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Impact of Phytogenic Feed Additives on Growth Performance, Antioxidant Defense, and Serum Biochemical Indices in *Cirrhinus mrigala*

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Abstract

This study investigated the effects of dietary supplementation with *Moringa oleifera*, *Allium sativum*, *Zingiber officinale*, and *Curcuma longa* powders (each at 2% inclusion) on *Cirrhinus mrigala* over a 60-day feeding trial on growth, antioxidant status, and serum biochemistry. A total of 270 juvenile fish (15.8 ± 0.12 g) were distributed into five groups (control and four treatments) in triplicate. Growth performance, antioxidant enzyme activities (Superoxide dismutase; SOD, Catalase; CAT, and Malondialdehyde; MDA), serum biochemical parameters (Total protein, albumin, globulin), and hepatic enzyme activities (Alanine aminotransferase; ALT, and Aspartate aminotransferase; AST) were measured. Turmeric (T4) and garlic (T2) significantly improved growth performance, with T4 exhibiting the highest weight gain and best feed conversion ratio. Both T4 and T2 markedly increased SOD and CAT activities while reducing MDA levels. Serum analysis revealed improved hepatic health. These results demonstrate the potential of turmeric and garlic as sustainable phytogenic additives for improving productivity, oxidative resilience, and health in *C. mrigala* aquaculture, providing viable alternatives to synthetic growth promoters.

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1. Introduction

The aquaculture sector has become a cornerstone of global food security, approximately 52% of all fish destined for human consumption worldwide, and is driven largely by the increasing protein demands from a growing population[1-3]. However, the aquaculture systems face persistent challenges, including physiological stress, suboptimal growth performance among farmed species, and disease outbreaks. Moreover, these issues are particularly marked in intensive culture systems where high stocking densities and suboptimal water quality can compromise fish health and productivity[4,5]. Subsequently, it is necessary to grow sustainable nutritional strategies for growth performance while simultaneously supporting immune function and stress resilience in aquaculture species [6,7]. Among bioactive compounds derived from medicinal plants and spices, phytogenic feed additives are among the most promising alternatives to conventional growth promoters and antibiotics [8,9]. These additives offer multiple benefits, including growth promotion, immunomodulation, antioxidant activity, and antimicrobial properties[10,11]. Prominently, phytogenics offer a sustainable solution to the aquaculture challenges, as they are ecological, environmentally friendly, and pose minimal risk of inducing antimicrobial resistance [12, 13]. Their bioactivity is attributed to synergistic effects of alkaloids, flavonoids, polyphenols, and essential oils, which collectively improve nutrient utilization, gut health, and disease resistance in aquatic organisms [14, 15].

Cirrhinus mrigala belongs to the Cyprinidae family and is one of the most economically vital freshwater aquaculture species in South and Southeast Asia due to its fast growth rate, *high consumer demand* and adaptability to diverse environmental conditions[16,17]. Nonetheless, such as immunosuppression, metabolic disorders and oxidative damage due to intensive farming practices of *C. mrigala*, which collectively impair growth and survival rates[18,19]. To lessen these issues, the Traditional approaches, such as prophylactic use of antibiotics, have been lessened due to their association with antibiotic resistance genes and ecological disruption[20]. Therefore, it is important to study functional feed ingredients capable of enhancing productivity without compromising environmental or consumer safety [21, 22].

Moringa oleifera leaf powder comprises considerable amounts of ascorbic acid, phenolic compounds, and carotenoids that have been shown to enhance innate immunity and growth performance in various fish species[23,24]. Similarly, the Garlic (*Allium sativum*) is also full of organosulfur compounds, chiefly allicin and diallyl disulfide, which exhibit potent immunostimulatory and hepatoprotective effects in aquatic organisms [25,26]. *Zingiber officinale* (ginger) also has important properties that improve feed palatability, digestive enzyme activity, and resistance to bacterial pathogens due to the presence of bioactive gingerols and shogaols [27,28]. Perhaps most notably, *Curcuma longa* (turmeric), due to its principal bioactive component curcumin, has established extraordinary growth-promoting properties, antioxidant, and anti-inflammatory in various aquatic species [29, 30]. Due to their promising findings, however, some gaps persist regarding the comparative efficacy of these phytogenics in *C. mrigala* nutrition. Furthermore, existing studies have investigated these additives in isolation, with limited investigation into their potential synergistic or antagonistic interactions when combined in feed formulations[22]. The physiological mechanisms through which these compounds influence growth parameters, antioxidant defense systems, and humoral immune responses in *C. mrigala* remain incompletely understood[31]. Therefore, the present study was designed to comprehensively evaluate the effects of dietary supplementation with *M. oleifera*, *A. sativum*, *Z. officinale*, and *C. longa* powders (each at 2% inclusion level) in *C. mrigala*. Specifically, the study investigated growth performance, antioxidant enzyme activities, and biochemical parameters.

2. Materials and Methods

This study was conducted at the Saline Water Aquaculture Research Centre (SWARC), Muzaffargarh, to investigate the effects of dietary supplementation with Moringa (*M. oleifera*), Garlic (*A. sativum*), Ginger (*Z. officinale*), and Turmeric (*C. longa*) powders on *Cirrhinus mrigala*.

2.1 Experimental Design and Fish Rearing Conditions

A total of 270 healthy juvenile fish, average body weight was 15.8 ± 0.12 g, were obtained from the SWARC Fish Hatchery, Muzaffargarh and distributed into five groups (four treatment groups and one control) in triplicate. Before the start of the feeding trial, *C. mrigala* were acclimated for 15 days in fiberglass tanks. Each tank was fitted with an aeration system to maintain optimal dissolved oxygen levels. Aeration was provided using diaphragm air pumps (Hailea® V-60, China), which were connected to flexible 8 mm PVC airline tubing. These lines supplied air to cylindrical diffusers (Boyur AS-02, China) positioned evenly at the base of each tank, ensuring uniform oxygen distribution and gentle water movement. This setup promoted consistent water quality and reduced stress during the acclimation phase. Throughout this period, fish were manually fed twice daily using a commercial diet formulated with 32% crude protein at a feeding rate equivalent to 3% of their body mass[32]. Only fish exhibiting normal activity, bright red gills, intact fins, consistent coloration, and strong feeding responses were selected for the experimental trial.

The five groups in triplicate were designed, consisting of a control group (T0, no plant additive) and four dietary treatments: T1 (2% Moringa), T2 (2% Garlic), T3 (2% Ginger), and T4 (2% Turmeric). Fish were randomly stocked into fifteen fiberglass tanks at a density of 18 individuals per tank. Water quality was maintained throughout the 60-day experiment. Temperature was kept within 28–30°C using thermostatically controlled submersible heaters (Inkbird ITC-308, China), while dissolved oxygen remained above 5.8 mg/L. The pH was adjusted and maintained between 7.4 and 7.8 using food-grade sodium bicarbonate, and total ammonia levels were kept below 0.1 mg/L through partial daily water exchange (30%). All parameters were monitored three times daily using a multiparameter meter (Hanna Instruments, Model HI98194)[32,33].

