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Dietary Supplementation of *Eichhornia crassipies* leaf meal on Growth Performance and Nutrient Utilization of *Clarias gariepinus* Post Fingerlings

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ABSTRACT

This study evaluated the potentials of replacement of fishmeal with *Eichhornia crassipes* leaf meals at varying inclusion levels on the growth performance and nutrient utilization of *Clarias gariepinus post fingerlings. A total of 300 post*-fingerlings were equally distributed across 15 experimental tanks. Five dietary treatments were formulated for this experimental study consisting of the control diet (T0) which contained 100% fish meal(FM), and four (4) *Eichhornia crassipes experimental diets* (T1: 25% ECLM; T2: 50% ECLM; T3:75% ECLM; and T4:100% ECLM) with three replicates each over a 112 days feeding trial. The Growth performance indices, including mean weight gain (WG), mean length gain, specific growth rate (SGR), Feed Conversion Ratio, Crude protein per diet, Protein efficiency ratio and economic indices were assessed. Other parameters assessed included proximate composition of the experimental diets using the Association of Official Analytical Chemists, 2019. Water parameters like pH, temperature, and dissolved oxygen were measured. The mean values recorded were pH: 7.42-7.72, Temperature: 27.1-27.6 (°C), and dissolved oxygen: 6.11-6.52 mg/L, all of which were within acceptable limits for the growth of African catfish.Data were analyzed using one-way ANOVA, and significant differences among means were separated using Duncan's Multiple Range Test at $p < 0.05$. Fish fed the control diet (T0) recorded initial mean weight gain (176.5±0.33g) and highest final mean weight gain (678.9 ±0.94g) and specific growth rate (1.46 ± 0.05 % day^{-1}). At 25% inclusion (T5), *Eichhornia crassipes leaf meal (ECLM) recorded an initial mean weight gain of (175.1±0.32g). It produced a* final mean weight gain of (480.4±0.60g) and SGR of (1.23± 0.04 % day^{-1}). However, at 100% inclusion (T4), Final mean weight gain declined sharply to 378.2 ± 12.8g for ECLM test diets and with corresponding SGR values of (0.97 ± 0.02) respectively. There were significant difference among the means (p<0.05). Also for the length gain, Fish fed the control diet (T0) recorded initial mean length gain (8.7±0.12cm) and highest final mean length (18.2±0.35cm). At 25% inclusion (T1), *Eichhornia crassipes leaf meal (ECLM) recorded an initial mean length of (8.6±0.10cm). It produced* a final mean length gain of (17.5±0.30cm). However, at 100% inclusion (T4), Final mean length gain reduced to (15.1±0.23cm) for ECLM test diets inclusion level increased.There were significant differences among the means (p<0.05). In conclusion, T1,25% *Eichhornia crassipes leaf meal* demonstrated superior growth performance and better profitability among the test diets.

INTRODUCTION

Fish is an important component of human nutrition, providing high-quality protein, essential fatty acids, vitamins, and minerals that contribute significantly to global food security. Aquaculture has become one of the fastest-growing food production sectors and plays a crucial role in meeting the increasing global demand for aquatic animal protein. According to the Food and Agriculture Organization, global fisheries and aquaculture production reached about 223 million tonnes in 2022, with aquaculture contributing more than half of total aquatic animal production for the first time (FAO, 2022). In Africa, aquaculture is increasingly recognized as an important strategy for improving food security and rural livelihoods. Among the cultured species in the region, African catfish (*Clarias gariepinus*) is widely farmed due to its rapid growth rate, high feed conversion efficiency, disease resistance, tolerance to low dissolved oxygen, and ability to utilize diverse feed ingredients. However, the profitability of aquaculture is largely constrained by the high cost of feed, which often accounts for 60–70% of total production costs (Okeke *et al.,* 2016). Conventional protein sources such as fishmeal and soybean meal are expensive and subject to price fluctuations, thereby increasing the need for sustainable and affordable alternative feed resources.

Water hyacinth (*Eichhornia crassipes*) is a free floating perennial aquatic plant belonging to the family *Pontederiaceae*. It is found in fresh water ecosystems and spread on the surface of rivers, lakes, canals and ponds and may root in the mud of shallow waters. However, it contains moderate crude protein, vitamins, fiber, and minerals, making it a potential low-cost fish feed ingredient. Using it in fish feed can provide nutritional benefits to the fish(Akinpelu *et al.,* 2022).

As fish meal prices continue to rise and its production poses significant environmental challenges. Therefore identifying locally available and renewable feed resources has become important. The rationale for exploring water hyacinth (*Eichhornia crassipes*) as a supplement for fish meal in the diet of African catfish (*Clarias gariepinus*) post fingerlings is driven by the increasing need for affordable and sustainable protein alternatives in aquaculture. The novelty of this study will help in replacing expensive fishmeal with locally available water hyacinth leaf meal by significantly reducing production costs, boosting profit margins for farmers and enhancing the economic viability of catfish farming. Therefore, this study aims to evaluate the Dietary Supplementation of *Eichhornia crassipies* leaf meal on growth performance and nutrient utlization of *Clarias gariepinus* post fingerlings as protein-substituted diets for fish meal.

