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Review article

A glimpse on influences of ginger and its derivatives as a feed additive in finfish farming: A mini-review

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ABSTRACT

Ginger (*Zingiber officinale*) has emerged as a promising feed additive in aquaculture due to its reported benefits for fish health and growth. Possessing a range of bioactive compounds, ginger exhibits antimicrobial, anti-parasite, immunostimulatory, anti-inflammatory, anti-oxidative, and growth-promoting properties. This review provides a comprehensive overview of recent research on dietary ginger and its derivatives for fish. It explores the various forms, bioactive compounds, biological activities, and preparation methods of these feed additives. The discussion focuses on the impacts of dietary ginger and its derivatives on growth performance, flesh quality, hematology profile, antioxidative responses, immune system, and disease resistance stimulation in fish. Additionally, the review examines the mechanisms of action of these additives and explores the optimal supplementation levels for inclusion in fish diets. Previous studies reported the optimal doses of dietary ginger and its derivatives were ranged from 0.0002 to 4 % of diet whereas 0.0004 % for bathing treatment. Bioactive compounds such as phenolic acids, flavonoids, zingerone, gingerols, shogaols, and paradols were responsible to the ginger and its derivatives beneficial effects. Overall, the findings suggest that dietary ginger and its derivatives hold significant promise for enhancing growth and health in fish farming.

1. Introduction

The aquaculture industry is experiencing a rapid growth, supplying nearly half of the world's consumed fish [1,2]. As the global population continues to rise, so too will the demand for fish protein. While conventional feed additives, such as antibiotics, have demonstrably boosted production, their use has compromised the quality and safety of aquaculture products due to antibiotic residue concerns [2,3]. Furthermore, aquaculture activities, including the movement of seed and broodstock, the introduction of new aquaculture species, and live product trade, can facilitate the spread of diseases [4]. Additionally, intensive fish farming can induce stress, negatively impacting the growth performance and health of farmed species [5,6]. Consequently, sustainable aquaculture practices are increasingly utilizing "green" feed additives like probiotics, prebiotics, and phytobiotics to address these limitations [7–10].

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Current research on phytobiotics as feed additives in aquaculture is expanding the applications previously dominated by probiotics and prebiotics [7,11,12]. Defined as plant or plant derivatives with beneficial effects on organism growth and health [5,8,13], phytobiotics represent a promising avenue in aquaculture. Numerous studies have explored their potential as feed additives for various aquaculture species [14]. Reported benefits include enhanced digestive enzyme activity, improved hematological profile, heightened antioxidative response, modulation of gut microbiota, stress mitigation, and stimulation of disease resistance [15,16].

Ginger (*Zingiber officinale*) is a widely used herb in traditional medicine [17] and as a culinary spice [18]. This medicinal plant exhibits a multitude of properties relevant to aquaculture, including antimicrobial [19,20], antiparasitic [21], immunostimulatory, anti-inflammatory [22], anti-oxidative, and growth-promoting effects [23]. Notably, ginger's bioactive compounds, zingerone, gingerol, and shogaol, possess well-documented antioxidative properties and have found applications in treating various diseases [24,25]. Dietary ginger consumption demonstrably benefits both physical and mental health, with its bioactive compound, gingerol, finding use in treating the flu, nausea, and the common cold [26,27]. Besides, dietary zingerone was reported has beneficial effects such as promoted growth, digestive enzyme activity, hematological profile, antioxidative capacity, immune system and stimulate disease resistant against *Vibrio alginolyticus* infected in Pacific White Shrimp, *Litopenaeus vannamei* [28] (Fig. 2). Furthermore, bioactive compounds such as 6-gingerol, 8-gingerol, and 6-shogaol in the ginger extract were found could protect *L. vannamei* from hepatopancreatic necrosis disease due to *V. parahemolyticus* [29].

A substantial body of research has documented the multifaceted benefits of dietary ginger and its derivatives in aquaculture. Studies have consistently reported positive impacts on a variety of fish species, including Nile tilapia, *Oreochromis niloticus* [30], common carp, *Cyrpinus carpio* [31], African catfish, *Clarias gariepinus* [32], rainbow trout, *Oncorhynchus mykiss* [33], black rockfish, *Sebastes schlegeli* [34], rohu, *Labeo rohita* [35], and striped catfish, *Pangasianodon hypohthalmus* [36]. This review paper aims to discuss and summarize the effects of ginger and its derivatives on growth performance, flesh quality, hematological profile, antioxidative responses, the microbiome, disease resistance stimulation, and gut microbiota modulation in fish.

