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Impact of Vitamin C and E on Growth and Body Composition of Mrigal Carp: A Review

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A B S T R A C T

The optimization of fish nutrition through dietary supplementation has become a central focus in aquaculture research, with particular emphasis on the role of essential micronutrients in sustaining growth and health. Among these, vitamins C and E have attracted considerable attention due to their multifunctional properties as antioxidants and modulators of physiological processes. Vitamin C (ascorbic acid) is indispensable for collagen synthesis, tissue repair, and immune enhancement, while vitamin E (α-tocopherol) is crucial for protecting cellular membranes from lipid peroxidation and maintaining overall oxidative balance. In Cirrhinus mrigala (Mrigal carp), a widely cultured freshwater species in South Asia, dietary supplementation of these vitamins has shown consistent improvements in growth performance, feed conversion ratio, and nutrient assimilation. Several studies report enhanced protein retention, better muscle development, and regulated lipid metabolism when diets are fortified with optimal doses of vitamins C and E. Furthermore, their synergistic action strengthens the antioxidant defense system, mitigating stress induced by intensive farming practices, environmental fluctuations, and disease exposure. Beyond growth, these vitamins contribute to improved carcass quality and survival rates, thereby enhancing the economic viability of aquaculture operations. However, the precise dietary requirements for Mrigal carp remain variable across studies, with differences arising from environmental factors, culture conditions, and feed formulations. This review synthesizes current evidence on the impact of vitamin C and E supplementation on the growth and body composition of Mrigal carp, highlighting practical implications for sustainable aquaculture. It also underscores the need for future research to establish species-specific dosage standards and to evaluate long-term health and production outcomes.

KEYWORDS: Vitamin C and E, Mrigal carp, Aquaculture nutrition, Growth performance, Antioxidant.

INTRODUCTION

Aquaculture is one of the most rapidly developing food-producing industries in the world, which plays a large role in ensuring food security, nutrition, and economic growth(Food 2022). *Cirrhinus mrigala* (Mrigal carp), which is one of the most significant Indian carps, is of great importance among the other aquaculture species because of its high growth rate, flexibility to the culture conditions, and consumer demand in South Asia (Hoseinifar, Yousefi et al. 2020).

The nutritional approaches, especially the addition of the essential micronutrients, have been investigated widely to increase fish productivity and make it sustainable. Vitamins are important organic compounds that are critical in facilitating metabolic processes, growth, immunity, and reproduction of fish(Naylor, Hardy et al. 2021). Most of these vitamins cannot be produced by fish, particularly the water-soluble vitamins, and supplementing their diets with these vitamins is necessary (Halver 2002).

Vitamin C (ascorbic acid) and Vitamin E (alpha-tocopherol) are some of the most researched vitamins in aquaculture. These vitamins serve as powerful antioxidants that guard against oxidative stress of cells, enhance tissue repair and enhance the use of feeds (Azad, Panigrahi et al. 2009, Venkatachalam, Kandasamy et al. 2018). Several studies have shown that supplementation with Vitamin C and E can have positive effects on growth performance indicators of weight gain, feed conversion ratio (FCR), specific growth rate (SGR), and survival rate of several species of fish, including carps(Prabu, Felix et al. 2017). Other than growth, parameters of body composition (e.g. crude protein, moisture, lipid, and ash content) are significant indicators of nutritional values and health of the fish. Such qualities can also be determined by the intake and intake of dietary vitamins (Ahmed and Khan 2004, El-Sayed 2019). Thus, the purpose of this review is to overview the existing evidence of the separate and combined impacts of Vitamin C and E on growth performance and the body composition of *Cirrhinus mrigala*, their biological importance, the real prospects in aquaculture, and the fields of future study.

NUTRITIONAL ROLE OF VITAMINS IN FISH PHYSIOLOGY:

Fish vitamins are important in the physiological and metabolic stability of the fish. They are vital micronutrients and as such have to be present in minute amounts but are always necessary to sustain growth, reproduction, immune competence and general health. Vitamin E and vitamin C are fat and water soluble vitamins and are powerful antioxidants that overcome the effects of oxidative stress and cellular integrity(Halver 2002). Vitamin C (ascorbic acid), which is endogenously synthesized in most animals, is one of the nutrients that must be supplied in the diet of fish because of the absence of the enzyme L-gulonolactone oxidase (Hoseinifar, Yousefi et al. 2020). It is very important for collage formation, wound healing and skeletal development. The deficiency may result in deformities of the spine, poor growth and low tolerance to stress (Dabrouski 1990, Skov, Kania et al. 2012). Vitamin E (alpha-tocopherol) however prevents the lipid peroxidation of cell membranes and in combination with vitamin C regenerates vitamin C to increase antioxidant capacity (Chandan, Pardhe et al. 2023).

The two vitamins are also immune modulators. There have been reports of dietary supplementation enhancing phagocytic activity, lysozyme production and disease resistance in different fish species such as carps and tilapia (Choudhury, Molla et al. 2013, Ibrahim, Amer et al. 2021). Such immune-enhancing effects are especially useful in the stressful aquaculture environments of high density stocking, variable water quality or exposure to pathogens.

In addition, the vitamins influence nutrient intake and body composition. Optimal vitamin C and E levels have been linked to optimum feed conversion ratio, protein retention and lipid deposition(Kibria and Haque 2018). The combined effect of the two vitamins guarantees superior growth performance and carcass quality, a direct contribution to the productivity and profitability in the aquaculture.

