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The Role of Turmeric Extract in Promoting Fish Health and Stress Resilience in Goldfish (*Carassius auratus L.)*

Dr.R. Hannah Jessie Rani [1*], Ved Vrat Verma [2], J. Guntaj [3], Dr. Yogesh Jadhav [4]

[1*] Assistant Professor, Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology, JAIN (Deemed-to-be University), Bangalore, India. E-mail: jr.hannah@jainuniversity.ac.in

[2] Assistant Professor, Department of Biotechnology, Noida International University, Greater Noida, Uttar Pradesh, India. E-mail: ved.verma@niu.edu.in

[3] Assistant Professor, Chitkara University Institute of Engineering and Technology, Centre for Research Impact and Outcome, Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India. E-mail: Id guntaj.j.orp@chitkara.edu.in

[4] Associate Professor, Department of uGDX, ATLAS SkillTech University, Mumbai, Maharashtra, India. E-mail: yogesh.jadhav@atlasuniversity.edu.in

Abstract

Turmeric extract (TE) is known for its potential health-promoting and stress-resilience properties across various species. The research evaluated the effects of dietary TE supplementation on the health and stress resilience of goldfish (Carassius auratus). Over 8 weeks, 480 fish (10.70 ± 0.5 g) were randomly assigned to six groups, with 10 replicates per group (8 fish per replicate). The control group (Group 1) was fed a basal diet without any supplementation. In contrast, the other groups received diets supplemented with TE at the following concentrations: 1 g/kg for Group 2, 2 g/kg for Group 3, 2.5 g/kg for Group 4, 3 g/kg for Group 5, and 4 g/kg for Group 6. Although growth performance and feed intake were unaffected by TE supplementation, significant improvements in fish coloration were observed, particularly in the head, abdominal, and tail regions. According to the research, adding TE to goldfish meals enhanced immunological response, decreased biomarkers linked to stress, and increased general well-being and stress tolerance. The 4 g/kg group showed the highest increase in serum carotenoid levels, while higher white and red blood cell counts, total protein, albumin, and globulin levels were observed. TE supplementation also reduced plasma cortisol and glucose levels, suggesting enhanced stress resistance. The research suggests that TE supplementation can enhance overall health and stress resilience in goldfish.

Keywords:

Fish health, stress resilience, turmeric extract, immune function, supplementation.

Corresponding Author: Dr.R. Hannah Jessie Rani, E-mail: jr.hannah@jainuniversity.ac.in

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Introduction

For thousands of years, people have utilized turmeric extract (TE), which is made from the rhizome of Curcuma longa, for its therapeutic benefits. It contains a variety of bioactive compounds, including curcumin, which have antioxidant, anti-inflammatory, and immune protection properties (de Oliveira Filho et al., 2021). In recent years the use of turmeric extract as a natural supplement to increase the health and survival of fish under stress conditions has emerged, mainly in aquaculture. The goldfish (*Carassius auratus*) a highly popular ornamental fish, is the species widely investigated in this regard (Saengsitthisak et al., 2023; Agarwal & Yadhav, 2023). The section highlights the potential benefits of TE in enhancing goldfish health with a focus on its stress-reducing activity and overall improvement in aquaculture. Turmeric bioactive components, particularly curcumin have been proven to have several beneficial effects on the health of aquatic species (Jatobá et al., 2024). These compounds possess strong antioxidant and anti-inflammatory activities, which can be crucial for the enhancement of the immune system of fish. The antioxidative activity of curcumin can improve oxidative stress resulting from environmental conditions. The ornamental species of goldfish are exposed to a variety of stressors, including sudden temperature fluctuations in water, poor water quality, or crowding (Shameena et al., 2021). These stressors compromise the immune system, making the goldfish easily infected with diseases. Modulating immune responses with turmeric extract could reduce these adverse effects and stress resilience in goldfish(Zhang et al., 2021; Sudagar et al., 2024). Inflammation is a well-known reaction in fish to both environmental stress and disease. Its active ingredient, curcumin of turmeric, exhibits significant anti-inflammatory effects, making it a vital supplement for maintaining the health of goldfish, especially under stress conditions (Isabegović & Mandžić, 2020). Preventing chronic inflammation can prevent irreversible damage to organs and tissues, thus enhancing goldfish vitality(Peng et al., 2021). The application of turmeric extract in aquaculture can serve to enhance the health and productivity of fish. Research on aquaculture fish species indicate the potential for enhanced growth rates, improved immune function, and increased disease resistance through turmeric supplementation. The optimal dosage level, bioavailability, and chronic exposure to its effects need to be addressed before turmeric supplementation can be expected to effectively ensure fish health(Edrees et al., 2025; Agnes Pravina et al., 2024). As goldfish belong to the family of cold-water fish are extremely susceptible to changes in environmental conditions (Jasim, 2022). The major changes in water quality, temperature, and stocking density can create environmental stress factors, which tend to decrease immunity and general health (Fatima et al., 2024). Adding the extract from turmeric can be used as a buffer against those stressors(Chen et al., 2022). The lack of follow-up monitoring over an extended period, especially to examine whether the curcuminoid supplement would result in sustained effects on the aquatic environment, is a limitation. Additionally, variability in fish populations or environmental conditions was not considered. The research assessed the impact of dietary TE supplementation on the health and stress resilience of goldfish (*Carassius auratus*).

