affects growth performance, body composition, haematology, serum and mucosal immune parameters in common carp (*Cyprinus carpio*). Fish Shellfish Immunol., 99: 267–273.

Mohammadi M., Heyrati F.P., Dorafshan S. (2019). Effects of Diet Containing Wood Betony, *Stachys Lavandulifolia* Extract On Growth, Gut Microbiota And Intestinal Structure Of The African Cichlid, *Sciaenochromis Fryeri*. Iran. J. Ichthyol., 6: 292–301.

Mohammady E.Y., Soaudy M.R., Abdel-Rahman A., Abdel-Tawwab M., Hassaan M.S. (2021). Comparative effects of dietary zinc forms on performance, immunity, and oxidative stress-related gene expression in Nile tilapia, (*Oreochromis niloticus*). Aquaculture, 532: 736006.

Mohan K., Muralisankar T., Uthayakumar V., Chandirasekar R., Revathi N., Ganesan A.R., Seedevi P. (2020). Trends in the extraction, purification, characterisation and biological activities of polysaccharides from tropical and sub-tropical fruits – a comprehensive review. Carbohydr. Poly., 238: 116185.

Mohan K., Ravichandran S., Muralisankar T., Uthayakumar V., Chandirasekar R., Seedevi P., Rajan D. K. (2019). Application of marine-derived polysaccharides as immunostimulants in aquaculture: A review of current knowledge and further perspectives. Fish Shellfish Immunol., 86: 1177–1193.

Mondal H., Chandrasekaran N., Mukherjee A., Thomas J. (2021). Viral infections in cultured fish and shrimps: current status and treatment methods. Aquacult. Int., 1–36.

Monto A.R., Li M., Wang X., Wijaya G.Y.A., Shi T., Xiong Z., Gao R. (2022). Recent developments in maintaining gel properties of surimi products under reduced salt conditions and use of additives. Critical Rev. Food Sci. Nutr., 62: 8518–8533.

Morshedi V., Bojarski B., Hamedi S., Torahi H., Hashemi G., Faggio C. (2021). Effects of dietary bovine lactoferrin on growth performance and immuno-physiological responses of Asian sea bass (*Lates calcarifer*) fingerlings. Prob. Antimicrob. Protein., 13: 1790–1797.

Munawar N., Aleem M., Abru S., Laraib T., Zainab S. N., Manzoor S. (2021). Interaction and applications of nanoparticles in fishes and aquaculture. Sch Bull, 7: 150–155.

Muralisankar T., Bhavan P.S., Radhakrishnan S., Seenivasan C., Srinivasan V. (2016). The effect of copper nanoparticles supplementation on freshwater prawn *Macrobrachium rosenbergii* post larvae. J. Trace Elem. Med. Biol., 34: 39–49.

Muralisankar T., Bhavan P. S., Radhakrishnan S., Seenivasan C., Manickam N., Srinivasan V. (2014). Dietary supplementation of zinc nanoparticles and its influence on biology, physiology and immune responses of the freshwater prawn, *Macrobrachium rosenbergii*. Biol. Trace Elem. Res., 160: 56–66.

Musharraf M., Khan M.A. (2019a). Dietary phosphorus requirement of fingerling Indian major carp, *Labeo rohita* (Hamilton). J. World Aquacult. Soc., 50: 469–484.

Musharraf M., Khan M.A. (2019b). Dietary zinc requirement of fingerling Indian major carp, *Labeo rohita* (Hamilton). Aquaculture, 503: 489–498.

Musharraf M., Khan M.A. (2019c). Requirement of fingerling Indian major carp, *Labeo rohita* (Hamilton) for dietary iron based on growth, whole body composition, haematological parameters, tissue iron concentration and serum antioxidant status. Aquaculture, 504: 148–157.

Nandeesha M.C., Gangadhar B., Varghese T.J., Keshavanath P. (1998). Effect of feeding *Spirulina platensis* on the growth, proximate composition and organoleptic quality of common carp, *Cyprinus carpio* L. Aquacult. Res., 29: 305–312.

Na-Phatthalung P., Teles M., Tort L., Oliveira M. (2018). Gold nanoparticles exposure modulates antioxidant and innate immune gene expression in the gills of *Sparus aurata*. Genomics, 110: 430–434.