Also, the specific objectives of the study are to assess the growth performance of *Clarias gariepinus* fed diets supplemented with *Eichhornia crassipies* leaf meals,evaluate the nutrient utilization of *Eichornia crassipes* leaf meal diets in *Clarias gariepinus*,evaluate the proximate composition of processed *Eichhornia crassipies* leaf meals experimental diets,determine the best optimal inclusion level of *Eichhornia crassipies* leaf meal in the diet of *Clarias gariepinus.*assess the effects of *Eichhornia crassipies* leaf meals inclusion on the survival rate of *Clarias gariepinus* and finally estimate the economic analysis of producing experimental diets containing *Eichornia crassipies* leaf meals.

The African catfish (*Clarias gariepinus*) dominates freshwater aquaculture due to its fast growth, high survival rate, ability to utilize a wide range of feedstuffs, and tolerance to poor environmental conditions (Djissou *et al.,* 2025). The species is widely preferred by farmers and consumers and significantly contributes to food security and income generation. However, feed cost remains the greatest barrier to expansion, as protein ingredients account for the bulk of feed expenses (Ajani *et al*., 2018).

Water hyacinth has a lot of potential that can be utilized by humans. One of the potentials of water hyacinth as an ingredient of fish feed is that it contains high proteins, lipids, carbohydrates, vitamins, and secondary metabolites (Sogbesan *et al*, 2015).

Several studies have proven that water hyacinth can be added to fish feed and has a positive effect on growth. Provision of water hyacinth leaf meal was also proven to increase the growth of African catfish (*Clarias gariepinus*) with a weight gain value of 14.79 g for fish fed water hyacinth leaf meal (Sotolu *et al.,* 2017). Provision of water hyacinth plant meal and water hyacinth leaf meal was also proven to increase the growth of grass carp (*Ctenopharyngodon idella*) fingerlings, with a weight gain value of 7.16 g for fish fed water hyacinth leaf meal (Mohapatra *et al.,* 2023)

MATERIALS AND METHODS

Experiment Area and Duration

The experiment was carried out in the research laboratory of the Department of Fisheries and Aquaculture, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. The experiment lasted for a period of 16 weeks (112 days).

Preparation of *Eichhornia crassipies* Leaf meal

Fresh water hyacinth (*Eichhornia crassipies*) leaves used for feed formulation were harvested from water bodies in Ogbaru metropolis, located in the Onitsha area of Anambra State, Nigeria. The leaves were thoroughly washed with distilled water to remove dirt and debris, then air dried under room temperature for seven days to minimize loss of essential nutrients according to (Okeke *et al*., 2016) and also to help reduce anti-nutritional factors, specifically mimosine according to (Hamid *et al.,* 2017) After drying, the dried leaves were milled into a fine powder separately using a petrol-powered grinding engine Gx200 6.5hp.The milling process was necessary to create a uniform texture and ensure that the powdered leaves could be easily incorporated into the fish feed following the method of (Sogbesan *et al*. 2015). It was then stored in airtight containers until feed formulation.

Feed Formulation

The feed ingredients used in the experiment, such as fish meal (FM), groundnut cake (GNC), soybean meal (SBM), bone meal (BM), maize meal (MM), vitamin premix, binder (starch), lysine, methionine and salt were pre-grounded and included and then carefully mixed with the grounded *Eichhornia crassipies* leaf meal. Each ingredient was measured as shown in Table 1. These diets were formulated according to the varying inclusion levels for the different treatments using the Crude Protein percentage(%) inclusion (ingredient contribution) method of feed formulation according to (Vasilaki *et al.,* 2023).The ingredients were then thoroughly hand-mixed to ensure uniform distribution, then water was added to form dough, and the mixture was pelleted using electric pelleting machine.The ingredients were blended, the mixture was processed through a pelletizer(Hobart Manufacturing Ltd) to form fish pellets (1.2mm) suitable for *Clarias gariepinus* post fingerlings. The control diet(T0) contained 100% fishmeal as the protein source without the grounded *Eichhornia crassipies.* For diets T1,T2,T3 and T4 ECLM were included to mainly replace fishmeal at substitution rates of 25%,50%, 75% and 100%. Also these formulated diets were subsequently dried at 55–60°C using a locally-made drier to remove moisture and enhance their shelf life. It was stored in seperate airtight plastic containers and labeled according to treatment before been used for feeding the fish (Sogbesan *et al*, 2022).

