

Development of Low-Cost, Sustainable Aquafeed Using Local Ingredients for Small-Scale Fish Farmers in Birnin-Kebbi, Kebbi State, Nigeria

Bello D. Muhammed^{1*}, Nkechi Funmilola Adebago², Matthew Sunday Oladele³,

Abdulrahman Dantani⁴, Abdulahi Alhassan⁵, Umar Abubakar⁶

Department of Fisheries Technology, Kebbi State Polytechnic, Dakingari, Kebbi State, Nigeria^{1,2,3,4,5,6}

Abstract: In northern Nigeria, feed constitutes the bulk of the cost of catfish production, and this is mainly due to imported fish meal. The effect of the 50:50 ratio of toasted sesame seed meal and sun-dried moringa leaf meal produced from farm-raised moringa leaves in replacing 0, 25, 50 and 75% of fishmeal in isonitrogenous (35% crude protein) diets on juveniles of *Clarias gariepinus* for 12 weeks was evaluated in the study in Birnin-Kebbi, Kebbi State. Replacement did not significantly affect final weight (33.21–34.51 g), specific growth rate (1.70–1.73% per day), survival (93.3–96.7%) or carcass composition ($p > 0.05$). Mortality-corrected feed conversion ratio was lowest at 50% (1.771) and 0% (1.775) replacement ($p < 0.001$). The cost of feed per kg gain decreased from ₦4,967 at control to ₦4,580 (7.8%) at 75% replacement. Replacement of up to 75% of fishmeal can be achieved, and 50% replacement is optimal in terms of feed efficiency and cost.

Keywords: *Clarias gariepinus*, fishmeal replacement, *Moringa oleifera*, *Sesamum indicum*, feed cost, small-scale aquaculture

INTRODUCTION

Capture fisheries and livestock production have not been able to match population growth in sub-Saharan Africa, which has seen one of its fastest-growing food production industries as aquaculture. One of the fastest-growing food production industries in sub-Saharan Africa is aquaculture, where capture fisheries and livestock production have not kept pace with population growth. Nevertheless, the African catfish, *Clarias gariepinus* (Burchell, 1822), is the most dominant species in commercial farming in Nigeria as it has a good growth rate, can withstand high stocking density and poor water quality and is well accepted by both the consumers and the smallholder farmers [2]. However, the increase in catfish culture is limited by the cost of fish feed, which amounts to 60 to 70% of the overall cost of fish production in the small fish farms in Nigeria [3].

Part of this expense is due to the high costs of fishmeal, which is the preferred protein source used in commercial aquafeeds because of its balanced amino acid profile, digestibility and palatability [4]. Fishmeal demand has been steadily increasing, whereas supply from reduced fisheries has remained stagnant [5], and high feed prices and currency volatility in Nigeria have resulted in high feed prices [2]. These costs are especially high for small-scale farmers in north-western Nigeria, who work on thin margins and don't have access to credit. There could be a cost reduction in feeds, less reliance on imports, and more value added within local economies by using part of the plant ingredients in the feeds that are available locally [6, 7].

Kebbi State has a variety of plant materials suitable for fish feed ingredients such as sesame, groundnut, maize, rice and cassava, amongst others, with moringa trees being prevalent around homesteads. There is little information on the effectiveness of blends of these ingredients in local catfish culture diets, or whether use of these blends actually saves fish culture costs. In this study, the proximate composition of the feed ingredients sourced in the study area was therefore determined. Diets in which 25, 50 and 75% of fishmeal was replaced with a 50:50 blend of processed sesame seed meal and moringa leaf meal were formulated, and their effects on the growth, feed utilisation, carcass composition and cost of the feed for the *C. gariepinus* juveniles were evaluated over a period of 12 weeks.

MATERIALS AND METHODS**3.1 Study Area**

The study was carried out in Birnin-Kebbi of Kebbi state, North-western Nigeria, between 4°12'East and 12°27'North and within the Sudan Savannah ecoregion, with wet and dry seasons from May to October and November to April, respectively.

