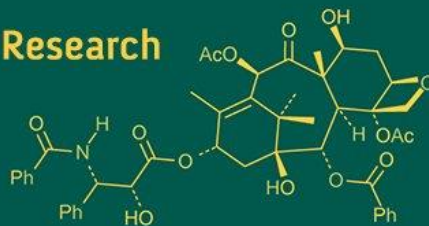


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Effects of dietary *Curcuma longa* extract supplementation on growth performance, hematological responses, antioxidant status, and intestinal protease activity in grass carp (*Ctenopharyngodon idella*) fingerlings

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Abstract

The present study evaluated the effects of dietary supplementation with *Curcuma longa* extract on growth performance, hematological parameters, antioxidant status, and digestive physiology of grass carp (*Ctenopharyngodon idella*) fingerlings. Healthy fingerlings (11 ± 4 g) were randomly distributed into four dietary treatments with three replicates per treatment (10 fish per replicate) and fed experimental diets containing 0% (control), 0.2%, 0.4%, and 0.6% *C. longa* extract for 30 days at a feeding rate of 5% body weight day^{-1} . Dietary supplementation with *C. longa* significantly improved growth performance and survival of grass carp fingerlings ($p < 0.05$). The highest final body weight (16.92 ± 1.63 g), weight gain (2.93 ± 0.43 g), percentage weight gain ($20.97 \pm 2.93\%$), and specific growth rate ($1.27 \pm 0.16\% \text{ day}^{-1}$) were observed in fish fed the 0.6% supplemented diet, while the highest survival rate (100%) was recorded in both the 0.4% and 0.6% treatment groups. Hematological parameters including hemoglobin concentration, red blood cell count, and white blood cell count increased significantly in turmeric-supplemented groups, whereas packed cell volume remained unaffected. Antioxidant enzyme activities showed a dose-dependent response, with significant increases in superoxide dismutase, catalase, and glutathione peroxidase activities in fish receiving higher levels of *C. longa* extract. Similarly, intestinal protease activity increased significantly with increasing dietary turmeric inclusion, indicating improved digestive capacity and nutrient utilization. The findings of the present study demonstrate that dietary supplementation with *Curcuma longa* extract enhances growth, physiological status, antioxidant defense, and digestive efficiency in grass carp fingerlings. Among the tested levels, dietary inclusion of 0.4-0.6% *C. longa* extract was found to be the most effective and may serve as a promising natural feed additive for sustainable aquaculture practices.

Keywords: *Curcuma longa*, grass carp, *Ctenopharyngodon idella*, growth performance, hematology, antioxidant enzymes, protease activity, phytochemical feed additive

Introduction

Aquaculture is one of the fastest-growing food production sectors and plays a vital role in meeting the increasing global demand for animal protein (FAO, 2024) ^[12]. However, intensive aquaculture practices often increase stress, disease susceptibility, and oxidative damage, negatively affecting fish health and productivity (Dawood *et al.*, 2018) ^[11]. Although antibiotics and synthetic growth promoters have traditionally been used to improve fish performance, their extensive use has raised concerns regarding antimicrobial resistance, environmental contamination, and food safety (Cabello, 2006) ^[9]. Consequently, natural feed additives have gained considerable attention as sustainable alternatives in aquaculture. Grass carp (*Ctenopharyngodon idella*) is an economically important herbivorous freshwater fish species widely cultured in Asia because of its rapid growth, efficient feed utilization, and high consumer acceptance (FAO, 2024; Wang *et al.*, 2015) ^[12, 26]. Therefore, improving the growth performance and health status of grass carp fingerlings is essential for sustainable aquaculture production. Phytochemical feed additives derived from medicinal plants have emerged as promising alternatives to synthetic growth promoters due to their growth-

