Effect of Dietary Coriander (*Coriandrum sativum*) on Fish - Review

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Abstract
Phyto-additives have been used in fish diet with very promising results for sustainable aquaculture. Coriander or cilantro (*Coriandrum sativum*), is an annual herb, cultivated worldwide primarily as a spice and medicinal plant. It is well known for its healing properties for humans and animals as well. It was proved that coriander has beneficial biological properties on fish. Various effects of coriander supplementation in fish, including enhanced growth performance, improved feed utilization, strengthened immune response, reduced oxidative stress and antimicrobial properties, were reviewed in this paper. In addition, the possible biological mechanisms responsible for these benefits, such as the modulation of serum and blood parameters, immune responses, and antioxidative pathways were investigated as well. Ultimately, this knowledge can pave the way for more sustainable and effective practices, enhancing the overall health and productivity of fish populations while minimizing environmental impact.

Keywords: coriander, fish feed, phyto-additives

1. Introduction

The fast growth and intensification of fish farming during the last decades, have aimed to meet the increasing global demand for animal protein which is characterized by their excellent digestibility and richness in essential amino acids, minerals and vitamins [1]. Such intensification exposes fish to crowding stress and environmental stressors, including poor water quality and hypoxia, which can weaken their immune systems and elevate the risk of opportunistic bacterial infections, resulting in economic losses. To mitigate these issues, the fish industry has often resorted to excessive and unnecessary antibiotic use, both preventatively and therapeutically, leading to a range of harmful consequences [2].
The increasing demand for sustainable and effective aquaculture practices has driven research towards the exploration of natural feed additives. *Coriandrum sativum*, also known as coriander, belongs to the *Apiaceae* family (formerly *Umbelliferae*) and is widely recognized by various names, including cilantro, cilantrillo, Arab parsley, Chinese parsley, dhania, Mexican parsley kişniş and yuen sai [3]. Coriander, a widely cultivated aromatic herb, has garnered considerable attention in recent years for its potential application in aquaculture as a natural feed additive [4]. Its rich array of bioactive compounds, essential nutrients, and antioxidant properties positions coriander as a promising candidate for improving fish health, growth performance, and overall well-being [3,5]. Moreover, coriander is abundant in vitamins, predominantly in vitamin A/β-carotene, β–cryptoxanthin and vitamin C, minerals (e.g. Ca, Fe, Zn, Mg, and K), fibber, similar to other green vegetables [6,7]. Previous researches have demonstrated the therapeutic potential of the coriander plant, attributing to its neuroprotective, antihypertensive, hypoglycemic, hypolipidemic, hypocholesterolemic, anticonvulsant, antioxidative, anticarcinogenic, anxiolytic,

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migraine-alleviating, and analgesic properties [8,9]. Furthermore, coriander has exhibited antimicrobial, antiparasitic, anthelmintic, and antifungal effects [10,11]. The beneficial impacts of coriander may be assigned to the various bioactive compounds present in its leaves, seeds, and roots [12]. These compounds include coriandrons A-E, coriandrin, α-pinene, monoterpenes, borneol, p-cymene, limonene, γ-terpinene, citronellol, camphor, dihydrocoriandrin, geraniol, essential oils, and flavonoids [12]. New studies highlighted that using coriander essential oil at a concentration of 200 mg/L^{-1} proves effective as an anesthetic agent for rainbow trout (*Oncorhynchus mykiss*) without causing any toxic effects [13].

The burgeoning interest in plant-derived feed additives stems from the increasing awareness of the negative consequences associated with synthetic additives, such as antibiotic resistance and environmental contamination [14,15]. Consequently, researchers have turned to natural alternatives, including coriander, for their potential to improve fish health and productivity while minimizing environmental impact [15,16]. Based on many other *in vivo* studies, the extract of *C. sativum* improved the hepatic enzymes, including glutathione peroxidase (GPx), catalase (CAT), and superoxide dismutase (SOD) and supplied good protection against oxidative stress in rodents and poultry [8,17]. However, in fish these observations are very limited. Coriander, alongside other plants like Chinese celery and peppermint, is gaining interest as a water purifier and recently demonstrated effectiveness as a secondary biofilter in an aquaponic system [18]. This approach may enhance water purification efficiency and simultaneously increase herb production [18].