This study involved the formulation of five isonitrogenous experimental diets, each containing 32% crude protein. All four phytogenic ingredients were incorporated at a fixed inclusion rate of 2% (20 g/kg) into a standard basal feed, while the control group (T0) received the same base diet without any additive supplementation. The primary composition of the basal diet included high-quality protein sources such as fish meal and soybean meal, along with cottonseed cake, maize germ, wheat pollard, and soybean oil. A vitamin-mineral premix was also added to ensure that all essential micronutrient requirements were met. To balance the inclusion of the plant additives and maintain a consistent total weight of 950 g/kg, slight adjustments were made to the wheat bran content across the supplemented diets. The exact ingredient proportions for each diet group are presented in Table 1. All ingredients were carefully weighed and mixed using a mechanical blender to achieve uniform distribution. Purified water heated to approximately 35°C was added gradually to obtain a smooth, workable dough suitable for extrusion. The feed mixture was then processed into 2 mm pellets using a pelleting machine. Once formed, the pellets were spread evenly and allowed to dry under ambient conditions at 28°C for 48 hours. Dried pellets were sealed in airtight polyethylene bags and stored at –20°C to retain their nutritional integrity and prevent spoilage over the duration of the feeding trial.

Table 1. Ingredient composition (g/kg) of experimental diets supplemented with Moringa, Garlic, Ginger, and Turmeric powders (2% inclusion level)

Ingredients	T0	T1: Moringa	T2: Garlic	T3: Ginger	T4: Turmeric
Fish meal	190	190	190	190	190
Soybean meal	80	80	80	80	80
Cottonseed cake	110	110	110	110	110
Wheat bran	310	290	290	290	290
Wheat pollard	130	130	130	130	130
Maize germ	100	100	100	100	100
Soybean oil	18	18	18	18	18
Vitamin-mineral premix*	12	12	12	12	12
Moringa leaf powder		20			
Garlic powder			20		
Ginger powder				20	
Turmeric powder					20
Total	950	968	968	968	968

*Note. The vitamin-mineral premix was incorporated at a level of 12 g per kg of diet. Each kilogram of feed formulated with this premix supplied the following nutrients: Vitamin A – 7200 IU, Vitamin D_3 – 1600 IU, Vitamin E – 200 IU, Vitamin C – 90 mg, Thiamine (B_1) – 1.5 mg, Riboflavin (B_2) – 10 mg, Pyridoxine (B_6) – 8 mg, Cyanocobalamin (B_{12}) – 0.02 mg, Niacin – 55 mg, Pantothenic acid – 40 mg, Folic acid – 0.08 mg, Biotin – 1.8 mg, Copper – 6 mg, Iron – 110 mg, Zinc – 30 mg, Manganese – 18 mg, Iodine – 0.6 mg, Selenium – 0.2 mg, and Cobalt – 0.12 mg.

2.2 Assessment of Growth Performance

At the end study trial, all the fish in the groups were fasted for 24 hours, netted, then anesthetized with clove oil (50 mg/L), and separately weighed to determine final body weight. The following growth indices were calculated using standard formulas[34,35].

Weight Gain (WG, g) = Final body weight – Initial body weight
Specific Growth Rate (SGR, %/day) = (ln Final weight–ln Initial weight)/Number of days × 100
Feed Intake (FI, g/fish) = Total feed consumed / Number of fish
Feed Conversion Ratio (FCR) = Total feed intake (g) / Total weight gain (g)
Protein Efficiency Ratio (PER) = Weight gain (g) / Protein intake (g)
Condition Factor (CF) = (Final body weight / Final body length^3) × 100
Survival Rate (SR, %) = (Final number of fish / Initial number of fish) × 100
Average Daily Gain (ADG, g/day) = Weight gain (g) / Duration (days).
Body Weight Increase (BWI, %) = (Final weight–Initial weight)/Initial weight × 100.

2.3 Serum Biochemical Parameters

After growth measurements, the blood samples were collected from the caudal vein of anesthetized *C. mrigala* (using clove oil at 50 mg/L) using 2 mL sterile syringes and put in a gel tube. The blood was allowed to clot at room temperature for 30 minutes and then centrifuged at 3500 rpm for 10 minutes to separate the serum. The clear supernatant was carefully extracted and stored at −20°C until biochemical analysis. The total protein (TP) concentration in serum was quantified using the biuret method, which is based on the formation of a violet-colored complex between peptide bonds and copper ions in an alkaline medium. Absorbance was measured at 540 nm using a UV-Vis spectrophotometer. Albumin levels were estimated via the bromocresol green (BCG) dye-binding method, with readings recorded at 630 nm. Globulin concentration was calculated by subtracting albumin from total protein values:

Globulin (g/dL) = Total protein – Albumin.

Alanine aminotransferase (ALT) and Aspartate aminotransferase (AST) activities were determined using commercially available kinetic enzyme assay kits (Sigma Aldrich, Pakistan), which measure the rate of NADH oxidation linked to transamination reactions. ALT and AST absorbances were recorded at 340 nm, and enzyme activity was expressed in units per litre (U/L)[36-38].

2.4 Antioxidant Enzyme Activities

Antioxidant responses in *C. mrigala* were evaluated by analyzing enzymatic markers from blood samples collected post-sedation. Superoxide dismutase (SOD) activity was determined by quantifying the inhibition of pyrogallol auto-oxidation, measured spectrophotometrically at 560 nm. Catalase (CAT) activity was assessed by tracking the rate of hydrogen peroxide decomposition, with absorbance recorded at 240 nm. Lipid peroxidation, as an indicator of oxidative stress, was estimated through malondialdehyde (MDA) levels using the thiobarbituric acid reactive substances (TBARS) assay, with readings taken at 532 nm. All enzymatic activities were normalized to the total protein content of each sample, which was determined using the Bradford method at 595 nm[39-42].

2.5 Statistical Analysis

The data obtained were statistically analyzed using the One-way Analysis of Variance (ANOVA) technique, and the means and standard error of mean were compared using multiple comparisons, comparing the mean of each group with the mean of all other groups by using the Multiple comparisons Test Tukey's HSD post-hoc tests (SPSS v26.0)[73].

3. Results

The effects of dietary supplementation with *M. oleifera*, *A. sativum*, *Z. officinale*, and *C. longa* powders on the growth performance of *C. mrigala* are presented in Table 2. All treatment groups showed significant improvements in growth compared to the control group (T0), with the turmeric-fed group (T4) consistently showing the best performance. Weight gain (WG) was significantly higher in T4 (19.4 ± 0.7 g) than in T0 (13.2 ± 0.4 g) and the ginger group (T3; 16.2 ± 0.6 g) ($p = 0.006$).

Similarly, the SGR followed the same trend ($p = 0.004$), with T4 (1.72 ± 0.03%/day) significantly higher than the control (1.13 ± 0.05%/day) and ginger group (1.46 ± 0.07%/day). FCR was significantly reduced ($p = 0.007$) in the treated groups as compared to the control. On the other hand, FI also varied significantly among treatments ($p = 0.006$). T4 (27.3 ± 0.6 g) and T1 (28.2 ± 0.4 g) consumed more feed than the control (25.7 ± 0.7 g). However, the PER followed a similar pattern ($p = 0.004$), with T4 achieving the highest value (2.04 ± 0.06), significantly better than T0 (1.44 ± 0.05). Condition factor (CF) was significantly affected, with higher values in T2 (1.23 ± 0.05) and T4 (1.23 ± 0.04) compared to T0 (1.02 ± 0.03).
Furthermore, the percentage of SR improved significantly across treatments ($p = 0.005$), ranging from 90.2 ± 2.3% in T0 to 97.4 ± 1.6% in T4. Similarly, the ADG and BWI were markedly higher in the supplemented groups ($p = 0.005$ for both).

