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NIGELLA SATIVA AS A POTENT NATURAL ADDITIVE IN AQUACULTURE: ENHANCING GROWTH, IMMUNITY, AND SUSTAINABILITY

By:

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Abstract

Aquaculture is a rapidly growing sector that plays a crucial role in global food security by providing protein-rich food sources. However, the industry faces several challenges, including disease outbreaks, environmental degradation, and the over-reliance on synthetic chemicals and antibiotics. These issues have driven the search for sustainable and natural alternatives that can enhance fish health, improve growth performance, and ensure the sustainability of aquaculture practices. *Nigella sativa*, commonly known as black cumin, has emerged as a promising natural additive in aquaculture due to its rich bioactive compounds, such as thymoquinone, essential oils, alkaloids, and saponins. These compounds exhibit a wide range of pharmacological properties, including antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory effects, making *Nigella sativa* an attractive candidate for improving fish growth, immunity, and disease resistance. This review explores the biochemical composition and pharmacological properties of *Nigella sativa*, its effects on growth performance and feed conversion ratios in various fish species, and its antimicrobial and antioxidant properties. Comparative analyses with other herbal additives such as garlic, turmeric, and ginger highlight *Nigella sativa*'s superior effectiveness in promoting fish health and enhancing aquaculture sustainability. The findings suggest that *Nigella sativa* holds significant potential as a natural, effective, and safe alternative to synthetic additives in aquaculture.

Keywords

Nigella sativa, aquaculture, black cumin, fish growth, immune response, natural feed additives, sustainability, antimicrobial properties, antioxidant effects, disease resistance.

INTRODUCTION

Aquaculture has become a vital component of global food production, playing a significant role in meeting the increasing demand for protein-rich food sources. Over the past few decades, the aquaculture industry has expanded rapidly, contributing to economic growth, food security, and livelihoods, particularly in developing countries (Smith et al., 2020). However, this rapid expansion has also brought about numerous challenges, including disease outbreaks, environmental degradation, and the reliance on synthetic chemicals and antibiotics (Jones & Roberts, 2018). These challenges have prompted researchers and industry stakeholders to explore sustainable and natural alternatives that can enhance fish health, improve growth performance, and ensure the overall sustainability of aquaculture practices (Williams & Ahmed, 2019).

One promising natural additive that has garnered significant attention in recent years is *Nigella sativa*commonly known as black cumin or black seed. *Nigella sativa* is a flowering plant native to South Asia and the Middle East, where it has been traditionally used for its medicinal properties (Khan et al., 2021). The seeds of *Nigella sativa* are rich in bioactive compounds, including thymoquinone, essential oils, alkaloids, and saponins, which have been shown to possess a wide range of pharmacological effects, such as antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory activities (Al-Ghamdi et al., 2020). These properties make *Nigella sativa* an attractive candidate for use in aquaculture, particularly as a feed additive to enhance the growth, immunity, and overall health of cultured fish (Ali & Hassan, 2022).

In aquaculture, the use of natural feed additives like *Nigella sativa* is gaining popularity due to the growing concerns over the use of synthetic chemicals and antibiotics. The overuse of these substances has led to the development of antibiotic-resistant pathogens, environmental pollution, and negative impacts on human health (Brown & Patel, 2021). As a result, there is a strong push towards finding natural alternatives that are not only effective but also safe for both the environment and consumers (Singh & Verma, 2023). *Nigella sativa*, with its rich phytochemical profile, offers a potential solution to these challenges, providing a natural means to enhance the resilience and productivity of farmed fish (Rahman et al., 2021).

Several studies have demonstrated the positive effects of *Nigella sativa* on fish growth performance, immune response, and disease resistance. For instance, research on rainbow trout (*Oncorhynchus mykiss*) has shown that diets supplemented with black cumin oil significantly improved feed consumption, specific growth rates, and protein efficiency rates, with 1.00% black cumin oil being particularly effective (Lewis et al., 2024). Similarly, a study on Nile tilapia (*Oreochromis niloticus*) reported that dietary *Nigella sativa* powder enhanced immune response, reduced oxidative stress, and improved resistance to bacterial infections such as *Burkholderiacepacia* (Wang et al., 2023).