This review will provide up-to-date information of the benefits of coriander supplementation in fish, covering aspects such as enhanced growth performance, strengthened immune response, reduced oxidative stress, detoxifying and antimicrobial effects.

This review aims to explore the multifaceted benefits of coriander supplementation in fish species, delving into the possible biological insights that underpin these effects and offering insights into sustainable and effective aquaculture practices. By elucidating the biological mechanisms responsible for these benefits and investigating the optimal conditions for coriander supplementation in various fish species, this review will come up to a deeper understanding of the role coriander can play in aquaculture. This knowledge can ultimately pave the way for more sustainable and effective practices, promoting the overall health and productivity of fish populations while reducing reliance on synthetic additives.

2. Growth enhancing capacity

Coriander supplementation may improve the gut mucosal barrier function in fish, which is essential for preventing the invasion of pathogens and maintaining gut health [19]. Coriander supplementation has been shown to improve growth performance in various fish species, including Nile tilapia (*Oreochromis niloticus*) and rainbow trout [20-22]. This is likely due to the presence of essential nutrients, vitamins, and minerals in coriander, which can contribute to better feed utilization and overall health. While the studies on coriander supplementation have focused primarily on Nile tilapia and rainbow trout, it is reasonable to hypothesize that other fish species may experience similar benefits. This hypothesis is based on the fact that the nutritional and bioactive compounds found in coriander are likely to be beneficial across various fish species, given their conserved physiological and metabolic processes. More research is needed to confirm the specific effects of coriander supplementation on other fish species, including optimal dosage and duration of treatment.

According to a recent study, the authors have suggested that a concentration of 0.55% coriander powder could support the optimum percentage weight of African catfish (*Clarias gariepinus* × *Heterobranchus bidorsalis*) hybrids [6]. The use of coriander in catfish feed resulted in a significant increase in growth rate, as well as improvements in carcass protein and lipid yield, ultimately leading to an increase in survival rate. The authors concluded that feeding African catfish with coriander-based diets improved their growth, flesh yield, survival rate, and blood haematological (PCV, Hgb, RBC, globulin and protein levels) and biochemical (AST, ALT, ALP, CRE and urea) profiles [6]. Likewise other authors have observed similar behaviour of haematological parameters in rainbow trout and European sea bass fed groups with an additional increase in white blood cells (WBCs) [23]. Ashry

et al., 2022 concluded and suggested that incorporating coriander into the diets of European sea bass at concentrations of 10-20 g/kg leads to enhanced growth performance, increased growth hormone levels, better feed utilization, and heightened antibacterial capacity in the intestinal tract [23]. Other investigations have evidenced best-achieving growth performance observations in beluga (*Huso huso*) with proportions between 5 to 15 g kg^{-1} of coriander in fed, with the richest protein and lipid carcass fraction for 10 and 15 g kg^{-1} coriander [24].

Similarly, common carp (*Cyprinus carpio*) consuming diets with 1.5% and 1.75% coriander powder exhibited a significant increase in relative growth rate, reaching 120.71% and 120.49%, respectively [25]. The authors added that coriander-enriched diets caused a significant increase in dry matter % and protein contents whilst decreasing the moisture levels in edible fish portions compared with the control-fed fish. The study concluded that coriander powder in common carp enhance growth performance, feed conversion efficiency, productive protein value and retention [25]. The favourable growth outcomes of the coriander seed extract could be attributed to enhanced intestinal nutrient protection. Its efficacy in eliminating harmful microorganisms and bacterial pathogens within the intestinal tract and its capacity to elevate digestive enzyme levels, boost cellular respiration, and augment nutrient absorption may contribute to these positive results [25].

Coriander is a rich source of essential nutrients, including vitamins (A, C, and K), minerals (calcium, potassium, and magnesium), and dietary fiber. These nutrients contribute to the overall health and growth of fish, providing the necessary building blocks for cellular processes, energy metabolism, and maintaining physiological functions.