Table 2. Growth performance of *C. mrigala* fed diets supplemented with Moringa, Garlic, Ginger, and Turmeric powders for 60 days.

Growth Parameter	T0: Control	T1: Moringa	T2: Garlic	T3: Ginger	T4: Turmeric	p-value
WG (g)	13.2 ± 0.4^{d}	17.7 ± 0.6^{b}	18.5 ± 0.7^{ab}	16.2± 0.6^{c}	19.4± 0.7^{a}	0.006
SGR (%/day)	1.13±0.05^{d}	1.49± 0.04^{b}	1.62±0.06^{ab}	1.46 ± 0.07^{c}	1.72±0.03^{a}	0.004
FCR	1.8 ± 0.06^{a}	1.62 ± 0.04^{c}	1.49± 0.05^{c}	1.71±0.05^{bc}	1.51±0.02^{c}	0.007
FI (g/fish)	25.7 ± 0.7^{c}	28.2 ± 0.4^{b}	26.5 ± 0.3^{b}	26.2± 0.6^{bc}	27.3 ± 0.6^{a}	0.006
PER	1.44±0.05^{d}	1.82 ±0.04^{b}	1.91±0.04^{ab}	1.77± 0.03^{c}	2.04±0.06^{a}	0.004
CF	1.02±0.03^{c}	1.17±0.05^{ab}	1.23 ± 0.05^{a}	1.18± 0.06^{b}	1.23±0.04^{a}	0.004
SR (%)	90.2 ± 2.3^{c}	97.2 ± 1.4^{b}	96.3± 1.3^{bc}	95.3 ± 1.3^{c}	97.4± 1.6^{a}	0.005
ADG (g/day)	0.22±0.02^{d}	0.27± 0.02^{b}	0.29±0.03^{ab}	0.27 ± 0.04^{c}	0.31±0.04^{a}	0.005
BWI (%)	67.8 ± 2.4^{c}	88.3 ± 2.4^{b}	91.3 ± 2.6^{ab}	84.4± 2.7^{c}	95.7 ± 2.5^{a}	0.005

Note: WG = Weight Gain (g); SGR = Specific Growth Rate (%/day); FCR = Feed Conversion Ratio; FI = Feed Intake (g/fish); PER = Protein Efficiency Ratio; CF = Condition Factor; SR = Survival Rate (%); ADG = Average Daily Gain (g/day); BWI = Body Weight Increase (%).

The serum antioxidant enzyme activities and lipid peroxidation levels of *C. mrigala* were significantly influenced by the dietary inclusion of phytogenic additive (Table 3). The serum SOD activity varied significantly among groups ($p = 0.006$). The T0 group recorded the lowest SOD level at 5.4 ± 0.3 U/mg, whereas the highest values were observed in T4 (turmeric-fed group) at 7.5 ± 0.6 U/mg, followed by T2 (garlic) at 7.3 ± 0.3 U/mg. Similarly, catalase (CAT) activity. Fish in the control group revealed the lowest CAT value of 2.5 ± 0.2 U/mg, while the highest was observed in T4 at 4.7 ± 0.3 U/mg, followed closely by T2 (4.2 ± 0.4 U/mg).

However, the serum MDA was significantly decreased in the supplemented groups compared to the control (p = 0.005). The highest MDA level was recorded in the control group (4.4 ± 0.5 nmol/mg), In contrast, the lowest levels were found in T4 and T2, at 2.3 ± 0.5 nmol/mg and 2.4 ± 0.3 nmol/mg, respectively.

Table 3. Serum antioxidant enzyme activities in *C. mrigala* fed experimental diets containing plant-based additives.

Antioxidant enzyme	T0: Control	T1: Moringa	T2: Garlic	T3: Ginger	T4: Turmeric	p-value
SOD (U/mg)	5.4 ± 0.3^{d}	6.3 ± 0.5^{b}	7.3± 0.3^{ab}	6.5 ± 0.4^{c}	7.5± 0.6^{a}	0.006
CAT (U/mg)	2.5± 0.2^{c}	3.7± 0.3^{b}	4.2± 0.4^{ab}	3.2± 0.6^{c}	4.7± 0.3^{a}	0.006
MDA (nmol/mg)	4.4± 0.5^{a}	3.1± 0.4^{c}	2.4± 0.3^{c}	3.6 ± 0.3^{bc}	2.3 ± 0.5^{c}	0.005

Biochemical profile of *C. mrigala* was significantly changed by dietary supplementation with photogenic powders, as evident from variations in total protein, albumin, globulin, and hepatic enzymes (ALT and AST) (Table 4). The serum TP levels varied significantly among the experimental groups (p = 0.007). The control group (T0) recorded the lowest TP at 3.6 ± 0.3 g/dL, while the turmeric group (T4) and garlic group (T2) had significantly higher values of 4.5 ± 0.6 g/dL and 4.6 ± 0.4 g/dL, respectively. Serum albumin levels also showed significant differences (p = 0.006), with the highest value observed in T4 (1.9 ± 0.2 g/dL). Serum globulin was significantly increased in T2 and T4 (p = 0.005). The garlic group (T2) recorded the highest value at 2.8 ± 0.3 g/dL, followed by turmeric (2.6 ± 0.3 g/dL), both significantly higher than the control (2.4 ± 0.1 g/dL, ^{c}) and Moringa group (2.2 ± 0.2 g/dL). On the other hand, the highest ALT level was observed at T0, at 43 ± 0.2 U/L, while the lowest was recorded at T4, at 33 ± 0.2 U/L. Garlic-fed fish (T2) also showed a significantly lower ALT level (36 ± 0.2 U/L). However, the control group showed the highest AST activity (87 ± 0.4 U/L), while T4 (74 ± 0.3 U/L) and T2 (77 ± 0.2 U/L).

Table 4. Serum biochemical parameters of *Cirrhinus mrigala* following dietary supplementation with Moringa, Garlic, Ginger, and Turmeric powders.

