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Production, Nutrient Utilization and Profitability of African Catfish (*Clarias gariepinus*, Burchell, 1822) Fed with Different Feed Types and Reared Under Two Production Systems

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Abstract

Growth performance, survival, nutrient utilization, body composition and profitability of *Clarias gariepinus* fed with imported extruded (Le), locally pelleted (Lpe) and locally extruded (Lex) feeds and reared under two production facilities was investigated. The study was conducted in nine IBC tanks and nine net hapas installed in a 500 m^2 earthen pond with holding water capacity ranging from 0.8 to 0.9 m^3. For each system, 900 juveniles of mean initial weight ranging from 10.68 ± 4.93 g to 15.15 ± 3.48 g were stocked at 100 juveniles holding system^{-1} and were fed thrice a day for 16 weeks. Final mean weights for tank system were respectively 758.46 ± 13.79 g, 289.03 ± 60.67 g and 339.27 ± 9.34 g for Le, Lpe and Lex feeds. As for hapas-in-pond system, final mean weights were 726.02 ± 82.91 g, 396.85 ± 18.96 g and 461.73±13.26 g respectively for Le, Lpe and Lex feeds. Fish fed with "Le" exhibited significantly higher growth performance and better nutrient utilisation irrespective of the production system. However, fish fed "Lpe" and "Lex" feeds exhibited higher growth performances in hapas-in-pond system. The economic assessment revealed that the use of "Le" and "Lpe" feeds to feed African catfish was economically efficient as indicated by the lower incidence cost and higher profit compared to "Lex" feeds. The studied feeds were profitable as indicated by the benefit cost ratio >1 irrespective of the production system proves that correctly formulated and properly blended ingredients in feeds can provide

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growth rates, survival and yields of African catfish similar to imported feeds.

INTRODUCTION

The African catfish (*Clarias gariepinus* Burchell, 1822), stands out as the most extensively cultured fish species, both within its native habitats and beyond, thriving particularly in tropical and subtropical regions (Farhat and Khan, 2011). Recognized as the fifth most cultured aquaculture species globally, it is featured in the top 10 aquaculture species groups based on quantity in the World's aquaculture production (FAO, 2021). The rising dominance of this aquaculture species can be attributed to several advantageous traits: its rapid growth rate, robust disease resistance, ability to withstand a range of environmental conditions, and strong consumer preference (Toko *et al*., 2007). These factors jointly contribute to its popularity and increasing importance in the aquaculture industry.

This fish has been farmed in the last decade for commercial purposes in Cameroon and a great majority of culture practice is semi-intensive especially in the country's economic and political regions. This is due to the Government policies initiated to support the development of aquaculture operations in order to increase supply of fish for domestic market, to create employment in rural areas (Efole, 2011) and to reduce fish importations which costs the government over 100 billion FCFA yearly (Business in Cameroon, 2014). The suitability of *C. gariepinus* for semi-intensive culture stems from its omnivorous feeding habits as it accepts a variety of diets from plant, animal-based and their mixtures under culture conditions with protein levels between 300 to 400g/Kg depending on its size (Hoffman *et al*., 1997).

However, the major constraint to catfish production expansion and growth remains the necessity to produce cost-effective and nutritionally adequate feeds. There is a strong emphasis on using locally available ingredients to mitigate high production costs, which generally accounts for 40-70% of the running cost (Hecht, 2013; Limbu, 2020). This underscores the importance of sustainable practices and innovation in feed formulation to enhance catfish farming's economic viability.

Feeds used in fish farming are either locally farm-made (sinking) or commercially extruded (floating). Floating diets are usually more costly than sinking diets because the extrusion process which is the main activity that makes them float adds extra cost (Kannadhason *et al*., 2009). Farmers producing catfish in intensive conditions (especially in raised ponds systems like tanks) prefer floating diets because it is easier to observe satiation level of the fish in tanks (Nwokocha and Nwokocha, 2013) and their production cycles are shortened by at least 3 months. Moreover, Cho *et al*. (2006) stated that the use of good quality pelleted and especially extruded feed, has proven to be less expensive, can minimize water pollution and spread of diseases owing to their high digestibility, low conversion rate, better fish growth and less organic waste per kg of fish produced. In ponds the situation is different, as due to its bottom feeding behaviour, *C. gariepinus* causes high turbidity that obscure water visibility making it impossible for farmers to observe satiation levels (Kadye and Booth, 2012; Limbu, 2015). Overall, the choice of feed type can significantly impact the efficiency and sustainability of fish farming operations, tailoring practices to specific farming environments (out of ponds vs. in-pond systems) and the unique behaviours of the fish being cultivated.

