



## Research Paper

# Growth Performance and Nutrient Utilization of African Catfish (*Clarias gariepinus*) Fingerlings Fed Diets Containing Giloy (*Tinospora cordifolia*) Root Powder

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### Abstract

This study evaluated the effects of dietary inclusion of *Tinospora cordifolia* root meal on the growth performance and nutrient utilization of *Clarias gariepinus* fingerlings during a 70-day feeding trial. A total of 225 fingerlings (initial mean weight:  $3.95 \pm 0.10$  g) were randomly distributed into 15 glass tanks at a stocking density of 15 fish per tank, with three replicates per treatment. The root meal was incorporated at 0.0, 0.5, 1.0, 1.5, and 2.0 g/100 g diet for treatments T1 (control), T2, T3, T4, and T5, respectively. Significant differences ( $P < 0.05$ ) were observed in growth performance, with fish fed the 1.0 g/100 g diet (T3) recording the highest weight gain, feed utilization, and nutrient efficiency. Growth performance declined at higher inclusion levels. Polynomial regression analysis of weight gain data estimated an optimum dietary inclusion level of approximately 0.9 g/100 g *T. cordifolia* root meal for *C. gariepinus*. Survival was high and unaffected by dietary treatment. Moderate inclusion levels enhanced hematological indices associated with oxygen transport and immune response, while serum biochemical parameters reflected improved metabolic activity, protein utilization, and physiological status. Carcass analysis showed increased protein deposition and reduced lipid content, particularly in fish fed the T3 diet. The findings demonstrate that *T. cordifolia* root meal is a safe and effective phytogenic feed additive that enhances growth performance, physiological condition, and carcass quality in *C. gariepinus*, thereby supporting sustainable aquaculture production.

## 1. Introduction

African catfish (*Clarias gariepinus*) is one of the most widely cultured freshwater fish species owing to its rapid growth, high survival rate, adaptability to diverse environmental conditions, and efficient feed utilization (Mbokane et al., 2022; Abubakar et al., 2026). However, the high cost of conventional feed ingredients, particularly fishmeal and soybean meal, remains a major constraint to profitable aquaculture production. This has prompted increasing interest in alternative feed resources and functional feed additives capable of enhancing growth performance, feed efficiency, fish health, and overall production sustainability (Nwanna et al., 2020; Gbadamosi, 2026). Among these alternatives, medicinal plants have gained considerable attention as phytogenic feed additives because of their antioxidant, antimicrobial, immunostimulatory, and growth-promoting properties. These beneficial effects are primarily attributed to bioactive compounds such as flavonoids, alkaloids, saponins, glycosides, and phenolic compounds, which improve digestive enzyme activity and nutrient absorption, gut health, immune function, and antioxidant status in cultured fish (Hoseinifar et al., 2017; Abdel-Latif et al., 2020).

Consequently, phytogenic additives are increasingly being considered sustainable alternatives to synthetic growth promoters and antibiotics in aquaculture. *Tinospora cordifolia* (Willd.) Miers, commonly known as Giloy or Guduchi, is a medicinal plant rich in alkaloids, flavonoids, glycosides, diterpenoid lactones, and polysaccharides. These phytochemicals exhibit antioxidant, antimicrobial, anti-inflammatory, hepatoprotective, and immunomodulatory activities (Kashyap et al., 2022).

Dietary supplementation with *T. cordifolia* has been reported to improve growth performance, feed utilization, antioxidant capacity, immune response, and disease resistance in several cultured fish species, including *Oreochromis mossambicus*, carp, and *Pangasius sutchi* (Alexander et al., 2010). Similar beneficial effects have also been documented in poultry and livestock production, further demonstrating its potential as a natural growth promoter and immunostimulant (Kashyap et al., 2022). Despite these promising findings, information on the dietary use of *T. cordifolia* root meal in African catfish (*Clarias gariepinus*) remains scarce, particularly regarding its effects on growth performance, nutrient utilization, hematological indices, serum biochemical characteristics, and carcass composition. Therefore, this study evaluated the effects of dietary inclusion of *T.*

*cordifolia* root meal on the growth performance, nutrient utilization, physiological responses, and carcass composition of *C. gariepinus* fingerlings to determine its potential as a sustainable phyto-genic feed additive for African catfish production.

## 2. Materials and Methods

### 2.1 Experimental Site and Duration

The study was conducted over a period of 70 days at the Research Laboratory of the Department of Fisheries and Aquaculture Technology, Federal University of Technology, Akure (FUTA), Ondo State, Nigeria. The laboratory is located at approximately 7°18' N latitude and 5°08' E longitude. The experiment was carried out under controlled laboratory conditions to ensure uniform environmental conditions throughout the feeding trial.