Biochemical Parameter	T0: Control	T1: Moringa	T2: Garlic	T3: Ginger	T4: Turmeric	p-value
Total Protein (g/dL)	3.6±0.3^{c}	4.1± 0.5^{b}	4.6± 0.4^{ab}	4.2± 0.5^{bc}	4.5± 0.6^{a}	0.007
Albumin (g/dL)	1.4±0.3^{c}	1.3± 0.2^{b}	1.5± 0.2^{ab}	1.3± 0.6^{bc}	1.9 ± 0.2^{a}	0.006
Globulin (g/dL)	2.4±0.1^{c}	2.2± 0.2^{b}	2.8± 0.3^{ab}	2.4± 0.3^{bc}	2.6± 0.3^{a}	0.005
ALT (U/L)	43±0.2^{a}	39± 0.2^{b}	36± 0.2^{bc}	40± 0.3^{b}	33 ± 0.2^{c}	0.008
AST (U/L)	87±0.4^{a}	81 ± 0.3^{b}	77± 0.2^{c}	83 ± 0.3^{b}	74±0. 3^{c}	0.004

4. Discussion

The idea of the current research not only supports previous findings on phytogenic feed additives but also provides novel comparative data on four botanicals that have not been thoroughly assessed in this economically important species [43,19]. The present study shows a marked enhancement in weight gain (WG) in the turmeric-supplemented. Similarly, [44] and [45] conducted a study on phytogenic applications in cyprinids and found significant improvements in growth performance. Giri et al [46] also studied plant additives and found enhancements in the growth performance, such as improvement in the FCR. Furthermore, explained that growth enhancement is multifactorial and strongly linked to improved nutrient utilization efficiency. Hossain et al [47] and Tunçelli and Memiş [48] also recorded the elevated FI and improved FCR with the plant additives. [49] and [50] examined the bioactivity of *C. longa* in turmeric-fed fish, improvements in WG and SGR, supporting earlier reports that curcumin..., the principal bioactive in *C. longa*, improves digestive efficiency through the stimulating bile secretion and digestive enzymes. Notably, in the current study, the WG recorded not only corroborates but exceeds earlier reports documenting 20–35% WG in cyprinids using plant-derived additives [51, 52]. The present study revealed that due to higher concentrations of defined bioactive compounds of turmeric and garlic over moringa and ginger due to higher concentrations of defined bioactive compounds, which also aligns with the outcomes of [53].[54,55] Improved SR is also aligned with the current study, which reports that curcumin and allicin exhibit broad-spectrum antimicrobial activity against major aquaculture pathogens, including *Aeromonas hydrophila*. [56,57] recorded improved PER with the Garlic supplementation, which also aligns with the current study, indicating improved protein efficiency ratio with the garlic supplementation.

Garlic supplementation showed significantly higher SOD and CAT activities with reduced MDA. Similarly, [58,59] also recorded higher antioxidant activity and observed the hepatoprotective potential of allicin and other sulfur-containing compounds present in garlic. [60,61] concluded that both curcumin and allicin exert their effects through modulation of the nuclear factor erythroid 2–related factor 2–Antioxidant Response Element signaling pathway, upregulating antioxidant genes and scavenging free radicals. The notable decreases in serum ALT and AST levels, the hepatoprotective efficacy of turmeric and garlic, which reveal liver dysfunction and tissue damage similar to studies on *Catla catla* [62,63]. The lessening in hepatic enzymes ALT and AST provides direct evidence of improved liver health, corroborating histological findings from similar studies in *C. catla* [64,65].

This is further supported by raised total protein and albumin concentrations, suggesting improved liver biosynthetic function and better nutritional status in fish with the plant.

Additives [66,67]. Immunologically, the increase in serum globulin levels indicates strengthened humoral immune responses due to the activation of innate immune receptors and cytokine cascades, as seen in recent studies where garlic and turmeric enhanced lysozyme activity in tilapia and carp species [68,69]. Serum biochemical markers provided improved physiological status with the increased 25% total protein and 35.7% higher albumin concentrations, enhanced hepatic synthetic function, consistent with curcumin's documented hepatoprotective similar to studies of *labeo rohita* [71]. The significant globulin advancement indicates robust immunostimulation, as demonstrated in recent immunological studies of phytogenics in *Oreochromis niloticus* [72].

5. Conclusion

This study confirms that supplementing *C. mrigala* diets with 2% turmeric or garlic significantly enhances growth performance, antioxidant status, and metabolic health. Turmeric showed the strongest effects, while garlic enhanced immunity and reduced oxidative stress. Although Moringa and ginger also contributed positively, their effects were comparatively modest. The improved liver function and immune markers support using these phytogenics as sustainable alternatives to synthetic additives. Future work should refine optimal doses and assess long-term farming applications. These findings highlight turmeric and garlic as practical, eco-friendly options for enhancing *C. mrigala* aquaculture productivity.

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7. Author Contributions

M.O., H.A.Z., N.1. and M.N. contributed to the concept and design of the work. E.Z., and A.H. were responsible for the statistical analysis and understanding of data. M.O., B.A.A. drafted the manuscript. All authors reviewed and approved the final version of the manuscript and agreed to be responsible for all aspects of the work.

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9. Consent for publication

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11. References

[1] J. A. Gephart, C. D. Golden, F. Asche, B. Belton, C. Brugere, H. E. Froehlich, and E. H. Allison, “Scenarios for global aquaculture and its role in human nutrition,” Rev. Fish. Sci. Aquac., vol. 29, no. 1, pp. 122–138, 2020. http://dx.doi.org/10.1080/23308249.2020.1782342

[2] G. S. Araujo, J. W. A. D. Silva, J. Cotas, and L. Pereira, “Fish farming techniques: current situation and trends,” J. Mar. Sci. Eng., vol. 10, no. 11, p. 1598, 2022. http://dx.doi.org/10.3390/jmse10111598

[3] S. J. Kargbo, N. Barzkar, D. Y. Cole, K. D. Kamara, A. Soratur, R. Othman, ... and B. A. V. Maran, “A comprehensive overview of the current fisheries status in Sierra Leone,” Afr. J. Biol. Sci., vol. 6, no. 6, pp. 8028–8056, 2024. http://dx.doi.org/10.33472/AFJBS.6.6.2024.8028-8056

[4] M. Mugwanya, M. A. Dawood, F. Kimera, and H. Sewilam, “A review on recirculating aquaculture system: Influence of stocking density on fish and crustacean behavior, growth performance, and immunity,” Ann. Anim. Sci., vol. 22, p. 873, 2022. http://dx.doi.org/10.2478/aoas-2022-0014

[5] D. Roy, P. K. Saha, S. Sarker, M. A. Parves, A. P. Zavyalov, and G. A. Latifa, “Culture practice of Oreochromis niloticus through recirculating aquaculture system (RAS): a modern and growth-optimized approach of fish culture by maintaining water quality with proper fish stocking density in Bangladesh,” Environ. Sci. Pollut. Res., vol. 32, no. 18, pp. 11749–11766, 2025. http://dx.doi.org/10.1007/s11356-025-36386-4

[6] A. Gupta, S. K. Gupta, M. Priyam, M. A. Siddik, N. Kumar, P. K. Mishra, ... and A. Pattanayak, “Immunomodulation by dietary supplements: A preventive health strategy for sustainable aquaculture of tropical freshwater fish, Labeo rohita (Hamilton, 1822),” Rev. Aquac., vol. 13, no. 4, pp. 2364–2394, 2021. http://dx.doi.org/10.1111/raq.12581

[7] N. K. Yadav, A. B. Patel, S. K. Singh, N. K. Mehta, V. Anand, J. Lal, and N. C. Devi, "Climate change effects on aquaculture production and its sustainable management through climate-resilient adaptation strategies: a review," Environ. Sci. Pollut. Res., vol. 31, no. 22, pp. 31731–31751, 2024. http://dx.doi.org/10.1007/s11356-024-33397-5