Studies in *C. gariepinus* have yielded inconsistent findings regarding the effects of floating versus sinking diets on the growth

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performance and nutrient utilization of *C. gariepinus* (Limbu, 2015). Previous research has produced mixed results; while Mustapha *et al*. (2014) reported significant increase in weight gain and specific growth rates for tank-cultured *C. gariepinus* fed floating feeds, Limbu (2015) and Ajani *et al*. (2011) observed comparable growth and nutrient utilization between floating and sinking feeds in different aquaculture systems. These discrepancies highlight the need for further investigation to clarify the impacts of different feeding strategies on *C. gariepinus* (Limbu, 2015), especially considering the limited understanding of their bottom-feeding habits. The rising production costs faced by farmers can partly be attributed to the lack of comprehensive scientific data regarding optimal feeding practices, which further emphasizes the necessity of this research. Understanding the relationship between feed type (floating vs. sinking) and the culture medium (tank vs. hapas-in-ponds) could provide crucial insights into maximizing growth performance, nutrient utilization, and overall yield (Opiyo *et al*., 2014). Moreover, a detailed analysis of carcass nutrient composition and the economic aspects of feeding strategies will contribute valuable information to aquaculture practitioners, ultimately enhancing profitability in *C. gariepinus* farming (Gabriel *et al*., 2007).

The present study was carried out to investigate the growth performance, nutrient utilization, carcass nutrient composition, yield and economics of *C. gariepinus* fed on floating and sinking feed in tank and hapas-in ponds culture systems. The findings are expected to support aquaculture development by informing the best practices for *C. gariepinus* feeding, paving the way for more effective management and improved yields in catfish farming.

METHODOLOGY

Ethical Approval

The investigated animals were not harmed or mistreated during the research. Animals tested during the study were treated properly according to the optimal environment, ranging from handling techniques, water quality, feed availability, feeding etc.

Place and Time

The study was conducted in the grow-out production unit of the Fish Farming Demonstration Association (FIFADA) located in Yaoundé for tank rearing and at an intensive commercial farm (ACA Farms) located at Ekok II, not far (~ 50 Km) from Yaoundé for hapas-in-pond rearing. The trials ran from August 2023 to January 2024.

Research Materials

The main research materials were rearing facilities, experimental fish and feeds. For the tank system, 09 IBC (Intermediate Bulk Container) tanks (1 x 1 x 1 m) (cut at the top) were used for grow-out and 03 tanks served as reservoir tanks. Holding water was domestic tap water that was left to dechlorinate for 48 hours before usage. Each tank was stocked with 800 L of water and the tops covered with mosquito to prevent fish from jumping out. Nine HDPE Hapa nets of 1 mm mesh size and dimension of 2 m x 1 m sown in rectangular shapes were partially immersed (0.9 m^3 holding capacity) in a 500 m^2 earthen pond that was lime-treated prior to installation. Holding water was mainly underground water stored in a reservoir pond.

African catfish fingerlings of mean initial weight 15.15 ± 3.48 g reared in water recirculating systems were obtained for grow-out in the tank rearing system. While for the hapas-in-pond rearing system, fingerlings of mean initial weight 10.68 ± 4.93 g reared in earthen ponds were obtained.

Locally available feed ingredients (Fishmeal, soybean cake, groundnut cake, wheat bran, cassava flour, palm kernel cake, premix, lysine, methionine and vegetable oil) were purchased for formulating the locally pelleted feed (Lpe) using Pearson square method and further enhanced with

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trial-and-error method for perfection. The ingredients were processed, mixed and pelletized with a flat die pelletizer (Capsfeed Ltd), sun-dried and stored in airtight containers at room temperature until further use. Locally extruded floating (Lex) and imported extruded floating (Le) feeds were purchased from respectable feed producers and retailers respectively in Yaoundé, Cameroon. A dried sample of locally pelleted and locally extruded feeds (300 g each) were sent to the Laboratory of Animal Nutrition and Feeding of the University of Dschang for proximate nutrient analyses according to the methods of AOAC (2005). The proximate analysis for the imported feed was as indicated by the Manufacturer. The chemical composition of the investigated feeds is presented in Table 1.

Table 1. Chemical composition of experimental diets.

Parameter	Le	Lpe	Lex
Crude protein (%)	44.00 ± 2.10	33.57 ± 0.11	34.00 ± 0.02
Crude fats (%)	11.00 ± 0.10	5.57 ± 0.05	5.60 ± 0.02
Crude fibre (%)	2.30 ± 0.67	3.90 ± 0.18	6.21 ± 0.01
Ash (%)	7.80 ± 2.00	7.40 ± 0.18	7.40 ± 0.18

Description: Le: imported feed, Lpe: locally pelleted feed, Lex: Locally extruded.

Research Design

The trial was conducted using the completely randomized block design into three dietary treatments namely imported extruded (Le), locally pelleted (Lpe) and locally extruded (Lex) with three replicates for each treatment. The fish were randomly stocked at a density of 100 fingerlings per tank/hapa and reared for 16 weeks.

Work Procedure

Fish collection and acclimatization

A total of one thousand eight hundred juveniles (nine hundred for each production system) of African catfish were obtained. For each system, the juveniles were acclimated for two weeks before the commencement of the experiment using the chosen commercial extruded feed for this study.

