Physiological Responses of African Catfish Hybrid (*Clarias gariepinus* ♀ ×*Heterobranchus bidorsalis* ♂) to Dietary Coriander Supplementation

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ABSTRACT

Physiological responses of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) to dietary coriander supplementation were evaluated in a 56-day feeding trial. Five isolipidic and isonitrogenous diets were formulated comprising a control (without coriander, DT1) and four test diets (supplementation of 0.5% coriander powder, (DT2), 1% (DT3), 1.5% (DT4), and 2% (DT5). The diets were allotted to triplicate groups of 15 fish (4.88±0.42 g average weight). The growth rate, carcass protein and lipid in the fish fed a 0.5% coriander-based diet were significantly higher ($p<0.05$) than those fed the control diet. The 0.5% coriander dietary group markedly ($p<0.05$) outperformed the other dietary groups in terms of protein, energy and lipid. The survival rate and flesh yield of the coriander-fed group were greater ($p>0.05$) than those of the control group. The levels of packed cell volume, hemoglobin content and red blood cells showed significant differences ($p<0.05$) among treatments, with the 0.5% dietary group showing the highest values for these parameters. Total protein and globulin levels in the 0.5 and 1% coriander-fed groups were greater ($p<0.05$) than those in the control group, while aspartate transaminase, alanine transaminase, alkaline phosphatase, urea and creatinine, and glucose were significantly ($p<0.05$) lower in the coriander supplementation group up to 1.5%. A 2^{nd}-order polynomial regression revealed that a 0.55% dosage of coriander powder (%) would support optimum percentage weight gain.

Keywords: African catfish hybrid, Coriander powder, Lymphocytes, Serum electrolytes, Total protein

INTRODUCTION

Fish production is expanding and diversifying in various areas all over the world, with Nigeria ranked second after Egypt in terms of African aquaculture production (Adeleke *et al*., 2021). Fish consumption per capita has more than tripled globally, accounting for nearly 20 % of world animal protein intake (Naylor *et al*., 2021). To increase feed conversion efficiency and fish culture production, a number of growth hormones and stimulants have been explored (Gule and Geremew, 2022). Demand for farmed fish has recently increased, with consumers prioritizing quality and safety as well as the lack of contaminants, antibiotics, and cancer-causing substances (Freitas *et al*., 2020). Consumers in Nigeria are prepared to pay a price increase of 3.1 % to 18.8 % for catfish that has been raised in a safe, approved farm environment (Tran *et al*., 2022). As a result, the fish production strategy must prioritize food hygiene in addition to growth performance. Fish nutritionists have focused their efforts on researching and creating safe nutritional supplements and additives for farmed fish that improve their health activity, and immune system (Turchini *et al*., 2019). Consumer and animal welfare concerns are driving the development of alternatives to expensive feed

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additives. The need to identify more natural and non-residual alternatives to the conventional fish feed additives has become imperative (Pandey *et al*., 2019). Researchers are investigating alternative applications of plant-derived compounds in animal feeding in light of recently enacted food safety regulations (Abd El-Hack *et al*., 2021). Plants with a variety of bioactive phytoconstituents have recently rekindled interest in using them in finfish diets to improve growth. Fish growth has been promoted by dietary supplementation with certain plant components and their extracts made from substances including water, hexane, acetone, ethanol, and methanol (Ghosh *et al*., 2022; Steinberg, 2022). Because of their natural origins, herbal materials have sparked a lot of interest in the aquaculture sector. Herbal intact materials/extracts have been shown in several studies to improve fish performance and well-being. Because they have therapeutic benefits such as antioxidant and antibacterial activity, they are used as a source of human nutrition and medicine all over the world. In other studies, food supplements using medicinal herbs that included various phytochemicals were given to fish to encourage growth (Bahrekazemi *et al*., 2020b; Raissy *et al*., 2022). Coriander (*Coriandrum sativum*), a member of the Apiaceae family, is a herb that thrives in a variety of climates worldwide (Maragoor *et al*., 2022), and hence has no limitation of availability. The high-value components of coriander seeds which include linalool, terpenoids, linoleic acid, vitamin C, and minerals (Ca, Zn, Mg, Fe, and K) and a high phenolic content (glycitein, pyrogallol, and caffeic acid) confer the therapeutic, immunostimulant, and antioxidant properties to coriander (Sahib *et al*., 2013). Fish growth improvement, appetite stimulation, immunological modulation, antibacterial, and anti-stress effects have all been well documented in the presence of these bioactive and functional substances in coriander (Farsani *et al*., 2019). Linalool, a terpenoid found in coriander seeds, is a potent cellular antioxidant, antibacterial, and anti-inflammatory compound (Dakhlaoui *et al*., 2022). Coriander has been widely used with promising results as an additive in the feeds of fishes such as rainbow trout (*Oncorhynchus mykiss*) (Ren *et al*., 2006, Farsani *et al*., 2019), spotted snakehead (*Channa punctatus*) (Talapatra *et al*., 2010), catla (*Catla catla*) (Innocent, 2011), Nile tilapia (*Oreochromis niloticus*) (Ahmed *et al*., 2020b), and European sea bass (*Dicentrarchus labrax*) (Ashry *et al*., 2022). Among the species raised in Nigeria's aquaculture industry are carp, tilapia, African catfish, and African bonytongue (*Heterotis niloticus*). Due to their hardiness, wide acceptability, and high market value, African catfish species (*Clarias* spp. and *Heterobranchus* spp. and their hybrids) are the most farmed species in Nigeria (Adeleke *et al*., 2020). The supplementation of coriander in African catfish diet, particularly the hybrid heteroclarias (*Clarias gariepinus* ♀× *Heterobranchus bidorsalis* ♂), is scarce to our knowledge. This study, therefore, investigates dietary coriander supplementation in the diets of an African catfish hybrid.

MATERIALS AND METHODS

Procurement of coriander and preparation of the experimental diets

Coriander powder, fish meal, soybean meal, and other pertinent feedstuffs were purchased from commercial sources in Ilorin, Nigeria. They were processed and screened individually to achieve a fine particle size. Duplicate samples were then tested for their proximate composition (AOAC, 2010). Based on the proximate composition of the feed ingredients, five isolipidic and isonitrogenous diets (12 % crude lipid and 38 % crude protein, respectively) were formulated with 0, 0.5, 1.0, 1.5, and 2.0% coriander supplementation (Table 1). The diets were labeled as control, D2, D3, D4, and D5, respectively. After grinding the ingredients, hot water was added to help bind the mixture. It was then run through pelleting and mixing equipment to generate 2 mm pellets, which were immediately sun-dried at 30-32 °C for 3 days. The nutritional content (fatty acid and amino acid) of the experimental meals (Table 1) was calculated using an Excel tool developed by the NACA (2008).

Table 1. Gross and nutrient composition (g·100 g^{-1}) of coriander-supplemented diet fed to African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂).

Ingredients	Control	Coriander-supplemented diets			
		D2 (0.5%)	D3 (1.0%)	D4 (1.5%)	D5 (2.0%)
Fishmeal@72%cp	27.80	27.80	27.80	27.80	27.80
SBM@44% cp	44.50	44.50	44.50	44.50	44.50
Yellow maize@10%cp	4.00	4.00	4.00	4.00	4.00
Coriander	0.00	0.50	1.00	1.50	2.00
Fish premix	5.00	5.00	5.00	5.00	5.00
Fish oil	2.50	2.50	2.50	2.50	2.50
Soy oil	2.50	2.50	2.50	2.50	2.50
Starch	13.70	13.20	12.70	12.20	11.70
Total	100	100	100	100	100
Proximate composition (%)					
Moisture	8.14	8.12	8.10	8.08	8.06
Crude protein	37.82	38.00	38.19	38.38	38.58
Crude lipid	12.31	12.40	12.50	12.59	12.69
Ash	7.39	7.42	7.44	7.47	7.50
Crude fiber	5.91	5.92	5.93	5.94	5.95
NFE	28.44	28.14	27.84	27.54	27.24
Amino acid composition (%)					
Arginine%	3.00	3.01	3.03	3.04	3.06
Histidine	0.94	0.94	0.94	0.95	0.95
Isoleucine	1.84	1.85	1.85	1.86	1.87
Leucine	3.00	3.01	3.03	3.04	3.06
Lysine	2.82	2.83	2.85	2.86	2.88
Methionine	0.86	0.87	0.87	0.88	0.88
M+C	1.38	1.39	1.39	1.40	1.41
Phenylalanine	1.76	1.77	1.78	1.79	1.80
P+T	3.05	3.07	3.08	3.10	3.11
Threonine	1.78	1.79	1.80	1.81	1.82
Tryptophan	0.47	0.47	0.47	0.47	0.48
Valine	2.00	2.01	2.02	2.03	2.04
Fatty acid composition (%)					
LOA (18:2n-6)	4.89	4.92	4.94	4.97	4.99
LNA (18:3n-3)	0.69	0.70	0.70	0.71	0.71
ARA (20:4n-6)	0.07	0.07	0.07	0.07	0.07
EPA (20:5n-3)	0.35	0.35	0.36	0.36	0.36
DHA (22:6n-3)	0.82	0.82	0.83	0.83	0.84
Total n-3	1.87	1.88	1.89	1.90	1.91
Total n-6	4.96	4.99	5.01	5.04	5.07
n3:n6	0.38	0.38	0.38	0.38	0.38
Total phospholipid%	2.69	2.70	2.72	2.73	2.74

Note: Each kg of the Agri-mix fish premix contains Vitamin A 1,500,000 i.u, Vitamin B1 800 mg, Vitamin B2 1,600 mg, Vitamin B6 1,500 mg, Vitamin B12 4 mg, Vitamin D3 3,000,000 i.u, Vitamin E 200,000 mg, Vitamin C 240 g, Folic acid 300 mg, Niacin 5,970 mg, Biotin 40 mg, Pantothenic Acid 4,000 mg, Copper 800 mg, Iodine 191 mg, Iron 1,200 mg, Manganese 20,323 mg, Selenium 60 mg, Zinc 15,996 mg, Choline 87,000 mg. Manufactured by Agri-Dom 20/22 Kolawole Shonibare Street, Ajao Estate, Lagos. www.agri-domintegrated.com.ng; LNA = Linolenic acid; LOA = Linoleic acid; EPA = Eicosapentanoic acid; ARA = Arachidonic acid; DHA = Docosahexanoic acid; NFE = Nitrogen-free extract

Fish rearing and feeding protocols

The experiment was carried out at the wet laboratory of the Department of Aquaculture and Fisheries at the University of Ilorin in Nigeria. The hybrid catfish fingerlings were purchased from an established hatchery in Ilorin and brought to the experiment site in an aerated bag. Hybrid catfish fingerlings (225 fish, with 4.88±0.42 g average weight) were acclimated on commercial catfish pelleted feed (1.8 mm Skretting® catfish starter feed) for a week before the feeding trial and thereafter randomly and equally distributed into fifteen experimental tanks. Completely randomized design was adopted wherein each dietary treatment was assigned to three (3) replicate tanks. The fifteen 84-L rectangular plastic tanks (80×35×30 cm) were gently aerated after being filled with water to a 70-L capacity. The experimental fish were fasted for 24 h prior to the feeding experiment. For 56 days, the fish were fed at 5 % of their body weight in two equal rations between 9:00 and 10:00 a.m. and between 5:00 and 6:00 p.m. Fish were bulk-weighed every two weeks in order to monitor growth and regulate feed. The water quality parameters were maintained throughout the culture period at 6.75± 0.12 $mg \cdot L^{-1}$ dissolved oxygen, 6.49±0.32 pH, and 27.11±0.28 °C.