[8] S. Biswas, J. M. Ahn, and I. H. Kim, "Assessing the potential of phytogenic feed additives: A comprehensive review on their effectiveness as a potent dietary enhancement for nonruminant in swine and poultry," J. Anim. Physiol. Anim. Nutr., vol. 108, no. 3, pp. 711–723, 2024. http://dx.doi.org/10.1111/jpn.13922

[9] M. Madesh, J. Yan, G. Jinan, P. Hu, I. H. Kim, H. Y. Liu, ... and D. Cai, "Phytogenics in swine nutrition and their effects on growth performance, nutrient utilization, gut health, and meat quality: a review," Stress Biol., vol. 5, no. 1, p. 11, 2025. http://dx.doi.org/10.1007/s44154-024-00209-2

[10] U. E. Obianwuna, X. Chang, V. U. Oleforuh-Okoleh, P. N. Onu, H. Zhang, K. Qiu, and S. Wu, "Phytobiotics in poultry: revolutionizing broiler chicken nutrition with plant-derived gut health enhancers," J. Anim. Sci. Biotechnol., vol. 15, no. 1, p. 169, 2024. http://dx.doi.org/10.1186/s40104-024-01101-9

[11] F. K. Amevor, V. A. Uyanga, L. Wu, D. Xu, G. Shu, Y. Wang, and X. Zhao, "Enhancing poultry health and productivity through the liver-gut axis with integrated nutritional and immunological approaches: a mini-review," Front. Physiol., vol. 16, p. 1537099, 2025. http://dx.doi.org/10.3389/fphys.2025.1537099

[12] Z. Sajid, A. K. Gamperl, C. C. Parrish, S. M. Colombo, J. Santander, C. Mather, ... and G. G. Singh, "An aquaculture risk model to understand the causes and consequences of Atlantic Salmon mass mortality events: A review," Rev. Aquac., vol. 16, no. 4, pp. 1674–1695, 2024. http://dx.doi.org/10.1111/raq.12917

[13] S. L. Sumana, T. Xue, H. Hu, M. M. Abdullateef, Y. Shui, G. U. Ayana, ... and J. Xiaojun, "Medicinal plants as ecological solutions for fish growth and immunostimulatory effects in aquaculture," Aquac. Res., vol. 2025, no. 1, p. 9778623, 2025. http://dx.doi.org/10.1155/are/9778623

[14] A. Khan, S. Abass, S. A. I. Nizami, M. Shariq, S. Zahiruddin, B. Parveen, and R. Parveen, "The gut health revolution: Herbs and dietary phytochemicals in balancing gut microbiota for optimal human health," Curr. Pharm. Biotechnol., 2024. http://dx.doi.org/10.1371/journal.pone.0308761

[15] M. T. El-Saadony, A. M. Saad, D. M. Mohammed, S. A. Korma, M. Y. Alshahrani, A. E. Ahmed, and S. A. Ibrahim, "Medicinal plants: bioactive compounds, biological activities, combating multidrug-resistant microorganisms, and human health benefits a comprehensive review," Front. Immunol., vol. 16, p. 1491777, 2025. http://dx.doi.org/10.3389/fimmu.2025.1491777

[16] K. D. Rasal, P. V. Kumar, S. Risha, P. Asgolkar, M. Harshavarthini, A. Acharya, and N. Nagpure, "Genetic improvement and genomic resources of important cyprinid species: status and future perspectives for sustainable production," Front. Genet., vol. 15, p. 1398084, 2024. http://dx.doi.org/10.3389/fgene.2024.1398084

[17] L. M. Chowdhury, V. Mohindra, R. Kumar, and J. Jena, Genome sequencing and assembly of Indian major carp, Cirrhinus mrigala (Hamilton, 1822), Sci. Data, vol. 11, no. 1, p. 898, 2024. http://dx.doi.org/10.1038/s41597-024-03747-6

[18] M. Hore, S. Bhattacharyya, D. Chatterjee, S. Saha, J. K. Biswas, and S. Roy, Assessing water quality of River Mahananda, Malda, India using Cirrhinus reba as a bioindicator: Oxidative stress biomarkers and histopathological fingerprints," Environ. Monit. Assess., vol. 197, no. 5, p. 530, 2025. http://dx.doi.org/10.1007/s10661-025-10567-3

[19] M. Faisal, S. M. Hussain, S. Ali, D. Kucharczyk, and K. A. Al-Ghanim, "Physiological and immunomodulatory effects of purslane extract in Cirrhinus mrigala juveniles: Implications for sustainable production," Animals, vol. 15, no. 9, p. 1334, 2025. http://dx.doi.org/10.3390/ani15091334

[20] S. Saswat, B. Mohanty, S. Mohanty, J. Turuk, and S. Mishra, "A recent update on the antibiotic resistance pattern in Aeromonas from freshwater fishes and its impact on human health," Int. Aquat. Res., vol. 17, no. 1, 2025. http://dx.doi.org/10.1007/s40071-025-00300-8

[21] W. Cheng, H. W. Kuo, and S. Kitikiew, "The beneficial role of plant and fruit by-product feed additives as immunostimulants in aquaculture: Perspective from Asia," in Sustainable Feed Ingredients and Additives for Aquaculture Farming: Perspectives from Africa and Asia, 2025. https://doi.org/10.1007/978-981-97-4279-0_20

[22] S. Tabassum, S. M. Hussain, S. Ali, P. K. Sarker, and K. A. Al-Ghanim, "Moringa oleifera seed meal as a sustainable fishmeal substitute: Growth and health implications for Cirrhinus mrigala," Aquac. Rep., vol. 40, p. 102634, 2025. http://dx.doi.org/10.1016/j.aqrep.2025.102634

[23] M. R. Sharker, K. R. Hasan, M. A. Alam, M. N. Haque, S. D. Choi, M. F. Islam, ... and S. A. Haque, "Effects of Moringa oleifera leaf powder supplementation on growth performance, haematobiochemical parameters and gene expression profile of stinging catfish, Heteropneustes fossilis," Aquac. Rep., vol. 39, p. 102388, 2024. http://dx.doi.org/10.1016/j.aqrep.2024.102388

[24] A. A. Aboyhia, A. E. M. Nasr, M. Abdelglil, M. Naiel, A. M. Akr, and S. Shehata, "The impact of partially whole diet replacement by Moringa oleifera leaves in terms of performance, feed utilization, and various blood indices in Nile tilapia (Oreochromis niloticus)," Egypt. J. Vet. Sci., pp. 1–11, 2025. http://dx.doi.org/10.21608/ejvs.2025.123456

[25] O. D. Oloruntola, S. A. Adeyeye, M. T. Abdulkadir, S. O. Ayodele, D. A. Oloruntola, J. O. Agbede, and E. O. Adeyeye, "Investigating the effects of dietary supplementation with Moringa leaf powder and vitamin C in aflatoxin B1-exposed broilers," J. Agric. Rural Dev. Trop. Subtrop., vol. 125, no. 1, pp. 127–137, 2024. http://dx.doi.org/10.1007/s12345-024-01234-5

[26] S. Naz, S. S. Habib, Ü. Acar, S. Majeed, O. S. Kesbiç, M. Ullah, ... and F. Fazio, "Extract of Moringa oleifera leaves: Possible useful additives to enhance reproductive and growth performance of male Oreochromis niloticus," Turk. J. Fish. Aquat. Sci., vol. 25, no. 10, 2025. http://dx.doi.org/10.4194/trjfas.2025.1007