2. Ginger and its derivatives

2.1. Sources

Ginger is a globally cultivated plant, with India and China being the primary producers. Its extensive use in both culinary applications and traditional medicine has driven a vibrant global trade [37]. Ginger is commercially available in various forms, including powder, juices, dried, and fresh rhizome, with a total value of billions of USD and over 10,000 tons annually [27,38,39].

2.2. Form, preparation, and uses of ginger

Ginger, particularly its rhizome, boasts a characteristically strong, pungent, and spicy aroma. It is consumed in various forms, including raw, dried, or powdered. Additionally, ginger can be processed into juice, extracts, and even oil (Table 1). In Asian, Middle Eastern, and European countries, ginger finds widespread use as a flavoring agent in beverages and a seasoning agent in cuisine [40]. For instance, ginger tea is a popular beverage enjoyed worldwide. Gingerbread, a well-known traditional sweet treat, is particularly associated with festive seasons like Christmas and winter [25]. Beyond culinary applications, ginger finds use as an ingredient in cosmetic products such as soaps and perfumes [27].

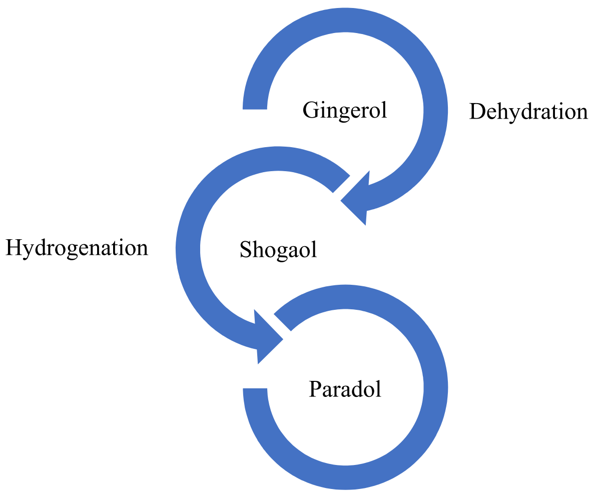

Fig. 1. Process of shogaol and paradol formation from gingerol. Shogoal was formed from dehydration of gingerol whereas hydrogenation of shogaol produced paradol.

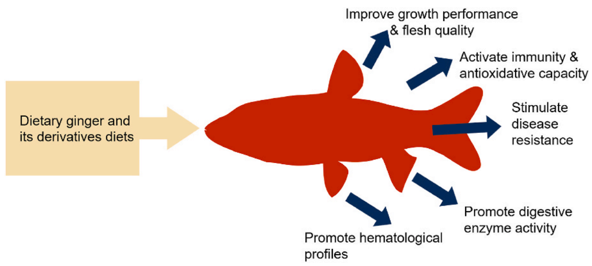

Fig. 2. Beneficial effects of dietary ginger and its derivatives diets in aquatic animals.

Table 1
Form, preparation, and uses of ginger.

Form	Preparation	Uses	References
Fresh ginger	Cut into small pieces through slicing or grating	Flavoring agent in cooking; Herbal medicine; Tea	[25]
Dried ginger	Sun dried; Mechanical dried	Herbal medicine; Tea	[25,40]
Ginger essential oil	Hydro-distillation; Supercritical fluid extraction	Herbal medicine; Food preservation	[75,76]
Ginger extract	Concentrated ginger extract	Herbal medicine	[25]

2.3. Ginger nutritional profile, bioactive compounds, and their uses

The ginger rhizome comprises a rich nutritional profile, with carbohydrates the largest fraction (60–70 %). Other notable components include protein (9–10 %), water (9–12 %), lipid (3–6%), fiber (3–8%), ash (7–8%) and essential oil (2–3%) [41]. Factors such as storage and processing conditions, geographical location, and growing, harvesting, and post-harvesting practices can influence the specific composition of ginger rhizomes [41].

Ginger rhizome carbohydrates primarily consist of glucose (94 %), galactose (3.27 %), and arabinose (1.67 %). The remaining fraction includes rhamnose, mannose, and xylose [42]. These monosaccharides play a role in gut microbiota modulation, promoting short-chain fatty acid production for enhanced health outcomes (Table 2) [43]. Additionally, they may contribute to immune system function [44].