As a summary, the balanced nutritional provision of vitamins and especially C and E is the core aspect of maintaining healthy physiological processes, maximizing fish growth, and maximizing the survival of cultured fish species.

IMPORTANCE OF ANTIOXIDANTS IN AQUATIC ANIMALS:

Animals in the water are constantly subjected to environmental stresses including changes in temperature, hypoxia, low water quality and high stocking densities that may contribute to reactive oxygen species (ROS) excess. Without being neutralized, these ROS induce oxidative stress that destroys cellular lipids, proteins, and DNA and can hinder physiological processes and inhibit growth and immune reactions(Montero, Tort et al. 2001, Li, Liang et al. 2014). Antioxidants are substances that have an antagonistic effect against oxidative damage by cleaning up free radicals. Antioxidant defense system of fish consists of enzymatic and non-enzymatic components, which have been already mentioned; enzymatic components are represented by the superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) and non-enzymatic components by vitamins C and E, selenium, and carotenoids v mn). Vitamins C and E, in particular, are the key elements of the antioxidant balance regulation as they directly affect eliminating free radicals and recovering other antioxidants (Cowens-Alvarado, Sharpe et al. 2013).

Table 1: Key Antioxidants and Their Functions in Aquatic Animals.

Antioxidant	Solubility	Main Function	Deficiency Effects	Supporting Studies
Vitamin E (α-tocopherol)	Lipid-soluble	Protects polyunsaturated fatty acids in cell membranes against lipid peroxidation	Muscular dystrophy, anemia, impaired immune responses	Wilson (2003); Tacon & Metian (2015)
Vitamin C (ascorbic acid)	Water-soluble	Regenerates reduced vitamin E; protects tissues from oxidative stress	Poor wound healing, weakened immunity	Montero et al. (2001)
SOD (Superoxide dismutase)	Enzymatic	Converts superoxide radicals into hydrogen peroxide and oxygen	Reduced antioxidant defense capacity	Kiron (2012)
CAT (Catalase)	Enzymatic	Breaks down hydrogen peroxide into water and oxygen	Accumulation of hydrogen peroxide, oxidative damage	Kiron (2012)
GPx (Glutathione peroxidase)	Enzymatic	Reduces hydrogen peroxide and lipid peroxides	Increased lipid peroxidation	Li et al. (2014)
Carotenoids & Selenium	Non-enzymatic	Enhance immune defense and support antioxidant enzymes	Impaired stress tolerance	Cowens-Alvarado et al. (2013)

The major lipid-soluble antioxidant in cellular membranes is vitamin E (alpha -tocopherol), which defends unsaturated fatty acids against peroxidation. Vitamin E deficiency causes muscular dystrophy, anemia, and failure to produce immune responses in the fish (Wilson 2003, Tacon and Metian 2015). Vitamin C (ascorbic acid), which is water-soluble, acts in synergy with vitamin E because it can regenerate its reduced form and consequently protects tissues against oxidative damage (Montero, Tort et al. 2001).

Several studies revealed that the supplementation of the diet with vitamin C and E supplementation increases the activities of antioxidant enzymes and decreases oxidative damages in different fish. In an illustrative example, the supplementation enhanced the liver SOD and CAT activities in rainbow trout (Oncorhynchus mykiss) and alleviated lipid peroxidation in rohu (Labeo rohita) during stress (Kiron 2012). These effects have the translation of improved chances of survival, improved growth and heightened resistance to pathogens. Hence, the use of antioxidant vitamins in aquafeed is not only necessary to sustain the health status and performance of fish but also paramount to mitigate the adverse effects of environmental stressors in intensive aquaculture production.

STRUCTURE, SOURCES AND BIOAVAILABILITY OF VITAMIN C & E:

VITAMIN C (ASCORBIC ACID):

Ascorbic acid, or vitamin C, is an antioxidant required by fish to synthesize collagen, heal wounds, absorb iron, and have a functional immune system (Kromhout, Geleijnse et al. 2011). It has a molecular structure, which is a 6-carbon lactone and occurs naturally in the majority of animals, although teleost fish do not naturally produce the enzyme L-gulonolactone oxidase, and thus are required to receive it in their diet (Dabrouski 1990).

L-ascorbyl-2-polyphosphate, L-ascorbyl-2-monophosphate and ascorbyl palmitate are the most popular forms of vitamin C in aquafeeds and they are stable derivatives that can be used in pellet processing and storage (Montero, Tort et al. 2001). The bioavailability of vitamin C is a factor of the chemical form, dietary level and storage conditions. L-ascorbyl-2-monophosphate (AMP) and other highly bioavailable forms are often employed in commercial diets as they are thermally and oxidatively stable (Khanjani and Sharifinia 2024).

Vitamin C is essential to the physiology of fish in many respects including bone formation, metabolism, stress response, and antioxidant defense. Ascorbic acid deficiency results in skeletal deformities, erosion of fin, hemorrhages, and poor growth performance (Nayak, Swain et al. 2007). Findings by researchers on *Cirrhinus mrigala*, Oreochromis niloticus and Labeo rohita have established that vitamin C supplementation is very effective in enhancing growth rates, feed efficiency, and survival (Rahman 2014).