promoting, antioxidant, antimicrobial, immunostimulatory, and digestive-enhancing properties (Reverter *et al.*, 2014; Dawood *et al.*, 2018) ^[22, 11]. Among these, turmeric (*Curcuma longa* L.) has attracted considerable interest because of its diverse biological activities, primarily attributed to curcuminoids, particularly curcumin (Ammon & Wahl, 1991; Aggarwal *et al.*, 2007) ^[4, 3]. Curcumin is known to enhance antioxidant defense by stimulating enzymes such as superoxide dismutase, catalase, and glutathione peroxidase, while also improving digestive enzyme secretion, nutrient utilization, and intestinal health (Menon & Sudheer, 2007; Sivaram *et al.*, 2004; Abdel-Tawwab *et al.*, 2010) ^[18, 24, 1]. Previous studies have demonstrated that dietary turmeric supplementation improves growth performance, hematological indices, antioxidant status, and immune responses in several fish species, including rohu, Nile tilapia, common carp, gilthead seabream, and orange-spotted grouper (Sahu *et al.*, 2008; Giri *et al.*, 2019; Pereira *et al.*, 2020; Ashry *et al.*, 2021) ^[23, 14, 21, 5]. Moreover, curcumin has been reported to activate antioxidant signaling pathways and reduce oxidative stress in fish (Ming *et al.*, 2020) ^[19]. However, information regarding the effects of graded dietary levels of *C. longa* extract on growth, hematology, antioxidant status, and digestive physiology in grass carp fingerlings remains limited. Therefore, the present study aimed to evaluate the effects of dietary supplementation with graded levels of

Curcuma longa extract (0.2%, 0.4%, and 0.6%) on growth performance, survival, hematological parameters, antioxidant enzyme activities, and intestinal protease activity in grass carp fingerlings during a 30-day feeding trial.

2. Materials and Methods

2.1 Experimental fish and acclimatization

Healthy fingerlings of grass carp (*Ctenopharyngodon idella*) with an average initial body weight of 11 ± 4 g were procured from a local fish farm and acclimatized to laboratory conditions for one week prior to the commencement of the feeding trial. During the acclimatization period, fish were fed a basal diet and maintained under optimal water quality conditions with continuous aeration and regular water exchange.

2.2 Experimental design and preparation of diets

A 30-day feeding trial was conducted following a completely randomized design consisting of four dietary treatments with three replicates per treatment. Each replicate contained 10 fish fingerlings, resulting in a total of 30 fish per treatment group. Fish were fed their respective experimental diets at a feeding rate of 5% of body weight per day throughout the experimental period. The daily feed ration was divided into two equal portions and administered twice daily, in the morning and evening.

Table 1: The experimental diets consisted of the following treatments:

Treatment	Description
T ₀ (Control)	Basal diet containing soybean flour, groundnut oil cake, rice bran, wheat flour, mineral mixture, and mustard oil cake
T ₁	Basal diet supplemented with 0.2% <i>Curcuma longa</i> extract
T ₂	Basal diet supplemented with 0.4% <i>Curcuma longa</i> extract
T ₃	Basal diet supplemented with 0.6% <i>Curcuma longa</i> extract

2.3 Effects of *Curcuma longa* extract supplementation on growth performance

Growth performance was evaluated at 15-day intervals throughout the experimental period (days 15 and 30). Individual body weight (± 1 g) of all fish from each replicate was recorded during each sampling period. The collected data were used to calculate weight gain (WG), percentage weight gain (%WG), specific growth rate (SGR), and survival rate (SR) according to the standard formulae described by Weatherley and Gill (1987) ^[27].

2.4 Effects of *Curcuma longa* extract supplementation on hematological parameters

At the end of the feeding trial (day 30), blood samples were collected aseptically from the caudal vein using heparinized syringes. Hematological parameters including hemoglobin concentration (Hb), red blood cell count (RBC), white blood cell count (WBC), and packed cell volume (PCV) were determined according to the methods described by Blaxhall and Daisley (1973) ^[8].

2.5 Effects of *Curcuma longa* extract supplementation on antioxidant enzyme activities

At the termination of the experiment, liver tissues were excised and homogenized in ice-cold phosphate buffer followed by centrifugation to obtain the supernatant for enzymatic assays. Antioxidant status was evaluated by measuring the activities of superoxide dismutase (SOD), catalase (CAT), and reduced glutathione (GSH) using

standard spectrophotometric methods described by Misra and Fridovich (1972) ^[20], Aebi (1984) ^[2], and Beutler *et al.* (1963) ^[7], respectively.

2.6 Effects of *Curcuma longa* extract supplementation on intestinal protease activity

At the end of the feeding trial, intestinal tissues were collected and homogenized in chilled phosphate buffer. The homogenate was centrifuged and the resulting supernatant was used for enzyme analysis. Intestinal protease activity was determined according to the method described by Walter (1984) ^[25], while total protein concentration in the enzyme extract was estimated following the method of Lowry *et al.* (1951) ^[16].

