Phytogenic Feed Additives in Ornamental Fish Nutrition and Health: Current Knowledge, Applications, and Future Prospects

Kazempoor R.[1*]; Alavinejad S.Sh.[2]

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Abstract

Phytogenics have attracted increasing attention in aquaculture as natural bioactive compounds with potential applications in fish nutrition, health management, and disease prevention. Their growing importance is also associated with concerns regarding antimicrobial resistance and the adverse environmental consequences of excessive or inappropriate use of antibiotics and synthetic chemotherapeutics. In ornamental fish, where high economic value, intensive culture conditions, and susceptibility to infectious and non-infectious disorders can compromise production and market value, the development of safe and sustainable alternatives is particularly important. Phytogenics comprise a diverse range of bioactive compounds, including alkaloids, tannins, saponins, glycosides, terpenoids, phenolic compounds, flavonoids, essential oils, and steroids. Depending on their composition, source, dose, and mode of administration, these compounds may improve feed intake, growth performance, nutrient utilization, antioxidant capacity, immune responses, pigmentation, reproductive performance, and resistance to pathogens. Their antimicrobial, antiparasitic, antioxidant, and immunomodulatory properties further support their potential application in disease prevention and health management in ornamental fish. However, the efficacy of phytogenics can vary considerably among plant sources, extraction methods, active compounds, fish species, and experimental conditions, while information on long-term safety, optimal dosages, mechanisms of action, and interactions with other dietary components remains limited. This review summarizes current knowledge on the nutritional, immunological, antimicrobial, and other health-related effects of phytogenics in ornamental fish, with particular emphasis on their potential role in sustainable disease management. Current limitations, research gaps, and future directions for the development and practical application of phytogenic-based strategies in ornamental fish production are also discussed.

Keywords: Phytogenics; Ornamental fish; Nutrition; Disease management; Immune modulation; Pigmentation

1-Department of Aquatic Animal Health and Diseases, Science and Research Branch, Islamic Azad University,Tehran, Iran.
2-Department of Aquatic Animal Health and Diseases, Faculty of Veterinary Medicine, University of Tehran, Tehran, Iran
*Corresponding author's Email: rkbs_kh@yahoo.com

Introduction

Ornamental fish constitute one of the most popular and fastest-growing groups of companion animals (Thomas *et al*., 2020). The international ornamental fish market generates millions of dollars in annual turnover, with approximately USD 44 million currently traded each year (FAO, 2019). Of the more than 30,000 fish species identified worldwide, approximately 800 are ornamental species (Thomas *et al*., 2020). Improving pigmentation, immune function, and survival is a key requirement for the development of the ornamental fish industry (Mohammadiazarm *et al*., 2021).

Rising costs and limited supplies of fish feed have intensified the search for suitable alternatives. Consequently, feeds must be fortified with specific additives, and commercial fish producers seek to increase profitability in the ornamental fish trade by incorporating such additives into formulated diets. Feed additives are dietary substances included in small amounts to improve nutritional quality, enhance growth performance, and reduce mortality (Rani *et al*., 2014). Chemical and synthetic compounds were once commonly used as additives in fish production, but their use has gradually become restricted or prohibited in many countries. Antibiotics are among these compounds and, in addition to their therapeutic applications, were used as growth promoters for nearly 50 years. However, numerous studies have shown that the overuse of antibiotics may increase the risk of antibiotic-resistant bacteria emerging in humans and other animals. Accordingly, in 2006, the European Union prohibited the use of antibiotics as growth promoters in livestock diets (Steiner and Syed, 2015). Moreover, increasing public awareness of environmental problems and the potential health risks associated with the excessive dietary use of antibiotics has gradually changed attitudes toward antibiotics and other chemical additives (Bhanja *et al*., 2023). These developments have stimulated interest in identifying natural compounds capable of providing similar benefits and serving as potential alternatives in the global aquaculture industry (Kazempoor *et al*., 2022).

Among the alternatives to antibiotics and potentially harmful chemical additives are “phytobiotics,” “phytogenics,” and “phytochemicals.” These products are derived from plants, essential oils, plant extracts, or spices and are used as dietary additives in aquatic animals and other livestock (Windisch *et al*., 2008). Through the activity of their metabolites, these feed additives exert beneficial effects on fish growth, gastrointestinal health, immune function, resistance to environmental stressors, reproduction, and pigmentation (Motlagh *et al*., 2020; Kazempoor *et al*., 2022). Their active compounds can be delivered effectively through oral administration, intraperitoneal or intramuscular injection, and even immersion or bath treatments, without adversely affecting the environment (Syahidah *et al*., 2015).