Nazeemashahul S., Prasad Sahu N., Sardar P., Fawole F. J., Kumar S. (2020). Additional feeding of vitamin–mineral based nutraceutical to stress-exposed rohu, *Labeo rohita*, enhances the IGF1 gene expression and growth. Aquacult. Res., 51: 2649–2666.

Ning Y., Wu X., Zhou X., Ding J., Chang Y., Yang Z., Zuo R. (2021). An evaluation on the selenium yeast supplementation in the practical diets of early juvenile sea cucumber (*Apostichopus japonicus*): Growth performance, digestive enzyme activities, immune and antioxidant capacity, and body composition. Aquacult. Nutr., 27: 2142–2153.

Novoveská L., Ross M.E., Stanley M.S., Pradelles R., Wasiolek V., Sassi J.F. (2019). Microalgal carotenoids: A review of production, current markets, regulations, and future direction. Mar. Drugs, 17: 640.

Nunes A.J., Sabry-Neto H., Oliveira-Neto S., Burri L. (2019). Feed preference and growth response of juvenile *Litopenaeus vannamei* to supplementation of marine chemoattractants in a fishmeal-challenged diet. J. World Aquacult. Soc., 50: 1048–1063.

Nurmalasari Liu C.H., Maftuch I.M., Hu S.Y. (2022). Dietary Supplementation with Prebiotic Chitooligosaccharides Enhances the Growth Performance, Innate Immunity and Disease Resistance of Nile Tilapia (*Oreochromis niloticus*). Fishes, 7: 313.

Ojerio V.T., Corre V.L., Toledo N.A., Andrino-Felarca K.G.S., Nievales L.M., Traifalgar R.F. M. (2018). Alginic acid as immunostimulant: effects of dose and frequency on growth performance, immune responses, and white spot syndrome virus resistance in tiger shrimp *Penaeus monodon* (Fabricius, 1798). Aquacult. Int., 26: 267–278.

Okeke E.S., Chukwudozie K.I., Nyaruaba R., Ita R.E., Oladipo A., Ejeromedoghene O., Okoye C. O. (2022). Antibiotic resistance in aquaculture and aquatic organisms: a review of current nanotechnology applications for sustainable management. Environ. Sci. Pollut. Res., 29: 69241–69274.

Okey I.B., Gabriel U.U., Deekae S.N. (2018). The use of synbiotics (Prebiotic and probiotic) in aquaculture development. Sumerianz J. Biotechnol., 1: 51–60

Oushani A.K., Soltani M., Sheikhzadeh N., Mehrgan M.S., Islami H. R. (2020). Effects of dietary chitosan and nano-chitosan loaded clinoptilolite on growth and immune responses of rainbow trout (*Oncorhynchus mykiss*). Fish Shellfish Immunol., 98: 210–217.

Öz M., Dikel S., Durmus M. (2018). Effect of black cumin oil (*Nigella sativa*) on the growth performance, body composition and fatty acid profile of rainbow trout (*Oncorhynchus mykiss*). Iran. J. Fisheries Sci., 17: 713–724.

Pastaki N.J., Abdollahpour H., Karimzadeh M., Zamani H., Multisanti C.R., Faggio C. (2023). Physiological and immunological impact of methanolic lavender extract on female goldfish (*Carassius auratus*). Aquacult. Rep., 33: 101841.

Pati P., Mondal K., Mandal M. (2021). The use of Aloe vera gel functionalized biogenic Zinc-Oxide nanoparticles against fish putative pathogens. Aquat. Sci. Eng., 36: 101–108.

Pattanaik S.S., Sawant P.B., KA M.X., Srivastava P.P., Dube K., Sawant B. T., Chadha N.K. (2021). Dietary carotenoprotien extracted from shrimp shell waste augments growth, feed utilization, physio-metabolic responses and colouration in Oscar, *Astronotus ocellatus* (Agassiz, 1831). Aquaculture, 534: 736303.

Paulpandian P., Beevi I.S., Somanath B., Kamatchi R.K., Paulraj B., Faggio C. (2023). Impact of *Camellia sinensis* iron oxide nanoparticle on growth, hemato-biochemical and antioxidant capacity of blue gourami (*Trichogaster trichopterus*) fingerlings. Biol. Trace Elem. Res., 201: 412–424.

Peres H., Freitas J.M.A., Carvalho P.L.P., Furuya W.M., Satori M.M.P., Oliva-Teles A., Barros M.M. (2022). Growth performance and metabolic responses of Nile tilapia fed diets with different protein to energy ratios. Aquaculture, 547: 737493.