Growth parameters

The following growth parameters were evaluated as described in Jimoh *et al*. (2019):

$$\text{Mean weight gain (g)} = \text{Final mean weight (g)} - \text{Initial mean weight (g)}$$

Weight gain (%)

$$= \frac{\text{Final weight (g)-Initial weight (g)}}{\text{Initial weight (g)}} \times 100$$

Specific growth rate ($\% \cdot d^{-1}$)

$$= \frac{[\ln(\text{final weight}) - \ln(\text{initial weight})]}{\text{Time of culture (days)}} \times 100$$

$$\text{Feed conversion ratio} = \frac{\text{Total feed fed (g)}}{\text{Weight gain (g)}}$$

$$\text{Protein efficiency ratio} = \frac{\text{Weight gain (g)}}{\text{Total protein fed (g)}}$$

Survival rate (%)

$$= \frac{\text{(Total initial number of fish-Mortality)}}{\text{The total initial number of fish}} \times 100$$

Growth-in-length parameters were assessed as described in Lugert *et al*. (2016):

$$\text{Absolute growth (cm)} = \text{Final length-Initial length}$$

Relative growth rate (%)

$$= \frac{\text{(Final length-Initial length)}}{\text{Initial length}} \times 100$$

Thermal growth coefficent

$$= \frac{\text{Final length-Initial length}}{\text{Temperature} \times \text{Period of culture}}$$

Body composition and nutrient retention studies

The AOAC (2010) methods were followed for overall body composition analysis; whole bodies of fish from the feeding trial (n = 6 fingerlings before; n = 3 fish per replicate tank after) were compared for proximate composition. The results were employed to calculate nutrient retention, which was calculated as follows:

Protein retention (%)

$$= \frac{\text{Total protein gain (g)}}{\text{Total protein fed (g)}} \times 100$$

Lipid retention (%)

$$= \frac{\text{Total lipid gain (g)}}{\text{Total lipid fed (g)}} \times 100$$

Energy retention (%)

$$= \frac{\text{Total energy gain (g)}}{\text{Total energy fed (g)}} \times 100$$

Condition factor and body indices

Fulton's condition factor (K) and body indices followed the procedures explained in Jimoh *et al*. (2019):

$$K = \frac{W}{L^3} \times 100$$

W is Final weight of each fish to the nearest 0.01 g

L is Final length of each fish to the nearest 0.1 cm

Hepatosomatic index (%)

$$= \frac{\text{Liver weight}}{\text{Total body weight}} \times 100$$

Viscerosomatic index (%)

$$= \frac{\text{Visceral weight}}{\text{Total body weight}} \times 100$$

Flesh yield (%)

$$= \frac{\text{(Total body weight-Waste yield)}}{\text{Total weight}} \times 100$$

Blood sampling and hematological assessment

At the conclusion of the feeding period, six fish from each experimental tank were removed for blood analysis. Before this, the fish were mildly euthanized with 100 mg·L^{-1} clove oil. One milliliter of blood was obtained per replicate by puncturing the caudal vein with a 23G needle and a 2 mL disposable syringe, and gathered in a container treated with EDTA for use in a 3-part full-auto haematology analyzer (Model BK VET 200 mini).

Serum biochemistry parameters

For serum biochemistry, samples of blood (2.5 mL) were drawn into untreated sampling vials and allowed to coagulate at 4 ºC. After 30 min of coagulation, the blood samples were centrifuged at 8,000 rpm for 6 min to collect the serum for the analysis of serum biomarkers following the procedures of Tomlinson *et al*. (2013). A commercial test kit (Randox Laboratories Ltd., U.K.) was used to determine the serum total protein level, and the bromocresol green method was used to estimate the albumin value (Doumas *et al*., 1971; Doumas and Peters Jr, 1997). The differential between serum total protein and serum albumin determines the serum globulin value (Colville, 2002). Blood glucose was measured using the technique of Toro and Ackermann (1975). The methods of Reitman and Frankel (1957) were used to measure serum aspartate aminotransferase (AST) and alanine aminotransferase (ALT). Using deproteinization and urease-Berhelot colorimetric procedures as modified by Berthelot-Searcy, a commercial kit (Randox Laboratories Ltd, U.K.) was used to detect serum urea nitrogen and creatinine (Searcy, 1967; Scott, 1979). The serum triglycerides were measured using a colorimetric method (Chawla, 2014).

Serum electrolytes

An atomic absorption spectrophotometer was used to measure serum electrolytes (Na^+, K^+, $Ca^{2+}$and Mg^{2+}). These were carried out at Central Laboratory Tanke, Ilorin, Nigeria.

Biochemical analysis

The proximate composition of fish, feed, and feed ingredients was assessed using AOAC (2010) techniques. The samples were heated to 105 °C for 24 h in a thermostat oven (DHG 9053A, Axiom Medical Ltd.) to assess their dry matter content, and for 4 h at 600 °C in a furnace (Krupp Widia-Fabrik) to determine their ash content. Using a protein auto-analyzer (Foss Tecator KjeltecTM 8400), crude protein was quantified following acid digestion. The nitrogen was converted into crude protein using a ratio of 6.25. Soxhlet extraction equipment was used to measure crude lipid (Foss Tecator SoxtecTM 8000). A hot extraction fiber analyzer was used to examine crude fiber (Foss Tecator Fibertec 2010).

Data analysis

After passing the Levene test for homogeneity of variance, the experimental results were reported as mean±SE and subjected to one-way ANOVA. Whenever there was a significant difference ($p<0.05$), Tukey's B test was employed to assess differences among individual treatment means. SPSS version 17.0 was used for all of the analyses. The optimum incorporation level of coriander powder that supported maximum weight gain was determined using second-order polynomial regression.

RESULTS AND DISCUSSION

Growth responses, body indices and survival

The growth performance parameters of hybrid African catfish are shown in Table 2. Fish fed 0.5% coriander-based diets exhibited considerably greater ($p<0.05$) mean weight gain than fish fed other coriander-based diets. Herbal supplementation in fish diets, in particular, has been advocated as a way of improving performance, stabilizing physiological conditions, increasing immunity, and improving antioxidative status in fish (Ciji and Akhtar, 2021; Gupta *et al*., 2021). Special advocacy was given to coriander as herbal medicine in the report of Abdou Said *et al*. (2021). According to the findings of this study, fish fed a 0.5% coriander-based diet had the highest values of growth performance parameters. Similar findings were reported in beluga (*Huso huso*) fed 0.5 % coriander-based diets (Bahrekazemi *et al*., 2020b), and common carp fed a 5 % mixture of coriander and other herbs. Coriander's functional components, including high linalool content (essential oils), high petroselinic acid content (fatty acids), and high glycitein, pyrogallol, and caffeic acid content (phenolic acids), which give the plant medicinal, immunostimulant, and antioxidant properties, could possibly account for the superior growth observed in the fish group given 0.5 % coriander-based diets (Ahmed *et al*., 2020b; Abdou Said *et al*., 2021). Figure 1 shows the bi-weekly changes in weight of African catfish hybrid fed coriander-based dietary treatments. The 2nd order polynomial regression of final weight and dosage of coriander administration in the African catfish hybrid diets (Figure 2) revealed that a dosage level of 0.55 % coriander powder would support optimum weight gain; the regression had a coefficient of determination of 0.7291, showing that 72.91 % of the variation in the percentage weight gain among dietary treatments was explained by the coriander supplementation (Hinton *et al*., 2014). The same approach was used by Raissy *et al*. (2022) to optimize a 1% inclusion of a blend of herbal extracts, including common mallow, oak acorn, and coriander. Although mean weight gain was higher for the 0.5% and 1.0% coriander treatments compared to the control, the difference was only significant for the 0.5% treatment; there were no significant differences ($p>0.05$) in the mean weight gain of the control group and fish fed 1% and 1.5% coriander-based diets. Lower growth performance was seen in fish fed 1.0 to 2.0% coriander diets, which could be attributed to the astringent flavor that coriander added to the diet at higher inclusion levels. This flavor likely decreases palatability and consequently feed intake (Cardoso-Ugarte and Sosa-Morales, 2021).

The coriander-fed group had a much greater ($p<0.05$) survival rate and flesh yield than the control group. With up to 1% coriander inclusion level in the diets, the coriander-fed group outperformed the control group in terms of flesh yield and survival rate, both of which were significantly ($p<0.05$) higher than the control group. Our findings imply that including dietary coriander powder into the fish diet will enhance the flesh yield and survival rate. Raissy *et al*. (2022) reported that the fish group treated with a mixture of therapeutic plant extracts containing common mallow, oak acorn and coriander had a much greater survival rate than the control group, and they found no fish deaths. In contrast to our result, in the report of Bahrekazemi *et al*. (2020b), all treatments, including the control group, had a 100 % survival rate except the fish fed 2% coriander. The flesh yield did not differ significantly ($p>0.05$) among the control, 1.5%, and 2.0% coriander-diet groups. The bioactive compounds in coriander have been reported to improve flesh yield (Sahib *et al*., 2013). Protein accretion is what yields flesh and true growth (Li *et al*., 2020; 2021).

Table 2. Growth performance of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets.

Parameter	Control (0%)	Coriander-supplemented diets			
		D2 (0.5%)	D3 (1.0%)	D4 (1.5%)	D5 (2.0%)
Initial weight (g)	4.64±0.12^{a}	5.09±0.16^{a}	4.69±0.31^{a}	5.04±0.18^{a}	4.93±0.40^{a}
Final weight (g)	23.01±0.03^{b}	31.98±1.14^{a}	23.18±0.29^{b}	22.38±0.59^{b}	20.11±0.59^{c}
Weight gain (g)	18.37±0.13^{b}	26.89±1.30^{a}	18.50±0.29^{b}	17.34±0.77^{bc}	15.18±0.20^{c}
Percentage weight gain	427.35±7.64^{c}	519.26±3.83^{a}	446.73±2.85^{b}	334.34±1.81^{d}	323.98±1.81^{d}
Specific growth rate (% ·d^{-1})	2.95±0.01^{c}	3.28±0.16^{a}	3.02±0.11^{b}	2.63±0.05^{d}	2.56±0.01^{d}
Food fed (g)	22.59±1.16^{b}	27.75±0.31^{a}	22.21±0.54^{b}	22.21±0.52^{b}	21.96±0.55^{b}
Feed conversion ratio	1.23±0.01^{b}	1.04±0.04^{c}	1.20±0.04^{b}	1.28±0.04^{b}	1.44±0.02^{a}
Protein fed (g)	9.04±0.06^{b}	11.10±0,12^{a}	8.88±0.21^{b}	8.88±0.21^{b}	8.78±0.22^{b}
Protein efficiency ratio	2.03±0.01^{b}	2.42±0.09^{a}	2.08±0.07^{b}	1.95±0.07^{b}	1.73±0.03^{c}
Survival rate (%)	73.01±0.64^{e}	84.52±0.31^{d}	93.15±0.96^{b}	97.19±0.31^{a}	88.81±0.87^{c}
Growth-in-length					
Initial length (cm)	8.95±0.11^{a}	9.12±0.18^{a}	9.09±0.29^{a}	9.06±0.33^{a}	8.84±0.35^{a}
Final length (cm)	16.08±0.11^{bc}	17.71±0.20^{a}	16.92±0.28^{ab}	16.26±0.33^{bc}	15.57±0.34^{c}
Absolute growth (cm)	7.13±0.01^{d}	8.59±0.02^{a}	7.83±0.01^{b}	7.20±0.01^{c}	6.73±0.01^{e}
Relative growth rate (%)	79.70±0.86^{bc}	94.21±1.64^{a}	86.36±2.70^{b}	79.64±2.96^{bc}	76.38±3.03^{c}
Thermal growth coefficient (10^{-3})	4.72±0.05^{d}	5.68±0.01^{a}	5.18±0.05^{b}	4.76±0.06^{c}	4.45±0.08^{e}
Body indices					
Flesh yield (%)	63.14±0.76^{b}	66.79±0.10^{a}	66.02±0.35^{a}	64.98±0.63^{ab}	64.73±1.01^{ab}
Viscerosomatic index	9.06±0.24^{a}	7.94±0.26^{b}	7.44±0.22^{bc}	6.19±0.05^{d}	7.02±0.21^{c}
Hepatosomatic index	1.17±0.04^{bc}	1.22±0.02^{b}	1.02±0.03^{d}	1.32±0.01^{a}	1.10±0.03^{c}
Condition factor (K)	0.72±0.01^{a}	0.70±0.02^{a}	0.69±0.01^{a}	0.67±0.01^{a}	0.71±0.02^{a}

Note: Means±SE in the same row superscripted with different lowercase letters are significantly ($p<0.05$) different.