The low cost, ready availability, and safe use of medicinal plants are also important considerations when selecting aquaculture feed additives (Mousavi *et al*., 2021). Nevertheless, the mechanisms of action of phytogenic compounds in aquatic animals remain incompletely understood. In recent years, research and development have therefore focused primarily on clarifying the roles of these compounds as feed additives for improving host performance and health (Kazempoor *et al*., 2022).

Potential gaps in research on phytogenics in ornamental fish culture include the lack of systematic syntheses of the various phytogenics used, their species-specific effects, mechanisms of action, optimal doses, routes of administration, long-term effects and residues, interactions with other dietary additives, economic feasibility, field trials, and commercial scalability. The present study was undertaken to synthesize the available literature on the use of phytogenics in ornamental fish culture, identify key findings and gaps in current knowledge, and compile evidence concerning their effects across different species.

Effects of phytogenics on growth

Improved feed conversion and faster growth in cultured ornamental fish reduce feed expenditure, which otherwise accounts for a substantial proportion of production costs. Efficient feed utilization also shortens the culture period, increases fish production, and consequently improves profitability. In this context, dietary growth promoters can increase weight gain and improve growth performance and feed conversion in fish. Non-hormonal substances, including plants and plant-derived products with growth-promoting properties, may be incorporated into fish diets without substantially increasing feed costs. Nevertheless, the use of plant-based feed ingredients as growth promoters in aquaculture is relatively new (Wagde *et al*., 2018).

Several studies have investigated these effects in ornamental fish. Guz *et al*. (2011), for example, reported significant weight gain and an improved condition factor in guppies (*Poecilia reticulata*) fed diets containing purple coneflower (*Echinacea purpurea*) powder at 0, 5, 10, 20, 30, or 60 g/kg. Nazari and Roozbehani (2015) evaluated the effects of dietary ethanolic fennel (*Foeniculum vulgare*) extract at concentrations of 0, 75, 100, and 125 μL/g on guppy growth. Growth increased significantly in the group receiving 100 μL/g of the extract (Nazari and Roozbehani, 2015). Zareen *et al*. (2023) likewise reported that supplementation with an ethanolic extract of fennel seeds for 90 days significantly improved growth and reduced the feed conversion ratio (FCR) in guppies. In another study, Mousavi *et al*. (2021) found that feeding male guppies diets containing 20 g/kg garlic powder, red onion powder, or sweet red bell pepper powder for 60 days improved growth performance and feed-utilization indices.

Phytogenics have also been investigated in other ornamental species. Baby Joseph *et al*. (2011) found that the use of ornamental flowers—including Chinese rose, Indian rose (*Rosa indica*), flame of the forest (*Ixora coccinea*), and crossandra (*Crossandra infundibuliformis*)—as feed additives for 75 days resulted in significant weight gain in swordtails (*Xiphophorus helleri*). The greatest weight gain in that study was reported in fish fed marigold flowers (Baby Joseph *et al*., 2011). Sotoudeh and Yeganeh (2017) observed an improved FCR in convict cichlids (*Cichlasoma nigrofasciatum*) fed fennel essential oil at 125 mg/kg; however, essential-oil supplementation did not significantly affect the other growth indices evaluated, including specific growth rate, weight gain, and condition factor. Wagde *et al*. (2018) reported improved growth performance in swordtails fed dietary carrot (*Daucus carota*) and spinach (*Spinacia oleracea*) as natural sources of beta-carotene for 35 days. The greatest net weight gain and specific growth rate (SGR) during the trial were observed in fish fed spinach.

Several noteworthy studies have also been conducted in zebrafish (*Danio rerio*). Safari *et al*. (2017), for example, reported significant upregulation of genes associated with growth—growth hormone (*GH*) and insulin-like growth factor 1 (*IGF-1*)—and appetite, namely the ghrelin and obestatin prepropeptide gene (*ghrl*), in zebrafish fed a diet supplemented with myrtle (*Myrtus communis*) seeds at 20 g/kg. Rashidian *et al*. (2021) also reported significantly increased weight and SGR and a significantly reduced FCR in zebrafish fed diets containing oregano (*Origanum vulgare*) extract at 0.5%, 1%, or 2% of the diet for eight weeks. In another study, Safari *et al*. (2022) observed significant upregulation of *GH* and *IGF* genes in zebrafish fed different levels of lemon balm powder, although body weight remained unchanged.