3.2 Collection and Processing of Ingredients

Clupeid fishmeal, sesame seed, groundnut cake, maize meal, rice bran, cassava flour, wheat and a commercial multivitamin premix were bought from markets and agro-processing centres in Birnin-Kebbi. However, fresh *Moringa oleifera* leaves were purchased in the local market that specializes in the freshly harvested leaves from local farms in the study area. Sesame seed was cleaned, toasted at 110 to 120 °C, cooled and milled. *Moringa* leaves were sorted, sun-dried on clean surfaces for four days and milled. All the ingredients used were milled and sieved to a uniform particle size, and then sun-dried when required, including groundnut cake. All ingredients used were dried in the sun when necessary and ground to a uniform particle size: groundnut cake, maize meal, and rice bran.

3.3 Diet Formulation

Four isonitrogenous diets (Table 2) were formulated containing 35% crude protein as fed. The control diet (T1) was based on 30% fishmeal. Fishmeal was substituted in the diets T2, T3 and T4 at 25, 50 and 75% by 50:50 *Moringa* Leaf Meal and Sesame Seed Meal, respectively. Maize meal, rice bran, wheat and the multivitamin premix were kept at constant levels. However, the blend was compared with fishmeal containing the same level of protein by increasing the amount of groundnut cake and decreasing the amount of cassava flour. Ingredients were weighed, blended with water and pelleted, and then oven-dried to less than 10% moisture content and placed in airtight containers. The price of the diet was obtained from the ingredient prices during diet production in Birnin-Kebbi.

3.4 Chemical Analyses

Proximate composition (moisture, crude protein, crude lipid, crude fibre and ash) of the ingredients, diets and fish carcasses was determined in duplicate according to the AOAC [16] procedure and nitrogen-free extract (NFE) was calculated as the difference. Values are given on an as-fed (wet) basis. The carcasses were analysed for calcium and phosphorus, using the atomic absorption spectrophotometric method and the ammonium molybdate colourimetric method, respectively. The phytate, tannin, oxalate, saponin and trypsin inhibitor contents of raw and processed sesame and moringa and of each diet were individually measured by standard wet chemistry and spectrophotometric methods.

3.5 Experimental Fish, Design and Feeding

Juveniles of *C. gariepinus* were collected from a commercial fish hatchery and were held for 14 days in an aerated holding tank. One hundred and twenty fish (initial mean weight about 8 g) were then randomly allocated to twelve 50-litre tanks (10 fish per tank) in a completely randomised design with three replicate tanks per diet. Fish were fed twice daily (08:00 and 16:00 h) at 3 to 5% of body weight for 12 weeks, from 2 June to 25 August 2026. Uneaten feed was siphoned about 1 hour after feeding, dried and weighed, and feed intake was determined as feed offered minus feed refused. All the fish were weighed and measured for total length at the beginning. At two-week intervals, and in between, the rations were calculated according to the biomass in the tank which was estimated as the average of the neighbouring fortnightly weighings. The water temperature, dissolved oxygen, pH and un-ionised ammonia nitrogen (NH₃-N) were determined three times a week at 08:30, 12:30 and 16:30 h in each tank.

3.6 Growth and Feed Utilisation Indices

Growth and feed utilisation were calculated as follows: W₁ and W₂ are mean initial and final weights (g), and t is the time of the trials (84 days):

$$\text{Weight gain (g)} = W_2 - W_1; \text{ Weight gain (\%)} = 100 \times (W_2 - W_1) / W_1$$

$$\text{Specific growth rate (\%/day)} = 100 \times (\ln W_2 - \ln W_1) / t$$

$$\text{Feed conversion ratio (FCR)} = \text{feed consumed (g)} / \text{mortality-corrected biomass gain (g)}$$

$$\text{Protein efficiency ratio (PER)} = \text{mortality-corrected biomass gain (g)} / \text{protein consumed (g)}$$

$$\text{Survival (\%)} = 100 \times \text{final number} / \text{initial number}; \text{ Condition factor } K = 100 \times W / L^3 \text{ [17]}$$

The mortality-corrected biomass gain is equal to the weight of each fish when it died (plus the last weight of the fish if it died once the experiment ended) subtracted from the initial weight of the fish at the start of the experiment, divided by the number of fish that survived.