Prem R., Tewari V.K. (2020). Development of human-powered fish feeding machine for freshwater aquaculture farms of developing countries. Aquacult. Eng., 88: 102028.

Pushparaj K., Kuchi Bhotla H., Pappuswamy M., Issara U., Balasubramanian B., Al-Dhabi N.A., Meyyazhagan A. (2022). Perspectives and implications of probiotics as beneficial mediators in aquaculture industry. In Aquaculture science and engineering (pp. 79–97). Singapore: Springer Nature Singapore.

Qin F., Shi M., Yuan H., Yuan L., Lu W., Zhang J., Song X. (2016). Dietary nano-selenium relieves hypoxia stress and, improves immunity and disease resistance in the Chinese mitten crab (*Eriocheir sinensis*). Fish Shellfish Immunol, 54: 481–488.

Radhakrishnan S., Belal I. E., Seenivasan C., Muralisankar T., Bhavan P. S. (2016). Impact of fishmeal replacement with Arthrospira platensis on growth performance, body composition and digestive enzyme activities of the freshwater prawn, *Macrobrachium rosenbergii*. Aquacult. Rep., 3: 35–44.

Ragunath C., Ramasubramanian V. (2022). Dietary effect of Padina boergesenii on growth, immune response, and disease resistance against *Pseudomonas aeruginosa* in *Cirrhinus mrigala*. Appl. Biochem. Biotechnol., 194: 1881–1897.

Rahman A.N.A., Khalil A.A., Abdallah H.M., ElHady M. (2018). The effects of the dietary supplementation of Echinacea purpurea extract and/or vitamin C on the intestinal histomorphology, phagocytic activity, and gene expression of the Nile tilapia. Fish Shellfish Immunol., 82: 312–318.

Ramadhani D. E., Widanarni W., Sukenda S. (2019). Microencapsulation of probiotics and its applications with prebiotic in Pacific white shrimp larvae through *Artemia* sp. J. Akuakultur Indonesia, 18: 130–140.

Rashidian G., Kajbaf K., Prokić M.D., Faggio C. (2020). Extract of common mallow (*Malvae sylvestris*) enhances growth, immunity, and resistance of rainbow trout (*Oncorhynchus mykiss*) fingerlings against *Yersinia ruckeri* infection. Fish Shellfish. Immunol., 96: 254–261.

Rashidian G., Lazado C.C., Mahboub H.H., Mohammadi-Aloucheh R., Prokić M.D., Nada H.S., Faggio C. (2021). Chemically and green synthesized ZnO nanoparticles alter key immunological molecules in common carp (*Cyprinus carpio*) skin mucus. Int. J. Mol. Sci., 22: 3270.

Ringø E., Song S. K. (2016). Application of dietary supplements (synbiotics and probiotics in combination with plant products and β-glucans) in aquaculture. Aquacult. Nutr., 22: 4–24.

Roy S., Bossier P., Norouzitallab P., Vanrompay D. (2020). Trained immunity and perspectives for shrimp aquaculture. Rev. Aquacult., 12: 2351–2370.

Rudi M., Sukenda S., Wahjuningrum D., Pasaribu W., Hidayatullah D. (2019). Seaweed extract of *Gracilaria verrucosa* as an antibacterial and treatment against Vibrio harveyi infection of *Litopenaeus vannamei*. J. Akuakult. Indonesia, 18: 120–129.

Saeed M., Arain M. A., Ali Fazlani S., Marghazani I.B., Umar M., Soomro J., Alagawany M. (2021). A comprehensive review on the health benefits and nutritional significance of fucoidan polysaccharide derived from brown seaweeds in human, animals and aquatic organisms. Aquacult. Nutr., 27: 633–654.

Salminen S., Collado M.C., Endo A., Hill C., Lebeer S., Quigley E.M., Vinderola, G. (2021). The International Scientific Association of Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of postbiotics. Nat. Rev. Gastroenterol. Hepatol., 18: 649–667.

Sampath W.W.H.A., Rathnayake R.M.D.S., Yang M., Zhang W., Mai K. (2020). Roles of dietary taurine in fish nutrition. Mar. Life Sci. Technol., 2: 360–375.

Sarkar B., Kumar M., Rathore R. M., Verma S. (2015). Effect of dietary nanosilver on gut proteases and general performance in Zebrafish (*Danio rerio*). Int. J. Aquatic Biol., 3: 60–67.