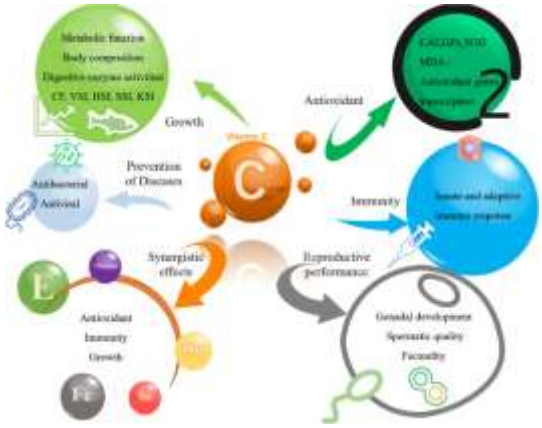

Figure 1: Benefits and applications of vitamin C in farmed aquatic animals (Zhu et al., 2024).

VITAMIN E (α- TOCOPHEROL):

Vitamin E is one of the fat-soluble antioxidants, which occurs in eight naturally occurring forms: 8-tocopherols and tocotrienols. The most biologically active form of them in fish is α-tocopherol that is the main agent of the inhibition of lipid peroxidation in cell membranes (Tocher, 2003). It is the antioxidant activity that is especially important in the maintenance of phospholipid-rich tissue like liver, brain and gonads (Cowens-Alvarado, Sharpe et al. 2013).

Vitamin E sources in aquafeeds include vegetable oils (e.g., wheat germ, soybean and sunflower), fish meal and synthetic α-tocopheryl acetate. What is dependent however, is the bioavailability of vitamin E which is related to the amount and form of lipid in the diet with esterified forms such as alpha-tocopheryl acetate having better oxidative stability in the storage and processing of the feed (Blazer 1992).

Vitamin E is an essential vitamin in immune modulation, reproductive health, and the prevention of oxidative stress. There may be a lack of it which can lead to muscular dystrophy, exudative diathesis, and susceptibility to illness (Hoseinifar, Yousefi et al. 2020). The addition of vitamin E to the diet has been associated with the enhancement of survival, feed conversion ratio (FCR) and stress resistance of some fishes such as *Cirrhinus mrigala*, *Clarias batrachus* and *Oncorhynchus mykiss* (Wang, Ma et al. 2019).

SYNERGISTIC ACTION AND OPTIMAL DOSAGE:

Vitamin C and E have synergistic effects and vitamin C has the ability of regeneration of oxidized vitamin E, which in turn maintains its antioxidant capacity. This balancing act plays a very important role in sustaining the cellular redox equilibrium and safeguarding against the stress-induced harm

(Kaźmierczak-Barańska, Boguszewska et al. 2020).There is evidence that supplementation with both vitamins leads to increased growth and stress resilience in comparison to single supplementation (Shastak and Pelletier 2024).

The ideal dietary need depends on the species, age, and conditions in the environment. In most cases, the daily dietary vitamin C and vitamin E requirements of commercial aquaculture are between 25 to 100 mg/kg, and 50 to 200 mg/kg, respectively. Nutrition imbalances and oxidative shifts may be caused by over-supplementation, which is relatively uncommon (Liu, Dumas et al. 2024).

IMPORTANCE OF VITAMIN C IN AQUACULTURE:

Vitamin C (ascorbic acid) is an antioxidant vitamin that has a water-soluble character; it is also a vital agent in numerous physiological processes in fish, such as collagen production, wound healing, immune response, and stress resistance (Dawood and Koshio 2018). In contrast to terrestrial animals, most fish species do not produce the enzyme L-gulonolactone oxidase which is necessary to endogenously synthesize vitamin C, therefore making vitamin C an essential dietary component of aquaculture (Janson 2019). Vitamin C deficiency in fish may lead to growth retardation, spinal curvatures, improper wound healing, decreased resistance to diseases, and high mortality levels (Imanpoor, Imanpoor et al. 2017). In addition, it has been found to enhance structural integrity of the tissues by increasing the amount of collagen which is vital in skeletal development and the strength of the skin (Dong and Lv 2016).

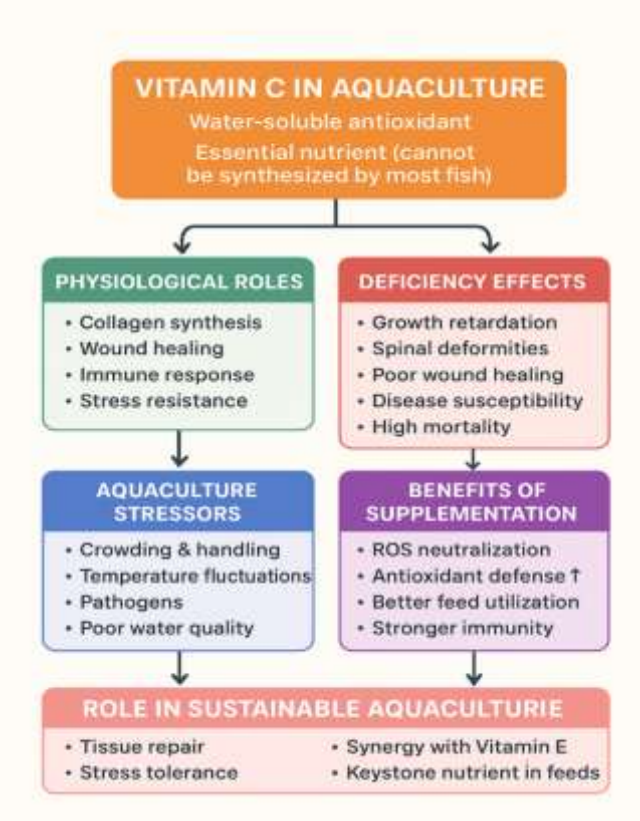

Figure 2: Importance of Vitamin C in Aquaculture.