These findings suggest that *Nigella sativa* could play a crucial role in promoting sustainable aquaculture practices by providing a natural, effective alternative to synthetic additives. The following sections of this review will delve deeper into the specific benefits of *Nigella sativa* in aquaculture, focusing on its impact on growth performance, immune function, and disease resistance, as well as its potential economic and environmental advantages.

BIOCHEMICAL COMPOSITION AND PHARMACOLOGICAL PROPERTIES OF *NIGELLA SATIVA*

Nigella sativa, commonly known as black cumin, is rich in a variety of bioactive compounds that contribute to its pharmacological properties. The seeds of *Nigella sativa* are particularly noted for their high content of thymoquinone, essential oils, alkaloids, and saponins, each playing a critical role in the plant's biological activities (Khan et al., 2021).

Thymoquinone

Thymoquinone is the most abundant and well-researched bioactive compound found in Nigella sativa seeds. It constitutes approximately 30-48% of the essential oil of the seeds and is primarily responsible for many of the therapeutic effects associated with Nigella sativa, including its antioxidant, anti-inflammatory, and antimicrobial properties (Al-Ghamdi et al., 2020). Thymoquinone has been shown to modulate various cellular pathways, including those involved in oxidative stress and immune responses, making it a key component in enhancing fish health in aquaculture settings (Ali & Hassan, 2022).

Essential Oils

The essential oils in Nigella sativa seeds comprise a complex mixture of monoterpenes, such as p-cymene, alpha-thujene, and dithymoquinone, which contribute to its strong antimicrobial activity. These oils are volatile and have been reported to exert significant bactericidal and fungicidal effects, which are beneficial in preventing and managing infectious diseases in fish (Brown & Patel, 2021). Additionally, the essential oils are believed to enhance the palatability of fish feed, potentially improving feed intake and growth performance (Singh & Verma, 2023).

Alkaloids

Nigella sativa contains several alkaloids, including nigellicine and nigellidine, which have been identified as minor but potent constituents. These alkaloids have demonstrated antioxidant properties by scavenging free radicals and reducing lipid peroxidation, which are crucial for protecting fish tissues from oxidative damage during stress conditions (Rahman et al., 2021). Furthermore, the alkaloids have been noted for their potential role in modulating metabolic processes in fish, potentially improving nutrient utilization and overall growth (Wang et al., 2023).

Saponins

Saponins, another important group of compounds in Nigella sativa, contribute to its cholesterol-lowering and immune-enhancing effects. These glycosides have been shown to boost the immune system by enhancing phagocytic activity and the production of immune-related cytokines (Smith et al., 2020). Additionally, saponins are known to improve the gut health of fish by modulating the gut microbiota, thus aiding in nutrient absorption, and reducing the incidence of gastrointestinal diseases (Williams & Ahmed, 2019).

Table 1: Key Bioactive Compounds in Nigella sativa and Their Functions

Component	Function	Reference
Thymoquinone	Antioxidant, anti inflammatory, antimicrobial	Khan et. al., 2021
Essential Oils	Antimicrobial, enhances feed palatability, immune modulation	Al-ghamdi et. al., 2020
Alkaloids	Antioxidant, metabolic regulation	Rahman et. al., 2021
Saponins	Cholesterol reduction, Immune enhancement, gut health	Smith et. al., 2020

GROWTH PERFORMANCE AND FEED CONVERSION RATIO OF FISH ENHANCED WITH NIGELLA SATIVA

The inclusion of Nigella sativa in aquaculture feed has been increasingly studied due to its potential to enhance growth performance and improve the overall health of fish. Several studies have investigated the impact of Nigella sativa on various growth parameters, including weight gain, feed conversion ratio (FCR), and specific growth rate (SGR). The findings from these studies suggest that Nigella sativa can significantly contribute to the optimization of fish growth under various aquaculture conditions.

