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The Role of Vitamin C, Vitamin E and Zinc Supplementation in Enhancing the Resilience of Cultured Fish to Environmental Stress: A Systematic Literature Review

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ABSTRACT

Background: The modern aquaculture industry faces serious challenges from environmental stressors such as temperature fluctuations, deteriorating water quality, and high stocking densities, all of which negatively affect cultured fish's growth and immune competence. Micronutrient supplementation—particularly vitamin C, vitamin E and zinc—has enhanced fish resilience to these stressors.

Aims & Methods: This article was prepared using a systematic literature-review approach on the effectiveness of vitamin C, vitamin E and zinc in strengthening the antioxidant and immune systems of fish. A systematic literature search was conducted for articles published within the last ten years in Scopus-or SINTA-indexed journals that examined the effects of these micronutrients on the physiological and immunological performance of cultured fish.

Results: The evidence indicates that vitamin C at 200–400 mg kg^{-1} feed, vitamin E at 50-100 mg kg^{-1} feed and zinc at 30–80 mg kg^{-1} feed elevate antioxidant-enzyme activity, improve tissue histology, and boost non-specific immune responses. Several species have documented positive outcomes, including *Oreochromis niloticus*, *Clarias batrachus*, and *Rachycentron canadum*. Nevertheless, inter-species variability, interactions with other nutrients, and limited molecular-level studies remain challenges. Further research is required to establish optimal dosages, clarify specific mechanisms of action, and design practical supplementation strategies for sustainable intensive aquaculture.

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1. Introduction

The aquaculture industry has experienced rapid growth as a key solution to meet the rising global demand for animal-based protein. However, intensive aquaculture practices often expose fish to various environmental stressors, such as temperature fluctuations, poor water quality, hypoxia, and high stocking densities. These stress conditions can disrupt fish homeostasis, reduce growth performance, and increase susceptibility to infections and diseases.

In this context, nutrition—particularly micronutrients such as vitamins and minerals—plays a critical role. Micronutrients not only support essential metabolic processes but also serve vital functions as antioxidants and immunostimulants. For instance, vitamin C has been shown to enhance immune responses and reduce oxidative stress in fish exposed to elevated temperatures (Barros *et al.,* 2015). Similarly, Zinc supplementation has been reported to strengthen immune function and upregulate genes related to growth and immune responses in fish under various environmental stressors (Mustafa *et al.,* 2024).

Improving fish resilience to environmental stress not only benefits fish health but also contributes significantly to aquaculture productivity. The productivity of Nile tilapia (*Oreochromis niloticus*), for example, plays a crucial role in supporting food security and the fisheries economy in Indonesia. Factors such as water quality management, feed selection, farming techniques, and the application of appropriate technologies have been identified as key determinants in improving tilapia aquaculture productivity (Mendrofa & Zebua, 2025).

Therefore, a comprehensive understanding of the role of micronutrients in mitigating the negative effects of environmental stress is essential. This review aims to summarize recent scientific findings on the effectiveness of vitamin C, vitamin E and zinc supplementation in enhancing the resilience of cultured fish to environmental stressors, as part of efforts to support healthier and more sustainable aquaculture systems.