Sarker P.K., Kapuscinski A.R., Bae A.Y., Donaldson E., Sitek A.J., Fitzgerald D.S., Edelson O. F. (2018). Towards sustainable aquafeeds: Evaluating substitution of fishmeal with lipid-extracted microalgal co-product (*Nannochloropsis oculata*) in diets of juvenile Nile tilapia (*Oreochromis niloticus*). PLoS One, 13: e0201315.

Sattanathan G., Palanisamy T., Padmapriya S., Arumugam V.A., Park S., Kim I.H., Balasubramanian, B. (2020). Influences of dietary inclusion of algae *Chaetomorpha aerea* enhanced growth performance, immunity, haematological response and disease resistance of *Labeo rohita* challenged with *Aeromonas hydrophila*. Aquacult. Rep., 17: 100353.

Sattanathan G., Tamizhazhagan V., Padmapriya S., Liu, W. C., Balasubramanian, B. (2020). Effect of green algae *Chaetomorpha antennina* extract on growth, modulate immunity, and defenses against Edwardsiella tarda infection in *Labeo rohita*. Animals, 10: 2033.

Shaalan M., El-Mahdy M., Saleh M., El-Matbouli M. (2018). Aquaculture in Egypt: insights on the current trends and future perspectives for sustainable development. Rev. Fish. Sci. Aquacult., 26: 99–110.

Sharawy Z. Z., Ashour M., Abbas E., Ashry O., Helal M., Nazmi H., Goda A. (2020). Effects of dietary marine microalgae, *Tetraselmis suecica*, on production, gene expression, protein markers and bacterial count of Pacific white shrimp *Litopenaeus vannamei*. Aquacult. Res., 51: 2216–2228.

Sharifuzzaman S. M., Austin B. (2017). Probiotics for disease control in aquaculture. Diag. Control Dis. Fish Shellfish., 189–222.

Shi Q., Wen Z., Wang J., Hu P., Zou Y., Wang S., Qin C. (2022). Effects of dietary pyrroloquinoline quinone on growth performance, serum biochemical parameters, antioxidant status, and growth-related genes expressions in juvenile yellow catfish, *Pelteobagrus fulvidraco.* Front. Mar. Sci., 9: 989948.

Siddik M.A., Foysal M.J., Fotedar R., Francis D.S., Gupta S.K. (2022). Probiotic yeast Saccharomyces cerevisiae coupled with *Lactobacillus casei* modulates physiological performance and promotes gut microbiota in juvenile barramundi, *Lates calcarifer*. Aquaculture, 546: 737346.

Soltani M., Pakzad K., Taheri-Mirghaed A., Mirzargar S., Shekarabi S.P. H., Yosefi P., Soleymani N. (2019). Dietary application of the probiotic *Lactobacillus plantarum* 426951 enhances immune status and growth of rainbow trout (*Oncorhynchus mykiss*) vaccinated against Yersinia ruckeri. Prob. Antimicrob. Protein., 11: 207–219.

Suehs B., Gatlin D. M., III (2021). Evaluating the dietary taurine requirement of hybrid striped bass (*Morone chrysops x M. saxatilis*). Aquaculture, 536, Article 736473.

Sukenik A., Tchernov D, Kaplan A. (2019) From biotechnology to food technology: Microalgae cultivation for biofuel, omega-3 fatty acids, protein, antioxidants, starch, and colorants, in Handbook of Microalgae-Based Processes and Products, Edited by Garcia-Vaquero M, Rajauria G, Academic Press, pp. 343–377.

Sun Z. G., Li Z. N., Miao X. W., Li S., Zhu H. L. (2021). Recent advances in natural products with antiviral activities. Mini Rev. Med. Chem., 21: 1888–1908.

Tang R.Y., Wu Z.L., Wang G.Z., Liu W. C. (2018). The effect of *Bacillus amyloliquefaciens* on productive performance of laying hens. It. J. Anim. Sci., 17: 436–441.

Technavio (2021). Animal feed market by animal type and geography – forecast and analysis 2021–2025.

Tejido-Nuñez Y., Aymerich E., Sancho L., Refardt D. (2020). Co-cultivation of microalgae in aquaculture water: Interactions, growth and nutrient removal efficiency at laboratory-and pilot-scale. Algal. Res., 49: 101940.