2.7 Statistical analysis

All experimental data are presented as mean $\pm$ standard deviation (SD) in tables. For graphical presentation, mean values with standard error (SE) as error bars were used to improve visualization of treatment differences. Statistical analyses were performed using IBM SPSS Statistics software. Growth parameters measured at different sampling intervals (days 15 and 30) were analyzed using two-way ANOVA, whereas hematological parameters, antioxidant enzyme activities, and intestinal protease activity measured at the end of the experiment were analyzed using one-way ANOVA, followed by Tukey's multiple comparison test. Differences among treatment means were considered statistically significant at $p < 0.05$.

3. Results and Discussion

3.1 Effects of *Curcuma longa* extract supplementation on growth performance and survival of *Ctenopharyngodon idella* fingerlings

The growth performance and survival of grass carp fingerlings were significantly influenced by dietary supplementation with *Curcuma longa* extract during the 30-day feeding trial ($p < 0.05$), as presented in Table 2. No significant differences were observed in the initial body weight among the treatment groups (11.30-11.64 g), indicating homogeneity of the experimental fish at the beginning of the study (Table 2). At the end of the feeding trial, fish fed turmeric-supplemented diets exhibited improved growth performance compared with the control group. The highest final body weight was recorded in the T₃ group (16.92 ± 1.63 g), followed by T₂ (15.96 ± 0.79 g), T₁ (15.60 ± 1.28 g), and the control group (14.69 ± 0.28 g) (Table 2). Similarly, the highest weight gain (2.93 ± 0.43 g), percentage weight gain ($20.97 \pm 2.93\%$), and specific growth rate ($1.27 \pm 0.16\%$ day⁻¹) were observed in fish receiving 0.6% *C. longa* extract supplementation. The T₂ and T₃ treatments resulted in significantly higher percentage weight gain and specific growth rate compared with the control treatment ($p < 0.05$) (Table 2). Furthermore, dietary turmeric supplementation positively affected fish survival, with T₂ and T₃ groups exhibiting 100% survival, whereas the control group recorded the lowest survival rate (80.33%) (Table 2). The improvement in growth performance observed in turmeric-supplemented groups may be attributed to the presence of bioactive compounds, particularly curcumin, which enhances feed utilization efficiency, nutrient absorption, and digestive processes. Similar improvements in growth performance following

dietary turmeric supplementation have been reported by Sivaram, V. *et al.* (2004) [24], who observed enhanced growth and disease resistance in juvenile Orange-spotted grouper fed turmeric-enriched diets.

The present findings are also in agreement with the observations of Abdel-Tawwab, Mohamed *et al.* (2018) [1], who reported that phytogetic feed additives improved growth performance and feed utilization in cultured fish species through enhanced digestive activity and improved intestinal health. Moreover, the growth-promoting effects of turmeric may be associated with its antioxidant and immunomodulatory properties, which reduce oxidative stress and allow more metabolic energy to be directed towards growth rather than maintenance and cellular repair. Similar conclusions were reported by Reverter, Mireia *et al.* (2014) [22], who demonstrated that phytogetic feed additives can improve growth performance and health status in aquaculture species by enhancing antioxidant defense and immune responses. The improved survival observed in the turmeric-fed groups may also be associated with the antimicrobial and immunostimulatory properties of curcumin, which contribute to enhanced stress tolerance and disease resistance in fish. Comparable findings were reported by Citarasu, Thavasimuthu (2010) [10], who highlighted the beneficial role of herbal feed additives in improving fish health and survivability under aquaculture conditions. Overall, the present study demonstrates that dietary supplementation with *Curcuma longa* extract, particularly at inclusion levels of 0.4% and 0.6%, effectively enhances growth performance and survival of grass carp fingerlings and may serve as a promising natural feed additive in sustainable aquaculture practices.

Table 2: Effects of dietary *Curcuma longa* extract supplementation on growth performance and survival

Treatment	Initial Weight (g)	Final Weight (g)	Weight Gain (g)	Weight Gain (%)	Final SGR (% day ⁻¹)	Survival Mean
Control	11.37 ± 0.22 ^a	14.69 ± 0.28 ^b	1.71 ± 0.45 ^b	13.21 ± 3.73 ^b	0.82 ± 0.22 ^b	80.33 ^a
T ₁ (0.2%)	11.31 ± 1.01 ^a	15.60 ± 1.28 ^{ab}	2.19 ± 0.62 ^{ab}	16.24 ± 4.08 ^{ab}	1.00 ± 0.25 ^{ab}	90.50 ^{ab}
T ₂ (0.4%)	11.30 ± 1.02 ^a	15.96 ± 0.79 ^{ab}	2.59 ± 0.44 ^{ab}	19.66 ± 5.14 ^a	1.19 ± 0.29 ^a	100.00 ^b
T ₃ (0.6%)	11.64 ± 0.98 ^a	16.92 ± 1.63 ^a	2.93 ± 0.43 ^a	20.97 ± 2.93 ^a	1.27 ± 0.16 ^a	100.00 ^b