Table 1: Formulated treatment diets with varying rates of fishmeal (FM) substitution with *Eichhornia crassipies* leaf meal (ECLM)

Ingredients/Feed Components	Treatment Diet 0 (Control) 100% FM	Treatment Diet 1(25% ECLM)	Treatment Diet 2(50% ECLM)	Treatment Diet 3) (75% ECLM)	Treatment Diet 4(100% ECLM)
Fish Meal (g)	30	20	15	10	0
Maize (g)	20	20	20	20	20
Groundnut Cake (g)	16	16	16	16	16
Soybean (g)	25	25	25	25	25
Bone Meal (g)	2.0	2.0	2.0	2.0	2.0
Methionine (g)	2.0	2.0	2.0	2.0	2.0
Lysine (g)	1.5	1.5	1.5	1.5	1.5
Vitamin B Complex(g)	1.5	1.5	1.5	1.5	1.5
Vitamin premix (g)	1.5	1.5	1.5	1.5	1.5
Salt (g)	0.5	0.5	0.5	0.5	0.5
Eichhornia crassipes* leaf meal *(g)	0	10	15	20	30
TOTAL	**100**	**100**	**100**	**100**	**100**

Procurement of Experimental Fish

A total of three hundred (300) *Clarias gariepinus* post fingerlings at four to five weeks old were purchased from a commercial fish farm in Awka, Anambra State for this feeding trial. The post-fingerlings were carefully transported from the Commercial fish farm in two large plastic containers of 50 litres capacity each to the experimental site. Upon arrival at the laboratory, the post fingerlings were transferred into a large holding tank and were allowed a one-week acclimatizing period to adjust to their new environment. The fish were fed twice daily with a commercial diet at 5% body weight per day before the practical study began.

Experimental Design

The experiment followed a completely randomized design (CRD) consisting of five(5) dietary treatments (T0, T1, T2, T3, and T4) with three (3) replicates each.The *Clarias gariepinus* fingerlings were randomly assigned to 100-liter plastic . Each experimental setup had three (3) replicates each, labeled as R1, R2, and R3, with each replicate containing 20 *Clarias gariepinus* fingerlings. This amounted to a total of 60 fingerlings for each Experimental Setup.

Water Quality Management and Monitoring

The water parameters, including pH, dissolved oxygen, and temperature, were monitored. Water was changed every two days. Water quality was monitored using a digital thermometer (Hanna HI 93510), pH meter (Hanna HI 98107), DO meter (YSI Pro20), and ammonia test kit (API), maintained within optimal ranges for *Clarias gariepinus*.Water quality was maintained within optimal ranges for *Clarias gariepinus*: Fresh, clean water was introduced to the tanks to remove waste, uneaten feed, and any potential toxins that could affect the health and growth of the fish. Regular water changes were essential to maintaining optimal water conditions, ensuring sufficient oxygen levels, and preventing the build-up of harmful substances (Olaniyi *et al.,* 2022). The post fingerlings were monitored for survival by removing the dead fish. The weight and length of the fish were measured and recorded on a weekly basis using sensitive weighing balance and meter rule respectively.

Growth Performance Indices of Fish fed different experimental diets

These growth indices included the following: Weight gain (g/fish), Length gain (cm/fish), specific growth rate (SGR) (%day),), survival rate was recorded as shown in Table 4.

Weight gain (g/fish):

Weight gain is a key performance indicator (KPI) that measures the increase in fish body mass, either in weight or length. It is calculated as the difference between final and initial weight or lenght. This Measures the total body weight or lenght increase over the experimental period (Giovanni *et al.,* 2025)

Weight gain = $(W_f - W_i)$

Where W_f =final weight at the end of the experiment, W_i =initial weight at the start of the experiment
Length gain = $(L_f - L_i)$

L_f= final length at the end of the experiment, L_i= initial length at the start of the experiment

Specific growth rate (SGR)

This is a metric used to quantify the growth of fish over a specific period of time. This refers to the percentage of weight gain in days, weeks or months. This measures the growth efficiency expressed as percentage per day. (Folorunso *et al.,* 2021)

$$SGR = \frac{1nW_2 - InW_1}{T_2 - T_1} \times 100$$

Where In = natural logarithm

W_2 and W_1= final and initial weight of fish, respectively in grams, T_2 and T_1-end of the growth period and beginning and same respectively.

Percentage survival:

This measures the Percentage of fish that survived during an experimental study. It is used in evaluating survival rates in in feeding trials comparing different feeds or stocking densities (Ogunji *et al.,* 2020)

$$\% \text{ Survival} = \frac{\text{Number of fish survival}}{\text{Number of fish stocked}} \times 100$$

Feed Utilization Indices

The following indices of feed utilization were studied using the data collected.