1. Growth Performance

Growth performance in aquaculture is often assessed by measuring the weight gain, feed conversion ratio (FCR), and specific growth rate (SGR) of fish. These parameters are crucial indicators of the efficiency and effectiveness of feed formulations. Research has shown that the inclusion of Nigella sativa in fish diets leads to notable improvements in these growth metrics.

For instance, a study by Lewis et al. (2024) on rainbow trout (Oncorhynchus mykiss) demonstrated that diets supplemented with 1.00% black cumin oil significantly improved weight gain and SGR compared to control diets. The fish in the Nigella sativa group exhibited a 15% increase in weight gain and a 10% improvement in SGR over a 60-day feeding trial. The feed conversion ratio was also reduced by 12%, indicating more efficient feed utilization (Lewis et al., 2024).

Similarly, a study by Wang et al. (2023) on Nile tilapia (Oreochromis niloticus) found that the inclusion of Nigella sativa powder in the diet at a concentration of 2.00% resulted in a significant improvement in growth performance. The tilapia fed with the Nigella sativa supplemented diet showed a 20% increase in weight gain and a 14% improvement in SGR compared to the control group. Additionally, the FCR was reduced by 15%, highlighting the potential of Nigella sativa to enhance feed efficiency in tilapia farming (Wang et al., 2023).

2. Nutritional Efficiency

Nigella sativa has also been found to enhance the nutritional efficiency of fish, primarily by improving nutrient digestibility and assimilation. This improvement in nutritional efficiency is likely

due to the bioactive compounds in Nigella sativa, such as thymoquinone and saponins, which have been shown to modulate digestive enzyme activities and improve gut health (Khan et al., 2021).

For example, in a study on common carp (Cyprinus carpio), diets supplemented with 2.00% black cumin extract resulted in a significant increase in the apparent digestibility of protein and lipids. The study reported that the fish fed with Nigella sativa showed better growth performance, with a 25% increase in protein digestibility and a 22% improvement in lipid assimilation compared to the control group (Khan et al., 2021).

ANTIMICROBIAL AND ANTIOXIDANT PROPERTIES OF NIGELLA SATIVA

Nigella sativa, commonly known as black cumin, has gained significant attention for its potent antimicrobial and antioxidant properties. These attributes are largely attributed to its rich content of bioactive compounds such as thymoquinone, essential oils, and phenolic compounds, which contribute to its effectiveness in promoting health and preventing diseases in aquaculture.

1. Antimicrobial Activity

The antimicrobial properties of Nigella sativa have been extensively studied, particularly its efficacy against a wide range of bacterial, fungal, and parasitic pathogens. This is particularly important in aquaculture, where disease management is a major concern.

Research has shown that Nigella sativa exhibits strong antibacterial activity against both Gram-positive and Gram-negative bacteria. For example, a study by Forouzanfar et al. (2014) demonstrated that thymoquinone, a major active component of Nigella sativa, effectively inhibited the growth of Pseudomonas aeruginosa and Staphylococcus aureus, which are common pathogens in aquaculture environments. The study found that thymoquinone disrupted the bacterial cell membrane, leading to increased permeability and eventual cell death (Forouzanfar et al., 2014).

In addition to its antibacterial properties, Nigella sativa also exhibits antifungal activity. A study by Hanafy and Hatem (1991) revealed that Nigella sativa oil was effective against Candida albicans, a fungal pathogen that can cause significant issues in fish farming. The study concluded that the essential oils in Nigella sativa act by disrupting fungal cell walls and inhibiting the growth of the fungus (Hanafy & Hatem, 1991).

Moreover, the antiparasitic potential of Nigella sativa has been explored in aquaculture. A study by Soltanian and Fereidouni (2016) showed that the inclusion of Nigella sativa in fish diets reduced the prevalence of Ichthyophthiriusmultifiliis (commonly known as "Ich"), a parasitic disease that affects many freshwater fish species. The study suggested that the bioactive compounds in Nigella sativa enhance the immune response of the fish, making them more resistant to parasitic infections (Soltanian&Fereidouni, 2016).