Teuling E., Wierenga P.A., Agboola J. O., Gruppen H., Schrama J. W. (2019). Cell wall disruption increases bioavailability of *Nannochloropsis gaditana* nutrients for juvenile Nile tilapia (*Oreochromis niloticus*). Aquaculture, 499: 269–282.

Teuling E., Wierenga P.A, Schrama J.W. (2019) Microalgae as sustainable ingredient for aquafeeds: A review on composition, production and applications. Aquaculture, 518: 734833.

Tibaldi E., Zittelli G. C., Parisi G., Bruno M., Giorgi G., Tulli F., Poli B.M. (2015). Growth performance and quality traits of European sea bass (*D. labrax*) fed diets including increasing levels of freeze-dried Isochrysis sp.(T-ISO) biomass as a source of protein and n-3 long chain PUFA in partial substitution of fish derivatives. Aquaculture, 440: 60–68.

Valladão G.M.R., Gallani S.U., Kotzent S., Assane I.M., Pilarski F. (2019). Effects of dietary thyme essential oil on hemato-immunological indices, intestinal morphology, and microbiota of Nile tilapia. Aquacult. Int., 27: 399–411.

Van Doan H., Hoseinifar S.H., Ringø E., Angeles Esteban M., Dadar M., Dawood M.A., Faggio C. (2020). Host-associated probiotics: a key factor in sustainable aquaculture. Rev. Fish. Sci. Aquacult., 28: 16–42.

Van Doan H., Hoseinifar S. H., Sringarm K., Jaturasitha S., Khamlor T., Dawood M.A., Musthafa M. S. (2019). Effects of elephant's foot (*Elephantopus scaber*) extract on growth performance, immune response, and disease resistance of Nile tilapia (*Oreochromis niloticus*) fingerlings. Fish Shellfish Immunol., 93: 328–335.

Vasantharaj S., Shivakumar P., Sathiyavimal S., Senthilkumar P., Vijayaram S., Shanmugavel M., Pugazhendhi A. (2023). Antibacterial activity and photocatalytic dye degradation of copper oxide nanoparticles (CuONPs) using Justicia gendarussa. Appl. Nanosci., 13: 2295–2302.

Vieira B.R.M., Guermandi I.I., Bellot M.S., Camargo dos Santos B., Favero-Neto J., Giaquinto P. C. (2021). The effects of tryptophan supplementation on stress and aggression in Nile tilapia. J. Appl. Ichthyol., 37: 578–584.

Vijayakumar S., Vaseeharan B., Sudhakaran R., Jeyakandan J., Ramasamy P., Sonawane A., Faggio C. (2019). Bioinspired zinc oxide nanoparticles using Lycopersicon esculentum for antimicrobial and anticancer applications. J. Cluster Sci., 30: 1465–1479.

Vijayaram S., Kannan S. (2018). Probiotics: The marvelous factor and health benefits. Biomed. a Biotechnol. Res. J., (BBRJ), 2: 1–8.

Vijayaram S., Chou C.C., Razafindralambo H., Ghafarifarsani H., Divsalar E., Van Doan H. (2024). *Bacillus* sp. as potential probiotics for use in tilapia fish farming aquaculture – a review. Ann. Anim. Sci., DOI:10.2478/aoas-2024-0031

Vijayaram S., Razafindralambo H., Sun Y.Z., Ghafarifarsani H., Hoseinifar S.H., Raeeszadeh M., Doan H.V. (2024). Application development on *Brassica* species in aquaculture – a review. Ann. Anim. Sci., 24: 321–329.

Vijayaram S., Razafindralambo H., Sun Y.Z., Piccione G., Multisanti C.R., Faggio C. (2024). Synergistic interaction of nanoparticles and probiotic delivery: A review. J. Fish Dis., e13916.

Vijayaram S., Razafindralambo H., Sun Y.Z., Vasantharaj S., Ghafarifarsani H., Hoseinifar S. H., Raeeszadeh M. (2023). Applications of Green Synthesized Metal Nanoparticles – A Review. Biol. Trace Elem. Res., 1–27.

Vijayaram S., Ringø E., Ghafarifarsani H., Hoseinifar S. H., Ahani S., Chou C. C. (2024). Use of Algae in Aquaculture: A Review. Fishes, 9: 63.

Vijayaram S., Sun Y.Z., Zuorro A., Ghafarifarsani H., Van Doan H., Hoseinifar S. H. (2022). Bioactive immunostimulants as health-promoting feed additives in aquaculture: A review. Fish Shellfish Immunol., 130: 294–308.