Feed conversion ratio (FCR)

This measures the efficiency of converting feed into body mass. A lower FCR indicates higher efficiency and a higher FCR indicates lower efficiency of the feed consumed by the fish. This refers to the weight gain in fish due to an increase in body weight. (Boyd *et al.* 2022)

$$FCR = \frac{\text{Feed intake (g)}}{\text{Fish weight gain (g)}}$$

Feed Efficiency Ratio (FER)

This is a metric used to determine how effectively a fish converts the food it consumes into body mass. It is the biological inverse of the Feed conversion Ratio, meaning that the higher the FCR, the lower the FER and the Lower the FCR, the higher the FER (Boyd, 2021). It is calculated by dividing the weight gain by the total feed intake using the method of Emil Von Wolff (1864).

$$FER = \frac{\text{Fish weight gain (g)}}{\text{Feed intake (g)}}$$

Crude Protein Intake (CPI)

This measures the actual weight of protein consumed by the fish over the entire experimental period or a specific time frame. It is calculated as the total feed intake and the crude protein concentration in the feed (Gopika *et al.,* 2020). It is calculated using the method of Delong, Haver and Yasutake (1958) It is expressed as :

CPI= Total Feed Intake Per Diet (g) x Dietary Crude Protein Content of the Feed (%) x 100.

Protein efficiency ratio (PER)

This measures the nutritional quality of a diet by calculating the grams of wet weight gain per gram of crude protein consumed. It is used to evaluate feed efficiency and the ability of a protein source to promote growth. (Oboh, 2022)

$$PER = \frac{\text{Weight gain (g wet fish)}}{\text{Weight of protein fed (g crude protein fed)}}$$

Proximate Analysis of Treatment Diets

The treatment diets as shown in Table 2 were analyzed for moisture, crude protein, crude fiber, ash, crude lipid, ether extract, and dry matter using standard methods from the Association of Official Analytical Chemists (AOAC, 2019).

Production Cost of the Experimental Diets and the economic evaluation of the feeding trials

The economic benefit of rearing the *Clarias gariepinus* post fingerlings to post juveniles stage within the period of 16 weeks(112 days) was assessed using the following economic analysis indices such as :Economic Conversion Ratio (ECR), Net production value (NPV), Profit Index (PI) and Benefit: Cost ratio (BCR) as shown in Table 6.

Statistical Analysis

The data was subjected to One-way Analysis of variance (Anova) using the statistical software for the social sciences (SPSS) to determine the significant difference between the experimental diets and the control. Significant means were separated using Duncan Multiple Range Test at $P < 0.05$

RESULTS

The proximate composition of the experimental diets showed clear variations across treatments as presented in Table 2. Crude protein was highest in the control diet (63.01%) and progressively declined across inclusion levels, reaching the lowest value in T4 (29.75%). Moisture was highest in the T4 (10.75) and increased across inclusion levels, reaching the lowest value in the Control diet (7.89).

Table 2: Proximate Composition of Experimental Diets

Experimental Diets	Moisture	Ash	Crude Protein	Crude Fiber	Fats/Oil	Carbohydrate
T0 (Control)	7.89	5.82	63.01	3.49	12.01	20.11
T1(25% ECLM)	9.65	7.11	42.16	4.46	10.28	29.71
T2 (50% ECLM)	9.68	7.87	37.00	5.14	10.14	33.68
T3 (75% ECLM)	9.45	7.97	32.65	6.26	8.20	39.52
T4 (100% ECLM)	10.75	8.15	29.75	6.72	8.13	44.55

Water Quality Parameters

Water quality variables monitored throughout the 112 days feeding trial remained within acceptable limits for freshwater fish culture. The water quality parameters of the experiment varied as follows: temperature ranged from 27.1 -27.6°C, pH 6.45-6.72, and dissolved oxygen 6.11-6.50mg/l and Biological Oxygen Demand(mg/L) 3.51-4.87 .The acceptable optimal range accepted in feeding trials for Temperature: 26–30°C, pH: 6.5–9.0, DO: >5 mg/L, and BOD: <6.0mg/L according to (Boyd, 2018).

Table 3: Physiochemical Parameters measured during the experimental period

Parameter	Treatments	Mean±SD	Recommended Range
Ph	T0	7.64 ± 0.33[a]	6.5 – 9.0
	T1	7.49 ± 0.22[a]	
	T2	7.42 ± 0.38[a]	
	T3	7.43 ± 0.55[a]	
	T4	7.46 ± 0.55[a]	
Temperature (°C)	T0	27.6 ± 0.03[a]	26–30°C
	T1	27.3 ± 2.89 [a]	
	T2	27.4 ± 0.77 [a]	
	T3	27.3 ± 1.87 [a]	
	T4	27.4 ± 1.87 [a]	
Dissolved Oxygen (mg/L)	T0	6.41 ± 0.33[a]	>5 mg/L
	T1	6.23 ± 0.66[a]	
	T2	6.34 ± 0.33[a]	
	T3	6.43 ± 0.88[a]	
	T4	6.52 ± 0.88[a]	
Biological OxygenDemand(mg/L)	T0	3.51 ± 0.14[a]	<6.0mg/L
	T1	4.56±0.33[a]	
	T2	4.61±0.34[a]	
	T3	4.73±0.35[a]	
	T4	4.87±0.37[a]	

a: Means within the same column with the same superscripts are not significantly different (P>0.05)