### 2.2 Plant Material

Fresh roots of *Tinospora cordifolia* were sourced from Oba Market in Akure, Ondo State, Nigeria. The plant material was identified and authenticated by a botanist in the Department of Crop, Soil and Pest Management of the Federal University of Technology, Akure, Ondo State, Nigeria. The roots were thoroughly washed to remove adhering soil particles and air-dried at room temperature to preserve heat-sensitive bioactive compounds. After drying, the roots were ground into a fine powder using a laboratory grinder (or hammer mill) and stored in an airtight container at 4°C until incorporation into the experimental diets.

### 2.3 Experimental Fish

Apparently healthy *Clarias gariepinus* fingerlings were obtained from the Federal University of Technology Fish Farm, Akure, Ondo State, Nigeria. The fish were acclimated to the experimental conditions for seven days before the commencement of the feeding trial. During the acclimation period, they were fed a control diet containing 40% crude protein to apparent satiation twice daily.

### 2.4 Experimental Diets

Five isonitrogenous experimental diets containing approximately 40% crude protein were formulated with graded levels of *T. cordifolia* root meal as a dietary additive. The root meal was incorporated at 0.0, 0.5, 1.0, 1.5, and 2.0 g/100 g diet for treatments T1 (control), T2, T3, T4, and T5, respectively. The diets were prepared using fish meal, soybean meal, groundnut cake, yellow maize, methionine, lysine, vitamin-mineral premix, vegetable oil, and starch (Table 1). All ingredients were thoroughly mixed and pelleted using a Hobart A-200T mixer/pelleting machine (Hobart Manufacturing Ltd., UK) fitted with a 2-mm die. The pellets were air-dried at room temperature for 48 h, packaged in labelled polyethylene bags, sealed, and stored at 4°C until use.

### 2.5 Experimental Design and Management

The experiment was conducted using a completely randomized design. Following the acclimation period, all fish were weighed, and 225 healthy *Clarias gariepinus* fingerlings with an average weight of  $3.95 \pm 0.04$  g were randomly selected and distributed into 15 glass tanks (70 × 45 × 45 cm) at a density of 15 fish per tank, representing five treatments with three replicates each. The experimental diets were administered twice daily to apparent satiation over a period of 70 days. Water temperature (°C), dissolved oxygen (mg L<sup>-1</sup>), and pH were monitored twice weekly throughout the experimental period. Temperature was measured using a mercury-in-glass thermometer, dissolved oxygen was determined using a portable dissolved oxygen meter, while pH was measured using a calibrated digital pH meter. Partial water exchange was carried out every three days to maintain suitable water quality throughout the experiment. Proximate analysis was carried out on the plant and experimental diets, and fish according to AOAC (2005).

### 2.6 Blood Collection

At the end of the 70-day feeding trial, three fish were randomly selected from each replicate tank (nine fish per treatment) for blood sampling. Fish were fasted for 24 h prior to sampling to minimize postprandial variation in blood metabolites. The fish were carefully netted and anaesthetized using tricaine methanesulfonate (MS-222) before blood collection. Blood samples were collected by caudal vein puncture using sterile disposable syringes fitted with 23-gauge needles. Approximately 2–3 mL of blood was collected from each fish. Blood intended for hematological analysis was transferred into EDTA-coated tubes, while samples for serum biochemical analysis were placed in plain tubes and allowed to clot before centrifugation at 3,000 rpm for 10 minutes to obtain serum (Bisht et al. 2020).

### 2.7 Haematological and Serum Biochemical Analyses

Haematological parameters including haemoglobin concentration (Hb), packed cell volume (PCV), red blood cell count (RBC), white blood cell count (WBC), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) were determined according to the procedures described by Svobodova et al. (1991). Serum biochemical parameters including glucose, total protein, albumin, globulin, and cholesterol were determined using standard commercial diagnostic kits following the manufacturers' instructions and procedures described by Morgan and Iwama (1997).

### 2.8 Growth Performance and Feed Utilization Indices

Growth performance and feed utilization parameters were calculated according to the methods described by Solomon et al. (2017). At the end of the feeding trial, the fish were counted and weighed. Thereafter, growth performance parameters and feed utilization indices were determined using the following formulas:

#### Specific Growth Rate (SGR)

This was calculated from data on changes in body weight over a given time interval:

$$\text{SGR (\%/day)} = \frac{\text{LN Final Weight} - \text{LN Initial Weight}}{\text{Number of days}} \times 100$$

#### Feed intake

Feed intake was determined as the cumulative amount of feed consumed by fish throughout the experimental period.

$$\text{Feed Conversion Ratio (FCR)} = \frac{\text{Feed intake (g)}}{\text{Weight gain (g)}}$$

$$\text{Feed Efficiency Ratio (FER)} = \frac{\text{Weight gain (g)}}{\text{Feed intake (g)}}$$

$$\text{Survival (\%)} = \frac{\text{Number of fish harvested}}{\text{Number of fish stocked}} \times 10$$

### 2.9 Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) to compare the means of different treatment groups. Tukey's post-hoc test was used to identify significant differences between the treatment groups. All statistical analyses were conducted using SPSS (Version 23), with a significance level set at  $P < 0.05$ .