Protein is the second most abundant micronutrient in ginger. It contains a variety of essential and non-essential amino acids, such as methionine, lysine, valine, threonine, isoleucine, histidine, leucine, glycine, phenylalanine, tryptophan, cystine, serine, tyrosine, glutamic acid, alanine, aspartic acid, and arginine [41]. These amino acids are crucial nutrients for growth promotion [45]. Interestingly, ginger protease, with its high proteolytic activity, finds application in cheese-making and other dairy industries [41].

The main fatty acids in ginger are linoleic acid (23.9 %), palmitic acid (22.2 %), and oleic acid (20.4 %). Behenic acid, caprylic acid, margaric acid, erucic acid, and arachidic acid are also present in smaller quantities. These fatty acids contribute to enhanced hematological profiles by stable blood lipid levels [41].

Ginger contains a diverse range of essential oils, with 43 identified compounds. α-zingiberene (17.94 %), β-phellandrene (10.81 %), *ar*-curcumene (10.31 %), β-sesquiphellandrene (7.69 %), β-bisabolene (7.59 %), L. camphene (7.26 %), and β-citral (6.62 %) are the major constituents. These essential oils exhibit antimicrobial properties and are widely used in food preservation [46].

Ginger is well-known for its abundance of phenolic compounds, such as phenolic acids, flavonoids, gingerols, shogaols, and paradols. Ginger phenolic acids encompass 3, 4-dihydroxybenzoic acid, gallic acid, *trans*-ferulic acid, syringic acid, caffeic acid, *p*-coumaric acid, and *trans*-cinnamic acid [47]. Flavonoids compounds primarily consist of hesperidin, rosmarinic acid, luteolin, naringenin, quercetin, kaempferol-7-dirhamnoside, naringin, luteolin-7-glucoside, rhamnetin, hesperetin, apigenin, quercitrin, rutin, and

Table 2
Beneficial effects of nutrients and bioactive compounds in ginger.

Nutrient/Bioactive compound	Beneficial effects	References
Carbohydrates: glucose, galactose, arabinose, rhamnose, mannose and xylose	- provide energy - modulate gut microbiota - promote short-chain fatty acid production - enhance immune system	[42–44]
Protein: essential and non – essential amino acids	- promote growth	[41,45]
Fatty acids: linoleic acid, palmitic acid, and oleic acid	- enhance hematological profiles	[41]
Essential oils	- antimicrobial activity	[46]
Phenolic compounds: phenolic acids, flavonoids, zingerone, gingerols, shogaols, and paradols	- enhance hematological profiles - antibacterial, antioxidant, anti-inflammation, anticancer, and antidiarrheal - hepatoprotective and androgenic effects - mitigate oxidative stress	[48–52]

apigenin-7-glucoside [48]. Gingerol serves as a precursor for shogaol and paradol formation [49] (Fig. 1). High-temperature exposure dehydrates gingerol, leading to shogaol formation [50]. Conversely, paradol is formed through the hydrogenation of shogaol [51]. The rich phenolic profile of ginger imparts potent antioxidative activity, contributing to the mitigation of oxidative stress [52]. Gingerols, shogaols, and paradols demonstrate a wide range of biological activities, including antibacterial, antioxidant, anti-inflammation, anticancer, and antidiarrheal [49]. They additionally exhibit hepatoprotective and androgenic effects. Furthermore, the phenolic compounds may regulate blood and cholesterol levels [49].

3. Safety level of ginger consumption

Ginger consumption is generally considered safe within a moderate daily intake. Studies reported no adverse health effects at levels not exceeding 2 g/kg body weight [52]. However, exceeding this recommended dosage may lead to potential reproductive system impairments. Research by Rong et al. [53] demonstrated a significant reduction ($p < 0.05$) in testes weight in male rats receiving a diet supplemented with 2 g/kg of body weight of ginger for 35 days. Similarly, ElMazoudy & Attia [54] observed progesterone deficiency and impaired corpus luteum growth in female mice injected daily with ginger extract at a dose of 2 g/kg body weight for 90 days. Importantly, studies by Rong et al. [53,54] found no adverse effects at ginger exposure levels below 2 g/kg body weight. Furthermore, Weidner & Stigwart [55] confirmed this safety profile, reporting no negative impacts on reproductive, growth and overall health in rats fed a diet containing 1 g/kg of ginger. These findings suggest that ginger consumption at moderate levels is safe. While current research supports the safety of moderate ginger consumption, further investigation into the potential toxicity of dietary ginger and its derivatives in aquatic animals is warranted. This research would be particularly valuable in the context of aquaculture practices that incorporate ginger into fish diets.