Vijayaram S., Tsigkou K., Zuorro A., Sun, Y. Z., Rabetafika H., Razafindralambo H. (2023). Inorganic nanoparticles for use in aquaculture. Rev. Aquacult., 15: 1600–1617.

Vijayaram,S., Elboughdiri N., Razafindralambo H., Sun, Y.Z., Nedaei S., Ghafarifarsani H. (2024). Application of herbal dietary supplements in aquaculture – a review. Ann. Anim. Sci., 24: 657–673.

Wang C. A., Li J., Wang L., Zhao Z., Luo L., Du X., Xu Q. (2017). Effects of dietary phosphorus on growth, body composition and immunity of young taimen *Hucho taimen* (Pallas, 1773). Aquacult. Res., 48: 3066–3079.

Wang F., Liu H., Liu F., Chen W. (2020). Effects of Chinese yam (*Dioscorea oppositifolia L.*) dietary supplementation on intestinal microflora, digestive enzyme activity and immunity in rainbow trout (*Oncorhynchus mykiss*). Aquacult. Res., 51: 4698–4712.

Wang H., Wang C., Tang Y., Sun B., Huang J., Song X. (2018). *Pseudoalteromonas* probiotics as potential biocontrol agents improve the survival of *Penaeus vannamei* challenged with acute hepatopancreatic necrosis disease (AHPND)-causing Vibrio parahaemolyticus. Aquaculture, 494: 30–36.

Wang J., Zhang D., Wang Y., Liu Z., Liu L., Shi C. (2021). Probiotic effects of the *Bacillus velezensis* GY65 strain in the mandarin fish, *Siniperca chuatsi*. Aquacult. Rep., 21: 100902.

Wang Q., Xu Z., Ai Q. (2021). Arginine metabolism and its functions in growth, nutrient utilization, and immunonutrition of fish. Anim. Nutr., 7: 716–727.

Wang X., Shen Z., Wang C., Li E., Qin J. G., Chen L. (2019). Dietary supplementation of selenium yeast enhances the antioxidant capacity and immune response of juvenile *Eriocheir Sinensis* under nitrite stress. Fish Shellfish Immunol., 87: 22–31.

Wanna W., Surachat K., Kaitimonchai P., Phongdara A. (2021). Evaluation of probiotic characteristics and whole genome analysis of *Pediococcus pentosaceus* MR001 for use as probiotic bacteria in shrimp aquaculture. Sci. Rep., 11: 18334.

Wongprasert K., Rudtanatip T., Praiboon J. (2014). Immunostimulatory activity of sulfated galactans isolated from the red seaweed *Gracilaria fisheri* and development of resistance against white spot syndrome virus (WSSV) in shrimp. Fish Shellfish Immunol., 36: 52–60.

Wu P., Qu B., Feng L., Jiang W. D., Kuang S. Y., Jiang J., Liu Y. (2020). Dietary histidine deficiency induced flesh quality loss associated with changes in muscle nutritive composition, antioxidant capacity, Nrf2 and TOR signaling molecules in on-growing grass carp (*Ctenopharyngodon idella*). Aquaculture, 526: 735399.

Xu C., Li Y.Y., Brown P.B., Liu W.B., Gao L.L., Ding Z.R., Xie D. Z. (2022). Interactions between dietary carbohydrate and thiamine: implications on the growth performance and intestinal mitochondrial biogenesis and function of *Megalobrama amblycephala*. British J. Nutr., 127: 321–334.

Yadav G., Meena D.K., Sahoo A.K., Das B.K., Sen R. (2020). Effective valorization of microalgal biomass for the production of nutritional fish-feed supplements. J. Clean. Prod., 243: 118697.

Yang H.L., Hu X., Ye J.D., Seerengaraj V., Yang W., Ai C.X., Sun Y.Z. (2021). Cell Wall Components of *Bacillus pumilus* SE5 Improved the Growth, Digestive and Immunity of Grouper (*Epinephelus coioides*). Curr. Chin. Sci., 1: 231–239.

Yang K., Qi X., He M., Song K., Luo F., Qu X., Ling F. (2020). Dietary supplementation of salidroside increases immune response and disease resistance of crucian carp (*Carassius auratus*) against *Aeromonas hydrophila*. Fish Shellfish Immunol., 106: 1–7.