## 3. Results

### 3.1 Proximate Composition of *T. cordifolia* Root

The proximate composition of *T. cordifolia* root showed a high carbohydrate content (57.26%), low lipid content (1.97%), and a crude protein content of 6.84% on a dry matter basis (Table 2).

### 3.2 Proximate Composition of Experimental Diets

Table 3 presents the proximate composition of the experimental diets fed to *Clarias gariepinus* fingerlings. Ash content ranged from 9.50 to 10.29%, with the highest value recorded in T4 and the lowest in T1. Crude fiber increased progressively with increasing inclusion levels of *Tinospora cordifolia* root meal, while crude lipid, moisture, and crude protein contents ranged from 7.34–7.63%, 10.04–10.90%, and 39.56–40.07%, respectively.

### 3.3 Water Quality Parameters

Water quality was consistently monitored throughout the 70-day feeding trial. Dissolved oxygen levels ranged from 6.25 to 6.28 mg/L, temperature varied between 27.53 and 27.58°C, and pH values ranged from 7.32 to 7.37 (Table 4). No significant differences ( $P > 0.05$ ) were observed among treatments, indicating that dietary inclusion of *T. cordifolia* root meal had no adverse effect on water quality.

### 3.4 Growth Performance of the Experimental Fish

The growth performance and nutrient utilization of *C. gariepinus* fed diets containing varying levels of *T. cordifolia* root meal are presented in Table 5. Fish fed diets containing *T. cordifolia* root meal exhibited higher final weight and weight gain than the control, with the highest values recorded in T3 (1.0 g/100 g diet). However, performance declined slightly at higher inclusion levels. Polynomial regression analysis of weight gain indicated an optimum inclusion level of approximately 0.9 g/100 g diet. Specific growth rate showed slight numerical improvements in the treated groups, particularly T3. Feed intake was also highest in T3, suggesting enhanced diet acceptability. Feed conversion ratio and feed efficiency ratio showed numerical improvements in the additive-fed groups, although differences were not significant ( $P > 0.05$ ). Survival remained high and was not significantly affected by dietary treatment, indicating that *T. cordifolia* root meal was safe at the tested inclusion levels.

### 3.5 Haematological Parameters

Table 6 presents the hematological parameters of *Clarias gariepinus* fingerlings fed diets containing *T. cordifolia* root meal. Haemoglobin, red blood cell, and white blood cell counts were generally higher in the additive-fed groups than in the control, with peak values recorded in T3 (RBC) and T5 (Hb and WBC), indicating improved oxygen transport and immune status. Packed cell volume remained relatively stable across treatments, suggesting that dietary inclusion of *T. cordifolia* root meal did not adversely affect blood integrity. Mean corpuscular volume, mean corpuscular haemoglobin, and mean corpuscular haemoglobin concentration showed only slight variations among treatments, indicating stable erythrocyte characteristics and the absence of adverse physiological effects.

**Table 1:** Ingredient compositions (g/100 g diet) of the experimental diets

| Ingredients          | T1 (0.0) | T2 (0.5) | T3 (1.0) | T4 (1.5) | T5 (2.0) |
|----------------------|----------|----------|----------|----------|----------|
| Fish meal            | 25.4     | 25.4     | 25.4     | 25.4     | 25.4     |
| Soybean meal         | 28.2     | 28.2     | 28.2     | 28.2     | 28.2     |
| Groundnut cake       | 23.5     | 23.5     | 23.5     | 23.5     | 23.5     |
| Yellow maize         | 13.1     | 13.1     | 13.1     | 13.1     | 13.1     |
| Vitamin-Mineral mix  | 2.30     | 2.30     | 2.30     | 2.30     | 2.30     |
| Vegetable oil        | 5.00     | 5.00     | 5.00     | 5.00     | 5.00     |
| Methionine           | 0.30     | 0.30     | 0.30     | 0.30     | 0.30     |
| Lysine               | 0.20     | 0.20     | 0.20     | 0.20     | 0.20     |
| Starch               | 2.00     | 2.00     | 2.00     | 2.00     | 2.00     |
| <i>T. cordifolia</i> | 0.0      | 0.5      | 1.0      | 1.5      | 2.0      |

**Table 2:** Proximate composition of *T. cordifolia* root

| Parameters (%)        | Values |
|-----------------------|--------|
| Ash                   | 7.32   |
| Fibre                 | 21.5   |
| Lipid                 | 1.97   |
| Moisture              | 5.12   |
| Protein               | 6.84   |
| Nitrogen Free Extract | 57.26  |