3.2 Effects of dietary *Curcuma longa* extract on haematological parameters

Dietary supplementation of *Curcuma longa* extract significantly affected the haematological profile of *Ctenopharyngodon idella* fingerlings (Table 3), with highly significant effects on Hb ($p < 0.001$) and significant effects on RBC ($p = 0.007$) and WBC ($p = 0.008$) counts, while PCV remained statistically unaffected ($p = 0.062$). RBC and Hb increased in a clear dose-dependent manner, from $1.38 \pm 0.05 \times 10^6/\mu\text{L}$ and 5.81 ± 0.13 g/dL in the control to peak values of $1.64 \pm 0.08 \times 10^6/\mu\text{L}$ and 6.84 ± 0.17 g/dL at T₂-T₃, respectively. Both indices plateaued beyond 0.4% inclusion, with no significant difference between T₂ and T₃. This trend is consistent with Ashry *et al.* (2021) [5], who reported dose-dependent increases in RBC and Hb in gilthead seabream (*Sparus aurata*) fed curcumin at 2-3%, and with Sahu *et al.* (2008) [23], who observed elevated RBC and Hb in rohu (*Labeo rohita*) supplemented with graded *C. longa* doses. The improvement is generally attributed to the antioxidant activity of curcuminoids, which protects erythrocyte membranes from oxidative damage and supports haemoglobin synthesis via improved hepatic function (Manju *et al.*, 2013) [17]. PCV rose only marginally (23.24% to 24.81%) without reaching significance, mirroring Manju *et al.* (2013) [17], who similarly found that Hb and RBC

responded significantly to dietary curcumin in *Anabas testudineus* while related volumetric indices did not reflecting the lower sensitivity of PCV, which depends on both cell number and corpuscular volume rather than erythrocyte count alone. WBC count increased significantly at T₂ ($68.26 \times 10^3/\mu\text{L}$) and T₃ ($67.84 \times 10^3/\mu\text{L}$) relative to control, indicating an immunostimulatory effect of *C. longa*, consistent with Pereira *et al.* (2020) [21], who reported elevated leukocyte counts in Nile tilapia fed 2.5% *Curcuma longa* hydrolate, with the effect plateauing at higher doses a pattern also seen here between T₂ and T₃. Notably, this leukocyte response is not universal: Manju *et al.* (2013) [17] found WBC unaffected by curcumin in *A. testudineus*, suggesting the response is species- and dose-dependent. Overall, the enhanced Hb, RBC, and WBC profiles indicate that dietary *C. longa* extract improved the physiological and immune status of *C. idella* fingerlings, most likely via the antioxidant, hepatoprotective, and immunomodulatory action of curcuminoids (Ashry *et al.*, 2021; Manju *et al.*, 2013; Pereira *et al.*, 2020) [5, 17, 21]. The plateau beyond 0.4% suggests T₂ (0.4%) as the near-optimal inclusion level, consistent with dose-saturation trends reported for curcumin in rainbow trout (Bakhtiari Aqmasjed *et al.*, 2023) [6] and Nile tilapia (Pereira *et al.*, 2020) [21].

Table 3: Effects of dietary *Curcuma longa* extract supplementation on haematological parameters

Treatment	RBC ($\times 10^6/\mu\text{L}$)	Hb (g/dL)	PCV (%)	WBC ($\times 10^3/\mu\text{L}$)
Control	1.38 ± 0.05^a	5.81 ± 0.13^a	23.24 ± 1.03^a	65.60 ± 0.59^a
T ₁ (0.2%)	1.47 ± 0.06^{ab}	6.33 ± 0.11^b	24.18 ± 0.35^a	66.47 ± 0.74^{ab}
T ₂ (0.4%)	1.64 ± 0.08^b	6.78 ± 0.23^c	24.81 ± 0.23^a	68.26 ± 0.64^b
T ₃ (0.6%)	1.63 ± 0.10^b	6.84 ± 0.17^c	24.14 ± 0.37^a	67.84 ± 0.93^b