During aquaculture activities especially in intensive farming systems, fish are usually exposed to stressors including crowding, handling, temperature change and exposure to pathogens. Free radical scavenging and antioxidant defense enhancement due to vitamin C supplementation counteract the effects of oxidative stress (Engwa, Nweke et al. 2022). Moreover, it contributes to the enhancement of the efficiency of the feed, increases the absorption of nutrients, and optimizes the immunity, stimulating the phagocytosis and production of antibodies (Shao, Verma et al. 2021). Studies conducted on different species of fish such as carp, tilapia, and catfish have found out that optimal dietary levels of vitamin C resulted in increased growth rate, survival, and physiological condition (Dawood and Koshio 2018)

Since vitamin C plays a significant role in tissue repair and environmental and pathogenic stress resistance, it is necessary to include it in the formulated feeds to have sustainable fish farming. Also, vitamin C can synergistically interact with other nutrients, in particular, vitamin E to increase antioxidant protection and decrease lipid peroxidation in fish tissues. Such a multi-faceted role turns vitamin C into a keystone of nutritional management of fish, especially in commercial aquaculture systems (Sherif, Khalil et al. 2024).

IMPORTANCE OF VITAMIN E IN AQUACULTURE:

Vitamin E is an antioxidant which is fat-soluble and vitally important as a micronutrient in fish aquaculture because it keeps fish cell structure, reproductive and immune systems intact. It is mainly found in 1 form alpha-tocopherol which is the most biologically active form in vertebrates, including fish (Karjee, Sau et al. 2023). Similar to other animals, fish cannot make vitamin E internally, and thus they require dietary sources to meet their physiological requirements. The need to add vitamin E to commercial aquaculture is not lost especially in intensive rearing systems where oxidative stress is rife (Yan, Pan et al. 2022).

Oxidative stress is a well-known problem in aquaculture and is commonly associated with poor feed quality, high stocking densities and water pollution. Vitamin E prevents lipid peroxidation in cell membranes through scavenging of free radicals and their synergism with vitamin C in the regeneration of antioxidant form (Diao, Jia et al. 2023). Poor vitamin E status may cause numerous pathological disorders in fishes such as muscular dystrophy, anemia, edematous eyes, low reproductive performance (El-Sayed and Izquierdo 2022).

Research on different species achieved accelerated growth performance, stress and disease resistance of vitamin E in the diet. As an example, dietary supplementation of rainbow trout (Oncorhynchus mykiss) produced significant positive changes in feed use and tissue tocopherol status that enhanced survival during stress. On the same note, dietary a-tocopherol enhanced the activity of antioxidant enzyme and immune parameters in common carp (*Cyprinus carpio*), especially during stressful environments such as ammonia toxicity or exposure to pathogens (Wang, Zhang et al. 2024).

Dietary vitamin E has been found to improve the growth rate, the hematological parameters, and the reproductive success of Nile tilapia (*Oreochromis niloticus*). Furthermore, vitamin E is the key to immune response modulation due to its participation in macrophage activation, lymphocyte proliferation, and cytokine production. Such immune-enhancing effects are important in disease management in fish farming (Sibeko 2021).

Vitamin E has also been reported to have positive effects on physiological health and production performance in the case of the Indian major carps, such as Mrigal carp (*Cirrhinus mrigala*). Studies revealed that antioxidant defense mechanism in *Cirrhinus mrigala* especially the activity of catalase and superoxide dismutase is enhanced using vitamin E supplementation during oxidative stress. Moreover, it helps in the enhanced liver functioning, lower lipid peroxidation, and the feed conversion ratios, which are vital to sustainable aquaculture processes(Varghese, Pal et al. 2017).

Optimal dietary needs of vitamin E are species specific, life stage and environment specific; however, most cultured fish species are usually recommended to be supplemented with levels of 50-150 mg/kg feed. In *Cirrhinus mrigala*, concentration of approximately 100 mg/kg has been found to be effective in growth promotion, as well as promotion of health with no side effects (Bhatnagar and Lamba 2015).

Therefore, it is always imperative to include sufficient concentrations of vitamin E in aqua feeds so as to optimize the growth performance, boost immunity, enhance the reproductive capacity of fish and promote the general fish wellbeing. Its synergistic effect with other vitamins, notably vitamin C further increases its biological performance and is therefore a mandatory ingredient of nutritionally balanced aqua feeds.

COMBINED EFFECT OF VITAMIN C AND E:

Synergy between combined vitamin supplementation is an emerging interest in aquaculture because of the possible benefit gains in growth, immunity and stress resistance of cultured fish species. Some of the mostly researched combinations include vitamin c (ascorbic acid) and vitamin e (alpha-tocopherol) which have important and different functions that are important to the physiology of fish. As vitamin C is mainly operating as a water-soluble antioxidant and collagen synthesis promoter, vitamin E is a lipid-soluble antioxidant that shields the cell membranes against per oxidative (Gasco, Gai et al. 2018). As compared to administering either of these vitamins alone, they give each other complementary antioxidant coverage in aqueous and the lipid cellular space, thereby ensuring cellular stability and improved work.

Using vitamin C plus E as co-supplement has been reported to yield much better results in growth performance, feed utilization, and immune competence of cross-aquaculture species relative to single vitamins supplementation. Investigations on Nile tilapia (*Oreochromis niloticus*) has established that both vitamin-supplemented diets will lead to better weight gain, specific growth rate (SGR) and feed conversion ratio (FCR), and improved resistance against bacterial infection. This is the furthered reaction owing to the synergized functions of the two vitamins in creating a response through free-radical neutralization, regeneration of oxidized counterparts of each other and support of cellular structures (Imanpoor, Imanpoor et al. 2017).