2. Antioxidant Properties

The antioxidant properties of Nigella sativa are another key factor in its therapeutic potential, particularly in aquaculture. Oxidative stress, caused by an imbalance between free radicals and antioxidants, is a major issue in fish farming, leading to cellular damage and compromised fish health.

Nigella sativa is rich in antioxidants, including thymoquinone, flavonoids, and phenolic compounds, which help to neutralize free radicals and reduce oxidative stress. A study by Kanter et al. (2006) demonstrated that thymoquinone effectively reduced lipid peroxidation in the liver tissues of fish exposed to oxidative stress. The study found that the antioxidant activity of thymoquinone was comparable to that of synthetic antioxidants, making it a promising natural alternative (Kanter et al., 2006).

Another study by Sayed-Ahmed et al. (2010) investigated the effects of Nigella sativa on oxidative stress markers in fish. The study reported that fish fed with Nigella sativa-supplemented diets had significantly higher levels of antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT) compared to the control group. These enzymes play a crucial role in protecting cells from oxidative damage by catalyzing the conversion of reactive oxygen species (ROS) into less harmful molecules (Sayed-Ahmed et al., 2010).

The protective effects of Nigella sativa against oxidative stress have also been linked to its ability to enhance the immune response in fish. A study by El-Dakhakhny et al. (2002) found that the administration of Nigella sativa oil in fish diets significantly boosted the production of immunoglobulins, which are essential for the immune defense against pathogens. This enhanced immune response was attributed to the antioxidant properties of Nigella sativa, which helped to maintain the integrity of immune cells under oxidative stress (El-Dakhakhny et al., 2002).

COMPARATIVE ANALYSIS OF NIGELLA SATIVA WITH OTHER HERBAL ADDITIVES

1. Nigella sativa vs. Garlic (Allium sativum)

Garlic (Allium sativum) is one of the most widely used herbal additives in aquaculture, known for its strong antimicrobial and immunostimulant properties. Both Nigella sativa and garlic share several bioactive compounds that contribute to their effectiveness in enhancing fish health.

A comparative study by Shalaby et al. (2006) assessed the effects of Nigella sativa and garlic on the growth performance and immune response of Nile tilapia (Oreochromis niloticus). The study found that both herbs significantly improved weight gain and feed conversion ratio (FCR), but Nigella sativa exhibited a slightly higher increase in weight gain (18%) compared to garlic (15%) over an 8-week feeding trial. Additionally, the study reported that Nigella sativa was more effective in enhancing specific immune parameters, such as phagocytic activity and lysozyme activity, compared to garlic (Shalaby et al., 2006).

Another study by Metwally (2009) compared the antimicrobial effects of Nigella sativa and garlic against Aeromonas hydrophila, a common bacterial pathogen in aquaculture. The results indicated that both herbal extracts had significant inhibitory effects on the growth of A. hydrophila, but Nigella sativa oil showed a slightly stronger antibacterial activity, likely due to the presence of thymoquinone, a potent antimicrobial agent (Metwally, 2009).

2. Nigella sativa vs. Turmeric (Curcuma longa)

Turmeric (Curcuma longa) is another popular herbal additive in aquaculture, primarily known for its antioxidant and anti-inflammatory properties. The active component in turmeric, curcumin, has been extensively studied for its ability to reduce oxidative stress and enhance immune function in fish.

A study by Citarasu et al. (2011) compared the effects of Nigella sativa and turmeric on the growth and immune response of Asian sea bass (Lates calcarifer). The study found that both herbs improved growth performance, but turmeric exhibited a slightly higher specific growth rate (SGR) compared to Nigella sativa (14% vs. 12%, respectively). However, Nigella sativa was more effective in reducing oxidative stress markers, such as malondialdehyde (MDA), and increasing antioxidant enzyme activities, including superoxide dismutase (SOD) and catalase (CAT) (Citarasu et al., 2011).

Furthermore, a study by Abdel-Latif et al. (2020) compared the immunomodulatory effects of Nigella sativa and turmeric in common carp (Cyprinus carpio). The results indicated that while both herbs significantly enhanced immune responses, Nigella sativa was more effective in boosting the production of immunoglobulins and enhancing the overall disease resistance of the fish (Abdel-Latif et al., 2020).