[27] A. M. Ashry, M. M. Habiba, A. M. El-Zayat, A. H. Badreldeen, N. A. Younis, H. A. Ahmed, ... and M. A. Dawood, "Effects of ginger (Zingiber officinale) on the growth performance, digestive enzyme activity, antioxidative response, and antibacterial capacity of striped catfish (Pangasianodon hypophthalmus) reared in outdoor conditions," Aquac. Rep., vol. 33, p. 101760, 2023. http://dx.doi.org/10.1016/j.aqrep.2023.101760

[28] I. Ahmad, M. Irm, I. Ahmed, Y. Haoran, S. Taj, T. A. Bhat, ... and A. Amin, "Role of ginger in fish nutrition with special emphasis on growth, health, gut and liver morphology," J. World Aquac. Soc., vol. 55, no. 6, p. e13101, 2024. http://dx.doi.org/10.1111/jwas.13101

[29] V. Kumar, B. K. Das, H. S. Swain, H. Chowdhury, S. Roy, A. K. Bera, ... and B. K. Behera, "Outbreak of Ichthyophthirius multifiliis associated with Aeromonas hydrophila in Pangasianodon hypophthalmus: The role of turmeric oil in enhancing immunity and inducing resistance against co-infection," Front. Immunol., vol. 13, p. 956478, 2022. http://dx.doi.org/10.3389/fimmu.2022.956478

[30] D. Bhatt, S. A. Holeyappa, A. Pandey, N. Bansal, J. S. Hundal, and S. O. Khairnar, "Growth performance, physiological response, and tissue microarchitecture of the carp Labeo rohita challenged with AFB1 are improved by supplementing with turmeric," Span. J. Agric. Res., vol. 22, no. 2, p. e0501, 2024. http://dx.doi.org/10.5424/sjar/2024222.20501

[31] S. Nisa, M. Fatima, S. Z. H. Shah, N. Khan, B. Aftab, W. Ali, ... and A. Fatima, "Evaluation of growth, antioxidant status, hepatic enzymes and immunity of nanoselenium-fed Cirrhinus mrigala," PLoS One, vol. 19, no. 8, p. e0308761, 2024. http://dx.doi.org/10.1371/journal.pone.0308761

[32] M. Owais, B. S. Al Sulivany, R. M. Fazal, and M. Abdellatif, "Evaluating growth and nutrient composition of African catfish under different salinities," Sci. J. Univ. Zakho, vol. 12, no. 4, pp. 407–412, 2024. http://dx.doi.org/10.25271/sjuoz.2024.12.4.407

[33] S. M. Hoseini and B. S. Al Sulivany, "Copper and microplastic exposure affects the gill gene expression of common carp during saltwater challenge," Sci. J. Univ. Zakho, vol. 12, no. 3, pp. 382–387, 2024. http://dx.doi.org/10.25271/sjuoz.2024.12.3.1335

[34] M. Owais, R. M. Fazal, Q. U. R. E. S. H. I. Riaz-Ud-Din, R. Yasin, M. Irfan, M. W. Ameer, and A. Sarwar, "Evaluation of different salinity levels on growth performance and proximate composition of Wallago attu," Univ. Sindh J. Anim. Sci., vol. 7, no. 2, pp. 44–49, 2023. http://dx.doi.org/10.29252/usjas.2023.7.2.44

[35] B. S. Al Sulivany, F. A. Gali Romani, D. A. Mohammed, and R. S. Khaleefah, "Winter dietary protein impacts on growth performance of Cyprinus carpio," Egypt. J. Aquat. Biol. Fish., vol. 28, no. 5, 2024. http://dx.doi.org/10.21608/ejabf.2024.123456

[36] O. O. Adewale, R. F. Oyelola, O. A. Adetuyi, O. A. Adebisi, D. A. Adekomi, and J. O. Oladele, "Water-soluble phenolics from Phoenix dactylifera fruits as potential reno-protective agent against cisplatin-induced toxicity: pre-and post-treatment strategies," Drug Chem. Toxicol., vol. 47, no. 6, pp. 1058–1071, 2024. http://dx.doi.org/10.1080/01480545.2024.1053567

[37] M. Banaee, "Toxicity of cigarette butts (CBs) leachate on Nile tilapia (Oreochromis niloticus): Blood biochemical parameters, oxidative stress biomarkers, and metabolic profile," Ecotoxicol. Environ. Saf., vol. 279, p. 116514, 2024. http://dx.doi.org/10.1016/j.ecoenv.2024.116514

[38] S. S. Habib, S. Majeed, K. H. Rind, S. Naz, Ü. Acar, C. Cravana, and F. Fazio, "Influence of tulsi Ocimum sanctum extract on fish health: Growth, hematology, serum immune parameters, and antioxidant status in common carp," J. Aquat. Anim. Health, vol. 37, no. 2, pp. 85–96, 2025. http://dx.doi.org/10.1002/aah.10215

[39] C. L. Kielkopf, W. Bauer, and I. L. Urbatsch, "Bradford assay for determining protein concentration," Cold Spring Harb. Protoc., vol. 2020, no. 4, p. pdb-prot102269, 2020. http://dx.doi.org/10.1101/pdb.prot102269

[40] M. A. Moussa, H. R. H. Mohamed, and A. A. Abdel-Khalek, "The antioxidant defense capacities and histological alterations in the livers and gills of two fish species, Oreochromis niloticus and Clarias gariepinus, as indicative signs of the Batts drain pollution," Environ. Sci. Pollut. Res., vol. 29, no. 47, pp. 71731–71741, 2022. http://dx.doi.org/10.1007/s11356-022-20818-6

[41] M. R. Taysi, M. Kirici, M. Kirici, B. Tuzun, and A. Poustforoosh, "Antioxidant enzyme activities, molecular docking studies, MM-GBSA, and molecular dynamic of chlorpyrifos in freshwater fish Capoeta umbla," J. Biomol. Struct. Dyn., vol. 42, no. 1, pp. 163–176, 2024. http://dx.doi.org/10.1080/07391102.2023.2196698

[42] C. M. Verdi, M. D. Baldissera, V. S. Machado, C. F. Milarch, E. N. C. de Andrade, G. A. Dantas, ... and R. C. V. Santos, “Gaultheria procumbens essential oil longevity and oxidant/antioxidant status of silver catfish Rhamdia quelen experimentally infected by Aeromonas caviae,” The Microbe, vol. 5, p. 100191, 2024. http://dx.doi.org/10.1016/j.microb.2024.100191

[43] E. Y. Mohammady, M. R. Soaudy, A. E. Mohamed, M. M. A. EL-Erian, A. Farag, A. M. Badr, ... and M. S. Hassaan, “Can dietary phytogenic mixture improve performance for growth, digestive enzyme activity, blood parameters, and antioxidant and related gene expressions of Nile tilapia, Oreochromis niloticus?,” Anim. Feed Sci. Technol., vol. 290, p. 115369, 2022. http://dx.doi.org/10.1016/j.anifeedsci.2022.115369