Claus et al., (2024) determine the critical thermal maximum (CTmax) of goldfish subjected to a range of high and current temperatures (18 °C, 21 °C, and 25 °C) and chloride concentrations (0 ppt, 1 ppt, and 6 ppt), which are pertinent to Great Lakes basin climate forecasts. Goldfish were chosen based on the circumstances in urban ponds and climate forecasts for different temperatures and chloride concentrations. Different combinations of temperatures and chloride levels were used to measure the CTmax. To better describe heat tolerance, agitation, and acclimation potential metrics were employed. Regardless of chloride treatment, goldfish exposed to temperatures close to growth optimum showed the greatest CTmax, indicating a beneficial response to acclimation temperatures. Eissa et al., (2024) assessed how red tilapia broodstock

responded to dietary curcumin supplementation. 168 fish used in the research were given a diet that included either free curcumin, a combination of curcumin and nano-curcumin, or nano-curcumin. The NCur group's hematological parameters, reproductive hormones, and reproductive capability, whereas liver function enzymes dropped, according to the results. Fish-fed NCur showed better reproductive performance and increased expression of reproductive genes in gonads.

A major financial loss for aquaculture is caused by the parasite Ichthyophthirius multifiliis, which causes white spot disease in freshwater fish,as examined by (Kumar et al., 2022). Fish immune responses are compromised by low water temperatures, which make themmore vulnerable to parasite diseases. Turmeric essential oil was employed as amanagement technique to comprehend the process of parasite-bacteria co-infection in fish. In *Pangasianodon hypophthalmus*, a spontaneous *I. multifiliis* epidemic was documented, resulting in bleeding, ulceration, discoloration, and redness. Supplementing with turmeric oil increased fingerling survival rates by fostering protective immunity against co-infection. The performance of Nile tilapia development, immunological response, antioxidant capacity, haemato-biochemical profile, carcass composition, and zinc bioaccumulation were all investigated about dietary curcumin-assisted green produced zinc oxide nanoparticles (CUR-ZnONPs) (Bhatt et al., 2024). The fish were challenged with *Aeromonas hydrophila* and fed diets enhanced with varying doses of CUR-ZnONPs for 56 days. CZP4 had the lowest feed conversion ratio and the best growth performance. Nevertheless, CZP4 markedly reduced levels of aspartate aminotransferase, cholesterol, body crude fat, and malondialdehyde.

Komal et al., (2024) looked into how curcumin affected the immune system, antioxidant response, and tilapia growth. At a density of 3.00 kg/m3, it was discovered that 50 mg/kg of curcumin was the ideal dosage; this might be further studied for intense cultivation. Three densities of fish were raised: medium density (MD), high density (HD), and low density (LD). All treatments had comparable amylase, lipase, and protease chemical compositions and activities. The C1 diet had the lowest levels of antioxidant enzymes and the lowest expression of IL-1β, pro-opiomelanocortin-α, and somatostatins-1.Khieokhajonkhet et al., (2023) examined the effects of turmeric *(Curcuma longa)* and black pepper (Piper nigrum) on common carp (*Cyprinus carpio*). Adding spices and active constituents had an effect on fish development but it had no discernible effect on food consumption. The Curc group had a greater level of total indispensableFatty Acid Amide(FAA), while Dietary Pip raised total lipids throughout the body. The present understanding of Pip's impact on nutrient flow and utilization is limited but further research is required with varying amounts of spices in fish diets.

A natural pigment can lead to color degeneration, and ornamental fish are lucrative because of theiraesthetic appeal. Wongphonprateep & Pichitkul (2021)created carotenoid nanoparticles from unrefined palm oil to improve the color of goldfish skin. Using an ionotropic gelation technique, carotenoid nanoparticles were produced and then freeze-dried. For eight weeks, goldfish were fed feed that included the nanoparticles in varying amounts. The research discovered that without influencing growth, survival, or other adverse consequences, the fish given 500 µg kg-1 of the skin color with the highest intensity of color had the highest color. The benefits of supplementing tiger shrimp diets with fermented herbal extracts (FHE) (Ilham, et al., 2024) were investigated, with particular attention paid to growth, feed efficiency, nutrient retention, and molting performance. P2 demonstrated greater weight increase, average daily gain, and length gain in comparison to the control diet after five doses of FHE supplementation were utilized. Lower crude protein content, greater energy contents, and improved protein and energy retention were also seen in P2 therapy groups.