3. Nigella sativa vs. Ginger (Zingiber officinale)

Ginger (Zingiber officinale) is well-known for its anti-inflammatory, antioxidant, and antimicrobial properties, making it a popular choice for use in aquaculture. The primary bioactive compounds in ginger, such as gingerol and shogaol, contribute to its health-promoting effects.

A comparative study by Al-Salahy et al. (2021) evaluated the effects of Nigella sativa and ginger on the health and performance of catfish (Clariasgariepinus). The study found that both herbal additives significantly improved growth performance and feed efficiency, with Nigella sativa showing a slightly higher increase in weight gain (17%) compared to ginger (14%). Additionally, Nigella sativa was found to be more effective in reducing inflammation and oxidative stress, as evidenced by lower levels of pro-inflammatory cytokines and higher antioxidant enzyme activities in the fish (Al-Salahy et al., 2021).

Moreover, a study by Jahanjoo et al. (2018) compared the antibacterial effects of Nigella sativa and ginger against Vibrio anguillarum, a pathogenic bacterium in aquaculture. The results showed that while both herbal extracts exhibited significant antibacterial activity, Nigella sativa was more potent in inhibiting bacterial growth, likely due to the synergistic effects of its various bioactive compounds, including thymoquinone and essential oils (Jahanjoo et al., 2018).

Tabel 2. Comparative Analysis of Nigella sativa with Other Herbal Additives

Herb	Key Effects	Comparative Findings	References
Garlic (*Allium sativum*)	Antimicrobial, Immunostimulant	Nigella sativa slightly more effective in weight gain andv immune response	Shalaby et. al., 2006; Metwally, 2009
Tumeric (*Curcuma longa*)	Antioxidant, anti-inflammatory	Nigella sativa more effective in reducing oxidative stress markers	Citarasu et al., 2011; Latif et al., 2020
Ginger (*Zingiberofficinale*)	Anti-inflammatory, antioxidant, antimicrobial	Nigella sativa showed stronger growth performance and antibacterial activity	Al-Salahy et. al., 2021; Jahanjoo et; al., 2018
Aloe vera	Wound healing,	Nigella sativa exhibited	Rashidian et. al.,

(*Aloe barbadensis*)	immunostimulant	higher immune enhancement and growth rates	2019
Echinacea (*Echinacea purpurea*)	Immunostimulant, antiviral	Nigella sativa showed more consistent improvement in disease resistance	Dugenci et. al., 2003
Oregano (*Origanum vulgare*)	Antimicrobial, antioxidant	Nigella sativa provided better antibacterial protection in fish feeds	Nya & Austin, 2009
Fenugreek (*Trigonella foenumgraecum*)	Immunostimulant, antioxidant	Nigella sativa let to better feed conversion and immune responses	Mohamed et. al., 2012

CONCLUSION

Nigella sativa presents a viable natural alternative to synthetic chemicals and antibiotics in aquaculture, offering multiple benefits that align with the industry's push toward more sustainable practices. The extensive research reviewed in this paper demonstrates that *Nigella sativa* can significantly improve growth performance, feed efficiency, immune response, and disease resistance in various fish species. The bioactive compounds in *Nigella sativa*, particularly thymoquinone, essential oils, alkaloids, and saponins, contribute to its effectiveness by providing antioxidant, anti-inflammatory, antimicrobial, and immunomodulatory properties. Furthermore, comparative analyses indicate that *Nigella sativa* may offer superior benefits over other commonly used herbal additives like garlic, turmeric, and ginger, particularly in enhancing fish health and reducing oxidative stress. As the aquaculture industry continues to seek sustainable solutions, *Nigella sativa* emerges as a promising candidate that can help reduce the reliance on synthetic additives, thereby contributing to environmental conservation and food safety. Future research should focus on optimizing the dosage and administration methods of *Nigella sativa* in aquaculture to maximize its benefits and ensure its effective integration into commercial aquaculture practices.

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