**Table 3:** Proximate composition of experimental diets

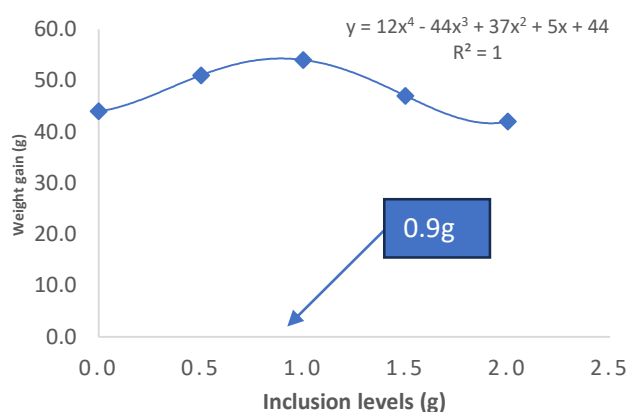
| Parameters (%)        | T1 (0.0) | T2 (0.5) | T3 (1.0) | T4 (1.5) | T5 (2.0) |
|-----------------------|----------|----------|----------|----------|----------|
| Ash                   | 9.50     | 10.06    | 9.72     | 10.29    | 10.3     |
| Fiber                 | 2.19     | 2.35     | 2.49     | 2.57     | 2.62     |
| Lipids                | 7.39     | 7.62     | 7.34     | 7.63     | 7.59     |
| Moisture              | 10.40    | 10.50    | 10.90    | 10.70    | 10.60    |
| Protein               | 39.56    | 40.01    | 40.07    | 40.03    | 40.05    |
| Nitrogen Free Extract | 30.96    | 29.46    | 29.48    | 28.78    | 28.84    |

**Table 4:** Water quality parameters of *Clarias gariepinus* fingerlings fed diets containing *Tinospora cordifolia* root meal

| Treatment | Dissolved oxygen (mg/L) | Temperature (°C)        | pH                     |
|-----------|-------------------------|-------------------------|------------------------|
| T1 (0.0)  | 6.26±0.05 <sup>a</sup>  | 27.55±0.23 <sup>a</sup> | 7.37±0.01 <sup>a</sup> |
| T2 (0.5)  | 6.25±0.01 <sup>a</sup>  | 27.53±0.08 <sup>a</sup> | 7.32±0.03 <sup>a</sup> |
| T3 (1.0)  | 6.28±0.13 <sup>a</sup>  | 27.57±0.02 <sup>a</sup> | 7.35±0.02 <sup>a</sup> |
| T4 (1.5)  | 6.25±0.30 <sup>a</sup>  | 27.54±0.00 <sup>a</sup> | 7.36±0.01 <sup>a</sup> |
| T5 (2.0)  | 6.28±0.05 <sup>a</sup>  | 27.58±0.04 <sup>a</sup> | 7.32±0.06 <sup>a</sup> |

**Table 5:** Growth Parameters and Nutrient Utilization

| Parameters   | T1 (0.0)                | T2 (0.5)                 | T3 (1.0)                | T4 (1.5)                | T5 (2.0)                |
|--------------|-------------------------|--------------------------|-------------------------|-------------------------|-------------------------|
| IW (g)       | 3.95±0.04 <sup>a</sup>  | 3.95±0.02 <sup>a</sup>   | 3.96±0.03 <sup>a</sup>  | 3.95±0.04 <sup>a</sup>  | 3.96±0.03 <sup>a</sup>  |
| FW (g)       | 46.69±1.35 <sup>a</sup> | 48.42±0.65 <sup>ab</sup> | 58.31±2.07 <sup>d</sup> | 54.87±1.05 <sup>c</sup> | 51.24±1.67 <sup>b</sup> |
| WG (g)       | 42.74±1.35 <sup>a</sup> | 44.47±0.66 <sup>ab</sup> | 54.35±2.11 <sup>d</sup> | 50.92±1.07 <sup>c</sup> | 47.28±1.67 <sup>b</sup> |
| SGR (%/day)  | 3.53±0.21 <sup>a</sup>  | 3.58±0.08 <sup>a</sup>   | 3.84±0.23 <sup>a</sup>  | 3.76±0.12 <sup>a</sup>  | 3.66±0.20 <sup>a</sup>  |
| FI (g/fish)  | 81.74±1.92 <sup>a</sup> | 83.76±1.65 <sup>ab</sup> | 96.27±3.16 <sup>d</sup> | 92.54±1.70 <sup>c</sup> | 87.42±3.80 <sup>b</sup> |
| FCR          | 1.91±0.19 <sup>a</sup>  | 1.88±0.03 <sup>a</sup>   | 1.77±0.05 <sup>a</sup>  | 1.82±0.14 <sup>a</sup>  | 1.85±0.08 <sup>a</sup>  |
| FER          | 0.52±0.06 <sup>a</sup>  | 0.53±0.01 <sup>a</sup>   | 0.56±0.01 <sup>a</sup>  | 0.55±0.03 <sup>a</sup>  | 0.54±0.02 <sup>a</sup>  |
| Survival (%) | 91.10±4.45 <sup>a</sup> | 95.55±4.45 <sup>a</sup>  | 93.33±3.85 <sup>a</sup> | 95.55±4.45 <sup>a</sup> | 93.33±3.85 <sup>a</sup> |