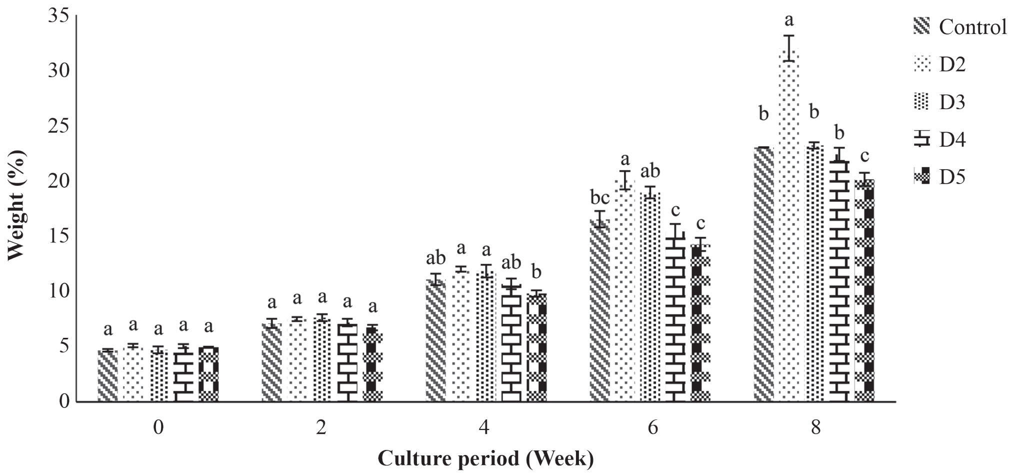

Figure 1. Average body weight of African catfish hybrids (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-based dietary treatments (D2, 0.5%; D3 1.0%, D4, 1.5%, D5, 2.0%) during eight weeks of rearing. Different superscripts above bars denote significant ($p<0.05$) difference among means within each week, error bars indicate SE.

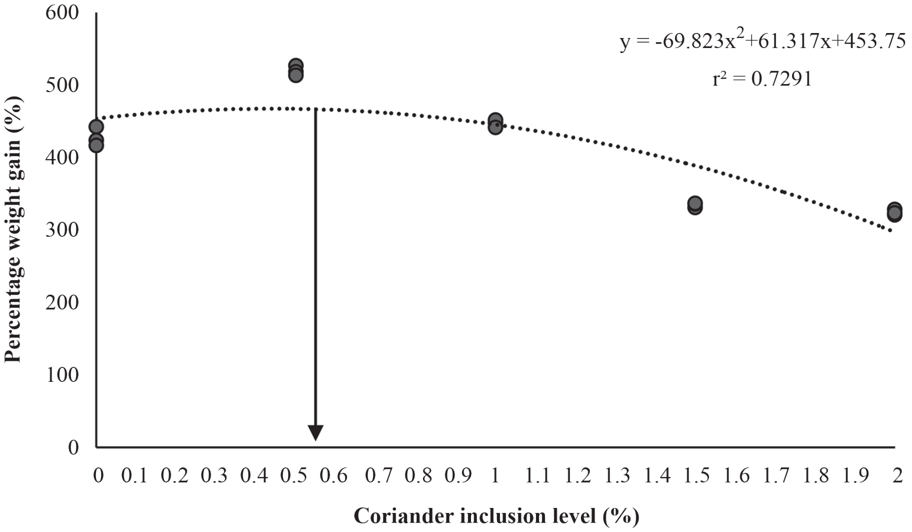

Figure 2. Second-order polynomial of percentage weight gain and dosage of coriander administration in diets of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂).

These functional compounds in coriander enhanced the flesh yield and promoted growth. The growth-in-length parameters of the 0.5 and 1.0% coriander-fed groups were more favorable than the control group in this study, further confirming the growth-promoting effect of the coriander supplementation. The growth enhancement effect of coriander has also been reported by other researchers (Farsani *et al.*, 2019; Abdou Said *et al.*, 2021; Ashry *et al.*, 2022).

Body composition and nutrient retention

The 0.5% coriander dietary group had a significantly higher carcass crude protein than the group fed 1.5 and 2.0% coriander, but were statistically similar to the control group and fish fed 1.0% coriander (Table 3). Fish fed 0.5% coriander had considerably ($p<0.05$) higher energy content than fish in other dietary groups. The 0.5% coriander group considerably ($p<0.05$) outperformed the other diet groups in terms of nutrient retention. The results of the lipid function test (triglycerides and cholesterol), where the 0.5% coriander dietary group had higher values, further established this. Abdou Said *et al.* (2021) reported hypolipidemic and growth-promoting effects of coriander supplementation that were consistent with what was observed in this study.

Hematological parameters

To further comprehend the effects of coriander-based diets on the physiological and health condition of hybrid catfish, more information, such as haematology, is required to support the results of growth performance and nutrient consumption. Hematological markers are significant in determining the health status of fish (Jimoh *et al.*, 2020a; Jimoh, 2021; Sezgin and Aydın, 2021). The hematological parameters of African catfish hybrid fed coriander-based diets are presented in Table 4. Significant variations ($p<0.05$) existed in the primary hematological parameters, principally HcT, HgB, and RBC, with the 0.5% coriander group having the highest values. Compared to the control group, the 0.5%, 1.0% and 1.5% coriander treatment groups had significantly increased HcT. The control group was statistically similar to the 0.5% coriander group in terms of HgB, MCH and MCHC. This demonstrates that fish can consume coriander powder without having a harmful impact on their health or their capacity to fight off disease. In other studies, fish fed coriander extract showed an increase in total hematocrit, erythrocyte and leukocyte count, as well as hemoglobin content (Innocent, 2011; Farsani *et al.*, 2019); results were similar in this study. Numerous internal and external factors have an impact on how different hematological values differ from one another (Fazio, 2019; Ahmed *et al*., 2020a). Changes in these parameters are influenced by a number of variables, including size, feeding, and stocking density (Bacchetta *et al*., 2020), nutritional status (Casanovas *et al*., 2021; Esmaeili, 2021), health status (Weichert *et al*., 2021), handling stress and transportation (Ventura *et al*., 2021; Okey *et al*., 2022). The presence of qualitative phytochemicals in coriander such as steroid, flavonoid, saponin, alkaloid and coumarin could lead to the significantly elevated amount of HcT and RBC observed for 0.5% and 1% coriander-fed groups. Fish have a limit to how much of the bioactive substances in their diets they can compensate for, and once that limit is reached, the bioactive substances start to show their antinutrient properties (Francis *et al*., 2001).

The lymphocytes and neutrophils were significantly (p<0.05) higher among the groups fed with up to 1.5% coriander supplementation than in the control group (Figure 3). Significantly (p<0.05) higher values for WBCs not classified as neutrophils or lymphocytes (i.e., basophils,

Table 3. Body composition (g·100 g^{-1} wet weight) and nutrient retention (% intake) of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets.

Parameter	Initial	Control (0%)	Coriander-supplemented diets			
			D2 (0.5%)	D3 (1.0%)	D4 (1.5%)	D5 (2.0%)
Moisture	78.56±0.38	74.66±0.71^{a}	73.57±1.83^{a}	76.09±0.92^{a}	77.12±0.07^{a}	77.88±0.23^{a}
Crude protein	12.83±0.05	13.78±0.53^{ab}	14.63±0.05^{a}	13.41±0.20^{ab}	13.06±0.07^{b}	12.91±0.03^{b}
Crude lipid	4.93±0.52	5.87±0.30^{a}	6.01±0.02^{a}	5.53±0.38^{a}	5.50±0.22^{a}	4.97±0.08^{a}
Ash	3.68±0.18	5.69±0.13^{a}	5.80±1.76^{a}	4.96±0.73^{a}	4.33±0.15^{a}	4.25±0.13^{a}
Energy (kcal·100 g^{-1})	299.75±6.68	448.82±5.48^{b}	585.94±1.93^{a}	427.04±5.79^{b}	341.24±18.14^{c}	318.69±1.13^{c}
Nutrient retention						
Protein retention		33.14±3.15^{b}	45.07±2.79^{a}	33.26±2.59^{b}	28.09±1.35^{b}	25.86±1.19^{b}
Lipid retention		135.02±12.86^{b}	180.38±11.65^{a}	132.04±10.97^{b}	112.77±5.82^{b}	96.85±4.08^{b}
Energy retention		184.26±14.34^{b}	365.51±7.57^{a}	170.34±9.41^{b}	76.29±8.31^{c}	58.64±5.45^{d}

Note: Means±SE in the same row superscripted with different lowercase letters are significantly (p<0.05) different.

Table 4. Hematological parameters of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets.