Rearing

The fish were randomly stocked at a density of 100 fingerlings per tank/hapa and reared for 16 weeks. The juveniles were hand-fed experimental diets thrice daily at progressively 5 %, 4 % and 3 % body weight and feeding adjusted accordingly every fortnightly. For tank system, one third of water from each tank was replaced daily and completely changed every fortnightly throughout the experimental period to maintain a relative uniform water quality and prevent fouling resulting from feed remnants and metabolic waste. In hapas-in-ponds, water flow throughout the whole rearing period at a speed of 50 L/min.

Every fortnightly, 30 fish from each holding medium were weighed and total length measured using a sensitive electronic balance (nearest 0.01 g) and digital caliper (nearest 0.1 mm) respectively in order to enable eventual calculation of growth performance parameters and condition factor. Survival was monitored by removing and counting carcasses from each replicate as soon as they were noticed.

Water parameters of importance to aquaculture were measured fortnightly (between 6 am to 7 am) according to APHA (2000) and Boyd (1979). All the parameters were within standard limits for aquaculture as recommended by Boyd (1979) except for dissolved oxygen which had low values (< 3 mg/L) in the tank system. This could be attributed to the time of sampling (Godoy *et al.*, 2021) and the non-flow through nature of the system.

Carcass nutrient composition analysis

Four fish were taken from each culture system prior to experimentation and three fish from each dietary treatment/culture system were harvested for initial and final proximate carcass nutrient analyses respectively. The fish were placed in iced flasks immediately after harvest and transported to the Laboratory of Animal Nutrition and Feeding of the University of Dschang for proximate nutrient analyses according to the methods of AOAC (2005). The following nutrients were analysed: crude protein, crude fat, ash, humidity, dry matter, organic matter.

Data collection

At the end of the experimental period, fish were deprived of feed for 24 hours and all the experimental holding systems were drained and all the fish were harvested, counted, weighed individually and the total biomass of each dietary treatment/species was determined. Fish performance and nutrient utilisation under the different dietary treatment/production system were evaluated using the following formulae:

Weight gain (WG) = Final weight (g) – Initial weight (g);

Percentage weight gain (PWG) = Final Weight – Initial Weight x 100/ Initial weight;

Specific growth rate (SGR) = $LnW_f – LnW_i$ x 100/ T2 – T1 (in days)

Where

Ln = Natural logarithm reading

W_f = final mean weight and W_i= initial mean weight;

Survival rate (SR) = (Initial number of fish stocked – mortality) x 100/ Initial number of fish;

Feed intake (FI) = This is the amount of feed throughout the period of the experiment;

Performance index = SR x ($W_f – W_i$)/Rearing period in days;

Feed conversion ratio (FCR)= Feed intake (g)/Net weight gain (g);

Feed Efficiency (FE) = 1/FCR;

Condition factor (K) =$100W_f/L^3$, where W_f is the mean final weight and L is the mean total length (cm).

Grade/ size classification

The total yield of *C. gariepinus* was classified according to 5 classes of body weight: Super: > 700 g; First class: 501 -700 g; Second class: 500-401 g; Third class: 251-400 g; and Fourth class: <250 g.

Production and Profitability parameters

Production parameters evaluated were biomass, net yields and net fish yields according to the following formulae:

Biomass= Number of fish x mean weight;

Net yield= Final biomass at harvest – initial biomass at stocking;

Net fish yield = Final biomass at harvest – initial biomass at stocking/ volume of holding water.

Enterprise budgeting analysis approach was used to compare profitability of the experimental diets. This analysis indicated whether or not a change in feeds was more or less cost-effective (Abu *et al.*, 2010). Only the cost of feeds, fingerlings, liming, feeding and cleaning were used in the calculations with the assumption that all other operating costs (tanks, hapa, ponds, labour, fish handling) remained constant. The prices of feeds and fingerling were based on market prices. Indices for profitability analyses used were:

Total sales/revenue (TR) = quantity of fish harvested (Kg) x unit price of fish (FCFA);

Total cost (TC) = Cost of feeds used + cost of fingerlings.

Incidence cost (IC): is the cost of feed used to produce 1.0 kg of fish (relative cost per unit weight gain), and the lower the figure for a particular feed, the more profitable it is using that feed (Abu *et al.*, 2010). This is computed as:

IC = Cost of feed (FCFA)/ Weight of fish produced (kg).

Net returns = TR – TC.

Profit Index (PI): The value of harvest fish was based on the prevailing price in the study area during the period of the study. The higher the PI, the more cost-effective (economical) a feed was (Abu *et al.*, 2010).

PI = value of fish produced/cost of feed used (FCFA).

Benefit cost ratio: TR/TC.

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Data Analysis

Statistical analyses were carried out to determine whether significant differences existed between the different treatments and the parameters tested. All results were analysed using a one-way variance analysis (ANOVA) to test differences among the various parameters of the dietary treatments. Tukey's (HSD) multiple comparisons of means was used to identify specific differences between pairs of treatments. Differences were regarded as significant when $p < 0.05$. Results were presented as means ± SD (standard deviation). All data were analysed using SPSS version 23.0 and graphical presentations were done using Microsoft excel programme and GraphPad Prism Version 8.0.