2. Methods

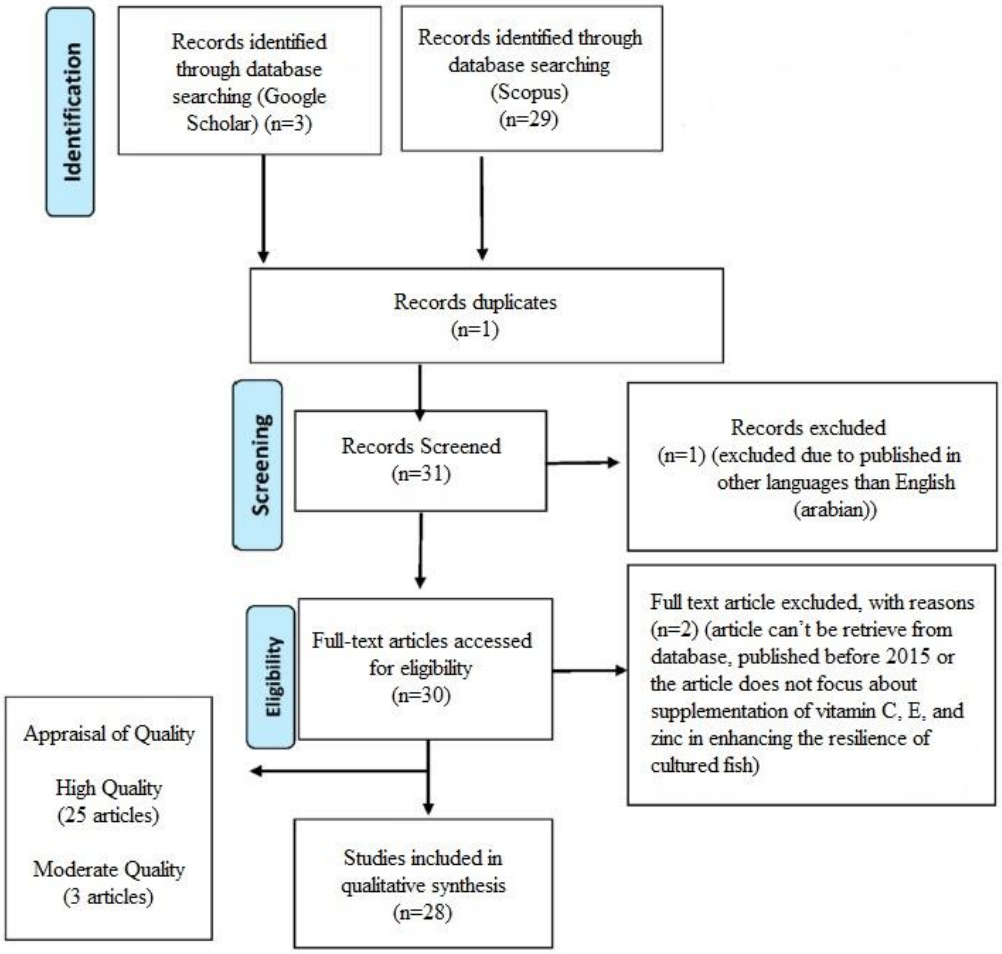
This article was prepared using a systematic literature-review approach. The objective was to identify, evaluate, and synthesize scientific findings on how micronutrient supplementation—specifically vitamin C, vitamin E and zinc—enhances the resilience of cultured fish to environmental stressors.

Literature selection criteria

Articles were included if they (i) were published within the last ten years (2015-2025); (ii) Original research articles, including in vivo or in vitro experimental studies; (iii) studies evaluating the effects of vitamin C**,** zinc, or other antioxidants on stress response**,** growth performance**,** or immune function in fish; and (iv) articles published in peer-reviewed scientific journals indexed in national (Sinta) and international databases (e.g., Scopus, Web of Science, DOAJ).

Search strategy

Relevant literature was retrieved from Google Scholar, ScienceDirect, SpringerLink, and Portal Garuda using combination of keywords such as “vitamin C”, “vitamin E”, “zinc”, “aquaculture”, “environmental stressors”, “antioxidant”, and “immune response.”



Data analysis

Eligible publications were analyzed qualitatively. Findings and conclusions were critically examined and descriptively synthesized to provide an integrated overview of how vitamin C and zinc alleviate environmental-stress effects on physiological, immunological, and growth responses in cultured fish. This qualitative-descriptive synthesis forms the scientific basis for developing nutrition-based stress-mitigation strategies in intensive aquaculture systems.