**Figure 1:** Fourth-degree polynomial regression showing the relationship between dietary *T. cordifolia* root meal inclusion level and weight gain of *Clarias gariepinus* fingerlings.**Table 6:** Haematological parameters of *C. gariepinus* fed *T. cordifolia* root meal

| Parameters                               | T1 (0.0)               | T2 (0.5)                | T3 (1.0)                | T4 (1.5)                | T5 (2.0)               |
|------------------------------------------|------------------------|-------------------------|-------------------------|-------------------------|------------------------|
| Hb (g/100ml)                             | 7.03±0.04 <sup>a</sup> | 7.73±0.09 <sup>a</sup>  | 9.96±0.05 <sup>b</sup>  | 8.60±0.11 <sup>ab</sup> | 9.07±0.06 <sup>b</sup> |
| PCV (%)                                  | 30.7±1.20 <sup>a</sup> | 32.1±0.33 <sup>ab</sup> | 31.8±0.88 <sup>ab</sup> | 34.5±0.01 <sup>b</sup>  | 33.7±1.20 <sup>b</sup> |
| WBC (x10 <sup>3</sup> /mm <sup>3</sup> ) | 4.90±0.12 <sup>a</sup> | 5.46±0.06 <sup>b</sup>  | 6.05±0.05 <sup>c</sup>  | 5.97±0.09 <sup>b</sup>  | 6.19±0.07 <sup>c</sup> |
| RBC (x10 <sup>3</sup> /mm <sup>3</sup> ) | 3.17±0.12 <sup>a</sup> | 3.52±0.04 <sup>a</sup>  | 4.26±0.14 <sup>a</sup>  | 3.30±0.10 <sup>a</sup>  | 3.65±0.02 <sup>a</sup> |
| MCV (fl)                                 | 96.8±1.01 <sup>c</sup> | 91.2±0.49 <sup>b</sup>  | 74.6±3.24 <sup>a</sup>  | 100.5±0.97 <sup>d</sup> | 92.3±0.10 <sup>b</sup> |
| MCH (pg)                                 | 22.2±0.93 <sup>a</sup> | 22.0±0.33 <sup>a</sup>  | 23.4±0.74 <sup>b</sup>  | 26.1±0.79 <sup>c</sup>  | 24.8±0.56 <sup>b</sup> |
| MCHC (%)                                 | 22.9±1.21 <sup>a</sup> | 24.1±0.37 <sup>b</sup>  | 31.3±0.36 <sup>d</sup>  | 24.9±0.63 <sup>b</sup>  | 26.9±0.59 <sup>c</sup> |

**Table 7:** Biochemical profile of *C. gariepinus* fed *T. cordifolia* root meal

| Parameters          | T1 (0.0)               | T2 (0.5)               | T3 (1.0)               | T4 (1.5)                | T5 (2.0)               |
|---------------------|------------------------|------------------------|------------------------|-------------------------|------------------------|
| Glucose (mg/dl)     | 38.0±1.15 <sup>a</sup> | 54.3±0.10 <sup>d</sup> | 51.0±2.08 <sup>c</sup> | 41.0±1.53 <sup>ab</sup> | 44.3±0.12 <sup>b</sup> |
| Protein (g/dl)      | 4.23±0.20 <sup>a</sup> | 5.63±0.09 <sup>c</sup> | 6.00±0.03 <sup>c</sup> | 4.77±0.10 <sup>ab</sup> | 5.67±0.08 <sup>c</sup> |
| Albumin (g/dl)      | 2.23±0.06 <sup>a</sup> | 2.57±0.20 <sup>b</sup> | 2.93±0.15 <sup>b</sup> | 2.37±0.12 <sup>a</sup>  | 2.53±0.47 <sup>b</sup> |
| Globulin (g/dl)     | 2.43±0.19 <sup>a</sup> | 3.63±0.41 <sup>b</sup> | 2.70±0.06 <sup>a</sup> | 3.53±0.15 <sup>b</sup>  | 2.50±0.26 <sup>a</sup> |
| Cholesterol (mg/dl) | 47.3±2.03 <sup>a</sup> | 62.7±2.33 <sup>d</sup> | 59.3±1.52 <sup>c</sup> | 51.7±1.76 <sup>b</sup>  | 63.7±1.20 <sup>d</sup> |