Parameter	Control (0%)	Coriander-supplemented diets			
		D2 (0.5%)	D3 (1.0%)	D4 (1.5%)	D5 (2.0%)
HcT (%)	28.99±0.27^{c}	32.47±0.27^{a}	31.72±0.32^{a}	30.28±0.17^{b}	28.80±0.25^{c}
HgB (g·dL^{-1})	9.43±0.14^{a}	9.82±0.22^{a}	8.61±0.18^{b}	7.84±0.25^{c}	7.65±0.13^{c}
RBC (10^{6}·L^{-1})	2.23±0.02^{b}	2.45±0.01^{a}	2.39±0.03^{a}	2.02±0.03^{c}	1.93±0.01^{d}
MCV (fL)	128.29±0.95^{b}	133.11±2.21^{ab}	132.51±2.52^{ab}	141.97±2.26^{a}	133.02±2.63^{ab}
MCH (ρg)	39.81±1.11^{ab}	41.51±0.73^{a}	37.24±0.20^{b}	37.32±0.88^{b}	35.95±1.14^{b}
MCHC (g·dL^{-1})	30.68±0.06^{a}	30.72±0.46^{a}	27.90±0.17^{b}	26.47±0.26^{bc}	27.39±0.36^{c}

Note: Means±SE in the same row superscripted with different lowercase letters are significantly (p<0.05) different; MXD = combined values of the other types of WBC not grouped as lymphocytes (Lym) or neutrophil (Neut); HcT = Hematocrit; HgB = Hemoglobin; RBC = Red Blood Corpuscle; WBC = White Blood Corpuscle; MCV = Mean Corpuscular Volume; MCH = Mean Corpuscular Hemoglobin; MCHC = Mean Corpuscular Hemoglobin Concentration

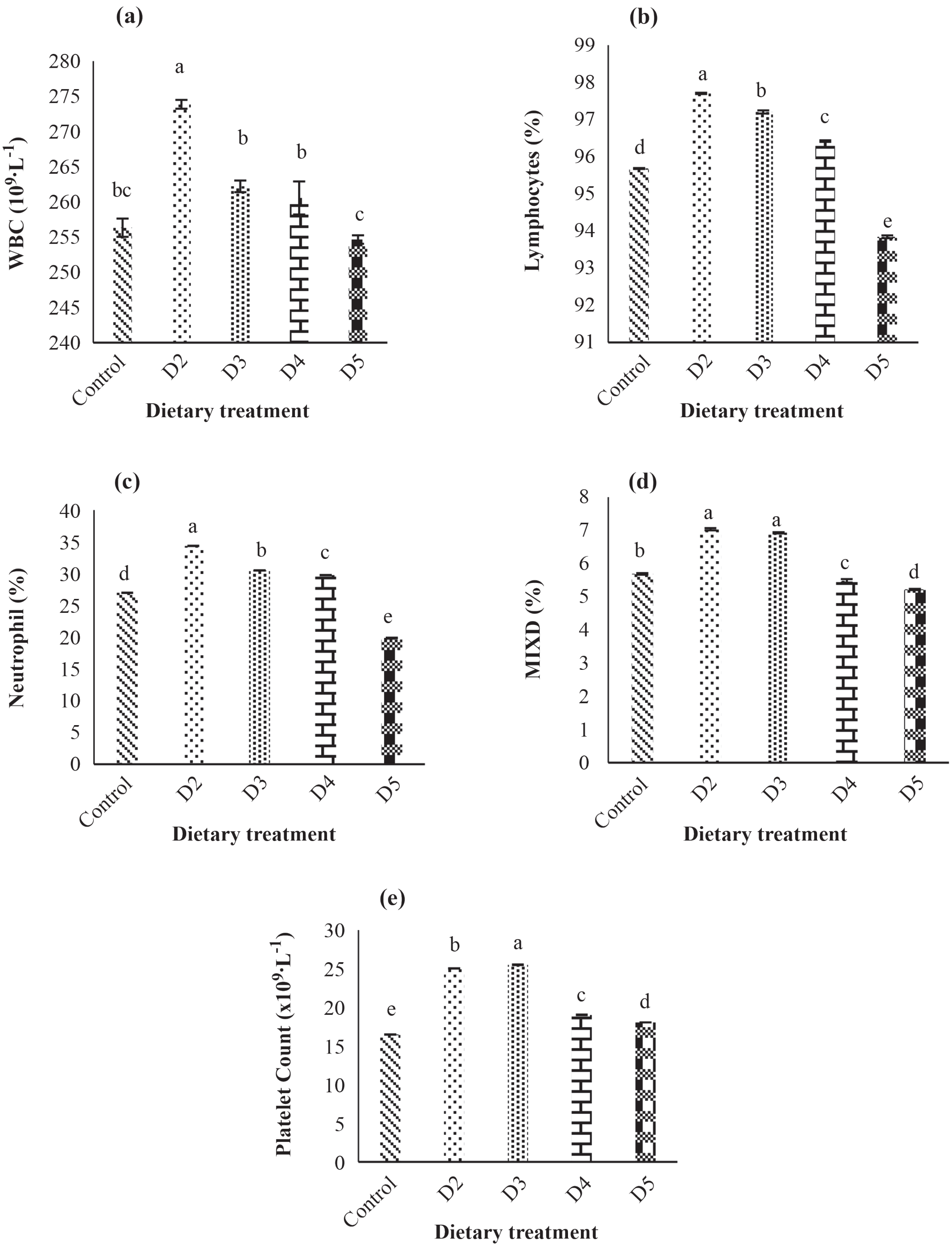

Figure 3. WBC, WBC differential and platelet count of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets (D2, 0.5%; D3, 1.0%, D4, 1.5%, D5, 2.0%). Different superscripts above bars denote significant ($p<0.05$) difference among means, error bars indicate SE. MXD = total value of the other forms of WBC that are not classified as neutrophils or lymphocytes (basophils, monocytes and eosinophils).

monocytes and eosinophils) were recorded among the 0.5 and 1% coriander dietary groups. The 0.5% group had significantly ($p<0.05$) higher WBC than other dietary groups. This potentiates a better capacity of the fish to fight off invading pathogens, as WBC are known components of innate immune responses (Eggestøl *et al*., 2018). In its most basic form, the innate immune system defends an organism from diseases and toxins. As a result, its inhibition and malfunction may increase the occurrence of infections (Whyte, 2007; Lu *et al*., 2019). The lymphocyte results followed similar patterns as the primary hematological parameters in this study. Immunoglobin (Ig) is produced by lymphocytes and aids in pathogen identification (Mirghaed *et al*., 2020). The platelet count of the coriander-fed group was significantly ($p<0.05$) different from that of the control group (Figure 3). Apart from their typical role in blood clotting, platelets are recognized as having an important role in innate immunological and inflammatory responses (Holinstat, 2017). Platelet counts also followed similar patterns as the primary hematological parameters; the platelet counts in the coriander dietary groups were significantly higher, indicating that these fish had better immunological responses. The above findings empirically demonstrated immunostimulatory properties of coriander, as previously reported (Ishida *et al*., 2017; Ahmed *et al*., 2020b). Coriander also possesses antibacterial and antioxidant properties (Mandal and Mandal, 2015; Farsani *et al*., 2019).

Serum biochemistry

Serum biochemistry has been widely used to determine the physiological reaction of animals to dietary composition in addition to hematological indicators (Jimoh, 2020b; Jimoh *et al*., 2021). The serum biochemistry of African catfish hybrids fed diets supplemented with coriander is shown in Table 5. In comparison to the control group, the 0.5 and 1% coriander-fed groups had significantly ($p<0.05$) greater levels of total protein, globulin and A/G ratio. The immunophysiological markers such as total protein and globulin were higher among the 0.5 and 1% coriander group than the control; this potentiates enhanced protein synthesis in the coriander groups, a result similar to the observation of Fawole *et al*. (2022), where higher total protein and globulin were observed when *Jatropha curcas* isolates were fed to rohu carp (*Labeo rohita*). The concentrations of total protein, albumin, and globulin in serum contain quantifiable amounts of the humoral components of the non-specific immune system, suggesting that the non-specific immune system of fishes is enhanced by substantial amounts of these serum proteins (Wang *et al*., 2016; Haghighi *et al*., 2017).

In the current study, 0.5 and 1% coriander-fed groups had higher plasma protein, albumin, and globulin concentrations in contrast to the fish in the control group, showing the capacity of the coriander supplementation to boost fish health and

Table 5. Physiological response of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets.

Parameter	Control (0%)	Coriander-supplemented diets			
		D2 (0.5%)	D3 (1.0%)	D4 (1.5%)	D5 (2.0%)
Total protein ($mg \cdot dL^{-1}$)	8.85 ± 0.05^{c}	9.74 ± 0.07^{a}	9.38 ± 0.03^{b}	8.64 ± 0.02^{d}	8.37 ± 0.03^{e}
Albumin ($mg \cdot dL^{-1}$)	1.22 ± 0.02^{c}	1.99 ± 0.02^{a}	1.62 ± 0.01^{b}	1.09 ± 0.02^{d}	0.72 ± 0.04^{e}
Globulin ($mg \cdot dL^{-1}$)	7.63 ± 0.02^{ab}	7.75 ± 0.04^{a}	7.76 ± 0.03^{a}	7.56 ± 0.03^{b}	7.65 ± 0.02^{ab}
A/G ratio	0.16 ± 0.01^{c}	0.26 ± 0.01^{a}	0.21 ± 0.00^{b}	0.14 ± 0.01^{d}	0.10 ± 0.01^{e}
Total cholesterol ($mg \cdot dL^{-1}$)	26.15 ± 0.45^{b}	34.33 ± 0.25^{a}	21.76 ± 0.29^{c}	19.76 ± 0.33^{d}	17.37 ± 0.22^{e}
Triglycerides ($mg \cdot dL^{-1}$)	162.78 ± 2.29^{a}	179.92 ± 1.57^{a}	138.16 ± 4.18^{b}	108.27 ± 5.77^{c}	100.00 ± 8.39^{c}
Glucose ($mg \cdot dL^{-1}$)	32.20 ± 0.31^{a}	25.41 ± 0.30^{b}	31.90 ± 0.28^{a}	31.93 ± 0.27^{a}	24.10 ± 0.16^{c}

Note: Means±SE in the same row superscripted with different lowercase letters are significantly ($p<0.05$) different.

immunological function. Other researchers have also shown that coriander supplementation had positive effects on serum total protein, albumin, and globulin (Farsani *et al*., 2019; Ahmed *et al*., 2020b; Bahrekazemi *et al*., 2020b; Raissy *et al*., 2022). Increased total protein, albumin, and globulin levels in fish indicate improved health and immunological function (Mohammadi *et al*., 2020; Mabrouk *et al*., 2022). Total protein and globulin in fish are recognized as crucial elements of the innate immune system (Wang *et al*., 2022). Feeding *Onchorhyncus mykiss* 2% coriander seed extract in addition to their diet had considerable stimulation of serum total immunoglobulin (IgM), total serum protein, and globulin, which has a wide range of biological activities in fish (Farsani *et al*., 2019). Fish immunity and antioxidant capacity are two of the many roles played by plasma globulin (Gerwick *et al*., 2002). When coriander-fed fish were compared to control fish, there was no significant difference ($p>0.05$) in their plasma globulin levels. Albumin concentration fluctuations are the primary cause of changes in serum total protein levels, although albumin plays a significantly larger role in serum total protein levels. Globulin could remain constant. The majority of researchers utilize the albumin-globulin ratio as a measure of fish health and immunity (Mohammadiazarm *et al*., 2021). In this study, the 0.5 and 1% coriander-fed fish had significantly heightened albumin-globulin ratio. Increased serum total protein levels, such as in the blood of fish in the 0.5 and 1% dietary groups in this study, have also been associated with higher levels of hematocrit, RBCs, neutrophils and lymphocytes, indicating a favorable impact on fish metabolic, physiological, and immunological state (Fazio, 2019). The enhancement of serum protein in the 0.5 and 1% coriander groups might be related to the phytochemicals in coriander, which are known to enhance fish health (Karmakar *et al*., 2022; Reddy *et al*., 2022).