4. Impacts of ginger and its derivatives on growth performance of finfish

Studies indicate that dietary ginger powder has a positive effect on the growth performance of striped catfish (*Pangasianodon hypophthalmus*) raised in outdoor aquaculture systems. Fish fed diets supplemented with ginger powder diet performed significantly ($p < 0.05$) better compared to the control group, with the 1 % ginger inclusion level demonstrating the most pronounced effect [36] (Table 3). This positive impact on growth performance is likely due to enhanced digestive enzyme activity and increased growth hormone levels observed in fish fed ginger. Similar growth-promoting effects of ginger powder have been reported in other fish species, including increased palatability and digestion in Nile tilapia [30,56]. Additionally, dietary ginger powder has been shown to enhance protein and fat metabolism in fish. Positive effects on growth performance with ginger supplementation have been observed across various fish species. These include beluga, *Huso* [57], rohu, *Labeo rohita* [22], African catfish, *Clarias gariepinus* Wei [32], and Asian seabass, *Lates calcarifer* [58]. In Nile tilapia, ginger oil supplementation particularly benefits fish fed diets with high in starch, improving growth performance and feed utilization [59,60]. It is believed that ginger essential oil alters the gastrointestinal tract morphology, leading to better nutrient consumption and absorption and, ultimately, increased growth [60,61]. Furthermore, studies have shown positive effects on Nile tilapia growth with other dietary ginger derivatives such as ginger residue from juice extraction (GRJE), ginger leaves powder, and ethanolic ginger extract [62]. Similar positive effects have been observed in African catfish, *Clarias gariepinus* [63], and common carp, *Cyrpinus carpio* [31].

Studies have shown mixed effects of dietary ginger on the growth of aquatic animals. While some studies observed significant improvements in fish fed ginger-supplemented diets (as discussed previously), others reported no impact on growth performance. For example, Zaman & Cho [18] found no influence of ginger powder on olive flounder growth, and similar observations were made in zebrafish by Ahmadifar et al. [64]. Additionally, Brum et al. [23] reported that dietary ginger essential oil had no effect on Nile tilapia growth performance. Several factors may influence the effectiveness of dietary ginger. These include the species of aquatic animal, the dosage of ginger administered, the duration of feeding, and the specific form of ginger used (leaves, roots, rhizomes, essential oil, extracts, or bioactive compounds) [36]. It is important to note that excessive doses of ginger essential oil in the diet can be detrimental. For instance, Chung et al. [60] observed a reduction in Nile tilapia growth performance when dietary ginger essential oil diet exceeded 0.05 %. Similarly, Wei et al. [32] reported a decrease in growth performance of African catfish fed ginger leaf powder exceeding 3 % in their diet. These findings highlight the importance of using appropriate ginger dosages in fish feed to ensure positive effects.

The beneficial effects of dietary ginger on growth performance in finfish are likely attributed to its bioactive compounds. Gingerol, terpene, and zingiberene, found in ginger rhizome, may enhance feed palatability and improve feed utilization efficiency [63,65]. Notably, zingiberene, the primary component of ginger essential oil, has been shown to promote growth in Nile tilapia [60]. Additionally, terpene, known for its flavor and smell, may improve the fish's feed intake and food conversion ratio. Moreover, ginger oil may act as a feed enhancer, increasing fish appetite. These positive impacts could ultimately lead to enhanced growth performance [60].

The positive influence of dietary ginger and its derivatives on finfish growth performance can be attributed to several mechanisms. Ginger may activate digestive enzyme activity such as amylase, lipase, and protease [66], leading to improved digestion and nutrient absorption. Ginger's antibacterial properties may also contribute to growth by reducing harmful bacteria in the gut [36]. Furthermore, ginger consumption may promote growth hormone production and enhance feed utilization [36].

5. Impacts of ginger and its derivatives on flesh quality of finfish

Several studies have investigated the potential of dietary ginger to improve flesh quality in fish. These studies suggest that ginger

Table 3
The impacts of ginger and its derivatives as a feed additive in finfish farming.