Research Contributions

- Dietary TE supplementation substantially enhanced the coloration of the goldfish, particularly in the regions of the head, abdomen, and tail to improve aesthetics in aquaculture.
- Supplementation with TE improved the immune functioning of goldfish by increasing white and red blood cell counts and raising total protein, albumin, and globulin levels.
- Stress resilience was enhanced, as plasma cortisol and glucose levels decreased, indicating improved stress resistance a critical factor in aquaculture practices.
- The 4 g/kg TE group showed the highest increase in serum carotenoid levels, promoting fish health.
- It suggested that TE supplementation could improve health and stress resilience in goldfish without affecting growth performance and feed intake.

Materials and Methods

The methodology started with the random distribution of 480 goldfish into six different groups, each having replicates. The control group was fed a basal diet, whereas the experimental groups received diets supplemented with different concentrations of TE. All these fish were followed up for 8 weeks for TE-supplemented effects on health and resilience to stress. Figure 1 shows the research flow.

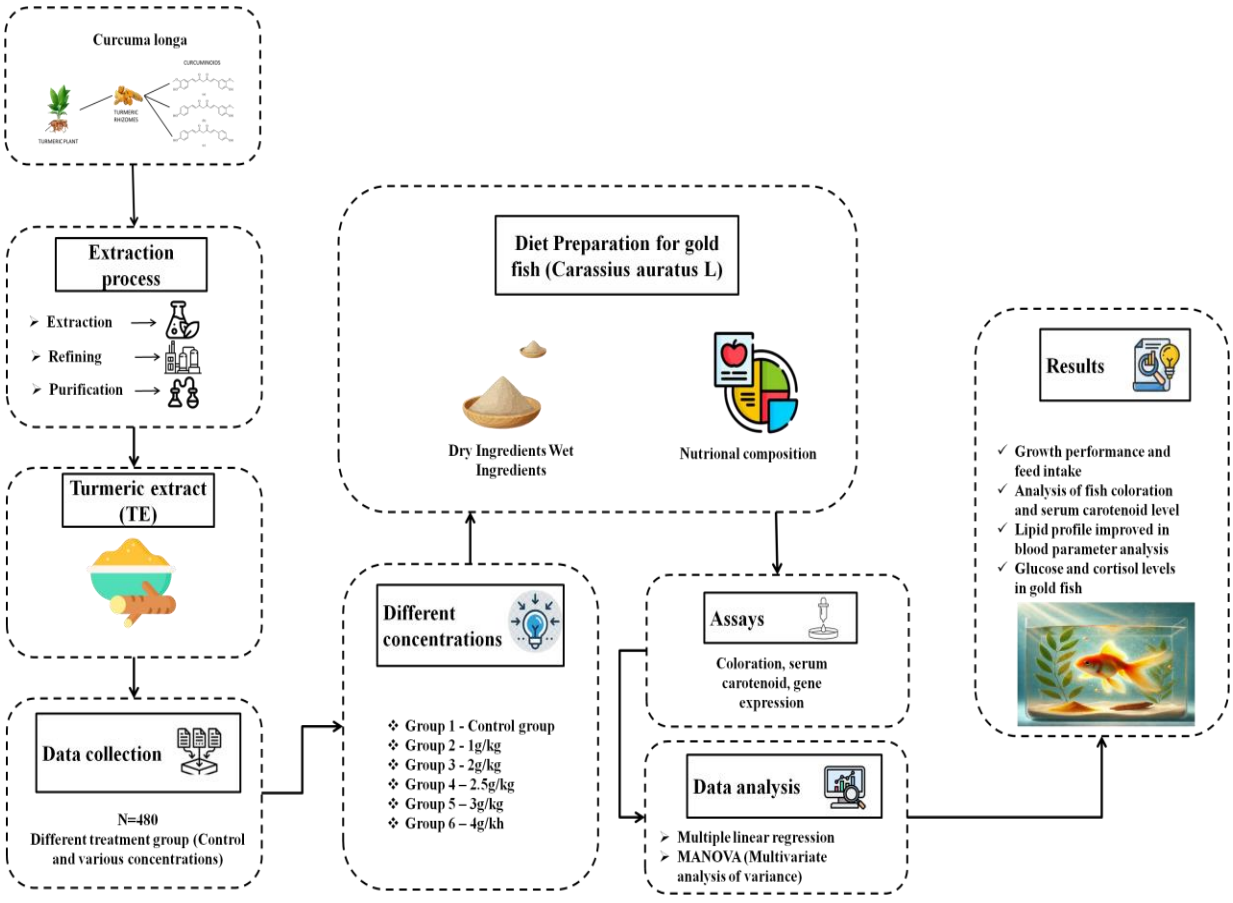

Figure 1. Research flow for turmeric extract in promoting fish health and stress resilience in goldfish

Protocol for Turmeric Root Extraction

The curcumin from the turmeric root is extracted and refined using purifications intended to produce high-purity curcumin crystals, according to the methodology. Among the four primary steps are:

- **Extraction:** Turmeric root was weighed out accurately and blended with 70–85% acetone; the mix gets ultrasonic super sound extractions thrice. The result gives a clear distinction in the extraction effectiveness of the release of curcumin by plant material as mentioned above: recovering acetone in reduced pressure having feed liquid mass volume ratios of about 1:8-10. And produces sepia-colored oily extracts from crude curcumin.
- **Refining:** Liquid-liquid extraction is performed on the crude curcumin extract. To selectively remove water-soluble and fat-soluble impurities, an appropriate extractant is added. The purified solution is lyophilized or freeze-dried to produce high-concentration curcumin powder with a lower level of contaminants.
- **Crystallization:** Crystallization from the alcohol-water mixture: The sublimed curcumin powder is crystallized using an alcohol-water mixture. This process produces orange-yellow, needle-like crystals that are primarily in the form of crystallized curcumin. These crystals are dried using lyophilization for proper dryness and stability.
- **Recrystallization:** The primary curcumin crystals are further recrystallized with the alcohol-water method to reach an higher level of purity. The orange-red crystals that are produced in needle-like form are lyophilized to prepare pure curcumin under optimal chemical stability and potency.

Data Collection

Assessment of goldfish growth, coloration, immune function, stress resilience, and gene expression were undertaken for the process of data collection. Goldfish were bulk-weighed after fasting with desensitization using clove oil every two weeks. Colorimetric measurements were undertaken at 8 weeks. The blood samples were taken for carotenoid content, hematological, and biochemical analyses that included lipid profiles, plasma cortisol, and glucose levels. Liver tissues were stored for gene expression analysis of lysozyme, IL-10, and IL-1β were kept at −80°C to preserve samples for further investigation.

Preparation of TE

The extraction of turmeric extract for goldfish is based on a simple extraction process using either fresh turmeric roots or turmeric powder. These fresh turmeric roots are well-washed, peeled, and chopped into smaller pieces. If turmeric powder is used, this step can be skipped. An aqueous extract involves mixing 50 grams of turmeric with 200 mL of distilled water. For an ethanolic extract, 50 grams of turmeric is mixed with 200 mL of 70% ethanol. The mixture is filtered using muslin cloth or filter paper to remove solid residues and collect the clear extract. Concentration of the extract can be done by evaporation of the solvent in a water bath at 40–50°C. The last extract is kept in an airtight dark bottle in the refrigerator at 4°C. The aqueous extracts keep well for a week and the ethanolic extracts for one month. It should be adequately diluted before applying to prevent toxicity, and the effect of this extract on the goldfish can be tried as a small-scale trial.

Goldfish Diet Preparation

Table 1 illustrates the Mix dry ingredients (flakes, pellets, rice bran, corn meal, vitamins, and mineral premixes) in one container and wet ingredients like brine shrimp, earthworms, spinach, blood worms, mussels, and daphnia in another. Mix both well with the addition of turmeric extract based on the applied Group 1 to Group

6 different treatments. To calculate the total daily feed requirement, multiply the average intake per fish by 450. Scale up/down the 1,000-gram formulation as necessary. Mix well, pelletize if needed, air dry or refrigerate, and store in airtight containers.

Table 1. Nutrient composition for goldfish feed across treatment groups

Items	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Feed Formula (g/kg)						
Pellets	200	200	200	200	200	200
Flakes	250	250	250	250	250	250
Brine Shrimp	100	100	100	100	100	100
Earthworm	50	50	50	50	50	50
Corn Meal	75	75	75	75	75	75
Spinach	53	53	53	53	53	53
Blood Worms	60	60	60	60	60	60
Rice Bran	80	80	80	80	80	80
Mussels	40	40	40	40	40	40
Daphnia	62	62	62	62	62	62
Vitamin Premix	14	14	14	12	13	10
Mineral Premix	16	15	14	15	13	15
Turmeric Extract	0	1	2	3	4	5
Total (g)	1000	1000	1000	1000	1000	1000

Nutritional Composition

The nutritional composition of the goldfish feed varies due to the presence of turmeric extract (Group 1 to Group 6). The crude protein was marginally higher, from 40.00% in Group 1 to 41.20% in Group 6, and the crude fat reduced from 8.50% to 8.20%. Total carotenoids elevated from 0.05 g/kg in Group 1 to 0.65 g/kg in Group 6. Gross energy went up from 18.50 MJ/kg to 19.10 MJ/kg shown in Figure 2.