A summary table of the reviewed studies—detailing journal titles, study species, supplementation protocols, key outcomes, and Scopus indexing status—is provided below.

Table 1. Table of the reviewed studies

No	Author(s) & Year	Fish Species	Nutrient	Research Focus	Key Findings	Indexing
1	Bazina *et al.*, (2025)	*Oreochromis niloticus*	nano-selenium and/or vitamin E	Effects of nano-selenium and/or vitamin E supplementation on growth performance, antioxidant status, histopathology and resistance	SeNPs and/or VE enhances growth, body composition, biochemical parameters, and histopathology	Scopus
2	Le *et al.*, (2025)	*Rachycentron canadum*	Vitamin C	Effects of extreme temperature	Vitamin C reduced	Scopus

					mortality under thermal stress	
3	Zeng *et al.,* (2024)	*Ctenopharyngodon idella*	Zinc	Immunity	Zn has a positive impact on the immune function of head kidney, spleen and skin	Scopus
4	Sherif *et al.,* (2024)	*Oreochromis niloticus*	Vitamins C & E	Growth performance and feed utilization	Improved growth, feed efficiency, and immune response	Scopus
5	Vicente *et al.,* (2024)	*Oreochromis niloticus*	Zinc, Vitamins C & E	Immune and antioxidant responses under stress	Supplementation enhanced antioxidant and immune responses	Scopus
6	Mustafa *et la*., (2024)	*Oreochromis niloticus*	Vitamin C & Zinc	Cold water stress	Combined Vitamin C and Zinc supplementation in improving the immune response and growth performance	Scopus
7	Farag *et al.,* (2024)	*Oreochromis niloticus*	Vitamin E	Vitamin E nanoparticles enhance performance and immune status of Nile tilapia	Fish were immune boosted, becoming less vulnerable to *A. hydrophila* infection	Scopus
8	Elnagar *et al.,* (2024)	*Oreochromis niloticus*	chitosan-vitamin C and vitamin E	A blend of chitosan-vitamin C and vitamin E nanoparticles robust the immunosuppressed	Nile tilapia diet could increase immune and antioxidant-related gene expression to counteract *S. agalactiae* infection	Scopus
9	Jewel *et al.,* (2024)	*Clarias batrachus*	Zinc nanoparticles	Growth and nutritional quality	Improved growth and nutritional profile	Scopus
10	Rathore *et al.,* (2023)	*Oreochromis niloticus*	Nano-selenium and Vitamin C	Dietary Administration of Engineered Nano-selenium and Vitamin C	Supplementation with nano-Se and VC is noteworthy for improving	Scopus

				Ameliorates Immune Response, Nutritional Physiology, Oxidative Stress, and Resistance	growth, serum biochemical status, immune response, antioxidant status, and disease resistance	
11	Inarto *et al.*, (2023)	*Oreochromis niloticus*	Zinc	The effects of dietary organic zinc (Zn) supplementation	Zn supplementation enhancing growth performance	Scopus
12	Rahman *et al.*, (2023)	Various species	Vitamin C	Effects of Dietary Vitamin C on the Growth Performance, Antioxidant Activity and Disease Resistance of Fish	Significantly improved the growth performance, antioxidant activity, immune response and disease resistance of fish	Scopus
13	Kumar *et al.*, (2023)	*Pangasianodon hypophthalmus*	Zinc	Nano-zinc enhances gene regulation of non-specific immunity and antioxidative status	Zn-NPs diets mitigate ammonia and arsenic toxicity, and high-temperature stress	Scopus
14	Rohani *et al.*, (2022)	*Oreochromis niloticus*	Zinc & Vitamin E	Effects of Zn and VE addition in the diet on growth and feed utilization	Zn and Vit E can be effectively incorporated into the diets of Nile tilapia for better growth with maximum feed utilization	Scopus
15	Ibrahim *et al.*, (2021)	*Oreochromis niloticus*	Selenium loaded chitosan	Dual effect of selenium loaded chitosan nanoparticles on growth, antioxidant, immune related genes expression	Effects of SeChNPs on Nile tilapia growth resulted from immune stimulatory and free radicals scavenging effects	Scopus
16	Perera & Bhujel (2021)	*Oreochromis niloticus*	Vitamin C	Potential role of L-ascorbic acid (Vitamin C)	Vitamin C (L-ascorbic acid, AA)	Scopus