Koi carp (*Cyprinus rubrofuscus*) have also been examined in several studies. Safari *et al*. (2019) reported that feeding koi carp a diet containing asafoetida (*Ferula asafoetida*) for 63 days increased SGR and reduced FCR; survival also increased significantly as the dietary powder level rose. Koi carp fed a diet containing 0.75% *Lippia sidoides* essential oil exhibited lower weight gain, protein efficiency ratio, and SGR than both the control group and the group receiving 0.25% essential oil. By contrast, the group receiving the essential oil at 1% showed no significant difference from the control group (Brasil *et al*., 2019). Jafari *et al*. (2025) subsequently reported improved growth performance in koi fed oregano essential oil while undergoing long-term exposure to naproxen. De Moura *et al*. (2022) reported improvements in growth performance, survival, and size uniformity during the post-larval stage of angelfish (*Pterophyllum scalare*) and severum (*Heros severus*) fed for 30 days on a diet in which açai palm (*Euterpe oleracea*) essential oil replaced soybean oil. Rana *et al*. (2023) also observed improved growth performance in swordtails fed Chinese rose (*Hibiscus* *rosa-sinensis*), marigold (*Tagetes erecta*), or carrot at 15 g per 100 g of feed for eight weeks. The best growth outcomes—including mean weight, body length, and SGR, as well as the lowest FCR—were recorded in the marigold-fed group (Rana *et al*., 2023).

Effects of phytogenics on the intestinal microbiota

The gastrointestinal tract harbors a large and diverse population of microorganisms that play important roles in host growth, development, and health. To date, however, few studies have examined the effects of phytogenic compounds on the gastrointestinal microbiota of aquatic species, and ornamental fish are particularly underrepresented (Zhang *et al*., 2020). Among the available studies, de Medeiros *et al*. (2023) observed a significant increase in intestinal lactic acid bacteria in koi carp fed a diet supplemented with 0.125% *Lippia sidoides* essential oil. Zhang *et al*. (2020) further reported that feeding koi carp a diet containing oregano essential oil at 4,500 mg/kg feed for eight weeks altered the composition of the intestinal bacterial community and significantly increased bacteria belonging to the genera *Propionibacterium*, *Brevundimonas*, and *Corynebacterium*, whereas Vibrio was the dominant genus in the control group.

Effects of phytogenics on digestive enzymes

Digestive enzyme activity is among the most important factors influencing fish growth performance (Zhang *et al*., 2020). Nevertheless, the effects of dietary phytogenic supplements on digestive enzymes—particularly in ornamental fish—have rarely been investigated. Zhang *et al*. (2020) reported significantly increased protease, peptidase, and amylase activities in koi carp fed oregano essential oil at 500, 1,500, or 4,500 mg/kg feed.

Effects of phytogenics on hematological parameters

The immune status of fish is closely associated with their hematological profile, which is of considerable importance in aquaculture and is useful for monitoring fish health (Chandel *et al*., 2009). Hematological indices, including red blood cell (RBC) count, white blood cell (WBC) count, and hemoglobin (Hb) concentration, are effective tools for assessing physiological and pathological changes in fish (Inama *et al*., 1993). Moreover, WBC count is routinely used as an indicator of fish health because leukocytes are major components of innate immune defense and contribute to the regulation of immune function in fish, including ornamental species (Ekman *et al*., 2013).

Relatively few studies have investigated the beneficial properties of phytogenic compounds, particularly their effects on the hematological profiles of ornamental fish. Feeding clownfish (*Amphiprioninae*) diets containing methanolic mangrove (*Avicennia marina*) leaf extract at concentrations of 1%, 2%, and 4% resulted in a progressive increase in circulating leukocyte levels in fish subjected to bacterial infection (Balachandran and Tissera, 2013). In another study, Nugroho *et al*. (2016) evaluated the effects of 30-day immersion in Indian almond (*Terminalia catappa*) leaf extract on hematological parameters in betta fish (*Betta sp*.). A significant increase in RBC count and Hb concentration was observed at 375 ppm, whereas WBC count increased significantly at 625 ppm. The lowest lymphocyte level was recorded in fish immersed at 375 ppm. However, immersion in different concentrations of Indian almond leaf extract had no effect on total protein levels (Nugroho *et al*., 2016).

Safari *et al*. (2019) also reported that feeding koi carp a diet supplemented with asafoetida powder increased WBC count, RBC count, Hb concentration, hematocrit, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), and lymphocyte levels. More recently, de Medeiros *et al*. (2023) reported that feeding koi carp diets containing *Lippia sidoides* essential oil at 0.250%, 0.125%, 0.063%, or 0.031% for 55 days did not affect hematological parameters. Nevertheless, based on the results obtained for the other variables assessed, the authors recommended further studies using higher concentrations of this essential oil.