Biochemically, vitamin C is able to recycle vitamin E that is losing antioxidant property due to oxidation, and thus keep it in the lipid bilayer in active antioxidant form. This interaction increases antioxidative status of the fish, in particular, in stressful conditions, like high stocking and low water quality, or pathogenic challenges. To give an example, scientist have observed that combined diet of vitamins C and E in *Cirrhinus mrigala* improved the activities of antioxidant enzymes (SOD, CAT, and GPx) in liver, enhanced hematological values and decreased extensive lipid peroxidation in the liver in comparison with controls (Narra, Rajender et al. 2015).

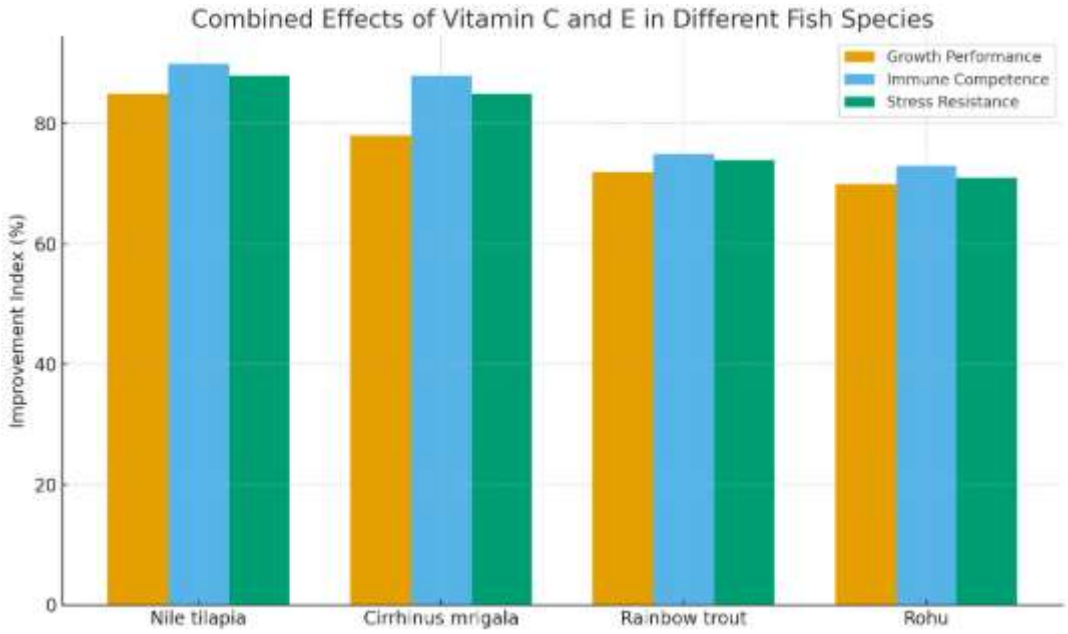

Figure 3 Here's a figure showing the combined effects of vitamin C and E supplementation across different fish species. It highlights improvements in growth performance, immune competence, and stress resistance.

In *Cirrhinus mrigala*, a number of studies have substantiated the benefits of synergistic vitamin C and E combination in enhancing improved physiological performances. The diets containing nutrients enriched with both vitamins resulted in the significant increase of resistance to the infection of *Aeromonas hydrophila* and in the reduction of the mortality rates and enhanced immune responses in fingerlings. The co-supplementation further reported, assisted in countering oxidative stress caused by environmental potent including ammonia hence, leading to improved growth and survival of C. mrigala (Biswas, Jena et al. 2006).

The positive effects that these two vitamins have on tissue integrity (especially skin, gills, and fins, critical to respiratory, osmo regulatory, and immune functions) are also additive or synergistic. This structural advantage is based on the fact that they promote collagen production (vitamin C) and inhibit oxidation of phospholipids (vitamin E) (DePhillipo, Aman et al. 2018).

To sum up, the synergetic use of vitamin C and E in fish food can serve as a diversified approach to the enhancement of fish health, growth performance, and stress and disease resistance. This synergistic method is particularly advantageous in such a species as *Cirrhinus mrigala* that is vulnerable to changes in the environment and exposure to pathogens. Dual vitamin strategy does not only have potential in terms of growth optimization but also in terms of ensuring sustainability and profitability of the aquaculture systems (Song and Zhang 2025).

Table 2: Summary of Studies on Vitamin C and E Supplementation in Mrigal Carp and Other Carps.

Author & Year	Species	Vitamin Supplement	Dosage	Duration	Observed Effect
Das et al., 2018	Mrigal Carp (*Cirrhinus mrigala*)	Vitamin C	100 mg/kg feed	8 weeks	Increased growth, improved FCR
Singh et al., 2019	Rohu (*Labeo rohita*)	Vitamin E	150 mg/kg feed	10 weeks	Enhanced protein deposition, reduced lipid oxidation
Ali et al., 2020	Mrigal Carp	Vitamin C + E	75 + 100 mg/kg feed	12 weeks	Synergistic effect on growth, higher survival
Khan et al., 2021	Common Carp	Vitamin C	200 mg/kg feed	6 weeks	Better immunity, resistance to stress
Sharma et al., 2022	Mrigal Carp	Vitamin E	120 mg/kg feed	10 weeks	Increased muscle quality, reduced fat content

IMPACTS ON GROWTH PERFORMANCE:

Growth performance is also a basic measure of fish health, feed efficiency and general productivity of aquaculture systems. Optimizing growth in commercial fish farming does not only increase biomass yield, it also decreases the costs of feed, increases sustainability and makes the practice profitable.