Growth Performance of the Experimental diets

The growth performance of *Clarias gariepinus* post fingerlings during the feeding trial are presented in Table 3. The highest growth performance was observed in fish fed the control diet T (678.9grams), This result indicates that 25% ECLM, T1 diet recorded 455.7grams, the highest mean weight gain among the tested diets. while the lowest growth was recorded in fish fed the 100% ECLM T4 diet (378.2 grams). There was significant difference between the control diet and the ECLM experimental diets(p<0.05)

Table 4: Growth performance of *Clarias gariepinus* post fingerlings fed with control, 25%, 50%,75% and 100% *Eichornia crassipies* Leaf Meal (ECLM) experimental diets for sixteen (16) weeks .

Parameters	Treatment Diet 0 (Control) 100% FM	Treatment Diet 1(25% ECLM)	Treatment Diet 2(50% ECLM)	Treatment Diet 3) (75% ECLM)	Treatment Diet 4(100% ECLM)
Initial Mean weight (g/fish)	176.5 ± 0.33[a]	175.1 ±0.32[a]	174.9 ± 0.31[b]	174.2 ± 0.31[b]	173.2 ± 0.30[c]
Final Mean Weight (g/fish)	678.9 ± 0.94[a]	480.4 ± 0.60[b]	455.7 ± 0.56[c]	422.8 ± 0.55[d]	378.2 ± 0.43[e]
Initial Mean length (cm/fish)	8.7 ± 0.12[a]	8.6 ± 0.10[a]	8.5 ± 0.11[a]	8.5± 0.09[a]	8.4 ± 0.08[a]
Final Mean length (cm/fish)	18.2 ± 0.35[a]	17.5 ± 0.30[b]	16.2 ± 0.28[c]	15.7 ± 0.25[d]	15.1 ± 0.23[d]
Initial Stocking Density	60	60	60	60	60
Final Stocking Density	51	50	50	49	48
Specific GrowthRate(%/day)	1.46 ± 0.05[a]	1.23 ± 0.04[b]	1.19 ± 0.03[b]	1.01 ± 0.03[c]	0.97 ± 0.02[d]
Survival (%)	85	83	83	81	80

[a,b,c,d:] Data within the same column with different superscripts (a–d) **a**re significantly different ($p < 0.05$)

Table 5: Nutrient Utilization of *Clarias gariepinus* fed Control and *Eichornia crassipies* leaf meal (ECLM) experimental diets.

Nutrient Utilization Parameters	Treatment Diet 0 (Control) 100% FM	Treatment Diet 1(25% ECLM)	Treatment Diet 2(50% ECLM)	Treatment Diet 3) (75% ECLM)	Treatment Diet 4(100% ECLM)
Feed Conversion Ratio	1.07[a]	1.59[b]	1.70[c]	1.88[d]	2.17[e]
Feed Efficiency Ratio	0.93[a]	0.62[b]	0.58[c]	0.53[c]	0.45[d]
Crude Protein/Diet	41.6	39.6	38.6	37.6	35.6
Crude Protein Intake	222.7[a]	192.0[b]	184.1[c]	175.4[d]	158.4[e]
Protein Efficiency Ratio	2.26[a]	1.59[b]	1.52[b]	1.42[c]	1.29[d]

[a,b,c,d:] Data within the same column with different superscripts (a–d) are significantly different ($p < 0.05$)

Table 6: Economic indices of *Clarias gariepinus* fed Control and *Eichornia crassipies* leaf meal (ECLM) experimental diets.

Economic Indices	Treatment Diet 0 (Control) 100% FM	Treatment Diet 1(25% ECLM)	Treatment Diet 2(50% ECLM)	Treatment Diet 3) (75% ECLM)	Treatment Diet 4(100% ECLM)
ECR (₦/kg fish	1,360.00e	1,933.60[d]	2,024.75[c]	2,192.14[b]	2,421.78[a]
NPV (₦/kg fish)	2,640.00[a]	2,066.40[b]	1,975.25[c]	1,807.86[d]	1,578.22[e]
BCR	2.94[a]	2.06[b]	1.96[c]	1.65[d]	1.27[e]
PI	1.94[a]	1.07[b]	0.97[c]	0.82[d]	0.65[e]

[a,b,c,d,e:] Data within the same column with different superscripts (a–e) are significantly different ($p < 0.05$)

DISCUSSION

Growth Performance of *Clarias gariepinus* fed Control and *Eichhornia crassipies* Leaf Meal (ECLM) experimental diets.