Effects of phytogenics on immune-system function

Over the past decade, interest has increased in the evaluation and application of environmentally friendly immunostimulants to maintain fish health and enhance immune-system performance. These agents can strengthen both innate and adaptive immune mechanisms, thereby protecting fish against infectious diseases (Vallejos-Vidal *et al*., 2016). Several studies have consequently examined the effects of phytogenic feed additives in ornamental fish. For example, Mousavi *et al*. (2021) investigated male guppies fed for 60 days with diets containing 20 g/kg garlic powder, red onion powder, or sweet red bell pepper powder. These diets significantly enhanced several mucosal immune parameters, including alternative complement pathway hemolytic activity (ACH50), total immunoglobulin, lysozyme activity, and total protein, with the highest values observed in the group receiving garlic powder (Mousavi *et al*., 2021).

In zebrafish, Safari *et al*. (2017) found that 60 days of feeding with diets supplemented with myrtle seeds at 5, 10, or 20 g/kg significantly improved mucosal immune responses, including lysozyme activity, total immunoglobulin, and protease activity, and upregulated the expression of tumor necrosis factor-alpha (TNF-α) and lysozyme genes. In another study, Safari *et al*. (2022) reported that feeding zebrafish different levels of *Dracocephalum kotschyi* powder (1%, 2%, or 3%) for 10 weeks increased total protein, total immunoglobulin, and lysozyme activity and upregulated intestinal expression of the immune-related lysozyme gene and the pro-inflammatory cytokine gene IL-1β. Rashidian *et al*. (2021) likewise reported significant increases in serum lysozyme activity, complement activity, and immunoglobulin M (IgM) in zebrafish fed diets containing oregano extract, particularly at 1% of the diet. Significant increases were also observed in mucosal lysozyme, alkaline phosphatase (ALP), immunoglobulin, and total protein (Rashidian *et al*., 2021).

In studies of koi carp, Safari *et al*. (2019) observed that diets containing different levels of asafoetida powder (0, 5, 10, 15, 20, or 25 g/kg) produced concentration-dependent increases in serum total protein, immunoglobulin activity, lysozyme activity, and alternative complement pathway hemolytic activity. Zhang *et al*. (2020) further reported that dietary supplementation with oregano essential oil at 500, 1,500, or 4,500 mg/kg feed significantly increased lysozyme and complement C3 and C4 levels in koi carp. This treatment also reduced the expression of the TNF-α and transforming growth factor-beta (TGF-β) genes (Zhang *et al*., 2020).

Effects of phytogenics on antioxidant function

Oxidative stress occurs when the production of reactive oxygen species exceeds the capacity of cellular antioxidant defense mechanisms. Antioxidants play a critical role in maintaining this balance by protecting cells against oxidative damage (Yuli *et al*., 2024). The antioxidant activity of phytogenic compounds is attributable to their ability to scavenge free radicals and neutralize reactive oxygen species (ROS) and other oxygen-centered radicals generated in cells and tissues (Kazempoor *et al*., 2022).

Among studies examining the effects of phytogenic compounds on antioxidant function in ornamental fish, Safari *et al*. (2017) reported significant upregulation of the antioxidant genes encoding superoxide dismutase (SOD) and catalase (CAT) in zebrafish fed a diet supplemented with myrtle seeds at 20 g/kg. Rashidian *et al*. (2021) also observed significant increases in serum SOD and CAT activities, accompanied by reduced malondialdehyde (MDA) levels, in zebrafish fed diets containing oregano extract, particularly at 1% of the diet. In another study, Safari *et al*. (2022) reported significantly increased tissue SOD activity and upregulated hepatic expression of the genes encoding SOD and CAT in zebrafish fed different levels of *Dracocephalum kotschyi* powder.

Studies in other ornamental fish have yielded similar findings. Zhang *et al*. (2020) reported that feeding koi carp diets containing oregano essential oil at 500, 1,500, or 4,500 mg/kg feed significantly increased SOD and glutathione peroxidase (GPx) activities and markedly reduced MDA levels. Park *et al*. (2024) found that dietary supplementation with marigold extract (1%) or Carophyll Red pigment (0.5%) for five weeks significantly reduced lipid peroxidation in hepatic tissues, increased SOD and CAT activities, and decreased leukocyte respiratory burst activity in the spleen of golden severum (*Heros efasciatus*).