3.7 Carcass Composition

Three fish were randomly sampled from the stock before allocation to get baseline carcass composition. Three fish/tank were sampled at the end of the trial, pooled per tank and analysed.

3.8 Economic Analysis

The cost of the feed per kg of diet, the feed budget per tank and the cost of the feed per kg of the corrected weight gain (cwg) were determined for each tank. The cost of fish produced per kilogram of weight gain was defined as the break-even selling price of fish, the lowest price per kg of live fish at which the value of the produced fish equals the cost of the feed.

3.9 Statistical Analysis

The experimental unit ($n = 3$) was the tank. One-way analysis of variance (ANOVA) was used to analyse the data, with means separating the treatments at $p < 0.05$ by Duncan's Multiple Range Test. Orthogonal polynomial contrasts were used to test for linear and quadratic responses to replacement level. Data are reported as mean $\pm$ SEM. Analysis was done using individual standard wet-chemistry and spectrophotometric procedures

RESULTS AND DISCUSSION

4.1 Proximate Composition of Ingredients

The ingredients' proximate composition is given in Table 1. The crude protein content of the fishmeal was the highest (71.09%), and that of moringa leaf meal was the lowest (29.58%). The highest lipid content was obtained from sesame seed meal (18.48%), while the highest fibre (10.86%) and ash (9.39%) content was found in moringa leaf meal. The protein content of the sesame seed meal, groundnut cake and rice bran are within the limits reported for these sources [1], indicating that the local sources were of normal nutritional value. Moringa leaf meal has moderate protein content and high fibre content, which makes it suitable to be used as a co-ingredient in fishmeal production [13].

TABLE-1: Proximate composition of feed ingredients sourced in Birnin-Kebbi (% , as-fed)

Ingredient	Moisture	Crude protein	Crude lipid	Crude fibre	Ash	NFE
Clupeid fishmeal	8.87	71.09	8.09	1.24	8.82	1.89
Moringa leaf meal	7.23	29.58	4.79	10.86	9.39	38.15
Sesame seed meal	6.83	41.98	18.48	5.98	7.04	19.69
Groundnut cake	7.26	45.69	8.36	4.95	6.31	27.43
Maize meal	10.48	9.74	4.08	2.30	1.62	71.78
Rice bran	10.23	13.84	13.08	9.02	8.73	45.10
Cassava flour	11.41	4.19	1.24	2.04	1.69	79.43
Wheat	11.41	12.10	1.98	2.24	1.76	70.51

Values are means of duplicate determinations. NFE = nitrogen-free extract.

4.2 Diet Composition, Cost and Anti-nutritional Factors

The composition, analysed proximate composition and cost of the diets are shown in Table 2. The diets were isonitrogenous (34.82 to 35.19 % protein) and were near iso-energetic (17.73 to 17.90 kJ/g estimated gross energy), as per the target of 35% protein [18]. Lipid increased from 6.20 to 8.25%, and fibre increased from 3.00 to 5.01% as the percentage of replacement increased, which is in line with the lipid-rich sesame and fibre-rich moringa. The protein level in the blend has been reduced to about half that of fishmeal, so groundnut cake was increased from 21.11% in T1 to 40.25% in T4 and was the predominant protein source at the high replacement level. Feed cost fell from ₦2,798.40/kg (T1) to ₦2,544.57/kg (T4), a reduction of 9.07%.

Processing significantly decreased all of the anti-nutritional factors measured (Table 3). The trypsin inhibitor activity of sesame was reduced by 51.4% by toasting and 46.6% by sun-drying of moringa, and the tannin activity was

reduced by 37.1% by toasting of sesame and 35.9% by sun-drying of moringa. Phytate decreased by only 24.8% and 21.3%, which agrees with its high level of heat stability [10, 9]. For all plant-based diets, there were more anti-nutrients than in the control. However, quantities were not proportional to the increasing inclusion of the blends, and the presence of these additional factors should be confirmed in T2 (higher than T3) and is possible for T3 also.