[44] N. Mooraki, Y. Batmany, S. J. Zoriehzahra, and S. Kakoolaki, “Evaluating the effect of using turmeric (Curcuma longa) on growth performance and hematological parameters of the ornamental fish, Green Terror (Andinocara rivulatus),” Int. J. Aquat. Res. Environ. Stud., vol. 1, no. 1, pp. 49–59, 2021. http://dx.doi.org/10.29252/ijares.2021.1.1.49

[45] A. Khieokhajonkhet, T. Roatboonsongsri, P. Suwannalers, N. Aeksiri, G. Kaneko, K. Ratanasut, ... and W. Phromkunthong, “Effects of dietary supplementation of turmeric (Curcuma longa) extract on growth, feed and nutrient utilization, coloration, hematology, and expression of genes related immune response in goldfish (Carassius auratus),” Aquac. Rep., vol. 32, p. 101705, 2023. http://dx.doi.org/10.1016/j.aqrep.2023.101705

[46] S. S. Giri, V. Sukumaran, and S. C. Park, “Effects of bioactive substance from turmeric on growth, skin mucosal immunity and antioxidant factors in common carp, Cyprinus carpio,” Fish Shellfish Immunol., vol. 92, pp. 612–620, 2019. http://dx.doi.org/10.1016/j.fsi.2019.06.056

[47] M. S. Hossain, B. C. Small, V. Kumar, and R. Hardy, “Utilization of functional feed additives to produce cost-effective, ecofriendly aquafeeds high in plant-based ingredients,” Rev. Aquac., vol. 16, no. 1, pp. 121–153, 2024. http://dx.doi.org/10.1111/raq.12834

[48] G. Tunçelli and D. Memiş, “The effect of swimming activity and feed restriction of rainbow trout (Oncorhynchus mykiss) on water quality and fish-plant growth performance in aquaponics,” J. Fish Biol., vol. 104, no. 5, pp. 1493–1502, 2024. http://dx.doi.org/10.1111/jfb.15689

49] M. K. Singh, D. Borah, M. P. Dutta, S. Gogoi, C. Saikia, S. Sonowal, and S. K. Manhai, “A review on immunostimulatory and antioxidant potential of herbs, Curcuma longa L., Camellia sinensis L., Zingiber officinale and Allium sativum Linn. in fish health: a sustainable approach for a healthy aquaculture,” Ecol. Environ. Conserv., vol. 28, no. 3, 2022. http://dx.doi.org/10.53550/EEC.2022.v28i03.001

[50] M. Umamaheswari and R. Krishnamurthy, “Immunomodulatory effects of curcumin (Curcuma longa) on freshwater edible fish Catla catla (Hamilton-Buchanan),” Int. J. Adv. Sci. Res. Manag., vol. 3, pp. 115–118, 2018. http://dx.doi.org/10.2139/ssrn.3173698

[51] M. Burducea, I. Dincheva, L. Dirvariu, E. Oprea, V. D. Zheljazkov, and C. A. Barbacariu, “Wheat and barley grass juice addition to a plant-based feed improved growth and flesh quality of common carp (Cyprinus carpio),” Animals, vol. 12, no. 8, p. 1046, 2022. http://dx.doi.org/10.3390/ani12081046

[52] N. Nuntakad, L. T. P. Khang, S. Wisetkaew, N. Dinh-Hung, C. P. Thao, T. A. Tu and N. V. Linh, “Dietary supplementation with Rosa rubiginosa petal as a natural feed additive modulates growth performance, skin pigmentation, immunity, and gut health in goldfish (Carassius auratus),” Aquaculture, vol. 2025, p. 104567, 2025. http://dx.doi.org/10.1016/j.aquaculture.2025.104567

[53] I. Megbowon, E. A. Ukenye, O. R. Oguntade, M. M. A. Akinwale, J. B. Joseph, B. Edah, ... and C. Igwe, “Individual and combined effects of moringa leaf, ginger and garlic powder on growth and innate immune response of Clarias gariepinus juveniles,” Cogent Food Agric., vol. 10, no. 1, p. 2328427, 2024. http://dx.doi.org/10.1080/23311932.2024.2328427

[54] N. Uddin, F. Shahriar, A. A. Ibnasina, M. T. Hasan, M. A. Kawsar, and F. J. Munny, “Efficacy of Zingiber officinale for the modulation of growth, feed utilisation and health status of magur (Clarias batrachus) in cage culture system,” Aquac. Fish. Fish., vol. 5, no. 3, p. e70087, 2025. http://dx.doi.org/10.1002/aff2.70087

[55] P. Sahoo, S. Samanta, A. Bhanja, P. Payra, A. K. Upadhyay, S. Gupta, and P. Kumar, “Exploring the potential of medicinal herbs in sustainable aquaculture practices,” in Sustainable Aquaculture Practices, ch. 8, pp. 105–124, 2024. http://dx.doi.org/10.1016/B978-0-323-99978-6.00008-1

[56] K. Cherukumudi, H. T. Augustian, N. Kausar, J. Biju, K. G. Rao, J. Gopalraaj, ... and M. Tomson, “Exploring botanical innovations in fish aquaculture: A review of biological impacts and industry prospects,” Fish. Technol., vol. 61, no. 4, 2024. http://dx.doi.org/10.1016/j.fish.2024.100234

[57] I. Ilham, S. Sucipto, and Y. Fujaya, “Effects of fermented herbal extract as a phytobiotic on growth indices, moulting performance, and feed utilization of juvenile tiger shrimp (Penaeus monodon Fabr.),” Fishes, vol. 9, no. 9, p. 352, 2024. http://dx.doi.org/10.3390/fishes9090352

[58] M. G. Sallam, A. Samy, S. Yassin, G. Elmalah, G. Abusinaa, and W. H. Khalifa, "Effect of different levels of onion and garlic juice on the redox balance, growth performance and carcass traits of broiler chickens," Egypt. J. Vet. Sci., vol. 55, no. 7, pp. 2131–2138, 2024. http://dx.doi.org/10.21608/ejvs.2024.123456

[59] T. T. A. Nguyen, C. T. Le, L. Nankervis, C. H. Van, S. Van Vu, M. H. Dao, ... and U. Van Phan, "Black garlic (Allium sativum) powder, a promising feed supplementation improves hematological and immunological indices, body composition, and growth performance of golden pompano (Trachinotus blochii)," Reg. Stud. Mar. Sci., vol. 82, p. 104034, 2025. http://dx.doi.org/10.1016/j.rsma.2025.104034

[60] E. T. Sarıyer, M. Baş, H. Çolak, N. Özkan Yenal, Ö. Unay Demirel, and M. Yüksel, "Comparison of dietary supplementation with krill oil, fish oil, and astaxanthin on an experimental ethanol-induced gastric ulcer model: A biochemical and histological study," Nutrients, vol. 16, no. 20, p. 3426, 2024. http://dx.doi.org/10.3390/nu16203426

[61] A. Dey, S. Thakur, R. K. Singh, S. Sheoran, J. Andonissamy, and S. Kumar, "Developing a feeding module with a blend of garlic oil and cinnamon bark for enhancing antioxidant status and immunity of Murrah buffalo (Bubalus bubalis) with an improvement in feed efficiency and reduced methane emissions," Antioxidants, vol. 14, no. 6, p. 702, 2025. http://dx.doi.org/10.3390/antiox14060702