Albumin is an indicator of liver functionality (Rashidi *et al*., 2020); the distribution of hormones, medications, vitamins, and other vital substances throughout the body is facilitated by albumin, a protein produced in the liver that prevents blood from spilling from blood vessels. The statistically higher values of albumin recorded among the 0.5 and 1% coriander groups might indicate that the liver functionality was improved by coriander supplementation, and that higher capacity to prevent blood from leaking from the blood vessels is conferred on these dietary groups. Our observation is consistent with the report of Adewusi and Afolayan (2009) on male wister rats orally exposed to extract from the roots of *Pelargonium reniforme* Curtis, an Eastern Cape of South Africa herb. Prabu *et al*. (2016) reported that the highest plasma protein, albumin, and globulin concentrations were found in the dietary group fed 3% fucoidan-rich seaweed extract (FRSE); a result similar to what was obtained in our study. The metabolic enzymes ALT, ALP, and AST can be used to assess the condition of the liver when released into the blood due to liver damage (Nguyen and Kim, 2022; Paulino *et al*., 2022). The levels of plasma AST and ALT (liver function test; Figure 4) which were significantly ($p<0.05$) lower in the coriander supplementation group up to 1.5% in our study further attested to this. Animal body indices, particularly the hepatosomatic index (HSI), are important indicators of metabolic activity and the status of the liver's energy reserves, whereas the condition factor is used to assess the general health of fish (Xu and Jing, 2012; M Darweesh *et al*., 2019; El-Agri *et al*., 2022). These morphological biomarkers are essentially corroborative of the overall condition of the fish. The trend of HSI results obtained in this study further confirmed the hepatoprotective effect of the coriander supplementation. The condition factor, which was statistically similar among treatments, indicated that the general health of fish in the experiment was not compromised. ALP may serve as a credible hepatic biomarker for evaluating fish nutrition and overall health. ALP functions as a useful biomarker of stress in biological systems, as well as being important for phosphate hydrolysis and membrane transport (Taheri *et al*., 2017). In this study, significantly lower ($p<0.05$) serum ALP was present in the 0.5% coriander-fed group. The 1 and 1.5% coriander-fed groups were statistically similar ($p>0.05$) to the control group. This trend be explained by the liver's reduced metabolism of energy substrates, which resulted in decreased hepatic ALP activity, decreased trans-membrane transport of ions and water, and decreased blood leakage of these enzymes (Congleton and Wagner, 2006). The reduced or similar ALP found with up to 1.5% coriander supplementation when compared with control showed that the liver cell integrity and function was not compromised by coriander supplementation. This may be attributed to the bioactive compounds in coriander that are known for their hepatoprotective function. The coriander plant contains a number of substances, including phenolic compounds, flavonoids, alkaloids, phospholipids, phytosterols, pyrogallic tannins, and coumarins, which have antioxidant properties that confer hepato- and nephroprotective effect on the fish (Ahmed *et al*., 2020b).

In a similar way, the coriander-fed animals showed substantially lower ($p<0.05$) levels of urea and creatinine (kidney function test; Figure 5) in comparison to the control group in a dose-dependent manner (Figure 5). The urea levels discovered in this study are lower than the average range for fish of 1-3 mmol·L^{-1} reported by Svobodova and Vykusova (1991) for normal physiology, or for the pure *Clarias gariepinus* physiological range of 1-5 mmol·L^{-1} (Myburgh *et al*., 2008).

The decreasing trends in AST, ALT, urea and creatinine with increasing coriander supplementation shows that the fish are well protected from hepato-renal damage; that is, the cellular integrity was maintained as these constitute

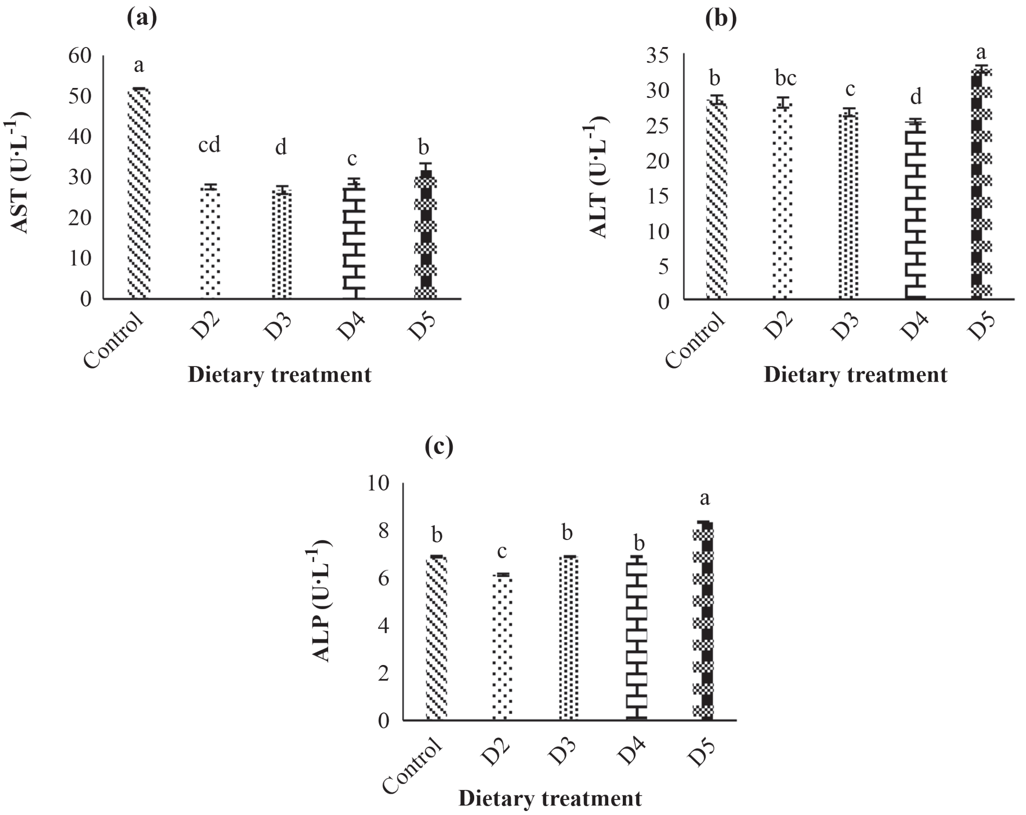

Figure 4. Liver function tests (AST, ALT and ALP) of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets (D2, 0.5%; D3, 1.0%, D4, 1.5%, D5, 2.0%). Different superscripts above bars denote significantly ($p<0.05$) different means, error bars indicate SE. AST = aspartate transaminase; ALT = alanine transaminase; ALP = alkaline phosphatase.

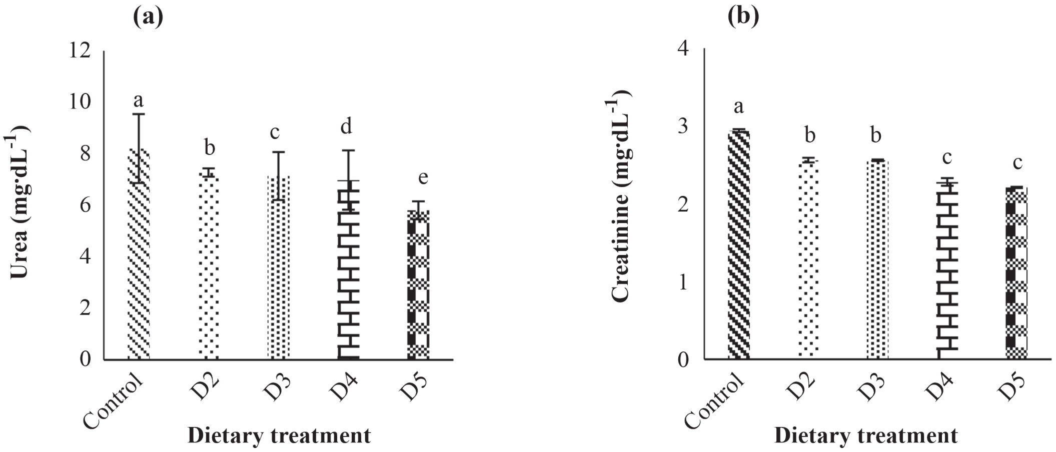

Figure 5. Kidney function tests (urea and creatinine) of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets (D2, 0.5%; D3 1.0%, D4, 1.5%, D5, 2.0%). Different superscripts above bars denote significantly ($p<0.05$) different means, error bars indicate SE.

markers for cellular integrity (Essa *et al*., 2019). This hepato- and nephroprotective effect of coriander may be related to the phenolic compounds and other bioactive elements that it contains (El-Hadary and Ramadan, 2016; Iqbal *et al*., 2018). The 2% coriander diet group had substantially ($p<0.05$) higher ALT and ALP values than the other dietary groups. The 0.5 and 2.0 % coriander-fed groups had reduced physiological stress indices (glucose), which were substantially ($p<0.05$) lower than the control group, while the 1 and 1.5 % coriander-fed group showed statistical similarity ($p>0.05$) with the control. The acknowledged and often-used indicators of fish stress are cortisol and glucose (Odhiambo *et al*., 2020). Cortisol is released into the blood from internal tissues when the fish is exposed to a stressful situation (Raposo de Magalhães *et al*., 2020). In order to meet the increasing needs of the cells for energy, it stimulates the liver to produce glucose by either glycogenolysis (the breakdown of glycogen to glucose) or gluconeogenesis (the breakdown of proteins to glucose) once it reaches the liver (Li *et al*., 2022). Thus an increase in glucose concentration is a secondary response to stress, and the degree of the increase is a measure of stress (Yousefi *et al*., 2019) because glucose is an innate immune parameter that is mediated by stress (Zheng *et al*., 2022). The glucose levels in stressed fish increase as the stress increases (Abdel-Tawwab *et al*., 2019; Paray *et al*., 2020). It has also been found that when fish are stressed, their glucose levels rise as a result of the action of catecholamines, stress-related substances generated by the adrenal cortex (Hoseini and Yousefi, 2019; Yousefi *et al*., 2019). A similar or significantly lower glucose level among some coriander-fed groups in this study when compared to the control implies a similar or reduced stress condition among the fish, and thus enhanced fish health and immunological function. This might plausibly explain why a reduction in triglycerides and cholesterol levels were recorded among the coriander-fed groups in this study. Triglycerides and cholesterol provide cells with energy and can be used as an indicator of energy stores. In times of stress, fish use them as an energy source (Prakash and Verma, 2020). Our findings are within the 3-10 $mmol \cdot L^{-1}$ range that Svobodova and Vykusova (1991) defined as normal for fish blood glucose. Raissy *et al*. (2022) reported a similar trend of results when a combination of medicinal plant extracts containing coriander, common mallow, and oak acorn was used in carp diets, and they attributed the reduction to the extract of the medicinal plants. It is generally accepted that fish in better health would grow faster, since they expend less energy on non-growth functions (Esmaeili, 2021). The lipid function test (triglycerides and cholesterol) yielded similar results among treatments, with the exception that the 0.5% dietary group had a substantially higher level ($p<0.05$) of triglycerides and cholesterol. This substantiates the hypo-cholesteric and hypo-lipidic effect of coriander powder. A similar observation was made by Bahrekazemi *et al*. (2020a) on beluga (*Huso huso*) fed coriander-supplemented diets. The findings of this investigation fall within the typical range of 1-4 $mmol \cdot L^{-1}$ that Svobodova and Vykusova (1991) established for fish triglycerides.