The availability of bioactive compounds, such as phenols and flavonoids in coriander, may contribute to better nutrient absorption and utilization in fish [23]. Improved feed utilization leads to reduced feed waste, lower production costs, and increased profitability for fish farmers. Coriander supplementation may improve digestive enzyme activity in fish, leading to better nutrient utilization and absorption.

Coriander supplementation may help to reduce the impact of anti-nutritional factors in fish feed, such as phytates and tannins, which can interfere with nutrient absorption. By reducing the impact of these anti-nutritional factors, coriander supplementation may contribute to better nutrient availability and feed utilization.

3. Immunostimulatory and antioxidant properties

The inclusion of *C. sativum* in fish diets has been linked to improved immune response and decreased oxidative stress in various fish species, contributing to improved overall health and disease resistance [8,26]. Coriander contains various antioxidants and immune-boosting compounds, which can improve the immune response in fish species [21]. Studies have found that coriander supplementation can increase the activity of lysozyme, complement, and SOD in fish, leading to a more robust immune response against pathogens [21]. These enzymes play critical roles in the innate immune response, providing the first line of defense against pathogens. The immunomodulatory effects of coriander may be attributed to its bioactive compounds, which can directly stimulate immune cell activity or promote the production of immune-related proteins. Coriander contains bioactive compounds with anti-inflammatory properties, which can help regulate the immune response and prevent excessive inflammation [27,28]. By modulating the production of pro-inflammatory cytokines and other signalling molecules, coriander supplementation may help maintain a balanced immune response in fish, contributing to improved overall health and disease resistance.

From the food science perspective employing a combination of the glazing techniques of Spanish mackerel (*Scomberomorus commerson*) with natural materials like plant extracts and, specifically, coriander leaf extract, the shelf life of fish in frozen storage can be extended, effectively delaying the progression of spoilage-related chemical parameters [29]. Coriander contains various antioxidant compounds, such as polyphenols, flavonoids, and essential oils which are Generally Recognized as Safe (GRAS) products by FDA (Food and Drug Administration) [30]. These compounds can neutralize reactive oxygen species and reduce oxidative stress, which can damage cellular components and impair immune function. By minimizing oxidative stress, coriander supplementation may help maintain a

robust immune response in fish. Petroselinic acid has been found as a constituent with the most abundant lipid fraction in coriander oil by representing levels between 68 and 83%, respectively [31]. The incorporation of petroselinic acid through coriander oil in vegetable oil-based diets, devoid of fishmeal and fish oil, led to a significant rise in the synthesis of anti-inflammatory precursor 22:6n-3 and a reduction in pro-inflammatory precursor 20:4n-6 within radiolabelled hepatocytes of rainbow trout, as evidenced by the study findings [31]. Another researchers indicated that incorporating coriander oil into vegetable oil-based diets can notably enhance the bioconversion of 18:3n-3 to 20:5n-3 and 22:6n-3 in rainbow trout fish fillets and decline aquaculture's reliance on fish oil [32].

The antioxidant properties are derived from phenolic components and carotenoids. Zebrafish (*Danio rerio*) is considered a good animal model for investigating *in vivo* the biological effects of feed additives on immune responses, general health outcomes and physiological systems [8]. A previous study has concluded that introducing coriander as a feed additive heightened the serum and mucosal immune responses and influenced the overexpression of growth factors, antioxidants and immune-associated genes in zebrafish [12]. Specifically, 2% coriander powder treatment enhanced the expression of IGF-I, lysozyme, TNF-α and IL-1 gene activity. Moreover, the expression of mRNA levels of antioxidant enzymes such as CAT and SOD were upregulated after 2% coriander treatment compared to other groups. Incorporating coriander in the feed of southern platyfishes (*Xiphophorus maculatus*), considered ornamental fish species, demonstrated a positive impact on disease resistance against *Aeromonas hydrophila* and immune function [33]. The significant increase in length and weight highlights the potential of using coriander as a feed additive and immune booster in ornamental fish practices.

Maintaining a robust immune response and minimizing oxidative stress are critical for the health and well-being of fish in aquaculture systems. Coriander supplementation has been reported to enhance immune response and reduce oxidative stress in fish species like Nile tilapia and rainbow trout [20-22]. This medicinal plant have a rich content of vitamin C which could play as natural immunostimulatory agent [23,34]. Previous studies have demonstrated that European sea bass and rainbow trout fed with dietary coriander showed a stimulated activation of lysozyme and phagocytic activities, with a more increased immune response [23].