Table 4 showed the growth performance responses of *Clarias gariepinus* fed a control diet (containing 100% fish meal) and experimental diets containing graded levels of ECLM at varying levels of (25%, 50%, 75%, and 100%) over a sixteen-week feeding trial.. Weight gain and SGR are direct reflections of how well fish can convert feed into body mass Sogbesan *et al.,* (2022). Fish fed the control diet (T0) recorded the highest final mean weight (678.9g), which was significantly higher (p < 0.05) than those of fish fed the ECLM experimental diets. The final mean weight progressively declined with fish fed the 100% replacement diet in T4 (100% ECLM) (378.2g) The results of this experimental study also demonstrated that dietary treatments of *Eichhornia crassipies* leaf meal ECLM significantly influenced the linear growth of *Clarias gariepinus as presented in Table 4* . Fish fed the control diet (T0) recorded the highest final length(18.2cm),this indicated superior nutrient availability and utilization in the control diet. However, compared to fish fed the ECLM diets, T5(25% ECLM) had final length of (17.5cm), and the lowest length gain was recorded for T4(100% ECLM) with final length of 15.1cm.

This pattern clearly demonstrates that increasing substitution of fish meal with (ECLM) negatively affected growth performance. This reduction in growth may be attributed to lower protein quality, reduced digestibility, and the presence of anti-nutritional factors such as mimosine and tannins commonly associated with plant leaf meals as reported by Francis *et al.,* 2017 who carried out a research on anti-nutritional factors in plant meals.

Specific growth rate (SGR), which expresses growth as a percentage increase in body weight per day, showed a similar declining trend. Fish fed the control diet (T0) exhibited the highest SGR (1.46%/day), while fish fed T1,25% ECLM inclusion diets showed moderate SGR values (1.23%/day). The lowest SGR was recorded in T4, fish fed 100% ECLM inclusion diet (0.87%/day). Since SGR integrates both initial and final weights, it is a reliable indicator of overall growth performance (Adeyemi *et al.,* 2023). The reduction in SGR with increasing ECLM indicates diminished growth efficiency and poorer feed utilization.

The superior growth performance recorded in the control (T0) and 25% ECLM (T1) inclusion diets suggests better nutrient digestibility and amino acid availability, leading to enhanced muscle development and improved carcass quality (Dawood *et al.,* 2024). The results showed that partial replacement of fish meal with *Eichhornia crassipies* leaf meal ECLM, specifically T5 (up to 25%) can support acceptable growth performance in *Clarias gariepinus* post fingerlings. However, higher inclusion levels T3 and T4(75–100%) significantly compromise growth efficiency These findings suggest that *Eichhornia crassipies* leaf meal is better suited as a partial rather than total replacement for fish meal in African catfish diets.

A 2022 study carried out by (Haetami *et al.,*2022) on *Clarias gariepinus* showed that diets formulated with complete replacement of fishmeal by alternative protein mixtures (including plant and animal sources) resulted in significantly different growth performance relative to a fishmeal control diet, emphasizing that essential amino acids and ingredient digestibility are key determinants of growth outcomes in catfish nutrition which also agrees with Li *et al*., (2019).

Similarly, a 2024 feeding trial evaluating *the use of* leaf meals as a partial fish meal substitute in *Clarias gariepinus* fingerling diets reported that moderate inclusion levels (around 20%) supported comparable growth and survival, whereas higher inclusion levels tended to reduce growth performance and feed conversion efficiency (Alabi *et al.,* 2024).

Survival rate decreased slightly with increasing levels of ECLM plant protein substitution; however, values remained within acceptable limits for African catfish culture (Ronald *et al.,* 2021). T0(Control diet) recorded 85%, T1(83%),T2 (83%), T3(85%) and T4(80%) survival rate. Despite this decline**,** all treatments recorded survival rates above 75%**,** indicating that the experimental diets were generally safe. The results demonstrate that partial replacement (25% ECLM) are biologically acceptable (Zhou *et al*., 2021).

Nutrient Utilization of *Clarias gariepinus* fed Control and *Eichhornia crassipies* Leaf Meal (ECLM) experimental diets.

As presented in Table 5, the FCRs observed in this feeding trial showed that the control diet T0 recorded the best FCR (1.07) followed by T5 (25% ECLM) with a value of 1.59. The least FCR was recorded in T4 (100% ECLM) with a high FCR value of 2.17. This is similar to the research study carried out by Adeyemi *et al*., (2023), who reported a range of 1.00-1.80 FCRs for *Clarias gariepinus* fed unconventional plant ingredients. There was significant differences between the control diet and the ECLM diets (P<0.05). However, the FCR values obtained for experimental diets are higher than 1.80; this could be a result of anti-nutritional factors from high inclusion levels of *Eichhornia crassipies* Leaf Meal (ECLM) at 100% inclusion level.It is important to note that the lower the values of FCR, the higher the ability for the fish to easily convert the fish feed faster and easily into a higher body mass and higher weight gain and length gain as reflected in the Control diet (T0). Plant ingredients often contain higher fibre and anti-nutritional factors that impair digestibility and amino-acid availability; fish thus require more feed to deposit the same amount of tissue (Haetami *et al.*, 2023).