TABLE-2: Gross composition, analysed proximate composition and cost of the experimental diets

Item	T1 (0%)	T2 (25%)	T3 (50%)	T4 (75%)
Ingredient (%)				
Clupeid fishmeal	30.00	22.50	15.00	7.50
Moringa leaf meal	0.00	3.75	7.50	11.25
Sesame seed meal	0.00	3.75	7.50	11.25
Groundnut cake	21.11	27.49	33.87	40.25
Maize meal	10.00	10.00	10.00	10.00
Rice bran	7.00	7.00	7.00	7.00
Cassava flour	20.89	14.51	8.13	1.75
Wheat	10.00	10.00	10.00	10.00
Multivitamin premix	1.00	1.00	1.00	1.00
Total	100.00	100.00	100.00	100.00
Analysed composition (% , as-fed)				
Moisture	9.57 ± 0.09	9.20 ± 0.19	8.64 ± 0.10	8.59 ± 0.21
Crude protein	35.19 ± 0.01	34.82 ± 0.17	35.10 ± 0.11	34.91 ± 0.26
Crude lipid	6.20 ± 0.21	6.59 ± 0.12	7.31 ± 0.05	8.25 ± 0.03
Crude fibre	3.00 ± 0.04	3.71 ± 0.04	4.36 ± 0.05	5.01 ± 0.14
Ash	5.31 ± 0.13	5.50 ± 0.02	5.87 ± 0.13	6.03 ± 0.04
NFE	40.73 ± 0.01	40.18 ± 0.26	38.72 ± 0.04	37.21 ± 0.27
Estimated gross energy (kJ/g)	17.76	17.73	17.83	17.90
Cost				
Feed cost (₦/kg)	2,798.40	2,713.80	2,629.18	2,544.57
Cost reduction relative to T1 (%)	0.00	3.02	6.05	9.07

Values analysed are mean ± SD of duplicate determinations. Ingredient prices (₦/kg): fishmeal 6,000; moringa leaf meal 3,000; sesame seed meal 3,000; groundnut cake 2,700; wheat 600; maize meal 500; cassava flour 500; rice bran 200; premix costed at ₦200/kg of feed. Gross energy was calculated based on 23.6, 39.5 and 17.2 kJ/g for protein, lipid and NFE, respectively.

TABLE-3: Anti-nutritional factors in raw and processed plant ingredients and in the experimental diets

Material	Stage	Phytate (mg/kg)	Tannin (mg/kg)	Oxalate (mg/kg)	Saponin (mg/kg)	Trypsin inhibitor (mg/g)
Sesame meal	Raw	8,400.0	620.0	410.0	290.0	7.20
Sesame meal	Processed	6,320.0	390.0	335.0	210.0	3.50
Moringa leaf meal	Raw	7,600.0	920.0	520.0	470.0	5.80
Moringa leaf meal	Processed	5,980.0	590.0	455.0	335.0	3.10
Diet T1	-	285.0	28.7	17.1	13.3	0.41
Diet T2	-	1,414.3	88.3	67.4	54.6	0.76
Diet T3	-	1,091.7	76.5	64.5	51.0	0.67
Diet T4	-	1,486.8	93.1	70.9	59.9	0.84

Sesame was toasted at 110–120 °C; moringa leaves were sun-dried for four days. Single determinations.