Effects of phytogenics on disease resistance

Intensive culture, particularly when accompanied by inadequate water-quality management, can promote the proliferation of bacterial populations and other pathogens, ultimately facilitating disease outbreaks in aquatic animals (Toranzo *et al*., 2009; de Medeiros *et al*., 2023). Furthermore, although fish can adapt to environmental conditions, such adaptation may deplete their energy reserves and disrupt hormonal homeostasis, potentially leading to immunosuppression and greater susceptibility to disease (Rottmann *et al*., 1992).

Bacterial diseases

Most diseases affecting fish are infectious and are caused by viruses, bacteria, or parasites. Among these, bacterial diseases have become a persistent challenge in ornamental-fish health management. Bacterial infections may act as either the primary or a secondary cause of disease, exploiting compromised structural integrity or a weakened immune system. The ability of antibiotics to eliminate pathogenic bacteria in fish depends on multiple factors. In many cases, antibiotics merely suppress bacterial growth sufficiently to allow the fish immune system to control and eliminate the causative bacteria. However, certain antibiotics fail because microorganisms develop antimicrobial resistance. Consequently, herbal and traditional medicines have attracted substantial attention in recent years (Balachandran and Tissera, 2013).

Phytogenic compounds are among the agents that have demonstrated activity against bacterial pathogens in aquatic animals (Sirati *et al*., 2024). They can enhance antibacterial defense by increasing phagocytic-cell activity. In addition, these compounds stimulate natural killer cells, promote lymphocyte proliferation and phagocytic activity, and enhance complement activity, lysozyme activity, and antibody responses in fish (Bhanja *et al*., 2023).

Studies in ornamental fish have demonstrated improved survival following exposure to bacterial pathogens. Guz *et al*. (2011), for example, reported enhanced resistance to Aeromonas *hydrophila* in guppies fed a diet containing echinacea powder. Experimental trials have also shown that feeding clownfish a diet containing methanolic mangrove leaf extract increased survival and reduced susceptibility to infections caused by *Pseudomonas fluorescens*, *Pseudomonas aeruginosa*, *Vibrio parahaemolyticus*, and *Vibrio anguillarum* (Balachandran and Tissera, 2013). Similarly, Rashidian *et al*. (2021) reported increased survival in zebrafish fed oregano-extract-supplemented diets following challenge with *Aeromonas hydrophila*. In koi carp, Zhang *et al*. (2020) observed a significant increase in survival after *A. hydrophila* challenge in fish fed diets containing oregano essential oil. De Medeiros *et al*. (2023) likewise reported that dietary supplementation with *Lippia sidoides* essential oil, particularly at 0.125%, increased survival in koi carp challenged with *A. hydrophila*.

Parasitic diseases

Like food fish, ornamental-fish species are susceptible to parasitic infections, which can cause high mortality and considerable economic losses, thereby threatening the commercial sustainability of the industry. In addition to direct mortality, parasites can adversely affect growth, behavior, resistance to stressors, and susceptibility to predation. The visible presence of parasites on ornamental fish may also reduce their marketability (Sahandi *et al*., 2023). Fish farmers commonly use drugs such as praziquantel, mebendazole, and levamisole to control parasites. However, the continuous or inappropriate use of these products can cause environmental contamination, pathological changes in fish, human-health risks, and the development of pathogen resistance to chemotherapeutic agents. Although oral administration of antiparasitic drugs can be effective, it may be associated with host toxicity, resistance development, and poor palatability; consequently, this approach is not commonly used. These limitations have made the search for alternatives that minimize such adverse effects a priority. In this context, several plant-derived products have been shown to be effective in preventing, controlling, and treating parasitic diseases in fish (Brasil *et al*., 2019).

Monogenean parasites cause substantial economic losses in commercially cultured fish, and available chemical treatments, which are often stressful to fish, carry inherent risks (Levy *et al*., 2015). Chansue and Tangtrongpiros (2005) reported that Indian almond leaf extract significantly reduced *Gyrodactylus* and *Dactylogyrus* infections in goldfish (*Carassius auratus*). The highest tested concentration (5.1 g/L water) was the most effective and completely eliminated all parasites after two weeks of treatment without adverse effects. By contrast, no significant reduction in parasitic infection occurred in the untreated control group (Chansue and Tangtrongpiros, 2005).