Serum electrolytes

Serum electrolytes, according to Mayer *et al*. (1992), are essential for preserving internal equilibrium. They play a crucial role in cellular metabolism (Karthikeyan *et al*., 2006). Table 6 shows the serum electrolytes of the fish fed the different diets. The serum electrolytes of the fish from the different dietary groups showed significant variation ($p<0.05$). In this study, the blood sodium, calcium, and potassium ions were substantially ($p<0.05$) decreased among the coriander dietary groups with up to 1.5% coriander supplementation as compared to the control group. The blood cells' membrane permeability may be impaired by Ca^{2+} when it is considerably raised (Edori *et al*., 2013). Despite not substantially differing from the control group in terms of potassium and magnesium ions ($p>0.05$), the 0.5% dietary group had the highest concentration of blood magnesium. The remaining dietary groups had substantially ($p<0.05$) lower blood magnesium ions. For blood cells to retain their proper physiological function and osmotic potentials, the ionic composition of fish serum is essential (Edori *et al*., 2013; Handayani *et al*., 2020). As a result of their osmoregulatory capabilities, serum electrolytes might be employed as indicators for monitoring stress levels in fish (Davis, 2006; Shui *et al*., 2018). Na^+ and K^+ are actively transported between blood cells and plasma to keep the blood volume in the body at a healthy level and improve physiological performance (Limbaugh *et al*., 2021; Jimoh *et al*., 2022). The statistically lower levels of serum electrolytes in the test dietary treatment groups than the control further revealed that supplementing coriander in the diets of fish had no detrimental influence on the permeability of blood cells, suggesting that the dietary groups were not under any stress. Fish achieve homeostasis by maintaining a balance between Na^+ and K^+, as these ions take part in the transport of Na^++K^+-ATPase activities (Towle and Mangum, 1985; Edori *et al*., 2013). As a result, the integrity of blood cells was preserved, since serum electrolytes of test dietary treatment groups were generally lower than those in the control group.

Table 6. Serum electrolytes of African catfish hybrid (*Clarias gariepinus* ♀×*Heterobranchus bidorsalis* ♂) fed coriander-supplemented diets.

Parameter	Control (0%)	Coriander-supplemented diets			
		D2 (0.5%)	D3 (1.0%)	D4 (1.5%)	D5 (2.0%)
Na^+ ($mg \cdot L^{-1}$)	12.68 ± 0.02^b	11.48 ± 0.03^d	11.40 ± 0.01^d	11.85 ± 0.04^c	14.40 ± 0.02^a
Ca^{2+} ($mg \cdot L^{-1}$)	1.67 ± 0.02^a	0.76 ± 0.05^b	0.70 ± 0.05^{bc}	0.45 ± 0.02^d	0.58 ± 0.02^c
K^+ ($mg \cdot L^{-1}$)	0.22 ± 0.01^a	0.14 ± 0.02^{ab}	0.08 ± 0.06^b	0.04 ± 0.01^b	0.05 ± 0.01^b
Mg^{2+} ($mg \cdot L^{-1}$)	4.57 ± 0.03^{ab}	4.68 ± 0.03^a	4.51 ± 0.01^b	4.35 ± 0.02^c	4.44 ± 0.05^{bc}

Note: Means±SE in the same row superscripted with different lowercase letters are significantly ($p<0.05$) different.

CONCLUSION

This study found that feeding African catfish with coriander-based diets aided their growth, enhanced flesh yield, supported survival rate and improved blood profile. To ensuremaximal growth of African catfish, the coriander supplementation quantity was optimized at 0.55% using second-order regression. Therefore, the utilization of coriander in fish diets to improve their growth and health profile is advocated.

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LITERATURE CITED

Abd El-Hack, M.E., M.T. El-Saadony, A.M. Saad, H.M. Salem, N.M. Ashry, M.M.A. Ghanima, M. Shukry, A.A. Swelum, A.E. Taha and A.M. El-Tahan. 2021. Essential oils and their nanoemulsions as green alternatives to antibiotics in poultry nutrition: a comprehensive review. **Poultry Science** 101(2) : 101584. DOI: 10.1016/j.psj.2021. 101584.

Abdel-Tawwab, M., M.N. Monier, S.H. Hoseinifar and C. Faggio. 2019. Fish response to hypoxia stress: growth, physiological, and immunological biomarkers. **Fish Physiology and Biochemistry** 45(3): 997-1013.

Abdou Said, A., R.M. Reda and H.M. Abd El-Hady. 2021. Overview of herbal biomedicines with special reference to coriander (*Coriandrum sativum*) as new alternative trend for the development of aquaculture. **Egyptian Journal of Aquatic Biology and Fisheries** 25(2): 539-550.

Adeleke, B., D. Robertson-Andersson, G. Moodley and S. Taylor. 2020. Aquaculture in Africa: A comparative review of Egypt, Nigeria, and Uganda Vis-À-Vis South Africa. **Reviews in Fisheries Science and Aquaculture** 29(2): 167-197.

Adeleke, B., R.A. Deborah, M. Gan and T. Simon. 2021. A quantitative SWOT analyses of key aquaculture players in Africa. **Aquaculture International** 29: 1753-1770.

Adewusi, E. and A. Afolayan. 2009. Safety evaluation of the extract from the roots of *Pelargonium reniforme* Curtis in male wistar rats. **African Journal of Pharmacy and Pharmacology** 3(8): 368-373.

Ahmed, I., Q.M. Reshi and F. Fazio. 2020a. The influence of the endogenous and exogenous factors on hematological parameters in different fish species: A review. **Aquaculture International** 28(3): 869-899.

Ahmed, S.A., R.M. Reda and M. ElHady. 2020b. Immunomodulation by *Coriandrum sativum* seeds (Coriander) and its ameliorative effect on lead-induced immunotoxicity in Nile tilapia (*Oreochromis niloticus* L.). **Aquaculture Research** 51(3): 1077-1088.

Ashry, A.M., M.M. Habiba, M.G. Desouky, A.M. El-Zayat, T. Moonmanee, H.V. Doan and M.A.O. Dawood. 2022. The effects of coriander seeds (*Coriandrum sativum*) on the growth performance, growth hormone, antibacterial capacity, and immune response of European sea bass (*Dicentrarchus labrax*). **Annals of Animal Science** 22(4): 1273-1280.

Association of Official Analytical Chemists (AOAC). 2010. **Official Methods of Analysis.** Association of Official Analytical Chemists, Washington, D.C., USA. 604 pp.

Bacchetta, C., A.S. Rossi, A. Ale and J. Cazenave. 2020. Physiological effects of stocking density on the fish *Piaractus mesopotamicus* fed with red seaweed (*Pyropia columbina*) and β-carotene-supplemented diets. **Aquaculture Research** 51(5): 1992-2003.

Bahrekazemi, M., M. Eslami and J. Nikbakhsh. 2020. The effect of dietary coriander supplementation on growth performance, biochemical responses, carcass proximate composition, and heavy metal accumulation in beluga, *Huso huso*. **Journal of Applied Aquaculture** 34(1): 23-42.

Cardoso-Ugarte, G.A. and M.E. Sosa-Morales. 2021. Essential oils from herbs and spices as natural antioxidants: Diversity of promising food applications in the past decade. **Food Reviews International** 38(1): 403-433.

Casanovas, P., S.P. Walker, H. Johnston, C. Johnston and J.E. Symonds. 2021. Comparative assessment of blood biochemistry and haematology normal ranges between Chinook salmon (*Oncorhynchus tshawytscha*) from seawater and freshwater farms. **Aquaculture** 537: 736464. DOI: 10.1016/j.aquaculture.2021.736464.

Chawla, R. 2014. **Practical Clinical Biochemistry: Methods and Interpretations.** JP Medical Ltd., New Delhi, India. 339 pp.

Ciji, A. and M.S. Akhtar. 2021. Stress management in aquaculture: A review of dietary interventions. **Reviews in Aquaculture** 13(4): 2190-2247.

Colville, J. 2002. **Blood chemistry.** In: Laboratory Procedures for Veterinary Technicians, 4th ed. (ed. C.M. Hendrix), pp. 75-103. Mosby, St. Louis, Missouri, USA.

Congleton, J. and T. Wagner. 2006. Blood-chemistry indicators of nutritional status in juvenile salmonids. **Journal of Fish Biology** 69(2): 473-490.

Dakhlaoui, S., W.A. Wannes, H. Sari, M.B. Hmida, O. Frouja, H. Limam, S. Tammar, S. Bachkouel, M.B. Jemaa and S. Jallouli. 2022. Combined effect of essential oils from lavender (*Lavandula officinalis* L.) aerial parts and coriander (*Coriandrum sativum* L.) seeds on antioxidant, anti-diabetic, anti-cancer and anti-inflammatory activities. **Journal of Essential Oil Bearing Plants** 25(1): 188-199.

Davis, K.B. 2006. Management of physiological stress in finfish aquaculture. **North American Journal of Aquaculture** 68(2): 116-121.

Doumas, B.T. and T. Peters Jr. 1997. Serum and urine albumin: a progress report on their measurement and clinical significance. **Clinica Chimica Acta** 258(1): 3-20.

Doumas, B.T., W.A. Watson and H.G. Biggs. 1971. Albumin standards and the measurement of serum albumin with bromcresol green. **Clinica Chimica Acta** 31(1): 87-96.

Edori, O., A. Dibofori-Orji and E. Edori. 2013. Biochemical changes in plasma and liver of *Clarias gariepinus* exposed to paraquat. **Journal of Pharmaceutical and Biological Sciences** 8(2): 35-39.

Eggestøl, H.Ø., H.S. Lunde, A. Rønneseth, D. Fredman, K. Petersen, C.K. Mishra, T. Furmanek, D.J. Colquhoun, H.I. Wergeland and G.T. Haugland. 2018. Transcriptome-wide mapping of signaling pathways and early immune responses in lumpfish leukocytes upon *in vitro* bacterial exposure. **Scientific Reports** 8(1): 1-14.

El-Agri, A.M., M.A. Emam, H.S. Gaber, E.A. Hassan and S.M. Hamdy. 2022. Integrated use of biomarkers to assess the impact of heavy metal pollution on *Solea aegyptiaca* fish in Lake Qarun. **Environmental Sciences Europe** 34(1): 1-24.

El-Hadary, A.E. and M.F. Ramadan. 2016. Potential protective effect of cold-pressed *Coriandrum sativum* oil against carbon tetrachloride-induced hepatotoxicity in rats. **Journal of Food Biochemistry** 40(2): 190-200.

Esmaeili, M. 2021. Blood performance: A new formula for fish growth and health. **Biology** 10(12): 1236. DOI: 10.3390/biology10121236.

Essa, R., A.M. El Sadek, M.E. Baset, M.A. Rawash, D.G. Sami, M.T. Badawy, M.E. Mansour, H. Attia, M.K. Saadeldin and A. Abdellatif. 2019. Effects of turmeric (*Curcuma longa*) extract in streptozocin-induced diabetic model. **Journal of Food Biochemistry** 43(9): e12988. DOI: 10.1111/jfbc.12988.

Farsani, M.N., S.H. Hoseinifar, G. Rashidian, H.G. Farsani, G. Ashouri and H. Van Doan. 2019. Dietary effects of *Coriandrum sativum* extract on growth performance, physiological and innate immune responses and resistance of rainbow trout (*Oncorhynchus mykiss*) against *Yersinia ruckeri*. **Fish and Shellfish Immunology** 91: 233-240.

Fawole, F.J., N.P. Sahu, N. Shamna, A.A. Adeoye, V. Phulia and B.O. Emikpe. 2022. Effects of dietary detoxified jatropha curcas protein isolate on some physiological parameters, intestine, and liver morphology of *Labeo rohita* fingerlings. **Turkish Journal of Fisheries and Aquatic Sciences** 23(1): 21623. DOI: 10.4194/TRJFAS21623.