4.3 Growth Performance and Feed Utilisation

Growth and feed utilisation are presented in Table 4 and Fig. 1. There was no difference in initial weight ($p=0.613$) between treatments. No significant difference was observed between diets ($p > 0.05$), and there was no linear or quadratic trend for final weight (33.21 to 34.51 g), weight gain, specific growth rate (1.702 to 1.732%/day), feed intake, survival (93.3 to 96.7%) and condition factor. The growth curves were almost parallel during the whole course of the trial (Fig. 1). Mortality-corrected FCR differed significantly ($p < 0.001$): it was lowest in T3 (1.771) and T1 (1.775), higher in T4 (1.800) and highest in T2 (1.817). PER reversed the trend ($p = 0.006$). These differences were negligible, with the worst FCR being only 2.6 % higher than the best, and were not on the ascending replacement gradient. The efficacy was lower for T2, which had an unexpectedly higher anti-nutritional factor load and lower for T4, which contained the highest fibre, phytate and groundnut cake contents. Maintenance of growth at 75% replacement is in the upper range of those reported by others for plant protein replacement in catfish diets (25 – 50% replacement) [1, 12]. Additionally, it is worth noting that there was no growth depression in T4 containing 11.25% moringa leaf meal, which was above the 10% reported in moringa only treatment [13, 14]. Three aspects of the formulation explain this possibility: moringa was only one component of a mixture containing complementary protein provided by sesame and groundnut cake; 7.5% fishmeal was even included in T4, and both the plant materials were processed to reduce their anti-nutritional factors. There was no change in feed intake, which means the blend did not decrease palatability.

TABLE-4: Growth performance and feed utilisation of *C. gariepinus* juveniles fed the experimental diets for 12 weeks

Parameter	T1 (0%)	T2 (25%)	T3 (50%)	T4 (75%)	p	p (linear)
Initial mean weight (g)	8.02 ± 0.11	7.95 ± 0.12	8.06 ± 0.08	8.13 ± 0.08	0.613	0.323
Final mean weight (g)	33.76 ± 0.53	33.21 ± 0.25	34.51 ± 0.28	33.98 ± 0.46	0.219	0.304
Mean weight gain (g/fish)	25.75 ± 0.42	25.26 ± 0.14	26.45 ± 0.23	25.85 ± 0.38	0.143	0.323
Weight gain (%)	321.20 ± 1.11	318.03 ± 3.29	328.36 ± 3.13	317.72 ± 2.11	0.061	0.992
Weekly weight gain (g/fish/week)	2.146 ± 0.035	2.105 ± 0.012	2.204 ± 0.019	2.154 ± 0.032	0.143	0.323
Specific growth rate (%/day)	1.712 ± 0.003	1.703 ± 0.009	1.732 ± 0.009	1.702 ± 0.006	0.062	0.984
Total feed intake (g/tank)	446.94 ± 3.33	442.42 ± 13.90	461.76 ± 3.22	442.30 ± 9.38	0.398	0.892
Biomass gain, mortality-corrected (g/tank)	251.78 ± 1.56	243.51 ± 7.00	260.69 ± 2.66	245.71 ± 4.83	0.102	0.961
Feed conversion ratio	1.775 ± 0.003 ^c	1.817 ± 0.005 ^a	1.771 ± 0.006 ^c	1.800 ± 0.003 ^b	<0.001	0.176
Protein intake (g/tank)	157.28 ± 1.17	154.05 ± 4.84	162.08 ± 1.13	154.41 ± 3.28	0.288	0.967
Protein efficiency ratio	1.601 ± 0.002 ^{ab}	1.581 ± 0.004 ^c	1.608 ± 0.005 ^a	1.591 ± 0.003 ^{bc}	0.006	0.960
Survival (%)	96.67 ± 3.33	93.33 ± 3.33	96.67 ± 3.33	93.33 ± 3.33	0.802	0.667
Final mean total length (cm)	15.55 ± 0.05	15.47 ± 0.06	15.59 ± 0.03	15.60 ± 0.02	0.195	0.185
Final condition factor (K)	0.898 ± 0.006	0.898 ± 0.007	0.911 ± 0.004	0.895 ± 0.009	0.408	0.867

Mean ± SEM (n = 3 tanks). Means in a row with different superscripts differ significantly (Duncan's test, $p < 0.05$). FCR and PER are based on mortality-corrected biomass gain.