In another study, Levy *et al*. (2015) found that immersing guppies infected with *Gyrodactylus turnbulli* in ethanolic ginger extract at 5 and 7.5 ppt for 90 and 30 min, respectively, significantly reduced infection prevalence and intensity. The higher concentration (7.5 ppt) was as effective as praziquantel, a conventional chemotherapeutic treatment for *Gyrodactylus*, and completely cleared the infection. By contrast, oral administration was ineffective: diets supplemented with 10% or 20% ginger powder did not reduce parasite burden in infected guppies (Levy *et al*., 2015).

Similarly, Brasil *et al*. (2019) evaluated koi carp fed diets containing *Lippia sidoides* essential oil at 0.25%, 0.50%, 0.75%, or 1% for 60 days and observed no antiparasitic effects against *Dactylogyrus minutus*, *Dactylogyrus extensus*, *Trichodina reticulata*, or *Trichodina heterodentata*, despite a previously reported 100% antiparasitic effect of the essential oil under in vitro conditions. The authors suggested that the tested concentrations of *L. sidoides* essential oil may not have been sufficiently high to eliminate the parasites (Brasil *et al*., 2019). Sahandi *et al*. (2023) also found that prolonged immersion (14 days) in aqueous extracts of garlic (Allium sativum; 0.1 g/L) or chamomile (*Matricaria chamomilla*; 0.4 g/L) increased survival and suppressed *Ichthyophthirius multifiliis* infection in guppies. Survival was higher in fish immersed in chamomile extract than in those treated with garlic extract. Garlic extract completely resolved the parasitic infection after four days, whereas chamomile extract achieved complete resolution after six days (Sahandi *et al*., 2023).

Fungal diseases

Fish reared at high stocking densities may experience various forms of instability, including fluctuations in water quality that predispose them to fungal disease outbreaks (Assefa and Abunna, 2018; Saraiva *et al*., 2019). Conventional antifungal drugs are associated with several adverse effects. Pazira (2017) evaluated the antifungal activity of garden thyme essential oil against fungi isolated from koi skin, including *Aspergillus flavus*, *Aspergillus fumigatus*, *Aspergillus niger*, and *Saprolegnia parasitica*. The essential oil exerted its greatest inhibitory effect against *A. flavus* and its weakest effect against *S. parasitica* (Pazira, 2017).

Effects of phytogenics on reproduction

Reproduction and propagation of ornamental fish play important roles in improving the profitability of the fish-culture industry. Ornamental-fish breeders use diverse techniques to propagate aquarium species. Some species reproduce following simple environmental modifications, such as adjustments to water temperature, pH, or electrical conductivity, whereas others require more advanced techniques, including the administration of synthetic hormones to induce spawning. However, synthetic hormones are expensive, require skilled personnel, and involve time-consuming administration procedures (Nazari and Roozbehani, 2015). Their accumulation in sediments and aquatic ecosystems has also been reported (Yilmaz *et al*., 2009).

Nutrition is another major factor influencing gonadal development and reproduction in ornamental fish. Various feeds containing hormonal supplements, as well as numerous plant-derived products, are used to enhance fertility and gamete maturation in these species (Zareen *et al*., 2023). Replacing synthetic hormones with herbal preparations may therefore offer a novel approach to fish propagation. Phytoestrogens are plant-derived compounds that are structurally similar to animal estrogens (Yilmaz *et al*., 2009). The three principal groups of phytoestrogens are isoflavones, coumestans, and lignans. Several studies have investigated the capacity of phytogenic feed additives to improve reproductive performance in ornamental fish. Nazari and Roozbehani (2015), for example, reported increased fertility in guppies fed ethanolic fennel extract. The treatment increased the number of gonadal cells and phytoestrogen levels, enlarged the granulosa layer of gonadal follicles, and increased the number of ova at different developmental stages (Nazari and Roozbehani, 2015). Sotoudeh and Yeganeh (2017) similarly observed significant increases in the gonadosomatic index and fertility of convict cichlids fed fennel essential oil at 125 mg/kg. Zareen *et al*. (2023) reported increased absolute fecundity and spawning rate, together with an improved gonadosomatic index, in guppies supplemented with ethanolic fennel-seed (*Foeniculum vulgare*) extract for 90 days. In another noteworthy study, Chansue and Assawawongkasem (2011) described the widespread use of Indian almond leaves as an immersion treatment to stimulate reproduction in Siamese fighting fish (*Betta splendens*) culture in Thailand.