Ginger and its derivatives	Aquatic animals – weight/length	Dose and duration	Impacts	References
Ginger powder	Nile tilapia, *Oreochromis niloticus* – 30 g	0.1–1 % of diet (70 days)	↑ Growth performance ↑Immune system ↑Disease resistance to *Aeromonas hydrophila*	[56]
Ginger polysaccharide	Crucian carp, *Carassius auratus* – 118 g	0.4–0.8 % of diet (56 days)	↑ Growth performance ↑Immune system ↑ Antioxidant system ↑ Gut microbiota ↑Disease resistance to *A. hydrophila*	[77]
Ginger powder	Olive flounder, *Paralichthys olivaceus* – 5.4 g	1 % of diet -(56 days)	= Growth performance ↑Disease resistance to *Edwardsiella tarda*	[18]
Ginger powder	Striped catfish, *Pangasianodon hypophthalmus* – 19.93 g	1.02–1.58 % of diet (90 days)	↑Growth performance ↑Flesh quality ↑Antioxidative response ↑Antibacterial capacity	[36]
Ginger residue from juice extraction (GJRE)	Black rockfish, *Sebastes schlegelii* – 2.2 g	0.75 % (56 days)	↑ Growth performance ↑Flesh quality ↑Immune system ↑Antioxidative responses ↑Disease resistance to *Streptococcus iniae*	[62]
Ginger powder	Rohu, *Labeo rohita* – 12.3 g	0.8 % of diet (60 days)	↑ Growth performance ↑Antioxidative response ↑Immune system ↑ upregulate immune related gene ↑Disease resistance to *A. hydrophila*	[22]
Ginger essential oil	Nile tilapia, *O. niloticus* – 1.84 g	0.5–1.5 % of diet (55 days)	= Growth performance ↑Immune system ↑Disease resistance to *S. agalactiae*	[23]
Ginger powder	Asian seabass, *Lates calcarifer* – 53 g	0.5–1 % of diet (15 days)	↑ Growth performance ↑Hematological profiles ↑Disease resistance to *Vibrio harveyi*	[58]
Ginger leaves powder	African catfish, *Clarias gariepinus* – 10 g	1–4 % of diet (56 days)	↑Growth performance ↑Antioxidative ↑Hematological profiles ↑Disease resistance to *E. tarda*	[63]
Ginger powder	Nile tilapia, *O. niloticus* – 1.6 g	1 % of diet (30 days)	↑ Growth performance ↑Antioxidative response ↑Immune system ↑Disease resistance to *A. hydrophila*	[30]
Ethanolic ginger extract	Common carp, *Cyprinus carpio* – 10.9 g	0.2 % of diet (60 days)	↑ Growth performance ↑Flesh quality ↑Hematological profiles ↑Serum and skin immune system	[31]
Ginger essential oil	Nile tilapia, *O. niloticus* – 0.64 g	0.057–0.227 % (53 days)	↑ Growth performance ↑Flesh quality ↑Nutrient utilization	[59]
Ginger essential oil	Nile tilapia, *O. niloticus* – 7.78 g	0.05 % of diet (60 days)	↑Growth performance ↑Hematological profiles	[60]
Ginger residue from juice extraction	Black rockfish, *S. schlegelii* – 4.2 g	1 % of diet (49 days)	↑ Growth performance ↑Immune system ↑Disease resistance to *V. harveyi*	[73]
Ginger powder	Rainbow trout, *Oncorhynchus mykiss* – 22 g	0.5 % of diet (14 days)	↑Growth performance ↑Hematological profiles ↑Disease resistance to *A. hydrophila*	[33]
Ginger essential oil	Zebrafish, *Danio rerio* – (54.1 mg)	1–3 % of diet (56 days)	= Growth performance ↑Immunological parameters = Immune related genes expression = Growth related genes expression = Antioxidant related genes expression	[69]
Ginger powder	Common carp, *C. carpio* – 16 g	1 % of diet (60 days)	↑Antioxidative response ↑Immune system	[70]
10-gingerol	Grass carp, *Ctenopharyngodon idella* – 13.1 cm	0.0004 % (2 h bath treatment)	↑Disease resistance to *Ichthyophthirius multifiliis*	[21]
Zingerone	Pacific white shrimp, *Litopenaeus vannamei* - juvenile	0.001–0.005 % of feed (56 days)	↑ Growth performance ↑Hematological profiles	[28]

(*continued on next page*)

Table 3 (*continued*)