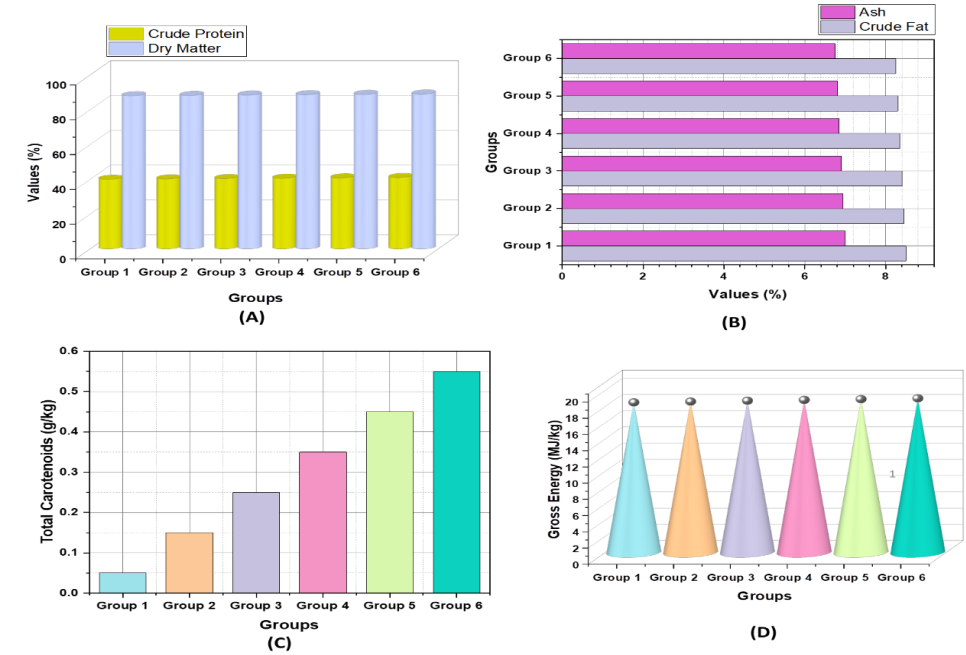

Figure 2. Nutrition composition includes (A) Crudse protein & dry matter, (B) Ash & crude fat, (C) Carotenoid, (D) Gross energy

Evaluation of Coloration, Carotenoid Levels, and Gene Expression in Goldfish

The research contains three major assay types. An assessment was made to report the color of the goldfish, sera carotenoids, and then the expression profile of the gene following exposure to turmeric extracts.

- **Coloration Assay:** The effect of supplementing TE on the pigmentation of fish was assessed by performing a coloration assay through observation and spectrophotometry. Fish from each group, including the control, and TE-treated, were monitored for altered in pigmentation, specifically in the head, abdominal, and tail portions. The intensity of the coloration was measured using standardized color charts or spectrophotometry to check significant alterations, especially in terms of carotenoid deposition. The assay proved to be a great importance for the visual improvement in the fish coloration by TE supplementation, especially in higher concentrations.
- **Serum Carotenoid Assay:** Carotenoids provide the goldfish with coloration, and this experiment was carried out to estimate the amount of carotenoids in the serum of the fish after 8 weeks of dietary supplementation. Blood samples were collected, and the carotenoid contents were estimated using high-performance liquid chromatography or High-Performance Liquid Chromatography (HPLC). The assay proved helpful in correlating the amount of TE supplement added with increased carotenoids, which peaked in the 4 g/kg TE group as an indicator that the supplement boosts pigmentation.
- **Gene Expression Assay (RT-PCR):** To investigate the molecular processes behind TE's immune-boosting and stress-resilience benefits, a reverse transcription polymerase chain reaction (RT-PCR) gene expression experiment was used. The expression of important genes linked to inflammation and immunity, such as lysozyme, an immunological marker; IL-10, an anti-inflammatory cytokine; and IL-1β, a pro-inflammatory cytokine, was assessed by extracting RNA from liver tissue samples taken from the fish. As a favorable indicator that a TE supplement did strengthen the immune system and reduce inflammatory reactions to stress, these demonstrated a positive response on lysozyme and IL-10 expressions and a decrease in IL-1β expressions, making fish more resilient. These assays altogether gave a detailed insight into how supplementation with TE could affect goldfish coloration, immune functions, and stress resistance; the beneficial effect of TE supplementation at higher concentration levels (2.5–4 g/kg) was indeed confirmed.

Data Analysis

All statistical analyses were performed using IBM SPSS software version29. Quadratic regression analysis made assumptions about non-linear associations, such as the effects of TE concentration on some biomarkers of stress, such as plasma glucose. Multivariate Analysis of Variance (MANOVA) testing considered whether supplementation of TEs to goldfish has multivariate impacts on several related outcomes, like immune status and serum biochemistry. These methods helped to reveal the general and specific effects of TE on the health of goldfish, thus assessing the best doses and response differences.

Results

Particularly at larger doses of TE, there were notable alterations in color parameters and carotenoid levels, indicating the impact of TE on goldfish development, color, and health. Hematological and biochemical improvements were noted, including Red Blood Cell (RBC) count increases and better lipid profiles. The research indicates that turmeric extract could be a good supplement for the health and pigmentation of goldfish.

Growth Performance and Feed Intake

Table 2 shows the growth performances and feed efficacies of TE-supplemented goldfish over eight weeks. On IBW the values ranged from 8.55 g up to 8.57g, while values on FBW ranged from 18.10 g up to 18.46 g but were not remarkably different ($p = 0.698$ $p = 0.732$). WG was in the range of 10.56 g to 10.91 g, and SGR was between 2.30% and 2.34%. Feed intake was constant at 38.50 g to 39.12 g, and FCR was between 4.16 and 4.22 with no significant difference ($p = 0.739$). The protein efficiency ratio (PER) scored from 1.63 to 1.70, while the percent protein value (PPV) scored between 26.32% and 27.67%, which did not show any significant effect.