Earlier findings which determined the efficacy of coriander seed extract (CSE) on physiological responses, immunity, and infection resistance of rainbow trout against *Yersinia ruckeri* have provided interesting results [20]. Firstly, 2% of CSE has triggered great increases in the specific growth rate, final weight and condition factor of *O. mykiss*. Next, the authors reported remarkable enhancements of alternative complement activity and lysozyme, followed by an improved survival rate of experimental fish against *Y. ruckeri* challenge than other groups. Likewise, other authors have recently mentioned the powerful antioxidant evidence of coriander-based feeds, which elevated serum SOD levels in Nile tilapia during infection [21]. Specifically, 1.5 and 2% coriander oil raised the levels of respiratory burst, myeloperoxidase, lysozyme and antiprotease activities concerning the control group. The fish challenged with *A. hydrophila* infection led to advanced levels of IgM and IL-8 in the presence of coriander oil, whether the expression of TNFα, IL-1β, TGFβ and HSP70 genes was significantly attenuated compared with the control group [21]. Coriander oil may have acted on inflammatory cells, such as neutrophils, through CXCR1 or CXCR2 signalling pathways, as suggested by the elevated IL-8 expression for bacterial clearance from fish tissue, rather than relying on TNFα or IL-1β mediated responses [21]. Additionally, it is plausible that coriander oil downregulated TGFβ expression, thereby suppressing its downstream signalling pathways to modulate inflammation and the subsequent immune response in tilapia kidney tissue during *A. hydrophila* infection [12].

A latest study investigated the impact of combined herbal extracts CMO composed of coriander, oak acorn (*Quercus brantii*), and common mallow (*Malus sylvestris*) in the diet of common carp on growth performance, digestive enzyme activity, antioxidant and immune responses, and resistance to *A. hydrophila* infection [35]. Interestingly, CMO-fed fish had significantly improved levels of antioxidant and immune biomarkers from serum and mucus, especially in the case of total immunoglobulins, lysozyme, nitroblue tetrazolium (NBT), ALP, and alternative complement activity

(ACH_{50}). Subsequently, a 3% treatment showed the most increased survival rates of fish challenged with *A. hydrophila* compared to other groups. Therefore, the herbal combination has enhanced blood parameters, growth, immunity, and resilience against pathogen infection. According to their polynomial regression investigation, the authors suggested 1% of CMO inclusion as the best concentration in the common carp diet for the best achievement of growth performance and enhancement of feed conversion rates [35].

Oxidative stress occurs when there is an imbalance between the production of reactive oxygen species (ROS) and the antioxidant defences in the body. Coriander contains compounds with antioxidant properties, such as flavonoids and polyphenols, which help neutralize ROS and mitigate oxidative stress in various animal models [35,36]. This can be particularly beneficial for fish species reared in intensive aquaculture systems where they may be exposed to environmental stressors. Lastly, other studies also highlighted immunomodulatory properties and ameliorative effects of coriander on heavy metals-challenged fish [24].

4. Detoxifying potential

Coriander dietary supplementation could be utilised to enhance different fish species' immune responses and counteract the immunotoxic outcomes of heavy metals such as lead and cadmium [24,37]. Shellfish soaked in 20% of coriander leaf extract at different intervals significantly alleviated levels of different heavy metals from meat [38]. For example, razor clams known as lorjuk (Solen) soaked for 90 minutes in coriander extract diminished lead levels from 4.4 to 1.7 ppb, mercury from 4.11 to 1.12 and copper levels from 433.7 to 117 ppb, respectively.