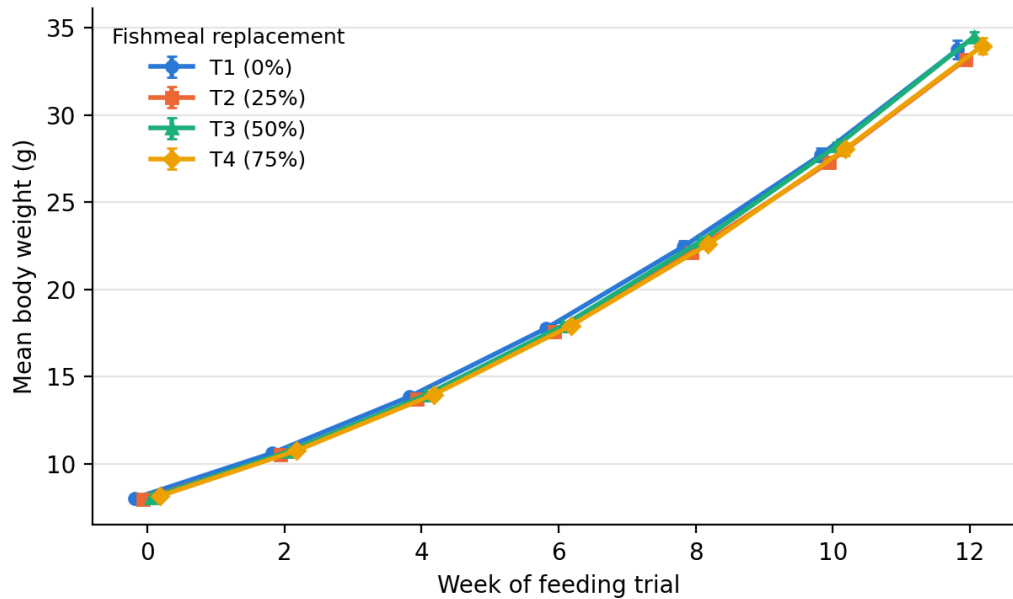


Fig. 1: Mean body weight of *C. gariepinus* juveniles fed diets with graded fishmeal replacement over 12 weeks (mean $\pm$ SEM, n = 3 tanks)

4.4 Carcass Composition and Water Quality

In Table 5, carcass composition is shown. In all treatments, during the baseline to the end of the trial, the moisture percentage in the carcass decreased from 74.00% to about 69.8%, and protein increased from 16.98% to 18.39–18.73%, while the lipid percentage increased from 4.82% to 7.03–7.12%, which confirmed normal growth. There were no significant differences between the final carcass components ($p = 0.201$ to 0.769), which indicated that the nutritional quality of the fish was not affected by fishmeal replacement. The increased dietary lipid of T3 and T4 did not contribute to carcass lipid accumulation, indicating that the extra lipid from sesame was used for energy and that neither calcium nor phosphorus in the carcass was affected by the increased phytate level in the plant-based diets.

Water quality (Table 6) was not significantly different between treatments ($p = 0.610$ to 0.992). The pH (6.85 to 7.55), $\text{NH}_3\text{-N}$ (0.018 to 0.113 mg/L) and dissolved oxygen (4.3 to 6.4 mg/L) were also within the allowable ranges for warm-water fish culture and culture of *C. gariepinus* [19, 4] and therefore cannot be implicated in the observed dietary effects.

TABLE-5: Whole-body carcass composition of *C. gariepinus* at the start and end of the trial (% wet weight)