Table 2. Feed efficiency and growth performance of goldfish fed graded TE levels

Attributes	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	MLR	MANOVA
GS								
Initial Body Weight (IBW) (g)	8.56 ± 0.01	8.57 ± 0.01	8.57 ± 0.01	8.55 ± 0.01	8.55 ± 0.01	8.56 ± 0.01	0.698	0.739
Final Body Weight (FBW) (g)	18.10 ± 0.27	18.17 ± 0.77	18.23 ± 0.54	18.46 ± 1.01	18.30 ± 0.65	18.35 ± 0.80	0.732	0.712
Weight Gain (WG) (g)	10.56 ± 0.27	10.60 ± 0.76	10.66 ± 0.54	10.91 ± 1.01	10.75 ± 0.67	10.79 ± 0.79	0.711	0.686
Specific Growth Rate (SGR) (%)	2.30 ± 0.03	2.30 ± 0.07	2.31 ± 0.05	2.33 ± 0.09	2.32 ± 0.06	2.34 ± 0.08	0.698	0.720
Survival Rate (%)	98.78 ± 3.85	101.00 ± 0.00	101.00 ± 0.00	98.78 ± 3.85	99.56 ± 2.34	100.23 ± 2.12	0.676	0.690
FU								
FCR	4.22 ± 0.04	4.19 ± 0.17	4.17 ± 0.12	4.16 ± 0.28	4.20 ± 0.25	4.18 ± 0.18	0.739	0.788
Dietary consumption (g/fish)	38.75 ± 0.78	38.50 ± 0.76	38.57 ± 0.54	39.11 ± 0.50	38.85 ± 0.66	39.12 ± 0.70	0.806	0.744
PER	1.63 ± 0.05	1.64 ± 0.06	1.66 ± 0.06	1.69 ± 0.03	1.68 ± 0.02	1.70 ± 0.02	0.708	0.762
Quantified TE Intake (g/fish)	8.00 ± 0.00	8.031 ± 0.001	8.061 ± 0.001	8.093 ± 0.002	8.120 ± 0.003	8.130 ± 0.004	N.D.	N.D.
PPV (%)	26.32 ± 1.65	27.10 ± 2.92	27.11 ± 1.49	27.67 ± 1.39	27.34 ± 1.55	27.52 ± 1.65	0.711	0.765

Note: Feed Utilization (FU), Growth and Survival, Feed Conversion Ratio (FCR), Percent Protein Value (PPV), Protein Efficiency Ratio (PER)

Analysis of Fish Coloration and Serum Carotenoid Level

The effects of supplementing goldfish with TE for up to 8 weeks on color parameters and total carotenoid concentrations. Redness (a*) was significantly increased at higher TE levels (Group 5 and Group 6) compared to the control (Group 1) with all p-values < 0.001. Changes in yellowness (b*) were found to be significant only in the abdominal region ($p = 0.001$), and changes in luminosity (L*) were less pronounced at $p = 0.144$. Total concentrations of carotenoids were significantly enhanced in the fin, muscle, skin, liver, and serum with higher TE levels, with strong significance ($p < 0.001$) shown in Table 3. The highest concentrations of carotenoids were seen in the skin, and in general, turmeric extract supplementation effectively enhanced both carotenoid accumulation and color intensity in goldfish.

Table 3. TE supplementation on color parameters and total carotenoids in goldfish

Attributes	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**	**MLR**	**MANOVA**
Lower Body Area								
Luminosity (L*)	72.15 ± 5.71	73.90 ± 5.64	71.47 ± 4.71	73.83 ± 5.51	78.40 ± 4.92*	80.05 ± 6.17*	0.065	0.502
Redness (a*)	70.97 ± 3.30	80.48 ± 1.59*	84.24 ± 4.05*	85.67 ± 2.66*	88.32 ± 3.28*	90.10 ± 2.89*	< 0.001	0.002
Yellowness (b*)	77.13 ± 4.05	88.22 ± 4.63*	81.84 ± 4.88	83.75 ± 3.46*	85.50 ± 5.35*	86.28 ± 4.74*	0.031	0.001
Posterior region								
Luminosity (L*)	77.29 ± 4.19	77.23 ± 6.12	74.20 ± 2.31	74.47 ± 3.14	79.01 ± 4.56*	81.87 ± 3.97*	0.058	0.675
Redness (a*)	72.66 ± 2.89	81.42 ± 3.26*	84.29 ± 5.08*	85.00 ± 2.22*	88.23 ± 2.75*	90.05 ± 3.47*	< 0.001	0.004
Yellowness (b*)	78.24 ± 3.31	79.70 ± 5.44	80.74 ± 2.95	81.51 ± 5.13	83.90 ± 4.83*	85.10 ± 5.12*	0.049	0.825
Anterior Region								
Luminosity (L*)	71.93 ± 3.54	75.56 ± 6.41*	77.83 ± 4.72	76.21 ± 3.81*	83.15 ± 5.23*	85.92 ± 4.56*	0.035	0.110
Redness (a*)	73.90 ± 2.68	83.37 ± 4.27*	83.73 ± 2.21*	86.59 ± 2.98*	92.25 ± 3.56*	95.45 ± 4.19*	< 0.001	0.001
Yellowness (b*)	76.03 ± 3.86	73.75 ± 4.96	77.55 ± 4.62	78.60 ± 3.44	82.05 ± 5.78	85.90 ± 4.13	0.071	0.256
Epidermal concentration (µg/g)	93.78 ± 11.52	187.66 ± 21.28*	169.07± 13.62*	193.03 ± 19.79*	210.40 ± 22.37*	220.24 ± 20.59*	< 0.001	0.002
Hepatic concentration (µg/g)	54.04 ± 3.44	73.93 ± 4.46*	97.89 ± 6.52*	104.05 ± 4.80*	115.31 ± 6.18*	120.60 ± 5.92*	< 0.001	0.005
Blood Serum Concentration (µg/mL)	11.15 ± 0.46	11.79 ± 0.19	11.75 ± 0.18	12.01 ± 0.18*	12.45 ± 0.16*	12.89 ± 0.15*	< 0.001	0.043