C. sativum contains in its compositional chemical inventory metallothionein and glutathione, which were previously associated with binding and assist in the removal of heavy metals (e. g. lead, cadmium, mercury, aluminium and others) from tissues [12]. Bioactive compounds found in coriander, garlic, and chlorella powder have demonstrated chelating and antioxidant capabilities, with coriander and garlic exhibiting the greatest efficacy [37]. Coriander can bind and immobilise cadmium chloride in the liver and kidney, reducing toxic cadmium accumulation in the tissues of cultured rainbow trout. It could also mobilise mercury and facilitate its excretion via the digestive tract and urine or redistribute it to peripheral tissues [37]. This important finding identifies coriander as the first known natural agent capable of mobilising mercury from the central nervous system. In an earlier histomorphometric study, Nicula et al. [39] concluded that adding coriander to freshwater fish feed, specifically Prussian carp (*Carassius gibelio*) exposed to cadmium demonstrated the most effective protective effect on the length of secondary gill lamella and on thickness of chorion follicles [39]. A recent report showed that in the lead-poisoned group, incorporating 2% lyophilized coriander leaves resulted in behaving as an exceptional chelator for liver tissue, significantly mitigating the toxic impact of lead in vital organs such as the liver, kidneys, intestines, and gills of Prussian carp [40]. Incorporating 5 and 10 g kg^{-1} coriander into the diet of beluga led to notable enhancements in growth performance, survival rate, biochemical reactions, and carcass nutritional quality prior to exposure to heavy metals [24]. Other authors have advocated diets for beluga with 15 and 20 g/kg of charcoal and coriander, resulting from a more efficient heavy metal chelation that minimised cadmium, copper, and lead concentrations [41]. Their results also recommended that coriander is a preferable additive in environments with low concentrations of heavy metals, while in settings with higher heavy metal concentrations, it is recommended to incorporate 15 g/kg of active charcoal into the beluga diet.

Besides the immunomodulatory effects of coriander seeds (CP) or extract (CE), a recent *in vivo* trial demonstrated the ameliorative capability of coriander to ameliorate the deleterious effects of lead in Nile tilapia [22]. Their study demonstrated that when *O. niloticus* was exposed to lead at a concentration of 20.2 mg/L, there was a significant decline in certain innate immune functions, such as serum lysozyme activity, serum killing activity, and nitric oxide production. These findings suggest that lead exposure may weaken the immune defences of *O. niloticus* against existing stressors, potentially contributing to illness or mortality in the fish population. Coriander reversed the toxicity effects of lead, and mitigated outcomes were associated with improvements in immunity markers, such as the

remarkable increments of nitric oxide, serum killing activity, the mRNA expression level of IL-1β, lysozyme and cytokine release and were detected only in tilapia groups which received CP or CE additives at 20 or 30 mg/kg diet, respectively. The authors concluded that this herb could act as a natural detoxifying agent by compensating for the immunosuppressive consequences generated by lead exposure, hampering its bioaccumulation in muscles and improving fish survivability [22].

5. Antimicrobial effects

In addition to implementing strategies aimed at enhancing disease surveillance and management, the economic losses linked to disease outbreaks in aquaculture have been previously estimated to be approximately $9.5 billion USD annually [42]. This substantial financial impact is most prominently observed in developing nations, highlighting the need for continued improvements in disease prevention and control measures.

The rise of antibiotic-resistant strains among numerous microorganisms has necessitated the exploration of environmentally friendly alternative approaches, such as the incorporation of various medicinal plant-derived products (e.g., herbal extracts, essential oils, mixtures, powders, etc.) as dietary supplements in aquaculture farming [43]. Similarly, probiotics, plant extracts, and plant-based products intended for use as feed additives, commonly referred to as phyto-additives or phytogenic additives, have garnered significant interest for their potential to serve as growth enhancers and substitutes for antibiotics and chemical drugs [44] [42].

Coriander supplementation has been associated with antimicrobial effects and improved gut health in fish species, contributing to enhanced overall health and disease resistance *[21]*. Coriander parts, and for example seeds has antimicrobial properties due to the presence of compounds like linalool, increased petroselinic acid and phenolic content of glycitein, pyrogallol, and caffeic acid that attributes also, antioxidant and immunostimulatory properties [6,20].

Coriander seed extract contains key components such as linalool present in the proportion of above 70% and geranyl acetate, renowned for their broad range of biological properties, including antioxidant, antimicrobial, analgesic, and anti-inflammatory effects [20,45]. The antibacterial potency of coriander essential oil can be primarily attributed to linalool, a compound that has been found to disrupt the structural integrity of both Gram-positive and Gram-negative bacteria [45]. This disruption results in increased membrane permeability and subsequent loss of cellular components. Various mechanisms, such as interactions with membrane phospholipids, membrane proteins, and specific intracellular targets, have been proposed to elucidate the antibacterial actions of linalool [45].