Component	Initial	T1 (0%)	T2 (25%)	T3 (50%)	T4 (75%)	p
Moisture	74.00 $\pm$ 0.06	69.97 $\pm$ 0.19	69.87 $\pm$ 0.08	69.68 $\pm$ 0.15	69.81 $\pm$ 0.18	0.632
Crude protein	16.98 $\pm$ 0.04	18.66 $\pm$ 0.14	18.57 $\pm$ 0.10	18.73 $\pm$ 0.10	18.39 $\pm$ 0.06	0.201
Crude lipid	4.82 $\pm$ 0.03	7.09 $\pm$ 0.03	7.07 $\pm$ 0.08	7.03 $\pm$ 0.06	7.12 $\pm$ 0.07	0.769
Ash	1.82 $\pm$ 0.02	2.00 $\pm$ 0.06	1.97 $\pm$ 0.03	1.99 $\pm$ 0.02	2.07 $\pm$ 0.05	0.461
Calcium	0.40 $\pm$ 0.00	0.43 $\pm$ 0.00	0.41 $\pm$ 0.00	0.42 $\pm$ 0.01	0.43 $\pm$ 0.01	0.521
Phosphorus	0.31 $\pm$ 0.00	0.35 $\pm$ 0.01	0.33 $\pm$ 0.00	0.34 $\pm$ 0.01	0.33 $\pm$ 0.01	0.579

Initial: mean $\pm$ SEM of 12 pooled samples from the stock; final: mean $\pm$ SEM of three tanks. p refers to final values.

TABLE-6: Water quality in the experimental tanks during the 12-week trial

Parameter	T1 (0%)	T2 (25%)	T3 (50%)	T4 (75%)	p
Temperature ($^{\circ}\text{C}$)	27.17 $\pm$ 0.07 (25.40–28.70)	27.06 $\pm$ 0.14 (25.40–28.90)	27.03 $\pm$ 0.04 (25.80–28.30)	26.93 $\pm$ 0.26 (25.70–28.80)	0.737
Dissolved oxygen (mg/L)	5.33 $\pm$ 0.04 (4.40–6.20)	5.37 $\pm$ 0.05 (4.50–6.30)	5.35 $\pm$ 0.02 (4.30–6.40)	5.38 $\pm$ 0.02 (4.40–6.30)	0.725

Parameter	T1 (0%)	T2 (25%)	T3 (50%)	T4 (75%)	p
pH	7.19 ± 0.01 (6.91–7.52)	7.19 ± 0.01 (6.85–7.52)	7.19 ± 0.02 (6.85–7.52)	7.19 ± 0.01 (6.87–7.55)	0.992
Ammonia, NH ₃ -N (mg/L)	0.056 ± 0.003 (0.018–0.105)	0.054 ± 0.001 (0.018–0.105)	0.056 ± 0.002 (0.018–0.113)	0.053 ± 0.001 (0.018–0.089)	0.610

Mean ± SEM of tank means; minimum–maximum of individual readings in parentheses.

4.5 Economic Analysis

Economic outcomes are given in Table 7 and Fig. 2. Feed expenditure per tank was lowest in T4 ($p = 0.028$; linear $p = 0.008$), and feed cost per kilogram of weight gain declined linearly with replacement ($p < 0.001$), from ₦4,967 in T1 and ₦4,930 in T2 to ₦4,657 in T3 and ₦4,580 in T4. The feed cost of production for one kg of fish decreased by 6.24% (50% replacement) and 7.80% (75% replacement) compared to the control. These are also the feed prices at which the feed will break even — at prices lower than these, the weight gained will not compensate for the feed used.

The savings gained are smaller than the 30–40% saved for some locally sourced feeds [6]. The moringa/sesame blend (₦3,000/kg, 36% protein) is cheaper per kg of protein than fishmeal (₦6,000/kg, 71% protein), and moringa is more expensive. The least expensive protein was groundnut cake, and its use made major contributions to the savings. The economic gain of the blend will thus be maximum if the farmers can get moringa from their own trees and sesame at the lower market price used in this study.