Lipid Profile Improvement and Hematological Analysis

Table 4 shows the blood parameters and chemical indicators obtained in goldfish given varied doses of turmeric extract (Group 1 to Group 6) after 8 weeks.

Table 4. Impact of dietary TE supplementation on carassius auratus

Attributes	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	MLR	MANOVA
Blood Parameters								
RBC ($\times 10^6$/µl)	1.05 ± 0.03	1.30 ± 0.08	1.40 ± 0.09	1.50 ± 0.11	1.60 ± 0.12	1.65 ± 0.13	0.001	0.003
WBC ($\times 10^4$/µl)	6.20 ± 0.60	7.10 ± 1.90	7.30 ± 1.50	7.80 ± 1.00	8.00 ± 1.20	8.20 ± 1.30	0.020	0.015
Hct (%)	31.00 ± 3.50	32.50 ± 2.40	33.50 ± 1.30	35.00 ± 0.70	36.30 ± 0.80	36.70 ± 0.90	0.045	0.050

Hb (g/dL)	8.50 ± 0.80	8.20 ± 0.90	8.40 ± 0.90	8.60 ± 0.70	8.80 ± 0.80	9.00 ± 0.85	0.085	0.090
Chemical Indicators								
Serum Globulin (g/dL)	1.54 ± 0.15	1.65 ± 0.09	1.87 ± 0.20	2.08 ± 0.00	2.20 ± 0.05	2.30 ± 0.05	0.007	0.005
AST (U/L)	11.00 ± 0.75	10.50 ± 1.00	11.30 ± 1.00	12.50 ± 1.30	12.80 ± 1.20	13.00 ± 1.30	0.095	0.080
Total Protein (g/dL)	2.15 ± 0.20	2.25 ± 0.13	2.50 ± 0.17	2.70 ± 0.20	2.90 ± 0.22	3.05 ± 0.23	0.003	0.002
ALT (U/L)	44.00 ± 1.20	41.00 ± 3.90	42.00 ± 0.68	40.50 ± 1.90	40.00 ± 2.00	39.50 ± 2.10	0.060	0.055
Serum Albumin (g/dL)	0.54 ± 0.04	0.56 ± 0.03	0.62 ± 0.02	0.75 ± 0.02	0.80 ± 0.03	0.85 ± 0.03	0.012	0.018
ALP (U/L)	36.50 ± 0.78	37.00 ± 1.90	37.50 ± 1.25	39.00 ± 0.60	39.80 ± 0.65	40.50 ± 0.70	0.040	0.035
Total Cholesterol (mg/dL)	115.00 ± 3.40	100.00 ± 3.70	107.00 ± 3.50	106.50 ± 4.20	105.00 ± 4.00	103.00 ± 4.10	0.014	0.010
Triglycerides (mg/dL)	235.00 ± 3.40	237.00 ± 6.00	220.00 ± 3.40	231.00 ± 1.40	228.00 ± 1.50	223.00 ± 1.60	0.070	0.065
HDL-c (mg/dL)	35.00 ± 0.70	38.00 ± 0.60	39.50 ± 0.70	38.50 ± 0.13	38.80 ± 0.14	39.00 ± 0.15	0.018	0.012
LDL-c (mg/dL)	125.00 ± 10.50	110.00 ± 8.00	105.00 ± 4.60	100.00 ± 3.30	95.00 ± 3.20	90.00 ± 3.00	0.005	0.004