**Table 8:** Proximate Composition (%) of *C. gariepinus* Fed *T. cordifolia* Root Meal

| Parameters (%) | T1 (0.0)                | T2 (0.5)                | T3 (1.0)                | T4 (1.5)                | T5 (2.0)                |
|----------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Ash            | 15.23±0.06 <sup>c</sup> | 14.36±0.01 <sup>b</sup> | 14.83±0.07 <sup>b</sup> | 14.12±0.22 <sup>a</sup> | 14.01±0.15 <sup>a</sup> |
| Lipid          | 13.16±0.02 <sup>b</sup> | 12.09±0.40 <sup>a</sup> | 12.37±0.00 <sup>a</sup> | 12.05±0.08 <sup>a</sup> | 12.42±0.02 <sup>a</sup> |
| Moisture       | 7.95±0.07 <sup>b</sup>  | 7.02±0.02 <sup>a</sup>  | 7.14±0.05 <sup>ab</sup> | 7.33±0.02 <sup>ab</sup> | 7.66±0.04 <sup>b</sup>  |
| Protein        | 57.68±0.01 <sup>a</sup> | 63.42±0.20 <sup>b</sup> | 62.28±0.05 <sup>b</sup> | 63.09±0.01 <sup>b</sup> | 62.40±0.01 <sup>b</sup> |
| NFE            | 5.98±0.49 <sup>b</sup>  | 3.11±0.35 <sup>a</sup>  | 3.38±0.22 <sup>a</sup>  | 3.41±0.60 <sup>a</sup>  | 3.51±0.00 <sup>a</sup>  |

### 3.6 Serum Biochemical Profiles

Table 7 presents the biochemical profile of *C. gariepinus* fingerlings fed diets containing *T. cordifolia* root meal. Serum glucose levels were significantly higher in the additive-fed groups, with the highest value recorded in T2, indicating increased metabolic activity. Total protein and albumin concentrations were generally elevated in the treated fish, particularly in T2, T3, and T5, suggesting improved nutrient utilization and physiological condition. Globulin levels were also higher in some treated groups, notably T2 and T4, indicating enhanced immune response. Cholesterol concentrations increased with dietary inclusion of *T. cordifolia* root meal but remained within normal physiological ranges, suggesting active lipid metabolism without adverse health effects. Overall, the biochemical indices indicate that *T. cordifolia* root meal positively influenced the metabolic and physiological status of *C. gariepinus* fingerlings.

### 3.7 Carcass Composition

Table 8 presents the carcass composition of *C.*

*gariepinus* fingerlings fed diets containing *T. cordifolia* root meal. Ash and lipid contents generally decreased in the additive-fed groups, with the lowest lipid values observed in T2, T3, and T4, indicating reduced fat deposition and improved carcass quality. Moisture content showed little variation among treatments. In contrast, crude protein content was significantly higher in all *T. cordifolia*-fed groups than in the control, suggesting enhanced protein deposition and nutrient utilization. Nitrogen-free extract (NFE) decreased in the treated groups, indicating greater utilization of dietary carbohydrates for energy.

## 4. Discussion

### 4.1 Proximate Composition of *T. cordifolia* Root

The proximate composition of *Tinospora cordifolia* root obtained in this study indicates that the plant material is characterized by a high carbohydrate content, moderate fibre content, and relatively low crude protein and lipid contents. The crude protein content (6.84%) agrees with the range of 5–8% previously reported by Modi et al.

(2021), confirming the consistency of the nutritional composition of the root across different growing environments. The low protein content indicates that *T. cordifolia* root is not intended to serve as a major protein source in aqua feeds but rather functions as a phytogenic feed additive. Its nutritional value is therefore derived primarily from its bioactive constituents, including alkaloids, flavonoids, glycosides, diterpenoid lactones, and phenolic compounds, which have been reported to possess antioxidant, antimicrobial, immunomodulatory, and growth-promoting properties (Kashyap et al., 2022). These bioactive compounds may enhance nutrient utilization and physiological functions in fish, thereby improving growth performance and health.

#### 4.2 Proximate Composition of Experimental Diets

The highest crude protein value was observed in T3, whereas T1 recorded the lowest values for most parameters. The observed variations in ash and fiber contents may be attributed to the inherent composition of *T. cordifolia* root meal, while protein and lipid levels remained relatively stable, indicating that the inclusion of the plant additive did not adversely affect dietary nutrient balance. These findings suggest that *T. cordifolia* root meal is a suitable functional ingredient for aqua feed formulation, with nutrient levels within the recommended range for optimal growth and maintenance of catfish fingerlings (Eyo and Ekanem, 2022).

#### 4.3 Water Quality Parameters

The water quality parameters recorded throughout the 70-day feeding trial remained within the optimum ranges recommended for the culture of *Clarias gariepinus* fingerlings (Okeke et al., 2022). Furthermore, the absence of significant differences ( $P > 0.05$ ) among treatments indicates that dietary supplementation with *Tinospora cordifolia* root meal did not adversely affect the culture water. This observation is expected because the additive was incorporated at relatively low inclusion levels and therefore had minimal influence on water chemistry. Maintaining stable water quality throughout the experimental period ensured that environmental conditions remained suitable for normal fish metabolism, feed intake, growth, and survival. Consequently, the observed differences in growth performance, hematological indices, serum biochemical characteristics, and carcass composition can be attributed primarily to the dietary treatments rather than variations in water quality. Similar observations have been reported in studies evaluating phytogenic feed additives in African catfish and other cultured fish species, where herbal dietary supplements improved fish performance without altering the physicochemical characteristics of the culture water (Adeniyi et al., 2023).