					supplementation would benefit in terms of survival, growth, and stress resistance	
17	Wang *et al.*, (2021)	*Eriocheir sinensis*	Zinc	Immunity and LPS tolerance	Enhanced growth and immune-related gene expression	Scopus
18	Ibrahim *et al.,* (2020)	*Oreochromis niloticus*	Vitamin C	Growth, immunity, histology, Aeromonas resistance	Improved growth and disease resistance	Scopus
19	El-Gabri *et al.*, (2020)	*Oreochromis niloticus*	Vitamin C	Growth, antioxidant activity, immune status, tissue histomorphology, and disease resistance	Enhancing the growth, hepatic and intestinal structures, immune status, and resistance against *A. sobria*	Scopus
20	Alkaladi, A (2019)	*Oreochromis niloticus*	Vitamins C & E	Vitamins E and C ameliorate the oxidative stresses	vitamin E and C highly effective in alleviation the toxic effect	Scopus
21	Abdelazim *et al.,* (2018)	*Oreochromis niloticus*	ZnO-NPs, Vitamins C & E	Oxidative stress and tissue protection	Vitamins C & E mitigated ZnO-NP-induced oxidative stress	Scopus
22	Farsani *et al.*, (2017)	*Oreochromis niloticus*	Vitamin E	The protective role of vitamin E	Vitamin E affecting antioxidant defenses	Scopus
23	Lu *et al.*, (2016)	*Pelteobagrus fulvidraco*	Vitamin E	Effects of dietary vitamin E on the growth performance, antioxidant status and innate immune response	MDA decreased, higher lysozyme, and higher cumulative survival	Scopus
24	Alkaladi *et al.,* (2015)	*Oreochromis niloticus*	Vitamins C & E	Hematological and biochemical investigations on the effect of vitamin E and C	Significant increase in the serum levels of alkaline phosphatase, aminotransferases, urea, creatinine and erythrocytic nuclear	Scopus

25	Barros *et al.*, (2015)	*Oreochromis niloticus*	Vitamin C	Immunomodulatory Effects of Dietary β-glucan and Vitamin C	vitamin C increased fish resistance to stress and β-glucan resulted in reduced immune responses regardless of the vitamin C supplementation level	Scopus
26	Abdan *et al.*, (2024)	*Anguilla bicolor*	Vitamin C	Effects of vitamin C dosage levels on growth and survival rate of sidat fish	Vitamin C increasing the growth and survival of eel fish	Scholar
27	Sumaraw *et al*., (2024)	*Oreochromis niloticus*	Vitamin C	Effects of Dietary Vitamin C with different dose	vitamin C significantly affects survival	Scholar
28	Komalasari *et al.,* (2018)	*Oreochromis niloticus*	Vitamin C	Effects of Dietary Vitamin C	The addition of vitamin C can increase the growth and survival of tilapia fish	Scholar

3. Results and Discussion

3.1 Mechanisms of Action of Vitamin C, Vitamin E And Zinc

3.1.1 Vitamin C, E and Zinc as Aquatic Immunostimulants

Vitamin C (ascorbic acid), vitamin E and zinc are essential micronutrients that play pivotal roles in sustaining the health and immune competence of aquatic organisms, particularly under environmental stressors such as temperature fluctuations, deteriorating water quality, and pathogenic challenges (Kumar *et al.,* 2023; Mustafa *et al.,* 2024; Sherif *et al.,* 2024). As a potent antioxidant, vitamin C neutralizes reactive oxygen species (ROS) generated in excess during oxidative stress. Its principal functions include collagen synthesis, tissue regeneration, and immune stimulation via enhanced lymphocyte proliferation and antibody production (El-Gabri *et al.,* 2020).