3.3 Effects of dietary *Curcuma longa* extract on antioxidant parameters

Dietary supplementation with *Curcuma longa* extract resulted in a significant and dose-dependent enhancement of antioxidant enzyme activities in *Ctenopharyngodon idella* fingerlings (Figure 1). Superoxide dismutase (SOD) activity increased progressively from 45.3 ± 0.39 U/mg protein in the control group to 48.5 ± 0.42 , 55.43 ± 0.56 , and 58.47 ± 0.77 U/mg protein in T₁, T₂, and T₃, respectively (Figure 1A), representing an approximately 29% increase over the control at the highest supplementation level. Similarly, catalase (CAT) activity increased significantly from 12.43 ± 0.20 U/mg protein in the control group to 19.27 ± 0.33 U/mg protein in the T₃ group (Figure 1B). Reduced glutathione (GSH) levels also exhibited a progressive increase from the control to the highest supplementation level, indicating enhanced non-enzymatic antioxidant defense in turmeric-fed fish (Figure 1C). The observed increase in SOD, CAT, and GSH suggests that dietary *C.*

longa supplementation enhanced both enzymatic and non-enzymatic antioxidant defense mechanisms in grass carp fingerlings. Similar findings were reported by Ming *et al.* (2020) [19], who observed elevated antioxidant enzyme activities and glutathione content in grass carp supplemented with dietary curcumin. Likewise, Giri *et al.* (2019) [14] reported improved antioxidant status in common carp following dietary turmeric supplementation. The antioxidant effects of turmeric are primarily attributed to curcumin, which functions both as a direct scavenger of reactive oxygen species (ROS) and as an activator of the Nrf2/Keap1 signaling pathway, thereby stimulating the expression of antioxidant defense genes (Ming *et al.*, 2020) [19]. Overall, the progressive increase in antioxidant parameters observed in the present study (Figure 1) indicates that dietary *C. longa* extract effectively improved the antioxidant capacity and physiological resilience of *C. idella* fingerlings.