Ginger and its derivatives	Aquatic animals – weight/length	Dose and duration	Impacts	References
Ginger extract	Pacific white shrimp, *Litopenaeus vannamei* - juvenile	0.0002–0.002 % of diet (7 days)	↑Antioxidative response ↑Immune system ↑Disease resistant to *V. alginolyticus* = Growth performance ↑Disease resistant to *V. parahemolyticus*	[29]

↑positive impact; ↓ negative impact; = no impact.

supplementation in fish diets may enhance flesh quality by elevating lipid and protein content. For instance, Ashry et al. [36] reported that dietary ginger powder supplementation for 90 days significantly improved lipid and protein properties in the flesh of striped catfish, *P. hypophthalmus*. Similar findings were observed in other studies, where dietary ginger powder enhanced flesh quality in juvenile rockfish, *S. schlegeli* [67]. Beyond ginger powder, ginger derivatives such as GRJE, ethanolic ginger extract, and ginger essential oil have also been shown to improve flesh quality enhancement in rockfish [62], common carp [31], and Nile tilapia [59]. This enhancement is likely attributed to improved feed utilization and the increased accumulation of digested nutrients like lipids and amino acids in the fish's flesh [68]. However, it is important to acknowledge conflicting findings. Zaman & Cho [18] reported that dietary ginger did not affect flesh quality in olive flounder. Similarly, Oh et al. [34] observed no significant effect ($p < 0.05$) of dietary GRJE on the flesh of rockfish. These contrasting results highlight potential variation in the response to dietary ginger across different fish species. Further research is necessary to comprehensively investigate the impacts of dietary ginger on flesh quality in a wider range of aquaculture species.

6. Impacts of ginger and its derivatives on hematology analysis of finfish

Dietary ginger and its derivatives have been shown to positively impact the hematological profiles of various fish. These include Asian seabass, *Lates calcarifer* [58], Zebra fish, *Danio reiro* [69], African catfish [32], Nile tilapia [60], and rainbow trout [33]. For instance, Nile tilapia fed a diet containing 0.05 % ginger essential oil exhibited increased levels of red blood cells (RBC), hemoglobin (HGB), and hematocrit (HCT). Similarly, another study reported that a diet containing 2 and 3 % ginger leaf powder enhanced white blood cells (WBC), RBC, HGB, and HCT in African catfish [32]. However, the effects of dietary ginger on hematological profiles are not always positive and can vary depending on the species and dosage. For example, Oh et al. [34] found no significant difference in all tested hematological parameters in rockfish fed a diet supplemented with GRJE. Chung et al. [60] also reported adverse effects on Nile tilapia hematological parameters, such as plasma glucose, triglyceride, albumin, total protein, aminotransferase (AST), alanine aminotransferase activity (ALT), and total cholesterol (T-CHO), with increasing concentration of ginger essential oil in the diet (0.1–0.2 %). These findings highlight the need for further research to determine the optimal dosage and form of ginger for specific fish species to maximize positive effects on their health.

7. Impacts of ginger and its derivatives on antioxidative responses of finfish

Ginger, an herb rich in phenolic compounds, possesses potent antioxidant properties. These phenolic compounds contribute to ginger's ability to enhance antioxidative responses in fish. Several antioxidative parameters, such as superoxide dismutase (SOD), catalase (CAT), and glutathione (GSH) activities, are commonly used to measure the effectiveness of feed additives in this regard. Studies have demonstrated that dietary ginger supplementation can significantly enhance these antioxidant activities in various fish species. For example, black rockfish fed a diet containing 0.75 % GJRE for 8 weeks exhibited increased SOD, CAT, and GSH activities. Similarly, African catfish fed a diet containing 2–3 % ginger leaf powder for 8 weeks displayed significant increases in SOD, CAT, and GSH [32]. The same trend was observed in common carp fed a 1 % ginger diet for 60 days, with all tested antioxidative parameters (SOD, CAT, and GSH) showing enhancement [70]. Ginger has been reported to act as an antioxidant by scavenging 1,1-diphenyl-2--picrylhydrazyl (DPPH) and inhibiting free radicals in the fish body [67]. Ginger's bioactive compounds, such as polyphenols, possess high chelating ability with Fe^{3+} and can inhibit free radical formation in the cell [67]. Furthermore, flavonoids in ginger can perform free radical inhibitory activities. Elevated levels of antioxidative enzymes indicate an improved ability to counteract oxidative stress. This stress can be caused by various factors, including environmental stressors, pathogens, and overcrowding in intensive aquaculture systems. Previous studies have established ginger as a potent antioxidant capable of scavenging free radicals within the host organism [71,72]. Consequently, incorporating ginger into fish diets offers beneficial effects on their antioxidant system.