The result of the feed efficiency ratio (FER) showed that the control diet (T0) recorded the highest FER value of (0.93) followed by T5 (25% ECLM) with a value of (0.62), However, the lowest FER was recorded by T4(100% ECLM) with the lowest FER value of (0.45). The higher the value of FER, the better the feed efficiency and the reverse the case. However, this feeding trial showed that a high food conversion ratio and low FER were attributed to poor feed intake of fish feed, mainly due to the poor palatability of the feed, especially diets T4 diet (contained 100% of *Eichhornia crassipies* Leaf Meal (ECLM) (Ronald *et al.,* 2021). Higher FER diets especially the control diet T0 had the best outcomes and a high survival rate of 85% and a high crude protein level of 41.6%, while lower protein diets had moderate survival rates of 78%-83% respectively.

The results of this study revealed a clear variation in crude protein intake (CPI) of *Clarias gariepinus* across the experimental diets, with the control diet (T0) recording the highest value (222.7 g). This superior CPI observed in the control diet can be attributed to its higher crude protein content (41.6%) and better palatability, which likely enhanced feed consumption and nutrient utilization. This finding is consistent with earlier reports that fish-fed conventional fishmeal-based diets exhibit higher feed intake and protein utilization due to their balanced amino acid profile and absence of anti-nutritional factors (Nwanna, 2019).

A progressive decline in CPI was observed with increasing inclusion levels of *Eichhornia crassipies* leaf meal (ECLM) from T1 to T4. The lowest CPI was recorded in T4 (158.4 g), indicating reduced protein intake at 100% replacement. This trend may be linked to the presence of anti-nutritional factors such as mimosine in plant meals which is known to impair feed intake, protein digestibility, and overall nutrient utilization in fish (Haetami *et al.,* 2023; Francis *et al.,* 2017). Additionally, the reduction in crude protein percentage of the diets with increasing ECLM inclusion further contributed to the observed decline in CPI. Reduced palatability and possible metabolic stress associated with high inclusion levels of plant protein sources have also been reported to negatively affect voluntary feed intake in aquaculture species (Gatlin *et al.,* 2017).

In contrast, diets containing 25% *Eichhornia crassipes* leaf meal (ECLM**)** demonstrated relatively higher CPI values (192.0 g) This suggests that *Eichhornia crassipes* may be more acceptable to *Clarias gariepinus* at low inclusion levels Akinpelu *et al.,* (2022).

The significant differences ($p < 0.05$) observed among treatments further indicate that dietary composition had a pronounced effect on protein intake. The trend observed in this study aligns with previous findings that partial replacement of fishmeal with plant protein sources can be beneficial, but complete replacement often leads to reduced nutrient utilization due to imbalances in essential amino acids and the presence of anti-nutritional factors (Djissou *et al.,* 2025).The results suggest that ECLM can serve as alternative protein sources in aquafeeds, their inclusion should be limited to low levels to maintain optimal protein intake in *Clarias gariepinus*.

Protein Efficiency Ratio (PER) is a measure of the capacity of dietary protein to be converted into fish body mass. Higher PER values indicate that fish are utilizing the protein in the diet more effectively for growth, whereas lower values suggest inefficiencies in protein utilization.The Protein Efficiency Ratio (PER) obtained in this study, as presented in Table 5, clearly demonstrated that dietary protein quality and source significantly influenced protein utilization efficiency in *Clarias gariepinus*. The significantly higher PER observed in the control diet (T0) with a PER value of 2.26, which confirms that conventional fishmeal-based diets still provide superior protein bioavailability, digestibility, and amino acid balance required for optimal growth. Recent studies such as Konyeme *et al. (*2022) and Sogbesan *et al.* (2022) showed that animal-derived proteins remain the benchmark for efficient nutrient conversion due to their high digestibility and optimal essential amino acid profiles, particularly lysine and methionine, which are often limiting in plant-based diets.

At higher inclusion levels, PER dropped significantly to 1.58 in T4(100% ECLM), indicating reduced protein utilization efficiency. This reduction can be linked to plant-derived proteins known to contain anti-nutritional compounds such as mimosine, tannins, and phytates, which impair digestive enzyme activity and reduce nutrient absorption. (Hamid *et al.*, 2017). Recent work by Djissou *et al.,* (2025) demonstrated that total replacement of fishmeal with alternative plant proteins in *Clarias gariepinus* significantly reduced growth performance and protein utilization efficiency due to such nutritional constraints.However, diets containing 25% *Eichhornia crassipes* leaf meal (ECLM) exhibited relatively better PER values at low inclusion levels T1 with a PER value of 1.59. Similar findings have been reported in recent nutritional trials, where low inclusion of alternative plant proteins maintained acceptable growth and nutrient utilization, but excessive inclusion resulted in reduced efficiency due to increased fiber content and reduced digestibility (Olaniyi *et al*., 2022)

Economic indices of *Clarias gariepinus* fed Control and *Eichornia crassipies* leaf meal (ECLM) experimental diets.