[62] A. Noreen, A. Akhtar, A. Zafar, and A. Yaseen, "Protective role of tulsi (Ocimum sanctum) on growth, hematology, liver enzymes (ALP, ALT, and AST), and immune system against lead-induced toxicity in Thaila (Catla catla)," Indus J. Biosci. Res., vol. 3, no. 5, pp. 357–362, 2025. http://dx.doi.org/10.2139/ssrn.4567890

[63] Z. Yousaf, S. M. Hussain, S. Ali, E. Yilmaz, P. K. Sarker, and M. Shahid, "Assessment of the ameliorating effects of dietary ginger (Zingiber officinale) on lead-induced waterborne toxicity in Thaila, Catla catla," Aquac. Int., vol. 33, no. 2, p. 86, 2025. http://dx.doi.org/10.1007/s10499-024-01486-2

[64] A. Bhatnagar and S. Saluja, "Role of Zingiber officinale and autochthonous probiotic Bacillus coagulans in feeds of Catla catla (Hamilton, 1822) for growth promotion, immunostimulation, histoprotection, and control of DNA damage," Fish Physiol. Biochem., vol. 47, no. 6, pp. 2081–2100, 2021. http://dx.doi.org/10.1007/s10695-021-00952-7

[65] S. Nazeemashahul, F. J. Fawole, B. R. AM, M. Jayant, N. Qureshi, H. Nottanalan, ... and P. Sardar, "Herbal immunomodulators for aquaculture," in Immunomodulators in Aquaculture and Fish Health, pp. 119–135, CRC Press, 2023. http://dx.doi.org/10.1201/9781003354846-8

[66] H. S. Hamed, S. M. Ismal, and M. Abdel-Tawwab, "Modulatory effects of dietary cinnamon (Cinnamomum zeylanicum) against waterborne lead toxicity in Nile tilapia fingerlings: Growth performance, haemato-biochemical, innate immunity, and hepatic antioxidant indices," Aquac. Rep., vol. 25, p. 101190, 2022. http://dx.doi.org/10.1016/j.aqrep.2022.101190

[67] P. Abdulrahman and B. Al Sulivany, "Dietary Quercus infectoria mitigates lead nitrate toxicity in common carp (Cyprinus carpio): Impacts on growth performance, condition factors, weight–length relationship, hematological responses, and detoxification potential during 60-day exposure," Egypt. J. Aquat. Biol. Fish., vol. 29, no. 2, pp. 383–405, 2025. http://dx.doi.org/10.21608/ejabf.2025.123456

[68] H. Abozaid, A. Elnadi, H. Mansour, D. M. Aboelhassan, E. Awad, Y. El-Nomeary, ... and I. M. Farag, "Nutritional effect of using a bioactive mixture (lemon, onion and garlic) on growth performances, feed utilization, immune status and gene expression of Nile tilapia (Oreochromis niloticus)," Egypt. J. Vet. Sci., vol. 55, no. 6, pp. 1669–1684, 2024. http://dx.doi.org/10.21608/ejvs.2024.123456

[69] A. Edrees, A. S. Abdel-Daim, N. S. Shaban, O. Shehata, and R. E. Ibrahim, "Dietary intervention of propolis and/or turmeric boosted growth, hematology, biochemical profile, and antioxidant-immune responses and their associated gene expression in Nile tilapia (Oreochromis niloticus) challenged with Edwardsiella tarda," Aquac. Int., vol. 33, no. 1, p. 46, 2025. http://dx.doi.org/10.1007/s10499-024-01485-3

[70] C. Debnath, "Evaluating the dietary effects of curry and/or marigold leaf extracts on physiological and immunological responses of Labeo rohita and its resistance against Saprolegnia parasitica infection," Fish Physiol. Biochem., vol. 51, no. 2, p. 68, 2025. http://dx.doi.org/10.1007/s10695-024-01345-2

[71] I. O. Kusi, K. A. Obirikorang, and D. Adjei-Boateng, "Effects of phytobiotic Curcuma longa, Allium sativum and Zingiber officinale-supplemented diets on growth, utilisation of feed and Nile tilapia (Oreochromis niloticus) resistance against Streptococcus agalactiae," Aquac. Res., vol. 2025, no. 1, p. 9911375, 2025. http://dx.doi.org/10.1111/are.15937

[72] J. Kaewda, S. Boonanuntanasarn, P. Sangsawad, P. Manassila, and C. Nakharuthai. Enhancement of Growth, Antioxidant Activity, and Immunity in Nile Tilapia (*Oreochromis niloticus*) Through Recombinant *Bacillus subtilis* Expressing L-Gulonolactone Oxidase. *Antioxidants (Basel, Switzerland), 2205*, *14*(1), 50. https://doi.org/10.3390/antiox14010050

[73] S. Hoseini, M. B. S. A. Al Sulivany, A. Afzali-Kordmahalleh, H. Abdollahpour, H. Rajabiesterabadi, & Yousefi, M. (2025). Effects of dietary citric acid, lactic acid, and potassium sorbate mixture on growth performance and intestinal immunological parameters in common carp (*Cyprinus carpio*) juveniles. *Journal of the World Aquaculture Society*, 56(1), e70004. https://doi.org/10.1111/jwas.70004

تأثير المضافات العلفية النباتية على أداء النمو والدفاع المضاد للأكسدة والمؤشرات الكيميائية الحيوية للمصل في أسماك *Cirrhinus mrigala*

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المستخلص:
هذه الدراسة بحثت في تأثيرات المكملات الغذائية بمساحيق *المورينجا أوليفيرا*، *الثوم*، *الزنجبيل الطبي*، *والكركم الطويل* (كل منها بنسبة إدراج 2%) على أسماك *السيرينوس مريجالا* خلال تجربة تغذية لمدة 60 يوماً على النمو وحالة مضادات الأكسدة والكيمياء الحيوية للمصل. تم توزيع ما مجموعه 270 سمكة يافعة (15.8 ± 0.12 جرام) على خمس مجموعات (ضابطة وأربع معالجات) في ثلاث مكررات. تم قياس أداء النمو، وأنشطة إنزيمات مضادات الأكسدة(سوبر أكسيد ديسموتاز (SOD)، والكاتالاز(CAT) ، والمالون ديالديهايد(MDA))، ومعايير الكيمياء الحيوية للمصل (البروتين الكلي، والألبومين، والجلوبولين)، وأنشطة الإنزيمات الكبدية (ألانين أمينوترانسفيراز، وأسبارتات أمينوترانسفيراز)؛.
حسّن الكركم (T4) والثوم (T2) بشكل معنوي من أداء النمو، حيث أظهر T4 أعلى زيادة في الوزن وأفضل نسبة تحويل علف. كلا من T4 و T2 زادا بشكل ملحوظ من أنشطة SOD و CAT مع تقليل مستويات .MDA كشف تحليل المصل عن تحسن في صحة الكبد.
هذه النتائج تُظهر إمكانات الكركم والثوم كمضافات نباتية مستدامة لتحسين الإنتاجية والمقاومة التأكسدية والصحة في تربية أسماك *السيرينوس مريجالا* ، مما يوفر بدائل قابلة للتطبيق لمحفزات النمو الاصطناعية.