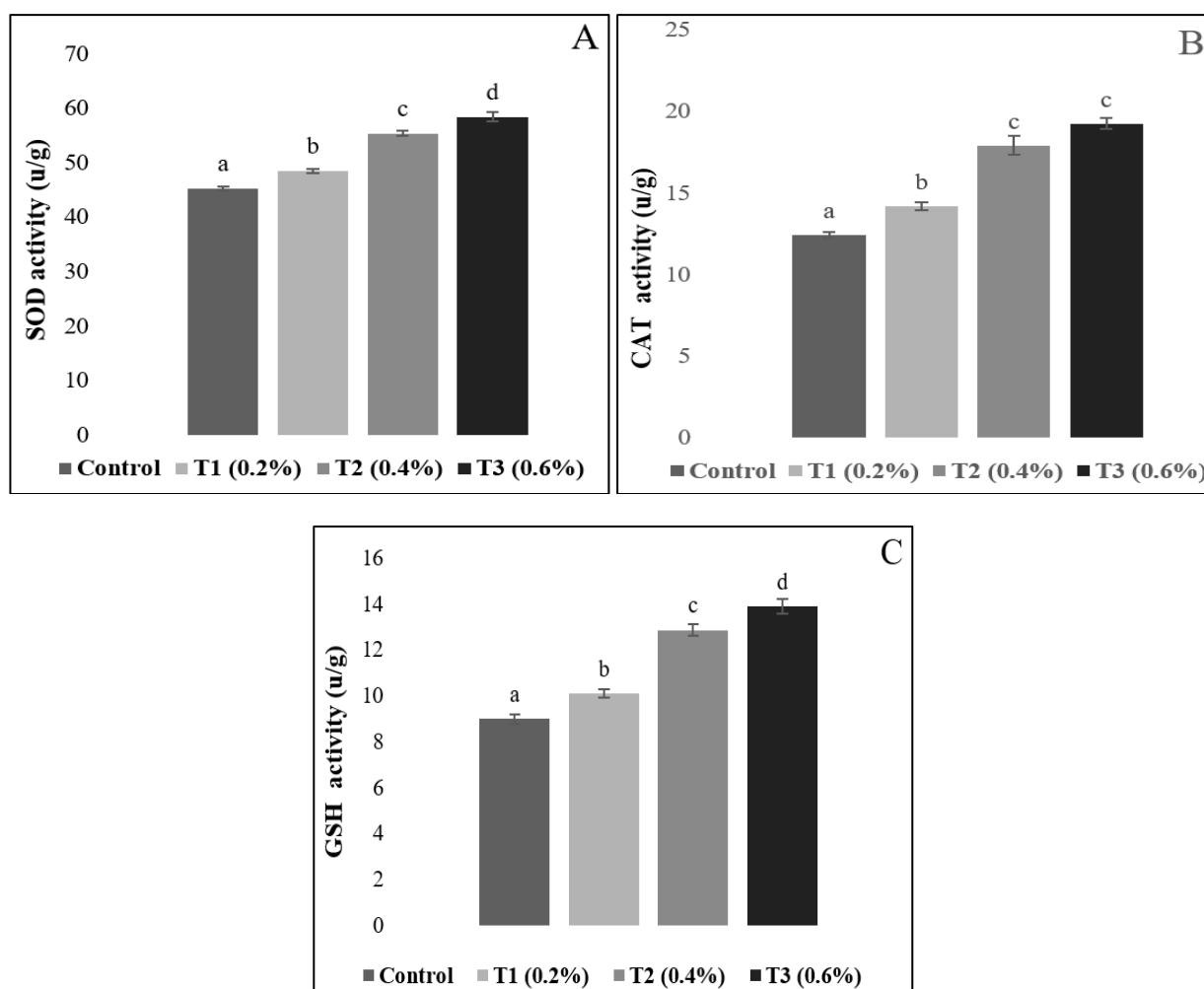


Fig 1: Effect of dietary *Curcuma longa* extract supplementation on antioxidant enzyme activities in *Ctenopharyngodon idella* fingerlings fed graded levels of *C. longa* extract (Control, T₁ = 0.2%, T₂ = 0.4%, T₃ = 0.6%). (A) Superoxide dismutase (SOD) activity; (B) Catalase (CAT) activity; (C) Reduced glutathione (GSH) activity. Enzyme activities are expressed as U/mg protein. Values are presented as mean $\pm$ SE (n = 3). Bars bearing different superscript letters within each panel differ significantly ($p < 0.05$, one-way ANOVA followed by Tukey's post-hoc test).

3.4 Effects of dietary *Curcuma longa* extract supplementation on intestinal protease activity Dietary supplementation with *Curcuma longa* extract significantly enhanced intestinal protease activity in grass carp fingerlings following the 30-day feeding trial (Fig 2). Protease activity increased progressively with increasing dietary inclusion levels of turmeric extract, with all treatment groups differing significantly from one another ($p < 0.05$). The highest protease activity was recorded in the T₃ group (14.60 ± 0.29), followed by T₂ (13.47 ± 0.23), T₁ (10.83 ± 0.19), and the control group (9.17 ± 0.16). As illustrated in Figure 5, the improvement in protease activity suggests enhanced digestive efficiency and protein utilization in turmeric-supplemented fish. This effect may be attributed to curcumin and other bioactive constituents of *C. longa*, which stimulate digestive secretions and enzyme synthesis, thereby improving nutrient digestion and absorption. Similar improvements in digestive enzyme activities following dietary turmeric supplementation have been reported by Sivaram, V. *et al.* (2004) [24] and Abdel-Tawwab, Mohamed *et al.* (2010) [1]. Furthermore, Reverter, Mireia *et al.* (2014) [22] suggested that phytogetic feed additives enhance digestive physiology and nutrient utilization, ultimately contributing to improved growth performance in cultured fish species. Overall, the results indicate that dietary inclusion of *C. longa* extract, particularly at 0.4% and 0.6%, effectively improves proteolytic activity and digestive capacity in grass carp fingerlings.