8. Impacts of ginger and its derivatives on immune system of finfish

Dietary ginger and its derivatives have been shown to positively impact the immune system of fish. For example, Ahmadifar et al. [69] reported that zebrafish fed diets supplemented with ginger essential oil at doses of 1, 2, and 3 % for 8 weeks exhibited enhanced immunological parameters, such as total immunoglobulin, total protein, alkaline phosphatase enzyme activity, and lysozyme activity. Similar findings were observed in Asian seabass [58] and rohu [22] fed diets containing ginger rhizome. Notably, total immunoglobulin and protein are key immunological parameters used to evaluate the effectiveness of feed additives in fish trials [69]. Increased alkaline phosphatase and lysozyme activities suggest heightened protection against pathogens, including viruses, bacteria, fungi, and parasites [69]. However, it is important to note that exceeding appropriate dosages can be detrimental. For instance, Chung et al. [60] reported liver impairment in Nile tilapia fed diets containing excessive ginger essential oil (>0.05 % of diet). Similarly, Wei et al. [32] observed a reduction in antioxidative responses (SOD, CAT, and GSH activities) in African catfish fed diets containing an overdose of ginger (4 %). These findings emphasize the importance of using appropriate ginger dosages to maximize the benefits and avoid adverse effects.

Numerous studies have demonstrated the ability of ginger and its derivatives to stimulate disease resistance in fish. For example, Hassanin [56] found that dietary ginger powder enhanced Nile tilapia's resistance against *Aeromonas hydrophila* infection. The bioactive compounds in ginger, such as flavonoids, polyphenols, saponins, and tannins, are believed to activate the fish's immune system to combat bacterial infections. Similarly, Zaman & Cho [18] reported that dietary ginger powder in olive flounder, *Paralichthys olivaceus,* stimulated disease resistance against *Edwardsiella tarda,* with fish fed ginger performing significantly better than those receiving a probiotic *Lactobacillus fermentum* supplement. Additionally, Oh et al. [34] found that dietary GJRE helped mitigate the effects of *Streptococcus iniae* infection in black rockfish. Furthermore, studies have shown that dietary ginger and its derivatives can significantly improve the cumulative survival rate of fish post-bacterial infection. Wei et al. [32] observed a significantly higher ($p < 0.05$) survival rate in African catfish fed diets containing 2 and 3 % ginger leaf powder for 8 weeks after *E. tarda* infection. Ginger and its derivatives have also been shown to stimulate resistance against various other bacterial infections in fish species, including *A. hydrophila* [22], *Vibrio harveyi* [58,73], and *S. agalactiae* [23]. Notably, Fu et al. [21] demonstrated the effectiveness of 10-gingerol in treating *Ichthyophthirius multifiliis*, a parasite infecting treatment for grass carp, *Ctenopharyngodon idella*.

The immunostimulatory properties of ginger powder are likely attributed to its various bioactive compounds that can promote health. Polyphenols and flavonoids are known to enhance antioxidative responses and disease prevention [74]. Saponins may play a role in eliminating pathogens that invade the host body, while tannins may aid in wound healing. In addition, gingerol has been shown to upregulate immune-related gene expression in aquatic animals, further supporting its role in disease resistance [21].

9. Conclusion

In conclusion, dietary ginger and its derivatives exhibited promising benefits for finfish health. These include enhanced growth performance, immune system function, antioxidative response, and disease resistance. However, exceeding recommended dosages of ginger essential oil (>0.05 % in diet) and ginger leaf (>3 % in diet) resulted in adverse effects on growth and overall health. Additionally, ginger's effectiveness varied across finfish species, with no significant impact observed on olive flounder and black rockfish. Notably, 10-gingerol displayed antiparasitic properties, suggesting its potential as a bathing treatment. Future research should investigate the effects of ginger and its derivatives on shellfish and other aquatic animals, exploring a wider range of aspects like reproductive health.

CRediT authorship contribution statement

Lee Seong Wei: Writing – original draft. **Albaris B. Tahiluddin:** Writing – review & editing. **Wendy Wee:** Writing – review & editing.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lee Seong Wei is an Associate Editor of Heliyon If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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