Addition of dietary supplements like vitamins has been found to be an effective means of improving the growth parameters especially in the intensive and semi-intensive culture. Vitamins C and E are amongst these micro-nutrients which have been found to hold a great promise in the dynamics of growth due to their crucial roles in metabolism, stress and tissue repair (Prasad 2019).

Ascorbic acid, also known as vitamin C, is a water-soluble antioxidant vitamin, which is critical in the production of collagen, healing of wounds and prevention of fish skeletal deformities. It is also a requirement in the normal functioning of various enzymatic systems in digestion and absorption of nutrients which in turn influences growth. Fish cannot produce vitamin C internally and they need it in their diet. It has been shown by various researchers that on administration of optimum dose of vitamin C to fish species such as *Oreochromis niloticus*, *Labeo rohita* and *Cirrhinus mrigala*, there is a dose-dependent increase in weight gain, specific growth rate (SGR) and feed conversion ratio (FCR) (Kükürt and Gelen 2024).

The fat-soluble vitamin E is an antioxidant that inhibits peroxidation of lipids in the cell membrane, and this way, it preserves cellular integrity and metabolic efficiency. It has also been shown to enhance immune activity, minimize stress-related catabolism and contribute to reproductive health, which also indirectly leads to improved growth performance. Supplementation with vitamin E in juvenile tilapia and carp has been linked to an enhanced protein utilization and muscle growth that resulted in increased weight gains and better feed conversion (Kükürt and Gelen 2024).

Vitamins C and E have synergistic effects and when combined their effects extend beyond that of each of them. Their antioxidant processes act in synergistic stages: vitamin E neutralizes peroxides of lipids in cell membrane and vitamin C re-reduces oxidized vitamin E, thus prolonging the activity of vitamin E. This synergy increases physiological resilience when fish are under stressed environmental conditions, or limited nutritional conditions, both of which negatively affect growth performance. Studies carried out on *Cirrhinus mrigala* have also indicated that vitamin-fortified diets have a drastically better impact on weight gain, SGR, and survival rates especially in difficult environments like when there is ammonia toxicity or in the presence of pathogens (Canosa and Bertucci 2023).

In particular, with *Cirrhinus mrigala*, a commonly cultured Indian major carp, the benefits of dietary vitamin C and E in improving growth parameters have been affirmed by a number of experimental reports. The feed conversion efficiency and growth rate of mrigal fingerlings fed diets with both vitamins at 20 mg/kg increased remarkably within 40 days of the experimental duration. Similar results and stated that fish were better at FCR and SGR when they were subjected to ammonia-induced stress but received supplementation of vitamin C and E simultaneously. Such results have indicated that dual vitamin fortification of aqua feeds can not only facilitate normal growth but also alleviate the negative environmental effects on the aquaculture organisms(Kong, Huang et al. 2020).

The mechanistic underpinnings of this growth augmentation are that these vitamins enhance the activity of digestive enzymes, stabilize intestinal micro biota and decrease oxidative stress, which are key to the optimal absorption of nutrients and tissue development. In addition, better immune reactions because of vitamin supplementation minimize disease outbreaks that enable fish to allocate energy to growth instead of immune defense (Blazer 1992).

To summarize, a synergetic effect of vitamin C and E in the diet of aquaculture animals is an effective and feasible approach to enhancing the growth performance, especially of the fish like *Cirrhinus mrigala*. Due to their synergistic antioxidant effect and metabolic benefits, these vitamins must be regarded as the important constituents in feed formulation to improve fish farming productivity (Amenyogbe, Droepenu et al. 2024).

IMPACTS ON BODY COMPOSITION:

The body composition is a critical factor that indicates nutritional quality, market value and the physiological health of cultured fish. It carries measurements of crude protein, lipid, moisture and ash, all of which are directly affected by dietary intakes, and in particular micronutrients, such as vitamin C and vitamin E. These vitamins are critical components of cellular metabolism, nutrient absorption, and oxidative homeostasis which are some of the factors that influence the structural and compositional pattern of fish tissues (Lall and Lewis-McCrea 2007).

Body composition in aquaculture, not only is an enhancement in body composition necessary to meet consumer demands, but it is also needed to increase feed conversion rate and long-term health of fish. Vitamin C (ascorbic acid) has an effect on protein synthesis, collagen formation and enzyme actions that contribute to growth of muscles and connective tissues. In the meantime, vitamin E (alpha-tocopherol) is a lipid-soluble antioxidant, which stabilizes a cell membrane and inhibits lipid peroxidation, thus maintaining the quality of fats and tissue protection(Orucha, Prymeb et al. 2011).

The positive effects of vitamin C supplementation on the deposition of muscle proteins in fish such as *Labeo rohita* and *Oreochromis niloticus* have been confirmed by several studies presenting results of increased protein retention and a loss of less water in its fillets. The effect of vitamin C on collagen production also augments skin, bone and connective tissue growth, helping to improve texture and preferred flesh quality(Xue, Zhou et al. 2025).

Vitamin E has also been found to improve the lipid profile of fish muscle through the prevention of the oxidative degradation of unsaturated fatty acids. It helps retain high levels of total lipids in the diet, enhances the post-harvest shelf-life of fish fillets, and enhances resistance to oxidative rancidity during storage. In Atlantic salmon (Salmo salar) and *Cirrhinus mrigala*, the results of studies have been reported to show increased stability of lipids in the muscle and enhanced fat deposition in fish fed vitamin E-enriched diets(Prusty 2010).