RESULTS AND DISCUSSIONS

Fish growth, survival and nutrient utilization parameters of *Clarias gariepinus*

Growth performance and nutrient utilization of *C. gariepinus* fed with imported extruded (Le), locally pelleted (Lpe) and locally extruded (Lex) feeds and reared in the studied production systems are presented in table 2.

Table 2. Growth performance, survival and nutrient utilization of *C. gariepinus* fed different feeds and reared in two production systems.

Parameter	Le		Lpe		Lex	
	Tank culture	Hapa culture	Tank culture	Hapa culture	Tank culture	Hapa culture
Initial weight (g)	38.45±1.04^{a}	38.91±0.71^{a}	38.45±1.04^{a}	38.91±0.7^{a}	38.45±1.04^{a}	38.91±0.7^{a}
Initial length (cm)	15.20±0.26^{a}	16.47±0.14^{b}	15.20±0.26^{a}	16.47±0.1^{b}	15.20±0.26^{a}	16.47±0.1^{b}
Final weight (g)	758.46±13.79^{a}	726.02±82.91^{a}	289.03±60.67^{b}	396.85±18.96^{c}	339.27±9.34^{c}	461.73±13.26^{d}
Final length (cm)	43.70±0.56^{a}	44.39±0.64^{a}	31.38±2.38^{bc}	37.01±0.7^{b}	33.02±0.56^{c}	38.64±0.5^{d}
Weight gain (g)	720.01±13.79^{a}	687.11±82.9^{a}	250.58±60.67^{bc}	357.94±18.96^{c}	300.05±9.34^{c}	422.82±13.26^{b}
Daily weight gain (g)	4.50±0.0^{a}	4.29±0.52^{a}	1.57±0.38^{bc}	2.24±0.12^{b}	1.88±0.06^{c}	2.64±0.08^{d}
Specific growth rate (%/day)	4.35±0.02^{a}	4.30±0.11^{a}	3.37±0.21^{b}	3.69±0.05^{b}	3.55±0.03^{c}	3.85±0.03^{d}
Survival (%)	82.58±3.53^{a}	83.48±4.06^{a}	88.64±3.18^{a}	83.78±4.6^{a}	77.12±7.39^{a}	83.66±8.56^{a}
Performance index	371.43±10.20^{a}	359.82±60.33^{a}	139.54±37.96^{bc}	187.55±16.59^{b}	144.93±13.45^{c}	221.20±25.03^{d}
Feed Conversion ratio	0.89±0.06^{a}	1.21±0.38^{a}	1.43±0.35^{ab}	2.15±0.20^{b}	1.39±0.19^{ac}	2.02±0.25^{c}
Condition factor	0.91±0.02^{a}	0.86±0.11^{a}	1.01±0.23^{a}	0.78±0.01^{ab}	0.94±0.23^{a}	0.8±0.01^{ac}

Description: Different letters indicate significant differences ($p < 0.05$), Le: imported feed, Lpe: locally pelleted feed, Lex: Locally extruded.

Comparison of mean initial weight showed no significant difference ($p > 0.05$) among the dietary treatments irrespective of the production systems. Overall, fish fed "Le" feed were statistically higher ($p < 0.05$) than fish fed with "Lpe" and "Lex" feeds in terms of mean final weight, daily weight gain, weight gain, percentage weight gain and specific growth rate irrespective of the production system. Fish fed with "Le" were statistically similar ($p > 0.05$) among the production systems in terms of mean final weight, daily weight gain, weight gain, percentage weight gain and specific growth

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rate. *C. gariepinus* attained mean weights of 758.46 ± 13.79 g and 726.02 ± 82.91 g respectively in tank and hapas-in-pond systems with mean daily weight gains respectively of 4.50 ± 0.0 g and 4.29 ± 0.52 g. Fish fed with "Lpe" feed exhibited significantly higher ($p < 0.05$) mean final weight, daily weight gain and percentage weight gain in hapas-in-pond system and were statistically similar ($p > 0.05$) for weight gain, daily weight gains and specific growth rate. The studied fish fed with "Lpe" feed attained mean weights of 396.85 ± 18.96 g and 289.03 ± 60.67 g respectively in hapas-in-pond and tanks systems with mean daily weight gains respectively of 2.24 ± 0.12 g and 1.57 ± 0.38 g.

As for fish fed with "Lex" feed, all the growth performance parameters were significantly higher in hapas-in-pond system ($p < 0.05$). The studied fish attained mean weights of 461.73 ± 13.26 g and 339.27 ± 9.34 g respectively in hapas-in-pond and tanks systems with mean daily weight gains respectively of 2.64 ± 0.08 g and 1.88 ± 0.06 g. There were no significant differences ($p > 0.05$) in survival rates among all the dietary treatments irrespective of the production system. Biweekly mean weights of *C. gariepinus* issued from the studied dietary treatments and production systems are illustrated in Figure 1. Growth curves were exponential for the first 6 weeks and after that assumed more or less linear trends. A clear separation of "Le" feed from both local feeds was observed from the 6th week up till the end of the experiment.