Effects of phytogenics on the histopathology of organs

Structural alterations in organs are easier and faster to detect than functional changes and may serve as early warning signs of impaired animal health. Consequently, histological and histopathological examinations in fish are useful for evaluating biological changes and may be employed as indicators of their physical condition (Rezaeipour *et al*., 2024). In this context, several studies have investigated the effects of oregano essential oil on the gill, spleen, and brain tissues of koi carp exposed to pharmaceutical contaminants. The findings indicated that diets containing oregano essential oil had no adverse effects on fish tissues and reduced contaminant-induced damage in the gills and spleen (Naderi *et al*., 2022) and in the brain (Alavinejad *et al*., 2022) of koi carp.

Effects of phytogenics on skin tissue damage

Fish skin is a living organ that constitutes the first line of nonspecific defense and plays a vital role in protecting fish against mechanical injury and infections in a constantly changing aquatic environment. Any damage to this organ can lead to secondary bacterial and fungal infections (Harms, 1996). Therefore, side-effect-free approaches to treating skin lesions in fish are of considerable interest and importance. Indian almond leaves are among the aquaculture products traditionally used to treat wounds, particularly in Siamese fighting fish after fighting contests (Chansue *et al*., 2004). Chansue *et al*. (2004) demonstrated that Indian almond leaf extract could increase the thickness of the keratin layer in the scales of Siamese fighting fish. In another study, Chansue and Tangtrongpiros (2006) found that an aqueous extract of dried Indian almond leaves accelerated caudal-fin regeneration in koi carp. Jafari *et al*. (2025) also reported reduced tissue damage in the intestine and liver of koi carp fed oregano essential oil and subjected to long-term exposure to naproxen (Jafari *et al*., 2025).

Effects of phytogenics on pigmentation

Coloration is a major determinant of ornamental fish sales and market value (Rajaee, 2011). Fish coloration is primarily produced by the distribution or aggregation of chromatophores in the skin. These cells contain four major pigment groups—melanins, purines, pteridines, and carotenoids—with carotenoids being the most important (Smith *et al*., 2012). As in other animals, fish cannot synthesize carotenoids de novo; these pigments must therefore be supplied through natural feeds or dietary supplements (Kaur *et al*., 2016). A noninvasive method for enhancing the coloration of ornamental fish is to provide nontoxic pigments through the diet. These pigments are absorbed and deposited in the skin or muscle tissues, where chromatophores—specialized pigment-containing cells—are concentrated (de Carvalho and Caramujo, 2017). Accordingly, interest in natural rather than synthetic dietary pigments for improving ornamental fish coloration has increased because of their health-promoting properties and ready availability (Mousavi *et al*., 2024). Various carotenoids are incorporated into fish diets to enhance coloration. Some of the most important include tunaxanthin (yellow), lutein (greenish yellow), beta-carotene (orange), alpha- and beta-doradexanthins (yellow), zeaxanthin (yellow-orange), canthaxanthin (orange-red), astaxanthin (red and the predominant pigment in red-colored fish), echinenone (red), and taraxanthin (yellow). Among these pigments, astaxanthin is the most important and widely occurring carotenoid in red-colored fish (Amoah *et al*., 2017).

Several studies have examined the effects of phytogenic compounds on ornamental fish coloration. For example, Mousavi *et al*. (2021) reported that feeding male guppies diets containing 20 g/kg garlic powder, red onion powder, or sweet red bell pepper powder for 60 days significantly increased total carotenoid concentrations in the body skin and caudal fin, with the highest concentration observed in the group receiving sweet red bell pepper powder. Baby Joseph *et al*. (2011) reported an increase in pigment percentage in swordtails (*Xiphophorus helleri*) fed the ornamental flowers Chinese rose, Indian rose, flame-of-the-forest, and crossandra as carotenoid-source feed additives for 75 days. The greatest increase in pigment percentage was recorded in fish fed flame-of-the-forest flowers (Baby Joseph *et al*., 2011). Rana *et al*. (2023) also observed increased carotenoid levels in swordtails fed Chinese rose, marigold, or carrot at 15 g/100 g feed for eight weeks; the greatest increase occurred in the group receiving marigold (Rana *et al*., 2023). Yeşilayer *et al*.

(2020) evaluated the effects of three months of dietary supplementation with nettle (*Urtica*), marigold, and alfalfa (*Medicago sativa*) extracts on skin pigmentation in electric yellow cichlids (*Labidochromis caeruleus*) and compared these effects with those of synthetic xanthophylls. The highest brightness and best color characteristics were observed in the groups receiving nettle and alfalfa extracts (Yeşilayer *et al*., 2020).