#### 4.4 Growth Performance of the Experimental Fish

The enhanced growth observed in fish fed the T3 diet may be attributed to the diverse bioactive compounds present in *T. cordifolia*, including alkaloids, flavonoids,

glycosides, diterpenoid lactones, and polysaccharides, which have been reported to improve digestive enzyme activity, nutrient absorption, antioxidant capacity, and intestinal health (Kumar et al., 2022). Improved digestive efficiency would enhance the utilisation of dietary nutrients for tissue growth, thereby resulting in greater weight gain and feed utilisation. Similar growth-promoting effects of *T. cordifolia* have been reported in Catla catla fry (Upreti and Chauhan, 2018) and Nile tilapia (*Oreochromis niloticus*) (El-Basuini et al., 2022), while comparable improvements have also been documented for other phytogenic feed additives in *Clarias gariepinus* (Olawale et al., 2023). Although growth performance declined slightly at the higher dietary inclusion levels (1.5 and 2.0 g/100 g diet), the values remained superior to those of the control group. This response suggests that the biological benefits of *T. cordifolia* may diminish beyond the optimum inclusion level. High concentrations of phytogenic compounds may reduce feed palatability, alter nutrient digestibility, or increase the metabolic cost of detoxifying excess phytochemicals, thereby limiting further improvements in growth. Similar dose-dependent responses have been reported for medicinal plant additives in aquaculture, where moderate inclusion levels produced superior growth compared with higher dietary concentrations (Kumar et al., 2022). Feed intake was highest in fish fed the T3 diet, indicating that moderate dietary supplementation did not reduce diet acceptability. The slight numerical improvements observed in feed conversion ratio (FCR), feed efficiency ratio (FER), and specific growth rate (SGR), despite not being statistically significant, suggest a trend towards more efficient nutrient utilization in the additive-fed groups. The absence of significant differences in these indices may be attributed to the relatively small variation among treatments or the duration of the feeding trial. Nevertheless, the consistent improvement in weight gain and final body weight demonstrates the beneficial effect of *T. cordifolia* supplementation on overall fish performance. Survival remained high and was not significantly influenced by dietary treatment, indicating that *T. cordifolia* root meal was safe at all inclusion levels evaluated. The high survival rate further suggests that the additive did not induce physiological stress or toxicity during the experimental period. Similar observations have been reported for African catfish and other cultured fish species fed medicinal plant-based diets, where phytogenic feed additives enhanced growth without adversely affecting fish survival (Tiamiyu et al., 2021).

#### 4.5 Haematological parameters

The higher haemoglobin (Hb) concentration and red blood cell (RBC) count observed in the supplemented groups, particularly at the optimum inclusion level, suggest enhanced erythropoiesis and improved oxygen-carrying capacity of the blood. Increased oxygen transport supports efficient tissue respiration, energy metabolism, and growth, which may partly explain the superior growth performance recorded in fish fed the T3 diet. These findings are consistent with previous studies reporting that phytogenic feed additives stimulate erythrocyte production and improve blood quality in cultured fish

through their antioxidant and haemopoietic properties (Abdel-Tawwab et al., 2018; Adeshina et al., 2021). The significant increase in white blood cell (WBC) count in fish receiving *T. cordifolia* supplementation indicates enhanced non-specific immune function. White blood cells play a critical role in the defence against pathogens, and their elevation is commonly associated with improved immunocompetence. The immunostimulatory effect observed in this study may be attributed to the bioactive constituents of *T. cordifolia*, particularly polysaccharides, flavonoids, and alkaloids, which have been reported to activate innate immune responses and improve disease resistance in fish and other animals (Kashyap et al., 2022). Similar improvements in leucocyte counts have been reported in *Clarias gariepinus* fed herbal supplemented diets (Fawole et al., 2022). Packed cell volume (PCV) remained within acceptable physiological limits across all dietary treatments, while the erythrocyte indices mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) showed only slight variations. These observations indicate that dietary inclusion of *T. cordifolia* root meal did not adversely affect erythrocyte morphology or blood cell integrity. The maintenance of normal erythrocyte indices further suggests that the experimental diets neither induced anaemia nor impaired normal haematopoietic processes.