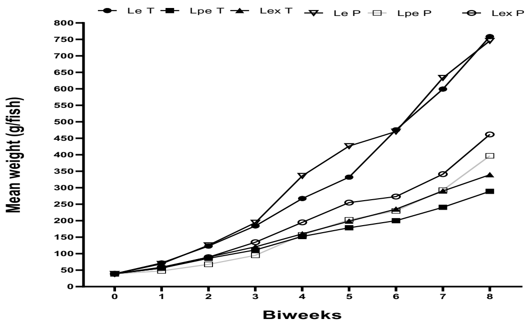

Figure 1. Mean weight of *Clarias gariepinus* fed on different diets reared in two productions.

Description : Le T: imported feed used in tank, Lpe T: locally pelleted feed used in tank, Lex T: Locally extruded feed used in tank; Le P: imported feed used in hapa, Lpe P: locally pelleted feed used in hapa, Lex T: Locally extruded feed used in hapa.

In this study, the positive response of *C. gariepinus* to both imported extruded diet (Le) and locally formulated diets (Lpe and Lex) was evident through various growth performance parameters, indicating effective nutrient utilization across the different production systems. This aligns with the findings of David and Afia (2017), who noted consistent biweekly increases in the mean weight of *C. gariepinus* fed with floating and sinking feeds, suggesting efficient conversion of these feeds into flesh.

Growth performance indices such as weight gain, length gain, daily weight gain, percentage weight gain, and specific growth rate serve as valuable indicators for assessing the impact of feed quality and composition on fish species (Mustapha *et al.*, 2014). The superior growth performance observed in fish fed the imported feed (Le) can be attributed to its nutrient composition, which aligns with the works of De Silva and Anderson (1995) regarding the importance of meeting an animal's nutrient requirements through quality feed. Furthermore, David and Afia (2017) and Mustapha *et al.* (2014) enriched the picture by stating that best growth performance, high digestibility and nutrient utilization of fish fed with floating diet are an indication that the

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feed contained well balanced nutrients as seen in the proximate composition. The protein content of the imported feed, ranging from 42 – 45 %, is well within the recommended levels for catfish grow-out (Ayinla, 2007; Fagbenro *et al*., 2008). Van Weerd (1995) also noted that young catfish perform best at these protein levels during the grow-out phase. Importantly, the lack of significant differences in growth parameters between the two production systems when using the imported feed indicates that its nutrient composition was optimal for *C. gariepinus*. This outcome suggests that the fish were adequately satiated by the imported feed, resulting in minimal reliance on natural food sources such as plankton, macroinvertebrates, and worms for additional nutrition.

Fish fed with the local feeds (Lpe and Lex) however, exhibited better growth performance in hapas-in-pond production system when compared to tank system. This could be linked to the presence of natural food in the hapas as concurred by the lower feed conversion ratios observed. While in the tank culture system, fish relied on supplementary feed, to satisfy their nutritional requirements, and the absence of natural food in the tank system elevated their feed conversion ratio. Though the local feeds were low in lipid content and high in fibre, indicators of poor growth response (Mustapha *et al*., 2014 and Ali *et al*., 2012), these nutrients were supplemented by natural foods in the hapas. Liti *et al*. (2005) demonstrated that during the exponential growth phase of the growth curve of pond-cultured fish, fish efficiently utilize dietary protein from the natural food until a critical biomass of the fish is reached (De Silva *et al*., 1991) and external nutrient supplements could lead to high growth rates as observed in this study. Naturally, a diversity of micro and macro-fauna is higher in earthen ponds than concrete or plastic tanks (Angahar, 2017). The abundance of plankton in earthen pond also directly supplements the diet of fish, or indirectly improves the aquatic food chain to which the fish is the ultimate beneficiary. The fact that survivals were similar among treatments irrespective of the production system revealed that survival rates were not a major concern as water quality seemed to be optimum for *C. gariepinus* survival in both production systems. Moreover, survival has never been a main fear in the culture of *C. gariepinus* because of its resistance to poor water quality, stress as well as diseases (Toko *et al*., 2007).

Feed nutrient utilization of the studied fish fed with the diets and reared in tanks and hapas- in-ponds revealed that feed conversion ratio (FCR) was significantly lower ($p < 0.05$) in tank systems irrespective of the dietary treatment. FCR values for “Le” treatment was similar among the production systems ($p > 0.05$) and lower ($p < 0.05$) when compared to the local feeds. As for “Lpe” and “Lex” treatments, FCR values were better ($p < 0.05$) in tank systems. Fish fed with “Le” and “Lpe” exhibited similar ($p > 0.05$) performance indices among production systems while fish fed with “Lex” differed significantly ($p < 0.05$). The same trend was observed for condition factor with similar tendencies ($p > 0.05$) observed for “Le” and “Lpe” treatments and significantly different ($p < 0.05$) for “Lex” treatment among the production systems. FCR is a crucial metric in aquaculture that assesses the efficiency of feed utilization in fish production. According to Nahar *et al.* (2000), a more efficient diet results in a lower FCR, meaning less feed is needed to achieve a unit weight gain in fish. The disparity in FCR values between imported and local feeds can be attributed to the differing proximate compositions of these feeds. Fish fed imported feed exhibit lower FCRs, indicating a more effective dietary composition, while local feeds require significantly more input—ranging from 1.3 to 2.02 kg— to gain a unit weight of fish, escalating production costs. While local feeds demonstrate higher FCRs, they still fall within the range reported for the African catfish (*C. gariepinus*) in studies conducted by Ekenem *et al*. (2012); Afia and David, 2017; Limbu 2015, 2020; Mustapha *et al*., 2014 and Opiyo *et*