Fazio, F. 2019. Fish hematology analysis as an important tool of aquaculture: A review. **Aquaculture** 500: 237-242.

Francis, G., H.P. Makkar and K. Becker. 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. **Aquaculture** 199(3-4): 197-227.

Freitas, J., P. Vaz-Pires and J.S. Câmara. 2020. From aquaculture production to consumption: Freshness, safety, traceability and authentication, the four pillars of quality. **Aquaculture** 518: 734857. DOI: 10.1016/j.aquaculture.2019.734857.

Gerwick, L., R. Steinhauer, S. Lapatra, T. Sandell, J. Ortuno, N. Hajiseyedjavadi and C.J. Bayne. 2002. The acute phase response of rainbow trout (*Oncorhynchus mykiss*) plasma proteins to viral, bacterial and fungal inflammatory agents. **Fish and Shellfish Immunology** 12(3): 229-242.

Ghosh, S., T. Sarkar, S. Pati, Z.A. Kari, H.A. Edinur and R. Chakraborty. 2022. Novel bioactive compounds from marine sources as a tool for functional food development. **Frontiers in Marine Science** 9: 832957. DOI: 10.3389/fmars.2022.832957.

Gule, T.T. and A. Geremew. 2022. Dietary strategies for better utilization of aquafeeds in tilapia farming. **Aquaculture Nutrition** 2022: 9463307. DOI: 10.1155/2022/9463307.

Gupta, A., S.K. Gupta, M. Priyam, M.A. Siddik, N. Kumar, P.K. Mishra, K.K. Gupta, B. Sarkar, T.R. Sharma and A. Pattanayak. 2021. Immunomodulation by dietary supplements: A preventive health strategy for sustainable aquaculture of tropical freshwater fish, *Labeo rohita* (Hamilton, 1822). **Reviews in Aquaculture** 13(4): 2364-2394.

Haghighi, M., M. Sharif Rohani, H. Pourmoghim, M. Samadi, M. Tavoli, M. Eslami and R. Yusefi. 2017. Enhancement of immune responses of rainbow trout (*Oncorhynchus mykiss*) fed a diet supplemented with *Aloe vera* extract. **Iranian Journal of Fisheries Sciences** 17(3): 884-896.

Handayani, K.S., A. Soegianto and J.H. Lignot. 2020. Change of osmoregulatory and hematological parameters in tilapia (*Oreochromis niloticus*) after exposure to sublethal mercury concentrations. **Emerging Contaminants** 6: 337-344.

Hinton, P.R., I. McMurray and C. Brownlow. 2014. **SPSS Explained.** Routledge Taylor and Francis Group, London, UK. 376 pp.

Holinstat, M. 2017. Normal platelet function. **Cancer and Metastasis Reviews** 36(2): 195-198.

Hoseini, S.M. and M. Yousefi. 2019. Beneficial effects of thyme (*Thymus vulgaris*) extract on oxytetracycline-induced stress response, immunosuppression, oxidative stress and enzymatic changes in rainbow trout (*Oncorhynchus mykiss*). **Aquaculture Nutrition** 25(2): 298-309.

Innocent, B.X. 2011. Studies on the immouostimulant activity of *Coriandrum sativum* and resistance to *Aeromonas hydrophila* in *Catla catla*. **Journal of Applied Pharmaceutical Science** 1(7): 132-135.

Iqbal, M.J., M.S. Butt, A. Shehzad and M. Asghar. 2018. Evaluating therapeutic potential of coriander seeds and leaves (*Coriandrum sativum* L.) to mitigate carbon tetrachloride-induced hepatotoxicity in rabbits. **Asian Pacific Journal of Tropical Medicine** 11(3): 209. DOI: 10.4103/1995-7645.228435.

Ishida, M., K. Nishi, N. Kunihiro, H. Onda, S. Nishimoto and T. Sugahara. 2017. Immunostimulatory effect of aqueous extract of *Coriandrum sativum* L. seed on macrophages. **Journal of the Science of Food and Agriculture** 97(14): 4727-4736.

Jimoh, W., M. Shittu, A. Ayeloja and S. Abdulsalami. 2020a. Histology, serum biochemistry and haematological profiles of *Clarias gariepinus* fed diets containing *Luffa cylindrica* seedmeal. **Agricultural Science and Technology** (1313-8820) 12(2): 130-139.

Jimoh, W.A. 2021. Use of toasted sesame seedmeal as a replacer of soybean meal in african catfish diets: Effect on growth, nutrient utilization, body composition, haematology and histopathology of the liver. **Journal of Applied Aquaculture** 34(4): 855-876.

Jimoh, W.A., A.A. Ayeloja, I.E. Mowete, Y.O. Yusuf and M.I. Abubakar. 2022. Aquaculture by-product meal as a fishmeal replacer in African catfish (*Clarias gariepinus*) diet: Effects on serum biochemistry, innate immune response, and oxidative stress markers. **International Journal of Aquatic Biology** 10(2): 119-130.

Jimoh, W.A., A.A. Ayeloja, M.I. Abubakar, Y.O. Yusuf, M.O. Shittu and S.A. Abdulsalami. 2020b. Toasted *Jatropha curcas* seed meal in Nile tilapia (*Oreochromis niloticus*) diet: Effect on growth, economic performance, haematology, serum biochemistry and liver histology. **International Journal of Aquatic Biology** 8(2): 98-108.

Jimoh, W.A., M.S. Kamarudin, M.A. Sulaiman and A.B. Dauda. 2019. Assessment of prebiotic potentials in selected leaf meals of high dietary fibre on growth performance, body composition, nutrient utilization and amylase activities of a tropical commercial carp fingerlings. **Aquaculture Research** 50(11): 3401-3411.

Karmakar, M., D. Jana, T. Manna, A. Banik, P. Raul, K.C. Guchhait, K.C. Mondal, A.K. Panda and C. Ghosh. 2022. **Immunostimulant properties of some commonly used Indian spices and herbs with special reference to region-specific cuisines.** In: Plants and Phytomolecules for Immunomodulation (eds. N.S. Sangwan, M.A. Farag and L.V. Modolo), pp. 191-249. Springer, Singapore.

Karthikeyan, S., M. Jambulingam, P. Sivakumar, A. Shekhar and J. Krithika. 2006. Impact of textile effluents on fresh water fish *Mastacembelus armatus* (Cuv. & Val). **E-journal of Chemistry** 3: 701612. DOI: 10.1155/2006/701612.

Li, X., S. Zheng and G. Wu. 2021. Nutrition and functions of amino acids in fish. **Advances in Experimental Medicine and Biology** 1285: 133-168.

Li, X., S. Zheng, X. Ma, K. Cheng and G. Wu. 2020. Effects of dietary starch and lipid levels on the protein retention and growth of largemouth bass (*Micropterus salmoides*). **Amino Acids** 52(6): 999-1016.

Li, X., T. Han, S. Zheng and G. Wu. 2022. **Hepatic glucose metabolism and its disorders in fish.** In: Recent Advances in Animal Nutrition and Metabolism. Advances in Experimental Medicine and Biology, vol. 1354. (ed. G. Wu), pp. 207-236. Springer, Cham, Switzerland.

Limbaugh, N., N. Romano, N. Egnew, J. Shrivastava, W.M. Bishop and A.K. Sinha. 2021. Coping strategies in response to different levels of elevated water hardness in channel catfish (*Ictalurus punctatus*): Insight into ion-regulatory and histopathological modulations. **Comparative Biochemistry and Physiology Part A: Molecular and Integrative Physiology** 260: 111040.

Lu, X., S. Luan, P. Dai, K. Luo, B. Chen, B. Cao, L. Sun, Y. Yan and J. Kong. 2019. Insights into the molecular basis of immunosuppression and increasing pathogen infection severity of ammonia toxicity by transcriptome analysis in pacific white shrimp *Litopenaeus vannamei*. **Fish and Shellfish Immunology** 88: 528-539.

Lugert, V., G. Thaller, J. Tetens, C. Schulz and J. Krieter. 2016. A review on fish growth calculation: multiple functions in fish production and their specific application. **Reviews in Aquaculture** 8(1): 30-42.

M Darweesh, M., H.M. Gamal El-Dein, S.M. Abou-Shleel and M.A. El-Shirbeny. 2019. Seasonal variation of heavy metals in water and organs of *Oreochromis niloticus* at Rosetta Branch, River Nile, Egypt. **Egyptian Journal of Aquatic Biology and Fisheries** 23(3): 513-526.

Mabrouk, M.M., M. Ashour, A. Labena, M.A. Zaki, A.F. Abdelhamid, M.S. Gewaily, M.A. Dawood, K.M. Abualnaja and H.F. Ayoub. 2022. Nanoparticles of *Arthrospira platensis* improves growth, antioxidative and immunological responses of Nile tilapia (*Oreochromis niloticus*) and its resistance to *Aeromonas hydrophila*. **Aquaculture Research** 53(1): 125-135.

Mandal, S. and M. Mandal. 2015. Coriander (*Coriandrum sativum* L.) essential oil: Chemistry and biological activity. **Asian Pacific Journal of Tropical Biomedicine** 5(6): 421-428.

Maragoor, H., A. Vastrad, S.R. Jambagi and C. Kinnal. 2022. Diversity and abundance of insect pollinator fauna in coriander (*Coriandrum sativum* L.) and ajwain (*Trachyspermum ammi* L.) in north Karnataka. **Indian Journal of Ecology** 49(4): 1449-1455.

Mayer, F., D. Versteeg, M. McKee, L. Folmar, R. Graney, D. McCume and B. Rattner. 1992. **Metabolic products as biomarkers.** In: Biomarkers, Biochemical, Physiological and Histological Markers of Anthropogenic Stress (ed. R.J. Huggett), pp. 5-86. Lewis Publishers, Chelsea, Michigan, USA.

Mirghaed, A.T., S.M. Hoseini, S.H. Hoseinifar and H. Van Doan. 2020. Effects of dietary thyme (*Zataria multiflora*) extract on antioxidant and immunological responses and immune-related gene expression of rainbow trout (*Oncorhynchus mykiss*) juveniles. **Fish and Shellfish Immunology** 106: 502-509.

Mohammadi, G., G. Rashidian, S.H. Hoseinifar, S.S. Naserabad and H. Van Doan. 2020. Ginger (*Zingiber officinale*) extract affects growth performance, body composition, haematology, serum and mucosal immune parameters in common carp (*Cyprinus carpio*). **Fish and Shellfish Immunology** 99: 267-273.

Mohammadiazarm, H., M. Maniat, K. Ghorbanijezeh and N. Ghotbeddin. 2021. Effects of spirulina powder (*Spirulina platensis*) as a dietary additive on Oscar fish, *Astronotus ocellatus*: Assessing growth performance, body composition, digestive enzyme activity, immune-biochemical parameters, blood indices and total pigmentation. **Aquaculture Nutrition** 27(1): 252-260.

Myburgh, J.G., C.J. Botha, D.G. Booyse and F. Reyers. 2008. Provisional clinical chemistry parameters in the African Sharptooth catfish (*Clarias gariepinus*). **Journal of the South African Veterinary Association** 79(4): 156-160.