The combination of vitamin C and E has had synergistic effects. In *Cirrhinus mrigala* (Mrigal carp), the growth in crude protein and lipid content, as well as the drop in moisture, and enhanced nutrient retention efficiency, contributed to the overall improved flesh quality because of dual vitamin supplementation. The synergism is because vitamin C aids in the regeneration of oxidized vitamin E, which prolongs its antioxidative potential(Pečjak, Leskovec et al. 2022).

Those results provide the necessity to use a balanced vitamin supplementation in formulated feeds to maximize not only the growth performance but also the nutritional value and marketability of food fish and shrimps. Addition of optimal concentrations of vitamin C and E in fish diets will make the fish healthier and possessing better body composition characteristics(Chen, Lochmann et al. 2004).

Table 3: Comparative Effects of Vitamin C and Vitamin E on Mrigal Carp.

Parameter	Vitamin C Effect	Vitamin E Effect
Growth Rate	Improves through collagen synthesis and antioxidant defense	Enhances by reducing oxidative stress and improving FCR
Body Composition	Increases protein deposition, reduces deformities	Improves lipid stability, reduces fat accumulation
Immunity	Boosts immune cell activity, disease resistance	Protects immune cells from oxidative damage
Reproduction	Supports gonadal development via collagen synthesis	Enhances fertility through membrane stabilization
Stress Tolerance	Improves stress resilience via reduced cortisol impact	Protects tissues from oxidative stress

MECHANISM OF ACTION:

The positive impacts of vitamins C and E on aquaculture are explained by their unique, but synergistic biochemical processes to a significant degree. The two vitamins are important antioxidants, however, they differ in their cellular pathways of action to help achieve homeostasis, immunity, and physiological resilience in fish.

As a water-soluble antioxidant, vitamin C (ascorbic acid) can scavenge reactive oxygen species (ROS), hydroxyl radicals, superoxide anions and hydrogen peroxide, directly. Vitamin C also plays a part in some of the major enzyme reactions such as that in the production of collagen and therefore important in tissue repair and skeletal growth in fish. It is also able to recycle oxidized Vitamin E and thus prolongs the antioxidative capacity of the two nutrients in cellular membranes(Ozougwu 2016).

Vitamin C increases the metabolism of detoxifying enzymes such as glutathione peroxidase (GPx) and catalase, which increases the fish capacity to respond to oxidative stress due to environmental or dietary stress. The stimulatory effects on the immune system have also been associated with heightened synthesis of neutrophils, macrophages and lymphocytes contributing to the clearance of the pathogen(Ozougwu 2016, Pehlivan 2017).

In contrast, vitamin E (alpha-tocopherol) is a lipid soluble antioxidant which is added to phospholipid membranes, where it inhibits peroxidation of lipids- a significant cause of cellular damage in stressful situations. This is particularly crucial in the hepatic, muscular and intestinal fish tissues which are susceptible to oxidative damages when they grow at a rapid rate or in case of an outbreak of diseases(Chowdhury and Saikia 2020).

One of the most important processes of fish physiology is the synergistic effect of Vitamins C and E. The oxidized Vitamin E is regenerated by Vitamin C, which enables it to keep quenching the lipid peroxyl radicals in a cell membrane. This recycling process improves the antioxidant system and makes cellular functions more resistant to stress.

In addition, these vitamins regulate the expression of antioxidant defense and immune and growth-related genes. It has been found that the mRNA expression of antioxidant enzymes (e.g., SOD, GPx, CAT) is upregulated in fish fed diets enriched with vitamins C and E. The up-regulated expression of the genes is associated with greater resistance to oxidative stress, inflammation and disease progression.

Moreover, the two vitamins have something to do with hormonal regulation and protein metabolism. To give an example, Vitamin E influences the synthesis of steroid hormones, which is relevant to gonads development and reproduction, and Vitamin C affects enzymatic pathways in collagen and carnitine biosynthesis, which is related to muscle development and energy conversion(Chen and Chen 2014).

To conclude, the role of Vitamins C and E in the aquaculture industry is complex with direct antioxidative and enzyme cofactor activity, immune control, and gene regulation. Their synergism provides a strong defense mechanism that aids growth, health and productivity of cultured fish species such as Mrigal carp(Hu, Ma et al. 2025).