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al., 2014) who showed FCR values ranging from 0.89 to 3.23 when using both farm-made and locally extruded feeds in various production system settings. The variations in FCR could be traced back to differences in feed sources, environmental conditions, and specific strains of catfish. This notion is supported by Guimarães *et al.* (2008), who noted that even within a single species, diet efficiency can fluctuate based on the particular strain and environmental variables. This underscores the importance of considering multiple factors, including feed composition and environmental traits, in optimizing fish production strategies in aquaculture.

Condition factor (K) is an index reflecting the effect of interactions between biotic and abiotic factors on the physiological condition of fishes. As noted by Blackwell *et al.* (2000), K values not only relate to the nutritional status of the fish but also indicate broader environmental conditions, which can include food availability, feeding intensity and predator pressures. The similarity in condition factors of fish fed with imported and farm-made feeds irrespective of the production system suggested that the studied feeds did not significantly differ in their effectiveness for maintaining fish health, a conclusion supported by findings indicating isometric growth of *C. gariepinus* on the studied diets (Limbu, 2015). Typically, fish reared in hapas-in-pond systems achieved K values of 1 or greater, aligning with the benchmarks set by Ujjania *et al*. (2012), who identified this threshold as indicative of optimal feeding and environmental conditions.

Figure 2 illustrates the different categories of produced *C. gariepinus* fed different diets. Fish fed with “Le” had upper class categories (p < 0.05) such as super, first and second irrespective of the production system. Fish fed with “Lpe” and “Lex” feeds were mostly found (p < 0.05) within the second and third categories irrespective of the production system.

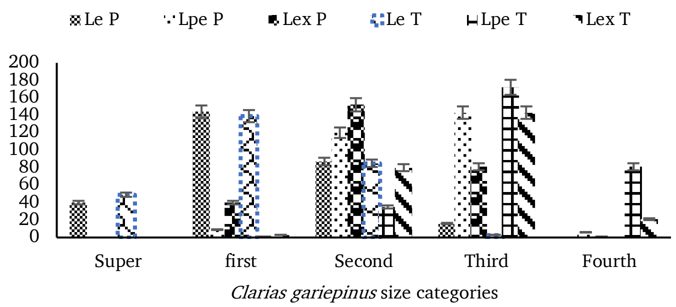

Figure 2. Weight size categories of *C. gariepinus* fed different feeds and reared under two production systems.
Description : Le T: imported feed used in tank, Lpe T: locally pelleted feed used in tank, Lex T: Locally extruded feed used in tank; Le P: imported feed used in hapa, Lpe P: locally pelleted feed used in hapa, Lex T: Locally extruded feed used in hapa.

Whole body carcass nutrient composition

The initial and final mean body nutrient compositions of *Clarias gariepinus* fed with studied feeds and reared in two production systems are presented in table 3. Crude fat, dry matter, total ash and organic matter were significantly higher (p < 0.05) in the tank system at initial stocking. Final crude protein, crude fats, organic matter and moisture content showed no significant difference (p < 0.05) irrespective of the dietary treatment or production system. Whereas dry matter and total ash were significantly different (p < 0.05) irrespective of the dietary treatment or production system.

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Table 3. Carcass proximate composition of *C. gariepinus* fed on commercial and local feeds reared in two production systems.

Parameter	Initial		Le		Lpe		Lex	
	Tank culture	Pond culture	Tank culture	Pond culture	Tank culture	Pond culture	Tank culture	Pond culture
Crude protein	16.12±0.08^{a}	15.21±0.03^{a}	16.45±0.04^{a}	16.40±0.11^{a}	15.16±0.01^{b}	15.18±0.03^{b}	14.51±0.03^{c}	14.48±0.01^{c}
Crude fat	3.57±0.02^{a}	2.52±0.11^{b}	3.45±0.00^{a}	3.39±0.00^{a}	2.81±0.01^{b}	2.72±0.11^{bc}	2.39±0.01^{c}	2.44±0.08^{c}
Dry matter	23.47±0.18^{a}	18.20±0.11^{b}	20.87±0.04^{a}	20.21±0.16^{b}	22.87±0.01^{b}	18.22±0.01^{c}	23.81±0.08^{cd}	17.13±0.01^{d}
Total ash	2.30±0.01^{a}	1.60±0.15^{b}	2.12±0.01^{a}	2.44±0.11^{b}	2.17±0.01^{a}	1.36±0.06^{ab}	2.19±0.00^{a}	1.17±0.06^{bc}
Organic matter	19.4±0.08^{a}	16.6±0.25^{b}	18.04±0.06^{a}	17.89±0.26^{a}	18.13±0.06^{b}	18.22±0.06^{ab}	18.03±0.01^{c}	18.08±0.08^{ac}
Moisture content	76.54±0.18^{a}	76.52±0.18^{a}	77.91±0.18^{a}	77.76±0.04^{a}	77.22±0.01^{b}	77.17±0.06^{ab}	77.20±0.04^{c}	77.18±0.06^{ac}

Description: Different letters indicate significant differences ($p < 0.05$), Le: imported feed, Lpe: locally pelleted feed, Lex: Locally extruded.