Yang L., Zhao M., Liu M., Zhang W., Zhi S., Qu L., Nie G. (2023). Effects of genistein on lipid metabolism, antioxidant activity, and immunity of common carp (*Cyprinus carpio L.*) fed with high-carbohydrate and high-fat diets. Aquacult. Nutr., 2023.

Yang X., Song X., Zhang C., Pang Y., Song Y., Cheng Y., Zong X. (2020). Effects of dietary melatonin on hematological immunity, antioxidant defense and antibacterial ability in the Chinese mitten crab, *Eriocheir sinensis*. Aquaculture, 529: 735578.

Yao W., Li X., Zhang C., Wang J., Cai Y., Leng X. (2021). Effects of dietary synbiotics supplementation methods on growth, intestinal health, non-specific immunity and disease resistance of Pacific white shrimp, *Litopenaeus vannamei*. Fish  Shellfish Immunol, 112: 46–55.

Yarnold J., Karan H., Oey M., Hankamer B. (2019). Microalgal aquafeeds as part of a circular bioeconomy. Trends Plant Sci., 24: 959–970.

Yilmaz E., Celik E. S., Ergun S., Yilmaz S. (2020b). Effects of dietary olive pomace oil on growth performance, some ımmune parameters and disease resistance (*Lactococcus garvieae*) of rainbow trout (*Oncorhynchus mykiss*). J. Anatolian Env. Anim. Sci., 5: 597–604.

Yilmaz S., Ergün S., Yigit M., Yilmaz E., Ahmadifar E. (2020). Dietary supplementation of black mulberry (*Morus nigra*) syrup improves the growth performance, innate immune response, antioxidant status, gene expression responses, and disease resistance of Nile tilapia (*Oreochromis niloticus*). Fish  Shellfish Immunol., 107: 211–217.

Younis E.S.M., Al-Quffail A.S., Al-Asgah N.A., Abdel-Warith A.W.A., Al-Hafedh Y.S. (2018). Effect of dietary fish meal replacement by red algae, *Gracilaria arcuata*, on growth performance and body composition of Nile tilapia *Oreochromis niloticus*. Saudi J. Boil. Sci., 25: 198–203.

Yousefi M., Hoseini S. M., Vatnikov Y.A., Kulikov E. V., Drukovsky S.G. (2019). Rosemary leaf powder improved growth performance, immune and antioxidant parameters, and crowding stress responses in common carp (*Cyprinus carpio*) fingerlings. Aquaculture, 505: 473–480.

Yu H., Chen B., Li, L., Zhang Q., Liu, D., Wang Z., Shan L. (2021). Dietary iron (Fe) requirement of coho salmon (*Oncorhynchus kisutch*) alevins assessed using growth, whole body and hepatic Fe concentrations and hepatic antioxidant enzymes activities. Aquacult. Res., 52: 4489–4497.

Yukgehnaish K., Kumar P., Sivachandran P., Marimuthu K., Arshad A., Paray B. A., Arockiaraj J. (2020). Gut microbiota metagenomics in aquaculture: factors influencing gut microbiome and its physiological role in fish. Rev. Aquacult., 12: 1903–1927.

Zemheri-Navruz F., Acar Ü., Yılmaz S. (2019). Dietary supplementation of olive leaf extract increases haematological, serum biochemical parameters and immune related genes expression level in common carp (*Cyprinus carpio*) juveniles. Fish  Shellfish Immunol., 89: 672–676.

Zheng T., Jia R., Cao L., Du J., Gu Z., He Q., Yin G. (2022). Alleviative effects of Ginkgo biloba extract on oxidative stress, inflammatory response and immune suppression induced by long-term glyphosate exposure in tilapia (*Oreochromis niloticus*). Aquaculture, 546: 737325.

Zhou L., Li, H., Qin J. G., Wang X., Chen L., Xu, C., Li E. (2020). Dietary prebiotic inulin benefits on growth performance, antioxidant capacity, immune response and intestinal microbiota in Pacific white shrimp (*Litopenaeus vannamei*) at low salinity. Aquaculture, 518: 734847.

Zhou X., Peng Y., Li L., He K., Huang T., Mou S., Li X. (2016). Effects of dietary supplementations with the fibrous root of Rhizoma Coptidis and its main alkaloids on non-specific immunity and disease resistance of common carp. Vet. Immunol. Immunopathol., 173: 34–38.

Received: 23 VII 2024

Accepted: 21 X 2024