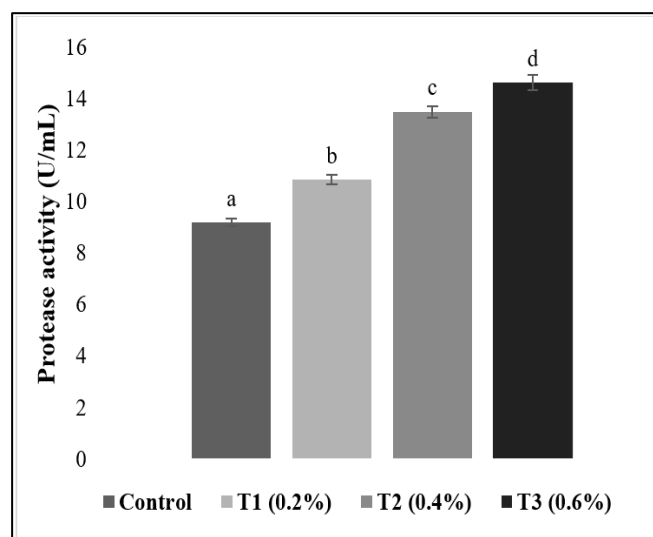


Fig 2: Effects of dietary *Curcuma longa* extract supplementation on intestinal protease activity in *Ctenopharyngodon idella* fingerlings after 30 days of feeding. Values are presented as mean $\pm$ SE ($n = 3$). Bars bearing different superscript letters indicate significant differences among treatments according to Tukey's multiple comparison test at $p < 0.05$.

Conclusion

The present study demonstrated that dietary supplementation with *Curcuma longa* extract positively influenced the growth performance, hematological profile, antioxidant status, and digestive physiology of grass carp (*Ctenopharyngodon idella*) fingerlings during the 30-day feeding trial. Fish fed turmeric-supplemented diets exhibited higher weight gain, percentage weight gain, specific growth rate, and survival compared to the control group. Dietary inclusion of *C. longa* extract also significantly improved

hematological parameters, particularly hemoglobin concentration, red blood cell count, and white blood cell count, indicating enhanced physiological condition and immune competence of the fish. Furthermore, supplementation with turmeric extract resulted in a dose-dependent increase in antioxidant enzyme activities, suggesting improved protection against oxidative stress and enhanced cellular defense mechanisms. The observed increase in intestinal protease activity further indicates improved digestive efficiency and nutrient utilization in turmeric-fed fish, which may have contributed to the enhanced growth performance observed in the supplemented groups. Overall, the findings of the present study suggest that *Curcuma longa* extract is an effective natural phytogetic feed additive for improving the health and productivity of grass carp fingerlings. Among the tested inclusion levels, dietary supplementation with 0.4% and 0.6% *C. longa* extract produced the most favorable responses, with 0.4% appearing to be the optimal level considering the comparable physiological benefits achieved relative to the higher inclusion level. Therefore, dietary turmeric supplementation may represent a sustainable and environmentally friendly strategy for improving fish performance and health in freshwater aquaculture.

Reference

1. Abdel-Tawwab M, Monier MN. Stimulatory effect of dietary taurine on growth performance, digestive enzymes activity, antioxidant capacity, and tolerance of common carp, *Cyprinus carpio* L., fry to salinity stress. *Fish Physiol Biochem.* 2018;44(2):639-649.
2. Aebi H. Catalase *in vitro*. *Methods Enzymol.* 1984;105:121-126.
3. Aggarwal BB, Sundaram C, Malani N, Ichikawa H. Curcumin: the Indian solid gold. In: *The Molecular Targets and Therapeutic Uses of Curcumin in Health and Disease.* 2007. p. 1-75.
4. Ammon HP, Wahl MA. Pharmacology of *Curcuma longa*. *Planta Med.* 1991;57(1):1-7.
5. Ashry AM, Hassan AM, Habiba MM, El-Zayat A, El-Sharnouby ME, Sewilam H, *et al.* The impact of dietary curcumin on the growth performance, intestinal antibacterial capacity, and haemato-biochemical parameters of gilthead seabream (*Sparus aurata*). *Animals.* 2021;11(6):1779.
6. Aqmasjed SB, Sajjadi MM, Falahatkar B, Safari R. Effects of dietary ginger (*Zingiber officinale*) extract and curcumin on growth, hematology, immunity, and antioxidant status in rainbow trout (*Oncorhynchus mykiss*). *Aquac Rep.* 2023;32:101714.
7. Beutler E, Duron O, Kelly BM. Improved method for the determination of blood glutathione. *J Lab Clin Med.* 1963;61:882-888.
8. Blaxhall PC, Daisley KW. Routine haematological methods for use with fish blood. *J Fish Biol.* 1973;5(6):771-781.
9. Cabello FC. Heavy use of prophylactic antibiotics in aquaculture: a growing problem for human and animal health and for the environment. *Environ Microbiol.* 2006;8(7):1137-1144.
10. Citarasu T. Herbal biomedicines: a new opportunity for aquaculture industry. *Aquac Int.* 2010;18(3):403-414.
11. Dawood MAO, Koshio S, Esteban MÁ, Van Doan H. Beneficial roles of feed additives as immunostimulants