Carcass composition measures the growth and quality of protein, lipid, ash and its utilization in fishes (Ahmed and Maqbool, 2017). Overall, the proximate analyses of the studied fish carcasses at the end of the experiment showed an increase in the value of crude protein (CP) and crude fats (CF) over the initial fish samples. The increase in CP of all the samples was be an indicator that the different feeds used had a positive effect on the studied fish suggesting that the fish converted and utilized the protein from the feeds into their body protein (Afia and David, 2017). However, irrespective of the production system, significant differences in terms of crude protein, crude fats and ash content were observed among the carcasses fed with the different dietary treatments. Several authors have illustrated that fish growth is significantly influenced by the protein content in the feed with 40 % dietary protein promoting maximum growth in *C. gariepinus* (Van Weerd, 1995) grow-out. That carcass protein of catfish increased as feeds passed from locally pelleted (33.34 %) through locally extruded (34.00 %) to imported (40-45 %) opines the results found by De Pedro *et al.* (2001), Tidwell *et al.* (2005) and Loum *et al.* (2013) who reported that increase in carcass protein content is linked to increase in dietary protein levels.

Crude fats were higher in fish fed imported feeds who exhibited the highest growth performances. High amount of crude fats ranging from 10 - 25 % has been certified to produce the best growth performance in fish species (Ali and Jauncey, 2004; Agokei *et al*., 2011; Ali *et al*., 2012). In several species, the protein sparing effects of lipids had been reported (Orire and Sadiku, 2011; Li *et al.,* 2012; Hasan and Khan, 2013) with higher levels of lipids in feeds resulting to higher weight gain in fish.

Production parameters and profit margins

Yield and input parameters of African catfish raised in tanks and hapas-in-pond and fed with the studied feeds are presented in table 4. Net yield was highest in fish fed with “Le” feed irrespective of the production system. While those fed with local feeds, yields were higher in the hapas-in-pond system and similar in the tank system. Feed intake in tank system was highest for “Le” treatment and that of local feeds had similar values. While in the hapas-in-pond system, feed intake was highest for “Lex” treatment and “Le” and “Lpe” treatments were similar. In the same line, feed intake was highest in fish fed with “Le” feed while those fed with “Lpe” and “Lex” were relatively similar within the production systems.

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Table 4. Production and yield parameters of African catfish raised in tanks and hapas-in-pond fed different feeds.

Parameter	Le		Lpe		Lex	
	Tanks	Hapas	Tanks	Hapas	Tanks	Hapas
Initial biomass (kg)	12.69	12.84	12.69	12.84	12.69	12.84
Final biomass (kg) (a)	201.31	195.64	84.35	111.45	84.95	130.03
Post-harvest losses (b)	3.12	1.3	5.8	2.4	3.01	1.05
Net yield (b-a)	198.19	194.34	78.55	109.05	81.94	128.98
Net fish yield (Kg/m^3)	82.58	71.19	32.73	39.95	34.14	47.25
Quantity of feed consumed (Kg)	161.24	205.8	97.53	200.33	97.32	223.27
Quantity of water consumed(m^3)	84.95	-	86.85	-	82.75	-

Description: Le: imported feed, Lpe: locally pelleted feed, Lex: Locally extruded.

The present study showed that "Le" feed produced higher catfish yield than "Lpe" and "Lex" diets irrespective of the production system. The higher yield of fish fed with "Le" was related to their better growth rates, good condition factor and feed efficiency. Similar results were obtained by Afia and David (2017) working with same species in similar rearing conditions.

That fish fed with the local feeds had better yield in the hapa-in-pond system when compared to the tank system could be linked to water quality and natural food present in the hapas-in-pond system. In fact, Shoko *et al*. (2016) observed significant positive correlations between growth rates with net fish yield when water quality did vary among diets. These results suggest that on-farm feeds when correctly formulated and produced with appropriate nutrient quality can improve fish production similar to imported feeds.

Table 5 shows the inputs used in producing African catfish in tank and hapas-in-pond systems using imported and local farm-made diets. The price of 1 kg of feed was highest for imported feed while those of the local feeds were similar. Feed accounted for the highest proportion (> 50 %) of the total variable cost irrespective of dietary treatment followed by cost of fingerlings.

Table 5. Input used for producing tank- and hapas-in-pond-raised African catfish fed with different feeds.