Vitamin E (VE) is an essential vitamin liposoluble antioxidant in aquatic animals that is usually lost during feed processing and digestion, whereas nano-chitosan, a polysaccharide, could protect VE. Vitamin E (a liposoluble vitamin) is the most reliable antioxidant and immunostimulant agent (Farag *et al.*, 2024). It inhibits lipid peroxidation and protects animal cells against generated reactive oxygen species (ROS) (Lu *et al.,* 2016).

Conversely, Zinc acts as a co-factor for important enzymes involved in the proper functioning of the antioxidant defense system, which protects cells against oxidative damage, acts in the stabilization of membranes and inhibits the enzyme nicotinamide adenine dinucleotide phosphate oxidase (NADPH-Oxidase) (Marreiro *et al*., 2017). Zinc also regulates immune-cell proliferation, phagocytic activity, wound healing, and tissue regeneration. Zinc particles are recognized for its ability to elevate fish health and well-being, enhancing antimicrobial and antioxidant capacities and reinforcing the immune system (Jewel *et al.,* 2022).

Combined supplementation of vitamin C, E and zinc exerts synergistic effects, stabilizing cellular redox balance and strengthening host defences against oxidative stress. Studies have shown that concurrent administration of these micronutrients improves the immune response and growth performance in fish (Rohani *et al.,* 2022; Mustafa *et al.,* 2024). Accordingly, the inclusion of vitamin C, E and zinc as immunostimulants in feed or culture systems represents an effective strategy for safeguarding fish and shrimp health under intensive farming conditions.

3.1.2 Efficacy in Diverse Cultured Fish Species

Extensive research confirms that vitamin C and zinc supplementation enhances stress resilience in several aquaculture species, including Nile tilapia (*Oreochromis niloticus*), African catfish (*Clarias gariepinus*), and common carp (*Cyprinus carpio*). Vitamin C, a strong antioxidant, supports collagen synthesis, tissue repair, and adaptive immunity (El-Gabri *et al.,* 2020). In *O. niloticus*, dietary vitamin C significantly improves growth, antioxidant capacity, and the histological integrity of liver and intestinal tissues while elevating resistance to *Aeromonas sobria* infection (Ibrahim *et al.,* 2020). Le *et al*., (2025) further demonstrated that vitamin C enhances thermal tolerance in cobia (*Rachycentron canadum*), lowering mortality and maintaining physiological stability under extreme temperatures. In *O. niloticus,* dietary vitamin E enhanced growth performance, feed utilization, health status and immune response (Sherif *et al.,* 2024).

Zinc is equally critical, acting as a co-factor for antioxidant enzymes such as SOD and contributing to non-specific immune defence. Zeng *et al.,* (2024) reported that zinc has a positive impact on the immune function of head kidney, spleen and skin of grass carp. In Chinese mitten crab (*Eriocheir sinensis*), zinc supplementation increased acid and alkaline phosphatase activities, antioxidant capacity, and the expression of immune-related genes, thereby improving tolerance to lipopolysaccharide exposure (Wang *et al.,* 2021).

Synergistic effects have also been observed when vitamin C is combined with other micronutrients. Alafari *et al.* (2025) found that vitamin C plus nano-selenium enhanced growth, haematological status, tissue morphology, and resistance to *Saprolegnia ferax* infection in Nile tilapia. Collectively, these findings underscore the value of vitamin C and zinc—administered singly or in combination—as preventive nutritional strategies to bolster fish health and optimise productivity in intensive aquaculture systems.