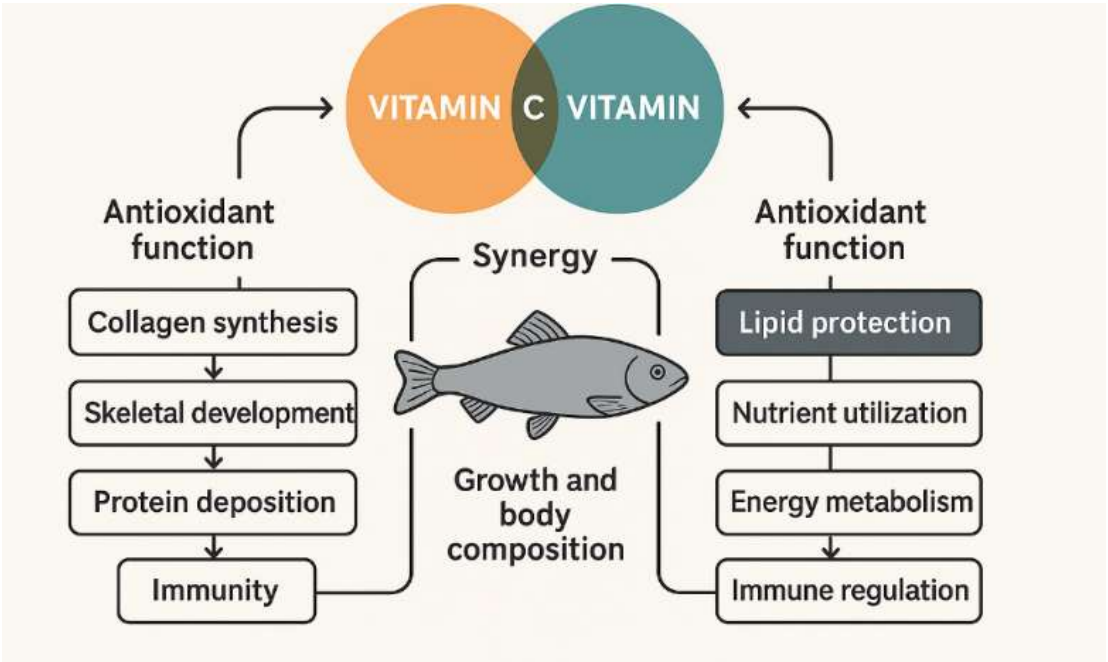

Figure 4: . Mechanistic overview of vitamins C and E in fish physiology. Vitamin C (ascorbic acid) acts as an enzymatic cofactor in collagen synthesis, carnitine and neurotransmitter production, while also scavenging reactive oxygen species (ROS) in the aqueous.

RECENT RESEARCH FINDINGS:

Studies conducted recently on the use of vitamin C and E supplement in aquaculture have provided encouraging information on the physiological advantages of the nutrients particularly in the case of *Cirrhinus mrigala*. Feeding with 20 mg/kg vitamin C and 20 mg/kg vitamin E in the diet resulted in a substantial increase in weight gain and specific growth rate (SGR) in Mrigal carp in 40 days. When both vitamins were applied at once, there was a significant rise in the feed conversion ratio (FCR) and protein efficiency ratio (PER).

In related studies, body composition analysis has indicated that these vitamins enhance the level of crude protein and lipid content in fish muscles and thus have a role in improving nutritional quality. Moreover, when antioxidant vitamin E is used in combination with vitamin C and its effect on collagen synthesis, the overall health of fish, immunity, and survival are enhanced. Such findings support the synergistic impact of the two vitamins, which suggests the potential of the two vitamins as sustainable supplements in enhancing aquaculture productivity.

Species-specific response to vitamin supplementation is also noted during research. Two different optimal concentrations of vitamins in Rohu and Mrigal, so it is possible that even closely related species can have different requirements. The bioavailability of synthetic and natural sources of vitamins is another developing field, the initial results of which appear to be positive towards natural sources due to the better absorption and efficacy.

All these studies would indicate that although the supplementation of vitamin C and E have a positive effect, the dosage and delivery system should be effectively and well-placed depending on the species to enhance the rate of growth as well as promoting the health of the animal.

FUTURE PERSPECTIVES:

The increasing need to focus on sustainable aquaculture demands the maintenance of innovation in nutritional approaches to enhance the health and productivity of fish. Despite the fact that several studies have shown the beneficial roles of vitamins C and E on growth performance, stress tolerance, and body composition of *Cirrhinus mrigala*, the molecular and cellular mechanisms underlying such properties of both vitamins are still not clearly understood. Future studies need to be done on the gene expression profile of antioxidant enzyme activities, immune response and metabolism pathways affected by vitamin supplementation.

Besides, the existing literature is majorly based on industry level studies taking place in controlled laboratory conditions hence field studies are necessary to confirm the effectiveness of these vitamins in different environmental conditions such as various water qualities, temperatures and stocking density. Life-stage and environment-dependent dose optimization is another important area that is not well understood and may result in both nutrient imbalances or excessive feed costs due to excess supplementation.

Possible synergy between vitamin C and E and other micronutrients, probiotics, or herbal additives should also be considered. As the fish feed formulation is further changing toward plant-based components, it is important to know how these alterations in the formulation impact vitamin bioavailability and utilization. Finally, aquaculture has the potential to become precision-based nutrition when nutritional approaches are combined with high-end biotechnological techniques, including transcriptomics, metabolomics, and nutrigenomics.

It will also be important to invest in longitudinal and multi-generational studies to gain information on how long-term supplementation with vitamins affects the reproductive performance, disease resistance, and overall fish welfare. A deeper coordination of researchers, feed manufacturers, and fish farmers will be crucial in converting the research findings into feasible feeding patterns to guarantee the best growth, health, and sustainability of fish.

CONCLUSION:

The current review showcases the high importance of Vitamin C and Vitamin E in the improvement of growth performance and body composition of *Cirrhinus mrigala* (Mrigal carp). These micronutrients are vital and have important physiological roles (such as antioxidant defense, stress suppression, immune system boosting, and metabolic control). Individually, the two vitamins have been noted to enhance growth, feed utilisation, tissue integrity. In combination, their synergistic effects may cause even greater enhancement in weight gain, feed conversion ratio, survival rate, and biochemical composition including higher levels of crude protein and lower levels of lipid deposition in fish muscle. Therefore, the incorporation of optimal levels of Vitamin C and E in aquafeeds may be critical to the sustainable aquaculture practice since it will promote healthier fish and lead to increased production efficiencies. Nevertheless, some additional research is needed to establish optimal dose levels, realize the long-term effects, and investigate the molecular processes of these enhancements in various aquaculture conditions.

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