Cost	Le		% of total cost for Le		Lpe		% of total cost for Lpe		Lex		% of total cost for Lex	
	Tanks	Hapas	Tanks	Hapas	Tanks	Hapas	Tanks	Hapas	Tanks	Hapas	Tanks	Hapas
Cost of 1kg of feed (FCFA)	1533.33		-	-	1050.04		-	-	1066.67		-	-
Cost of fingerlings (FCFA)	30000	30000	10.00	8.58	30000	30000	19.64	14.2	30000	30000	16.93	10.66
Cost of water consumption (FCFA)	24890.35	-	8.30	-	25447.05	-	16.67	-	24245.75	-	13.68	-
Cost of feed consumed (FCFA)	237000	303000	79.03	86.69	89280	164800	58.46	77.98	115000	235000	64.88	83.47
Transportation of feed (FCFA)	3000	5000	1.00	1.43	3000	5000	1.96	2.37	3000	5000	1.69	1.78
Lime (FCFA)	-	4530	-	1.30	-	4530	-	2.14	-	4530	-	1.61
Labour (Feeding/clearing and cleaning) (FCFA)	5000	7000	1.67	2.00	5000	7000	3.27	3.31	5000	7000	2.82	2.49
Total cost (FCFA)	299890.4	349530	100	100	152727.1	211330	100	100	177245.8	281530	100	100

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Description: Le: imported feed, Lpe: locally pelleted feed, Lex: Locally extruded. Exchange rate 1USD = 601FCFA.

Cost analysis (costs and returns, profitability ratios) of rearing catfish in tank and hapas-in-pond systems fed with imported and local feeds is presented in table 6. This analysis showed that it was least expensive (1058.45 HCHA and 1177.29 FCFA) to produce 1 kg of table-size catfish using “Lpe” and "Le" feed in tank system whilst the use of local feeds costed most (1353.74-1807.28 FCFA) irrespective of the production system. Highest net returns and profits were observed for “Le” feed followed by far by “Lpe” then “Lex” feeds. Benefit cost ratios (BCR) were greater than one irrespective of the dietary treatment and production system.

Table 6. Costs and returns and profitability ratios of tank- and hapas-in-pond-raised African catfish fed with different feeds.

Parameters	Le		Lpe		Lex	
	Tanks	Hapas	Tanks	Hapas	Tanks	Hapas
Sales at 2500fcfa/kg	270000	260625	12500	62850	65900	135250
Sales at 2300fcfa/kg	214613	210197	182505	198513	134757	174639
Total sales (FCFA)	484613	470822	195005	261363	200657	309889
Incidence cost (FCFA)	1177.29	1548.76	1058.45	1478.69	1353.74	1807.28
Net returns (FCFA)	184722.7	121292	42277.95	50033	23411.25	28359
Profit index	2.04	1.55	2.18	1.59	1.74	1.32
Economic efficiency	56.84	33.56	20.36	21.94	7.82	8.91
BCR	1.62	1.35	1.28	1.24	1.13	1.10

Description: Le: imported feed, Lpe: locally pelleted feed, Lex: Locally extruded.

Incidence cost (IC)/production cost reflects the monetary value of feed required to produce a kilogram of fish, where lower value indicates more profitability (Abu *et al.*, 2010). Thus, the IC for producing African catfish in both rearing systems was lower than 30 % and PI was higher than 15 % for “*Le*” and “*Lpe*” feeds than the “*Lex*” feed, implying that “*Lpe*” diet can enhance the production of *C. gariepinus* at lower cost. That these indices (IC and PI) were < 50 % showed that local feeds when correctly formulated and produced with appropriate nutrient quality can improve fish production similar to imported feeds.

Benefit cost ratio (BCR) is a suitable indicator to be utilised to determine the profitability of small-scale aquaculture since fish production involves cost and benefit over a specific period of time (Magna *et al.*, 2023). That BCR values were greater than one irrespective of the production system indicated that the financial benefits outweighed the costs, thus affirming the profitability and viability of the feeds and production systems used in the study for intensive aquaculture operations.

CONCLUSION

This study revealed that irrespective of the production system, the African catfish fed with imported extruded feed exhibited higher growth rates, better feed utilization and proximate analysis of carcass. As for the locally pelleted and locally extruded feeds, higher growth rates and better feed utilization were observed in hapas-in-pond systems which was attributed to the presence of natural food and better water quality.

The economic assessment revealed that the use of imported extruded and locally pelleted feeds to feed African catfish was economically efficient as indicated by the lower incidence cost, higher profit and net returns when compared to the local feeds. The fact that the studied feeds were profitable as indicated by the benefit cost ratio > 1 proves that if the ingredients used to

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formulate the local feeds possess the right nutrient composition and if these ingredients are correctly formulated and blended properly, these feeds can provide similar growth rates, survival and yields to imported feeds.

CONFLICT OF INTEREST

There is no conflict of interest among all authors upon writing and publishing the manuscript.

AUTHOR CONTRIBUTION

NNSY: conceptualization, methodology, investigation, formal analysis and writing-original draft; JWT, CKN, TWJ, AMEE: investigation and assisted in formal analysis; SYS, KAE: supervision, validation, writing-review and editing; MN, SHTZ: resources, supervision, validation and writing-review and editing.

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