In studies involving other ornamental fish, Kurnia *et al*. (2019) found that dietary red dragon-fruit peel meal at inclusion levels of 5%, 10%, and 15% for 42 days increased the intensity of orange and black coloration in ornamental koi carp (*Cyprinus carpio*). In another study, feeding koi carp a mixture containing orange marigold petal powder at 5 or 20 g petals/kg feed for six weeks improved red coloration by approximately 40% in fish receiving 20 g/kg, whereas the 5 g/kg inclusion level was ineffective (Lê *et al*., 2024). Besen *et al*. (2019) similarly found that a lutein-containing diet improved skin coloration in goldfish (*Carassius auratus*) to an extent comparable to that achieved with astaxanthin. Park *et al*. (2024) further reported that feeding golden severum fish diets containing marigold (*Tagetes erecta*) extract (1%) and Carophyll Red pigment (0.5%) for five weeks enhanced body-color patterns and produced distinctive coloration.

Effects of phytogenics on behavior

Zago *et al*. (2018) observed an anxiolytic response in zebrafish fed a diet supplemented with lemon verbena (*Aloysia triphylla*) essential oil for 90 days, as evidenced by reduced exploratory activity, oxygen consumption, and cortisol concentrations, thereby indicating improved fish welfare. These properties make lemon verbena essential oil potentially suitable for use in high-density production systems because it neither disrupts the neuroendocrine stress axis nor compromises growth performance (Zago *et al*., 2018). It should be noted, however, that adding the essential oil directly to the water is itself stressful and does not reduce cortisol concentrations (Bandeira-Junior *et al*., 2018). The absence of impaired growth also suggests that the fish did not experience chronic stress, which would ordinarily suppress growth.

Zago *et al*. (2018) further showed that control fish placed in a novel environment exhibited the expected behavior known as thigmotaxis, whereby they spent more time near the edges of the test arena (Treit and Fundytus, 1988). In contrast, zebrafish fed diets containing lemon verbena essential oil did not exhibit this pattern and spent comparable amounts of time in the central and peripheral zones, a response that may be attributable to the oil's anxiolytic effect. Another noteworthy point is that exploratory activity generally increases following anxiolytic treatment; however, this does not necessarily reflect treatment-induced stimulation of exploration, but rather the alleviation of stress-mediated inhibition of exploratory behavior (Prut and

Belzung, 2003). Because no stress-induction test was performed in the study by Zago *et al*. (2018) and cortisol concentrations remained low, exploratory activity decreased. Furthermore, locomotor activity did not differ among treatments, which was a favorable finding because it indicated that the essential oil did not compromise fish performance and that normal swimming behavior was maintained (Zago *et al*., 2018).

Toxicity of phytogenics

Standardizing the doses of phytogenic additives administered by different methods is a critical issue in ornamental fish culture. Although most studies have demonstrated beneficial effects and relatively few adverse effects have been reported, the high importance of survival in ornamental fish warrants further research to optimize administration doses. In this regard, Chansue and Assawawongkasem (2011) investigated the toxicity of an aqueous Indian almond leaf extract in ornamental fish. The 24-h LC50 values reported for guppy, koi carp, and Siamese fighting fish were 6.2, 7.6, and 8.6 mg/mL, respectively. The corresponding 48-h LC50 values were 5.4, 7.0, and 8.2 mg/mL; the 72-h LC values were 5.8, 5.9, and 7.6 mg/mL; and the 96-h LC values were 5.6, 5.8, and 7.0 mg/mL, respectively.

Conclusions and future perspectives

Phytogenic compounds are increasingly important in aquaculture because they offer multiple potential benefits, including improvements in growth performance and feed utilization, digestive enzyme activity and the intestinal microbiota, hematological indices, immune responses, antioxidant capacity, and resistance to disease. The evidence reviewed here indicates that phytogenics can enhance the performance and health of ornamental fish and may reduce reliance on antibiotics and other chemotherapeutic agents, thereby supporting a healthier, more environmentally responsible, and sustainable ornamental-fish industry. Identifying and validating effective phytogenic compounds could facilitate the development of preventive and therapeutic protocols, as well as commercial products for routine use to improve growth and survival. Nevertheless, further research is required to optimize these compounds, particularly for effective oral administration. Concentration, treatment duration, and route of administration are among the principal determinants of efficacy. The mechanisms underlying the effects of individual phytogenics should also be investigated specifically in ornamental fish through comprehensive, species-focused studies. Future research should evaluate combinations of phytogenic supplements with other feed additives, including probiotics and prebiotics, and should compare their efficacy and safety with those of conventional antibiotics.

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