- in aquaculture: a review. *Rev Aquac.* 2018;10(4):950-974.
12. Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2024: Blue Transformation in Action. Rome: FAO; 2024.
 13. Peng XR, Feng L, Jiang WD, Wu P, Liu Y, Jiang J, *et al.* Supplementation exogenous bile acid improved growth and intestinal immune function associated with NF- κ B and TOR signalling pathways in on-growing grass carp (*Ctenopharyngodon idella*): enhancement the effect of protein-sparing by dietary lipid. *Fish Shellfish Immunol.* 2019;92:552-569.
 14. Giri SS, Sukumaran V, Park SC. Effects of bioactive substance from turmeric on growth, skin mucosal immunity and antioxidant factors in common carp, *Cyprinus carpio*. *Fish Shellfish Immunol.* 2019;92:612-620.
 15. Jiang J, Wu XY, Zhou XQ, Feng L, Liu Y, Jiang WD, *et al.* Effects of dietary curcumin supplementation on growth performance, intestinal digestive enzyme activities and antioxidant capacity of crucian carp *Carassius auratus*. *Aquaculture.* 2016;463:174-180.
 16. Lowry OH, Rosebrough NJ, Farr AL, Randall RJ. Protein measurement with the Folin phenol reagent. *J Biol Chem.* 1951;193(1):265-275.
 17. Manju M, Vijayasree AS, Akbarsha MA, Oommen OV. Protective effect of dietary curcumin in *Anabas testudineus* (Bloch) with a special note on DNA fragmentation assay on hepatocytes and micronucleus assay on erythrocytes *in vivo*. *Fish Physiol Biochem.* 2013;39(5):1323-1330.
 18. Menon VP, Sudheer AR. Antioxidant and anti-inflammatory properties of curcumin. In: *The Molecular Targets and Therapeutic Uses of Curcumin in Health and Disease*. 2007. p. 105-125.
 19. Ming J, Ye J, Zhang Y, Xu Q, Yang X, Shao X, *et al.* Optimal dietary curcumin improved growth performance, and modulated innate immunity, antioxidant capacity and related genes expression of NF- κ B and Nrf2 signaling pathways in grass carp (*Ctenopharyngodon idella*) after infection with *Aeromonas hydrophila*. *Fish Shellfish Immunol.* 2020;97:540-553.
 20. Misra HP, Fridovich I. The role of superoxide anion in the autoxidation of epinephrine and a simple assay for superoxide dismutase. *J Biol Chem.* 1972;247(10):3170-3175.
 21. Pereira MO, Moraes AV, Rodhermel JCB, Hess JD, Alves L, Chaaban A, *et al.* Supplementation of *Curcuma longa* hydrolate improves immunomodulatory response in Nile tilapia reared in a recirculation aquaculture system. *Arq Bras Med Vet Zootec.* 2020;72(5):1805-1812.
 22. Reverter M, Bontemps N, Lecchini D, Banaigs B, Sasal P. Use of plant extracts in fish aquaculture as an alternative to chemotherapy: current status and future perspectives. *Aquaculture.* 2014;433:50-61.
 23. Sahu S, Das BK, Mishra BK, Pradhan J, Samal SK, Sarangi N. Effect of dietary *Curcuma longa* on enzymatic and immunological profiles of rohu, *Labeo rohita* (Ham.), infected with *Aeromonas hydrophila*. *Aquac Res.* 2008;39(16):1720-1730.
 24. Sivaram V, Babu MM, Immanuel G, Murugadass S, Citarasu T, Marian MP. Growth and immune response of juvenile greasy groupers (*Epinephelus tauvina*) fed with herbal antibacterial active principle supplemented diets against *Vibrio harveyi* infections. *Aquaculture.* 2004;237(1-4):9-20.
 25. Walter HE. Proteinases: methods with hemoglobin, casein and azocoll as substrates. In: Bergmeyer HU, editor. *Methods of Enzymatic Analysis*. 3rd ed. Vol. 5. Verlag Chemie; 1984. p. 270-277.
 26. Wang Y, Lu Y, Zhang Y, Ning Z, Li Y, Zhao Q, *et al.* The draft genome of the grass carp (*Ctenopharyngodon idellus*) provides insights into its evolution and vegetarian adaptation. *Nat Genet.* 2015;47(6):625-631.
 27. Weatherley AH, Gill HS. *The Biology of Fish Growth*. London: Academic Press; 1987.