Network of Aquaculture Centers in Asia-Pacific (NACA). 2008. **Diet Formulator Program** (Excel). http://www.enaca.org/modules/library/publication.php?publication_id=952. Cited 16 Jun 2015.

Naylor, R.L., R.W. Hardy, A.H. Buschmann, S.R. Bush, L. Cao, D.H. Klinger, D.C. Little, J. Lubchenco, S.E. Shumway and M. Troell. 2021. A 20-year retrospective review of global aquaculture. **Nature** 591(7851): 551-563.

Nguyen, H.D. and M.S. Kim. 2022. Effects of chemical mixtures on liver function biomarkers in the Korean adult population: thresholds and molecular mechanisms for non-alcoholic fatty liver disease involved. **Environmental Science and Pollution Research** 29(52): 78555-78587.

Odhiambo, E., P.O. Angienda, P. Okoth and D. Onyango. 2020. Stocking density induced stress on plasma cortisol and whole blood glucose concentration in Nile tilapia fish (*Oreochromis niloticus*) of Lake Victoria, Kenya. **International Journal of Zoology** 2020: 9395268. DOI: 10.1155/2020/9395268.

Okey, I., M. Igiri, J. Ekpenyong and F. Inya. 2022. Haematological and Biochemical responses in African catfish,(*Clarias gariepinus*) juveniles immobilized with clove basil, *(Ocimum gratissimum*) powder Anaesthetic. **Journal Aquatic Sciences and Oceanographye** 3(1): 102-122.

Pandey, A.K., P. Kumar and M. Saxena. 2019. **Feed additives in animal health.** In: Nutraceuticals in Veterinary Medicine (eds. R. Gupta, A. Srivastava and R. Lall), pp. 345-362. Springer, Cham, Switzerland.

Paray, B.A., S.M. Hoseini, S.H. Hoseinifar and H. Van Doan. 2020. Effects of dietary oak (*Quercus castaneifolia*) leaf extract on growth, antioxidant, and immune characteristics and responses to crowding stress in common carp (*Cyprinus carpio*). **Aquaculture** 524: 735276. DOI: 10.1016/j.aquaculture.2020.735276.

Paulino, M.G., P.A. Rossi, F.P. Venturini, D. Tavares, M.M. Sakuragui, G. Moraes, A.P. Terezan, J.B. Fernandes, A. Giani and M.N. Fernandes. 2022. Liver dysfunction and energy storage mobilization in traíra, *Hoplias malabaricus* (Teleostei, Erythrinidae) induced by subchronic exposure to toxic cyanobacterial crude extract. **Environmental Toxicology** 37(11): 2683-2691.

Prabu, D.L., N.P. Sahu, A.K. Pal, S. Dasgupta and A. Narendra. 2016. Immunomodulation and interferon gamma gene expression in sutchi catfish, *Pangasianodon hypophthalmus*: effect of dietary fucoidan rich seaweed extract (FRSE) on pre and post challenge period. **Aquaculture Research** 47(1): 199-218.

Prakash, S. and A.K. Verma. 2020. Effect of arsenic on serum biochemical parameters of a fresh water cat fish, *Mystus vittatus*. **International Journal of Biological Innovations** 2(1): 11-19.

Raissy, M., H. Ghafarifarsani, S.H. Hoseinifar, E.R. El-Haroun, S.S. Naserabad and H. Van Doan. 2022. The effect of dietary combined herbs extracts (oak acorn, coriander, and common mallow) on growth, digestive enzymes, antioxidant and immune response, and resistance against *Aeromonas hydrophila* infection in common carp, *Cyprinus carpio*. **Aquaculture** 546: 737287. DOI: 10.1016/j.aquaculture.2021.737287.

Raposo de Magalhães, C., D. Schrama, A.P. Farinha, D. Revets, A. Kuehn, S. Planchon, P.M. Rodrigues and M. Cerqueira. 2020. Protein changes as robust signatures of fish chronic stress: a proteomics approach to fish welfare research. **BMC Genomics** 21(1): 1-16.

Rashidi, M., M. Rashidmayvan, S. Alboativi and F. Amiri. 2020. The effect of fish oil supplements on serum levels of albumin, lipid profiles, and kidney function in patients with hypoalbuminemia admitted to an intensive care unit, Randomized controlled trial. **PharmaNutrition** 13: 100197. DOI: 10.1016/j.phanu.2020.100197.

Reddy, S., P. Barathe, K. Kaur, U. Anand, V. Shriram and V. Kumar. 2022. **Antimicrobial resistance and medicinal plant products as potential alternatives to antibiotics in animal husbandry.** In: Antimicrobial Resistance (eds. V. Kumar, V. Shriram, A. Paul and M. Thakur), pp. 357-384. Springer, Singapore.

Reitman, S. and S. Frankel. 1957. A colorimetric method for the determination of serum glutamic oxalacetic and glutamic pyruvic transaminases. **American Journal of Clinical Pathology** 28(1): 56-63.

Ren, H., H. Jia, S. Kim, M. Maita, S. Sato, M. Yasui, H. Endo and T. Hayashi. 2006. Effect of chinese parsley *Coriandrum sativum* and chitosan on inhibiting the accumulation of cadmium in cultured rainbow trout *Oncorhynchus mykiss*. **Fisheries Science** 72(2): 263-269.

Sahib, N.G., F. Anwar, A.H. Gilani, A.A. Hamid, N. Saari and K.M. Alkharfy. 2013. Coriander (*Coriandrum sativum* L.): A potential source of high-value components for functional foods and nutraceuticals- A review. **Phytotherapy Research** 27(10): 1439-1456

Scott, R.W. 1979. Colorimetric determination of hexuronic acids in plant materials. **Analytical Chemistry** 51(7): 936-941.

Searcy, R. 1967. A new photometric method for serum urea nitrogen determination. **American Journal of Medical Technology** 33: 15-20.

Sezgin, A. and B. Aydın. 2021. Effect of replacing dietary soybean meal with pumpkin (*Cucurbita pepo*) seed cake on growth, feed utilization, haematological parameters and fatty acid composition of mirror carp (*Cyprinus carpio*). **Aquaculture Research** 52(11): 5870-5881.

Shui, C., Y. Shi, X. Hua, Z. Zhang, H. Zhang, G. Lu and Y. Xie. 2018. Serum osmolality and ions, and gill Na^+/K^+-ATPase of spottedtail goby *Synechogobius ommaturus* (R.) in response to acute salinity changes. **Aquaculture and Fisheries** 3(2): 79-83.

Steinberg, C.E. 2022. **Aquatic Animal Nutrition: Organic Macro-and Micro-Nutrients.** Springer, Cham, Switzerland. 1084 pp.

Svobodova, Z. and B. Vykusova. 1991. **Diagnostics, Prevention and Therapy of Fish Diseases and Intoxications: Manual for International Training Course on Fresh-Water Fish Diseases and Intoxications: Diagnostics, Prophylaxis and Therapy.** Research Institute of Fish Culture and Hydrobiology, Vodnany, Czech Republic. 270 pp.

Taheri, S., M. Banaee, B.N. Haghi and M. Mohiseni. 2017. Effects of dietary supplementation of zinc oxide nanoparticles on some biochemical biomarkers in common carp (*Cyprinus carpio*). **International Journal of Aquatic Biology** 5(5): 286-294.

Talapatra, S.N., S. Dasgupta, G. Guha, M. Auddy and A. Mukhopadhyay. 2010. Therapeutic efficacies of *Coriandrum sativum* aqueous extract against metronidazole-induced genotoxicity in *Channa punctatus* peripheral erythrocytes. **Food and Chemical Toxicology** 48(12): 3458-3461.

Tomlinson, L., L.I. Boone, L. Ramaiah, K.A. Penraat, B.R. von Beust, M. Ameri, F.M. Poitout-Belissent, K. Weingand, H.C. Workman and A.D. Aulbach. 2013. Best practices for veterinary toxicologic clinical pathology, with emphasis on the pharmaceutical and biotechnology industries. **Veterinary Clinical Pathology** 42(3): 252-269.

Toro, G. and P.G. Ackermann. 1975. **Practical Clinical Chemistry.** Little Brown and Company, Boston, USA. 779 pp.

Towle, D.W. and C.P. Mangum. 1985. Ionic regulation and transport atpase activities during the molt cycle in the blue crab *Callinectes sapidus*. **Journal of Crustacean Biology** 5(2): 216-222.

Tran, N., K.M. Shikuku, V. Hoffmann, C.J. Lagerkvist, L. Pincus, S.L. Akintola, K.A. Fakoya, O.F. Olagunju and C. Bailey. 2022. Are consumers in developing countries willing to pay for aquaculture food safety certification? Evidence from a field experiment in Nigeria. **Aquaculture** 550: 737829. DOI: 10.1016/j.aquaculture.2021.737829.

Turchini, G.M., J.T. Trushenski and B.D. Glencross. 2019. Thoughts for the future of aquaculture nutrition: realigning perspectives to reflect contemporary issues related to judicious use of marine resources in aquafeeds. **North American Journal of Aquaculture** 81(1): 13-39.

Ventura, A.S., A.M.D. Araújo Gabriel, J.R. Gandra, I.Z. Noia, J.A. Povh and G.T. Jerônimo. 2021. Thermal dynamics and physiological implications in pacu *Piaractus mesopotamicus* anaesthetised with *Ocimum basilicum* essential oil. **International Aquatic Research** 13(4): 261-270.

Wang, E., X. Chen, K. Wang, J. Wang, D. Chen, Y. Geng, W. Lai and X. Wei. 2016. Plant polysaccharides used as immunostimulants enhance innate immune response and disease resistance against *Aeromonas hydrophila* infection in fish. **Fish and Shellfish Immunology** 59: 196-202.

Wang, E., X. Chen, T. Liu and K. Wang. 2022. Effect of dietary *Ficus carica* polysaccharides on the growth performance, innate immune response and survival of crucian carp against *Aeromonas hydrophila* infection. **Fish and Shellfish Immunology** 120: 434-440.

Weichert, F.G., C. Axén, L. Förlin, P.A. Inostroza, U. Kammann, A. Welling, J. Sturve and N. Asker. 2021. A multi-biomarker study on Atlantic salmon (*Salmo salar* L.) affected by the emerging Red Skin Disease in the Baltic Sea. **Journal of Fish Diseases** 44(4): 429-440.

Whyte, S.K. 2007. The innate immune response of finfish-a review of current knowledge. **Fish and Shellfish Immunology** 23(6): 1127-1151.

Xu, J. and N. Jing. 2012. Effects of 2,4-dinitrotoluene exposure on enzyme activity, energy reserves and condition factors in common carp (*Cyprinus carpio*). **Journal of Hazardous Materials** 203-204: 299-307.

Yousefi, M., S.M. Hoseini, Y.A. Vatnikov, E.V. Kulikov and S.G. Drukovsky. 2019. Rosemary leaf powder improved growth performance, immune and antioxidant parameters, and crowding stress responses in common carp (*Cyprinus carpio*) fingerlings. **Aquaculture** 505: 473-480.

Zheng, T., Z. Song, Y. Tao, J. Qiang, J. Ma, S. Lu and P. Xu. 2022. Transport stress induces innate immunity responses through TLR and NLR signaling pathways and increases mucus cell number in gills of hybrid yellow catfish (*Tachysurus fulvidraco* ♀×*Pseudobagrus vachellii* ♂). **Fish and Shellfish Immunology** 127: 166-175.