Multiple studies consistently show that vitamin C and vitamin E supplementation reduces malondialdehyde (MDA) levels, a biomarker of oxidative stress, while boosting antioxidant-enzyme activities (Mustafa *et al*., 2024; Farag *et al.,* 2024; Elnagar *et al*., 2024). Zinc likewise improves immune responses and lowers mortality in fish exposed to stressors such as extreme temperature and poor water quality (Rohani *et al.,* 2022; Mustafa *et al.,* 2024). The demonstrated efficacy of both micronutrients highlights their fundamental roles in supporting fish health and performance under culture conditions.

3.2 Effective Dosage and Administration of Vitamin C, Vitamin E and Zinc in Cultured Fish

The optimal dosage of vitamin C and zinc in aquafeeds varies depending on the species, age, and environmental conditions. Vitamin C, as an essential antioxidant, plays a critical role in fish growth and immune function. Le *et al.,* (2022) demonstrated that vitamin C supplementation at 200–400 mg/kg feed reduced mortality in cobia (*Rachycentron canadum*) exposed to extreme temperatures. In Nile tilapia (*Oreochromis niloticus*), a dose of 400 mg/kg feed improved liver histology and enhanced antioxidant capacity (El-Gabri *et al.,* 2020). Similarly, studies on coho salmon (*Oncorhynchus kisutch*) reported that vitamin C doses ranging from 93.08 to 224.68 mg/kg feed significantly promoted growth and antioxidant enzyme activity (Zhang *et al.,* 2023). Farag *et al.,* (2024) demonstrated that vitamin E supplementation at 50, 75, and 100 mg/kg feed promoted enhance performance and immune status of Nile tilapia (*Oreochromis niloticus*).

Zinc, as a cofactor of antioxidant enzymes such as superoxide dismutase (SOD), is also vital in enhancing fish immune responses. Wang *et al.,* (2021) found that zinc supplementation at 80 mg/kg feed improved immunity and tolerance to toxic exposure in Chinese mitten crab (*Eriocheir sinensis*). For Nile tilapia, zinc proteinate at 40 mg/kg feed increased digestive enzyme activities and antioxidant capacity (Inarto *et al.,* 2023). Moreover, Alafari *et al.,* (2025) showed that combined supplementation of vitamin C and nano-selenium enhanced growth performance, hematological status, and resistance against *Saprolegnia ferax* fungal infection in Nile tilapia.

Generally, vitamin C, vitamin E and zinc are administered through feed formulations containing these micronutrients, either continuously or in cycles tailored to fish requirements. Continuous supplementation at appropriate dosages can improve growth performance and strengthen the immune system without causing toxic effects. However, dosage adjustments should be species-specific and consider fish age and culture environment quality, since excessive supplementation may lead to heavy metal accumulation or metabolic disturbances.

4. Conclusion & Recommendations

Supplementation of vitamin C, vitamin E and zinc has been proven to positively impact the physiological and immunological resilience of cultured fish, particularly in coping with environmental stressors such as temperature fluctuations, poor water quality, and pathogen exposure. These three micronutrients play crucial roles in enhancing the endogenous antioxidant system and non-specific immune responses, thereby contributing to improved growth performance and survival rates. Various studies have demonstrated that vitamin C supplementation within the range of 200–400 mg/kg feed, vitamin E supplementation within 50-100 mg/kg feed and zinc supplementation between 30–80 mg/kg feed, depending on the species, can yield significant benefits without inducing toxic effects.

To promote sustainable aquaculture productivity, it is recommended that vitamin C, vitamin E and zinc supplementation be administered in a controlled manner through precisely formulated feeds that consider the specific requirements of fish species, growth stages, and environmental conditions. Appropriate dosage adjustments should also take into account interactions with other micronutrients to avoid undesirable antagonistic or synergistic effects. Therefore, further in-depth research is necessary to elucidate the molecular mechanisms, assess the effectiveness of combined micronutrient formulations, and develop cost-effective, practical supplementation strategies for industrial-scale aquaculture systems.

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