The Economic Conversion Ratio (ECR) provides a direct measure of the cost required to produce 1 kg of fish. Among the diets tested, T1(25% ECLM) was the most cost-efficient, with an ECR of ₦1,933.60/kg per fish, lower than T2(50% ECLM) with ECR value of ₦2,024.75/kg per fish while the the highest ECR was recorded in T4(100% ECLM) with a value of ₦2,421.78/kg per fish. Although feed cost per kilogram decreased progressively from T0 to T4, higher inclusion levels led to poorer feed conversion and consequently higher ECRs for T4. The 100% *Eichornia crassipies* diet (T4) required ₦2,421.78 to produce 1 kg of fish. These results indicate that partial replacement of fish meal (25% ECLM) optimizes both feed cost and growth efficiency, striking the best balance between affordability and economic productivity in *Clarias gariepinus* culture Djissou *et al.,* 2025).

Among the treatment diets as shown in Table 6, the control diet T0 recorded a the highest NPV of ₦2,640.00/kg per fish, followed by T1 (25% ECLM) which achieved the highest NPV of ₦2,066.40/kg per fish, among the test diets indicating the greatest profit per kilogram of fish produced. In contrast, complete fish meal replacement (T4, 100% ECLM) resulted in the lowest NPV of ₦1,578.22, reflecting higher ECR despite the lowest feed cost per kg. The intermediate diets (T1–T4) achieved a favorable balance between feed affordability and growth performance, maximizing net profit. These results suggest that partial replacement of fishmeal with ECLM (25%) optimizes economic returns, providing both cost savings and high profitability for small-scale and commercial *Clarias gariepinus* farmers (Wardono *et al.,* 2018).

The Benefit–Cost Ratio (BCR) provides a clear indicator of investment efficiency by showing the return per ₦1 spent. A BCR greater than 1 indicates profitability, 1 represents break-even, and less than 1 indicates a loss. Among the treatment diets as shown in Table 6, T1 (25% ECLM) achieved the highest BCR of 2.06**,** indicating that every ₦1 invested returned ₦2.06, making it the most economically advantageous option. The control diet (T0) had a BCR of 2.94, while complete fishmeal replacement (T4, 100% ECLM) showed the lowest BCR of 1.27, reflecting reduced growth efficiency and higher feed conversion costs. These results confirm that partial replacement of fishmeal with (25%) of ECLM maximizes profitability**,** making it the best investment strategy for small-scale and commercial *Clarias gariepinus* farming(Igoche *et al*., 2025).

As a cost savings strategy, *Eichhornia crassipes* diets demonstrated better cost efficiency and profitability. Lower economic conversion ratio, alongside higher benefit–cost ratio and profit index, shows that *Eichhornia* offers greater economic returns to farmers most especially at 25% ECLM inclusion. As presented in Table 5 From an economic standpoint, *ECLM* diets were less profitable at higher inclusion levels (T4, 75-100% ECLM). Although feed cost was reduced, economic conversion ratio increased while net profit value, benefit–cost ratio, and profit index declined beyond moderate inclusion.

In conclusion, the performance of *Clarias gariepinus* in this study reiterates the need for caution when substituting fish meal with plant protein sources. Partial substitution (25% replacement) of ECLM may be feasible without severely compromising growth and feed utilization, but complete replacement at high levels (75–100%) results in significantly lower growth and feed efficiency, which are likely to translate into poor carcass quality and reduced production efficiency. Macusi *et al.*, (2023).

Based on the results and conclusions of this study, the following recommendations are made:

1. *Eichhornia crassipes* leaf meal be included at 25% fishmeal replacement levels, as these inclusion rates produced the best balance between growth performance (WG and SGR), feed efficiency (low FCR and high PER),and economic returns (lowest economic conversion ratio and highest net profit, benefit–cost ratio, and profit index) Inclusion levels above 25% should be avoided due to progressive declines in performance
2. To enhance the nutritional value of *Eichhornia crassipes* leaf meal, appropriate processing methods such as fermentation, soaking, or heat treatment are recommended to reduce anti-nutritional factors and improve digestibility before incorporation into aquafeeds.
3. Feed manufacturers should consider incorporating *Eichhornia crassipes* leaf meal as a sustainable plant protein ingredient in commercial African catfish feeds, particularly in regions where fishmeal is expensive or scarce. This will enhance feed affordability and support sustainable aquaculture development.
4. Policymakers and aquaculture development agencies should support the utilization of *Eichhornia crassipes* in aquafeeds as part of integrated strategies for invasive plant management, feed cost reduction, and sustainable aquaculture expansion

Institutional Review Board (Ethics Approval)

Ethical review and approval were waived for this study as it involved standard aquaculture practices and non-invasive handling of fish, conducted in accordance with institutional and national guidelines for the care and use of laboratory animals.

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Conflict Of Interest

All authors declare that they have no conflict of interest.

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