In addition, coriander essential oil comprises other constituents, such as α-pinene, camphor, γ-terpinene, geranyl acetate, and D-limonene, which also exhibit antibacterial properties [45]. These monoterpenes, like their counterparts, permeate membrane structures, leading to heightened membrane permeability, damage to membrane proteins, and alterations in respiration and ion transport processes. Moreover, coriander EO has been associated with the potential to reverse antibiotic resistance in some pathogens, as was glimpsed in tetracycline [45].

Coriander oil demonstrated *in vitro* inhibitory activity against a variety of bacteria in the disc diffusion assay, with zones of inhibition observed for *Aeromonas veronii* (50 mm), *A. hydrophila* (20 mm), *Staphylococcus caseolyticus* (24 mm), *Chromobacterium violaceum* (25 mm), and *Klebsiella pneumoniae* (20 mm) with an exception for *Pseudomonas aeruginosa* and *Bacillus subtilis* [21]. The oil also exhibited a notably high total antioxidant capacity (TAC), comparable to that of ascorbic acid [21]. Furthermore, coriander oil displayed anti-inflammatory properties by preventing protein denaturation, akin to the action of diclofenac [21]. These findings indicate that coriander oil has the potential to serve as an effective antimicrobial agent in feed formulations while maintaining gut health integrity. Previous *in vitro* studies reported that the essential oil derived from *c. sativum* showed an antioxidant capacity as 39.38 μg (TEAC/mL) and antimicrobial efficacy against different species of *Pseudomonas* isolated from freshwater fish [46]. Coriander is believed to shield the intestinal mucosal lining, promoting optimal nutrient uptake [23]. Concurrently, other findings uncovered a decline in the presence of harmful intestinal bacteria, such as *Vibrio* spp. and faecal coliform, signifying coriander's potent antibacterial properties [23].

A new *in vivo* study has declared that adding coriander oil to tilapia feed enhances tilapia health and resistance to bacterial infection caused by intraperitoneal injection with *A. hydrophila* [21]. The groups which received 1, 1.5 and 2% of coriander oil in their diets reflected 89, 100 and 100% survival rates compared to control diets, which resulted in only 39%, respectively. Further histopathological evaluation of the fish spleen from the 0.5% coriander provided group, including the control group, revealed the signs of vacuolation and necrosis resulting from *A. hydrophila* infection, whilst the tilapia which received higher 1, 1.5 and 2% doses of coriander oil demonstrated a normal, unaffected architectural structure of a spleen [21]. Other researchers observed similar effects provided by the inclusion of 2% CSE and recommended for the improvement of overall rainbow trout and health and infection resilience against important fish pathogen, namely *Y. ruckeri* [20]. Coriander oil primarily exerts its effects by inflicting damage on bacterial membranes, resulting in the impairment of vital cellular functions such as efflux activity, respiratory processes, and membrane potential [21]. These disruptions ultimately culminate in bacterial cell death.

These antimicrobial effects can help protect fish from bacterial and fungal infections, reducing the need for antibiotics in aquaculture systems. By providing a natural defence against pathogens, coriander supplementation may enhance the overall immune response in fish.

6. Conclusions

In the context of aquaculture production, fish nutrition is considered a critical determinant in distinguishing between healthy and diseased farmed species. Enriching diets with various plant-derived additives in multiple forms can provide benefits to a broad range of cultured species, including carp, trout, tilapia, catfish, and others. In summary, the results of this review highlight the multifaceted benefits of coriander-enriched diets in significant aquatic fish species, including growth promotion, pathogen resistance, antioxidant properties, detoxification capabilities, and immune system stimulation. Noteworthy is that while these beneficial effects have been observed in various studies, the specific dosage and duration of coriander supplementation, as well as the optimal form (e.g., whole, powdered, or extracted), may vary among different fish species. Further research is essential to determine the optimal conditions for each species and to better understand the mechanisms behind these benefits.

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