The significant improvements in various hematological, biochemical, and lipid parameters in fish with increasing concentrations of turmeric extract. The RBC count rose from $1.05 \pm 0.03 \times 10^6$/µl (Group 1) to $1.65 \pm 0.13 \times 10^6$/µl (Group 6) ($p = 0.001$), indicating enhanced oxygen transport, while the WBC count increased from $6.20 \pm 0.60 \times 10^4$/µl to $8.20 \pm 1.30 \times 10^4$/µl ($p = 0.020$), reflecting a stronger immune response. Hematocrit levels improved from 31.00 ± 3.50% to 36.70 ± 0.90% ($p = 0.045$), and hemoglobin rose slightly from 8.50 ± 0.80 g/dL to 9.00 ± 0.85 g/dL ($p = 0.085$). Biochemically, total protein increased from 2.15 ± 0.20 g/dL to 3.05 ± 0.23 g/dL ($p = 0.003$), albumin from 0.52 ± 0.04 g/dL to 0.85 ± 0.03 g/dL ($p = 0.012$), and globulin from 1.53 ± 0.15 g/dL to 2.30 ± 0.05 g/dL ($p = 0.007$), indicating improved health and immunity. Liver enzymes showed slight increases: AST from 11.00 ± 0.75 U/L to 13.00 ± 1.30 U/L ($p = 0.095$), ALT from 44.00 ± 1.20 U/L to 39.50 ± 2.10 U/L ($p = 0.060$), and ALP from 36.50 ± 0.78 U/L to 40.50 ± 0.70 U/L ($p = 0.040$), suggesting mild liver activity stimulation. The lipid profile showed reduced total cholesterol from 115.00 ± 3.40 mg/dL to 103.00 ± 4.10 mg/dL ($p = 0.014$), a slight drop in triglycerides from 235.00 ± 3.40 mg/dL to 223.00 ± 1.60 mg/dL ($p = 0.070$), increased HDL-c from 35.00 ± 0.70 mg/dL to 39.00 ± 0.15 mg/dL ($p = 0.018$), and a significant decrease in LDL-c from 125.00 ± 10.50 mg/dL to 90.00 ± 3.00 mg/dL ($p = 0.005$), indicating better lipid metabolism and cardiovascular health.

Glucose and Cortisol Levels in Goldfish Fed Turmeric Extract

Table 5 indicates the glucose level in the goldfish increased with all the groups supplemented with a higher concentration of curcumin extract. Starting from 43.50 ± 0.70 mmol/dL in Group1, glucose levels shoot up dramatically to 57.00 ± 4.00 mmol/dL in Group 6, Asterisks (*) are used to show significant differences with Group 1; quadratic regression and MANOVA results show a statistically significant change. An increase in the level of cortisol has been recorded from 15.50 ± 0.71 mg/mL (Group 1) to 18.00 ± 0.90 mg/mL (Group 6). The increase can imply a stress response or possibly another physiological variation triggered by the curcumin

extract. P-values for quadratic regression at 0.087 and MANOVA at 0.001 have further reinforced significant changes in the cortisol level.

Table 5. Glucose and plasma cortisol levels in goldfish fed varying amounts of turmeric extract

Attributes	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	MLR	MANOVA
Serum cortisol concentration (mg/mL)	15.53± 0.71	16.06± 0.80 *	16.55± 0.60 *	17.00 ± 0.70 *	17.50 ± 0.80 *	18.00 ± 0.90 *	0.087	0.001
Blood glucose concentration (mmol/dL)	45.50 ± 0.70	46.00 ± 5.00	52.00 ± 2.00 *	52.00 ± 3.00 *	55.00 ± 4.50 *	57.00 ± 4.00 *	0.047	0.015

Discussion

The investigation focuses on the positive attributes associated with turmeric extract supplementation to the goldfish, such as growth, color intensification, and enhancement of the immune system. Although growth parameters like weight gain and specific growth rate were relatively unaffected by TE supplementation, there were some significant improvements regarding color intensity, as the higher TE levels resulted in intensifications of redness and yellowness in different body regions. Carotenoid levels in skin, muscle, and liver also increased and could also imply a positive role of turmeric extract in pigmentation as well as boosting the antioxidant levels. Hematological and biochemical investigation revealed an improvement in red blood cell count, immune cell levels, and protein markers indicating general health. Turmeric extract also positively affected the lipid profiles by lowering cholesterol and Low-Density Lipoprotein (LDL) with increased levels of High-Density Lipoprotein (HDL). However, cortisol was increased with TE supplementation, possibly as a result of stress, and glucose also increased with greater doses of TE, indicating that there can have some change in metabolism. In overall, results indicate the use of turmeric extract to increase goldfish health, color, immune ability, and Fisheries biology.

Conclusion

Research indicated to be potential for fish health enhancement, pigmentation, and improvement of immune responses in goldfish, with better general welfare. Stress resilience and metabolic functions can be enhanced through and promise many aquaculture-friendly advantages. Coloration improved and increased the level of carotenoids by the supplementation of the goldfish diet with turmeric extract; improvements in hematological and biochemical parameters like RBC count and lipid profiles were also observed, without a decrease in growth performance or feed efficiency. In summary, turmeric extract showed potential health benefits in goldfish related to health, pigmentation, and immune functions. The limitation of the present research is a short experimental duration and the research focused on a single fish species. Future research studies should investigate long-term effects, diverse aquatic species, and optimal dosages of turmeric extract. The molecular mechanisms behind observed health benefits should be studied.

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