TABLE-7: Feed cost of producing *C. gariepinus* juveniles on the experimental diets

Parameter	T1 (0%)	T2 (25%)	T3 (50%)	T4 (75%)	p
Feed cost (₦/kg diet)	2,798.40	2,713.80	2,629.18	2,544.57	-
Feed consumed (kg/tank)	0.447 ± 0.003	0.442 ± 0.014	0.462 ± 0.003	0.442 ± 0.009	0.398
Feed expenditure (₦/tank)	1250.71 ± 9.33 ^a	1200.64 ± 37.72 ^{ab}	1214.06 ± 8.47 ^a	1125.45 ± 23.88 ^b	0.028
Biomass gain, mortality-corrected (kg/tank)	0.252 ± 0.002	0.244 ± 0.007	0.261 ± 0.003	0.246 ± 0.005	0.102
Feed cost per kg weight gain (₦/kg)	4967 ± 7 ^a	4930 ± 14 ^a	4657 ± 16 ^b	4580 ± 9 ^c	<0.001
Reduction in feed cost per kg gain relative to T1 (%)	0.00	0.76	6.24	7.80	-

Mean ± SEM ($n = 3$ tanks). Means in a row with different superscripts differ significantly ($p < 0.05$). Weight gain is mortality-corrected.

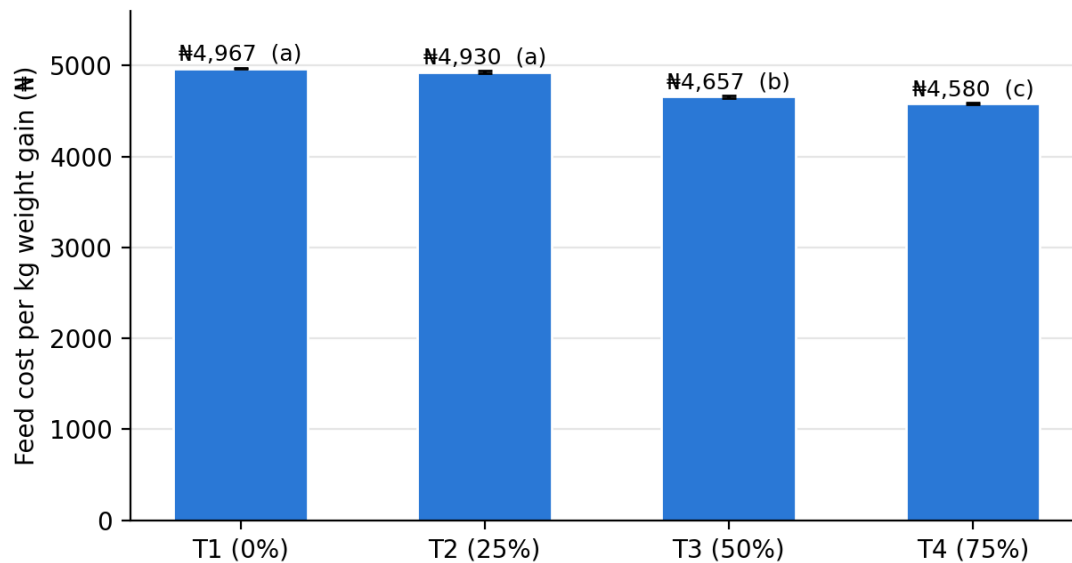


Fig. 2: Feed cost per kilogram of weight gain of *C. gariepinus* juveniles fed diets with graded fishmeal replacement (letters show Duncan groupings, $p < 0.05$)

CONCLUSION

There was no negative effect on the growth, survival and carcass composition of *C. gariepinus* juveniles when replacing up to 75% of the fishmeal in the diet with toasted sesame seed meal and sun-dried moringa leaf meal in a 50:50 ratio. The fish produced with the above feed mix cost up to 7.8% less than those produced using fishmeal. The 50% replacement diet was as efficient as the control diet in feed and protein efficiency and is suggested as the optimum compromise between efficiency and feed cost; the 75% replacement diet resulted in the lowest feed cost per kg gain. Farmers are advised to check prices for the ingredients in the diets before using them, as there were significant savings in the production of groundnut cake, and the groundnut cake should be kept dry to reduce the risk of contamination with aflatoxins.

The diets should be further tested for grow-out to market size, amino acid digestibility, effect of lysine and methionine supplementation, repeating anti-nutritional factor analyses, and a complete economic analysis should be conducted based on farm-gate prices in Birnin-Kebbi.

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