#### 4.6 Serum Biochemical Profiles

The higher serum glucose concentrations observed in the supplemented groups may reflect increased energy availability associated with enhanced nutrient digestion and metabolism rather than a stress response. Under favorable culture conditions, moderate elevations in blood glucose can indicate improved carbohydrate utilization to meet the increased energy demands associated with growth. Similar responses have been reported in fish fed phytogetic feed additives that stimulate digestive activity and improve nutrient assimilation (Kumar et al., 2022). The significant increases in total protein, albumin, and globulin concentrations further demonstrate the beneficial effects of *T. cordifolia* supplementation. Serum total protein is widely regarded as an indicator of protein metabolism and nutritional status, while albumin reflects hepatic protein synthesis and the transport of metabolites within the bloodstream. The elevated values observed in the treated fish suggest improved dietary protein utilization and enhanced liver function. Likewise, the increased globulin concentration, particularly in the supplemented groups, indicates enhanced innate immune competence, since globulins include several immune-related proteins involved in host defense. These findings are consistent with reports by Rada et al. (2021) and Al-Turaihi et al. (2023), who observed improved serum protein fractions and immune responses in fish receiving phytogetic dietary supplements. Serum cholesterol concentrations increased moderately with dietary supplementation but remained within normal physiological limits for healthy fish. This response suggests active lipid metabolism associated with rapid

tissue growth rather than impaired lipid homeostasis. The absence of abnormal cholesterol levels indicates that dietary inclusion of *T. cordifolia* did not adversely affect lipid metabolism or liver function. Similar observations have been reported in fish fed herbal feed additives, where moderate increases in cholesterol were associated with enhanced physiological activity and improved nutrient utilization rather than pathological conditions (Kumar et al., 2022).

#### 4.7 Carcass Composition

The significantly higher carcass crude protein content observed in fish fed *T. cordifolia*-supplemented diets suggests more efficient utilization of dietary protein for muscle growth and tissue accretion. This improvement is consistent with the superior growth performance and feed utilization recorded in the treated groups, particularly at the optimum inclusion level. Enhanced protein deposition may be attributed to the ability of the bioactive compounds present in *T. cordifolia*, including flavonoids, alkaloids, and phenolic compounds, to improve digestive enzyme activity, intestinal nutrient absorption, and protein metabolism (Kumar et al., 2022). Similar increases in carcass protein have been reported in *Oreochromis niloticus*, and other cultured fish species fed phytogetic feed additives (Mansour et al., 2023; Mbokane et al., 2022). Conversely, the reduction in carcass lipid content observed in the supplemented groups suggests improved lipid utilization and reduced fat deposition. Lower carcass lipid levels are generally considered desirable because they indicate that a greater proportion of dietary energy was directed towards lean tissue growth rather than fat accumulation. This response may be associated with improved lipid metabolism and enhanced nutrient partitioning promoted by the phytochemicals present in *T. cordifolia*. Similar observations have been reported for fish receiving herbal feed additives, where improved growth was accompanied by reduced carcass fat deposition and enhanced feed efficiency (Kumar et al., 2022). The relatively stable moisture content across treatments indicates that dietary supplementation did not adversely affect the water content of fish tissues, while the slight reduction in nitrogen-free extract (NFE) may reflect greater utilization of dietary carbohydrates as an energy source. This efficient utilization of carbohydrates could have spared dietary protein for tissue synthesis, thereby contributing to the higher carcass protein content observed in the treated fish.

#### 5. Conclusion

The present study demonstrated that dietary supplementation with *Tinospora cordifolia* root meal positively influenced the growth performance, nutrient utilization, physiological status, and carcass composition of *Clarias gariepinus* fingerlings. Fish fed diets containing the additive exhibited improved weight gain, feed utilization, hematological and serum biochemical profiles, and greater carcass protein deposition, indicating enhanced nutrient metabolism and overall health. Among the dietary treatments, the inclusion level of 1.0 g/100 g diet produced the most favorable response, while

polynomial regression analysis estimated an optimum dietary inclusion level of approximately 0.9 g/100 g diet for maximizing growth performance. The findings demonstrate that *T. cordifolia* root meal can be used safely as a natural phytogenic feed additive in African catfish diets. Its incorporation into aqua feeds offers a sustainable strategy for improving fish growth, physiological condition, and product quality while reducing reliance on synthetic growth promoters and antibiotics. Although the present study provides evidence of the growth-promoting and physiological benefits of *T. cordifolia* root meal, it was conducted under controlled laboratory conditions and evaluated only short-term dietary responses. Therefore, further studies should investigate its long-term effects on digestive enzyme activities, antioxidant responses, immune-related gene expression, disease resistance, reproductive performance, and economic viability under commercial aquaculture conditions.

## 6. Statements and Declarations

**Ethical Approval:** All experimental procedures involving fish were conducted in accordance with institutional and national guidelines for the care and use of animals in research. Appropriate measures were taken throughout the study to minimize stress and ensure the welfare of the experimental fish during handling, feeding, and sampling.

**Conflict of Interest:** The author declares that there is no conflict of interest regarding the publication of this manuscript.

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