Effect of Different Fish Feed Sources on Growth and Economic Performance of Nile Tilapia (*Oreochromis niloticus)* Within Subsistence Setup in Liberia

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Abstract

The wide adoption of O. niloticus for farming, particularly among smallholder farmers, can be attributed to its feeding versatility. However, its production in Liberia remains low, despite possessing desirable culture characteristics. This limited yield hampers the potential for commercialization and delays the overarching goal of utilizing fish farming to alleviate poverty and hunger. One of the primary challenges faced by fish farmers is the utilization of subpar feeds. To address this issue, we conducted a study to evaluate the effects of various feed recipes available to Liberian farmers, including two feeds formulated by farmers themselves (FF1 and FF2) and two commercially manufactured feeds (CF1 and CF2). These feeds were compared with a research-formulated feed designated as PF. The growth and economic performance of O. niloticus were assessed over a six-month period using fifteen Hapa nets. The findings of our study revealed that the feeds formulated by farmers and commercial feed CF2 exhibited inferior performance in terms of Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), and Weight Gain (WG). In contrast, PF and CF1 demonstrated significantly higher values (P<0.05) with FCR scores of 7.87 and 8.27, and SGR values of 1.08 and 1.05, respectively. The present study also introduced a production cost index (PCI) that can be used as an indicator of fish feed performance in fish farming, while holding the other costs constant. PF and CF1 feeds displayed the lowest PCI of 0.92 and 1.57, surpassing the other tested feeds. The lower PCI values were associated with higher economic returns compared to alternative feeds. This study concludes that feed quality is a major factor sustaining poor O. niloticus production, however with right formulation of the locally available materials farmers can achieve optimal yields for commercial aquaculture.

Keywords: Specific Growth Rate, Farmer Formulated Fish Feeds, Nile tilapia, Fish Farming, Proximate composition.

INTRODUCTION

Recently, adoption of fish farming has recorded an incredible increase in sub-Saharan Africa (FAO, 2018), however, it is yet to achieve significant impacts on food and nutrition security of these nations (Béné *et al.*, 2016; Chan *et al.*, 2019; Garlock *et al.*, 2022; Pradeepkiran, 2019). Among the constraints hampering development of the sector is lack of high-quality feeds among smallholder farmers. Fish feeds is the most important and expensive component of fish farming (Hodar *et al.*, 2020; Stankus, 2021) and account for more than 60% of production costs. Use of poor-quality feeds not only compromises gross production but also limits the chances of commercializing the sector. In Liberia the problem of poor feeds persists as fish farmers mainly use locally available ingredients to formulate feeds with low crude protein content (Hinneh *et al.*, 2022).

Among the fish species whose production has been suppressed by poor quality feeds in Liberia is *O. niloticus* (Addo *et al.*, 2021). The species has widely been adopted across Liberia and in many sub-Saharan Africa countries, accounting for more than 80% of farmed fish (FAO, 2018). The high adoption rate has been attributed to its tolerant to high fluctuating biophysical conditions (El Basuini *et al.*, 2022; Nobrega *et al.*, 2020), fast growth rate and high feed conversion efficiency. These attributes have made farming of this species a vital tool in elevating food and income for the poor communities (Harohau *et al.*, 2020; Munguti *et al.*, 2022). However, some studies report a decline in *O. niloticus* productivity, establishing that the current fish yield is not commensurate with production resources allocated to its farming (Hebicha *et al.*, 2013). One of the major factors attributed to the declining productivity is persistent scarcity in high quality feeds (Afram *et al.*, 2021).

Farmers in Liberia mainly use rice bran, vegetables and left-over human food to feed fish. Some fish farmers also produce their own fish feed by blending two or more local feed ingredients (BNF, 2010). These feeds are mostly of poor quality with inadequate crude protein and other important nutrients (Hinneh *et al.*, 2022). Such practice of using poor quality feeds has been sustained with adverse impact on the performance of the sector due to lack of information among farmers on the quality of available commercial and farmer formulated feeds. Farmers have also limited capacity in formulating nutritionally balanced feeds to support intensive aquaculture for commercial purposes. Consequently, development and commercialization of *O. niloticus* farming in Liberia is therefore depressed resulting in reduced chances of intensification of fish farming. This study was conducted to evaluate the performance of some of the available fish feeds in Liberia and provide information on the most suitable fish feeds by evaluating their effects on growth performance of *O. niloticus.* The study also explored and developed an index that could be used assess the economic performance of various fish feeds without going through the tedious economic enterprise budgets.

MATERIALS AND METHODS

Description of *O. niloticus* culture site

This study was conducted at Central Agriculture Research Institute, (CARI) station located in Bong County. The county is among the three most highly ranked fish farming counties in Liberia. It is located at 6°52'0" N and 10°10'0" W, with an altitude of 291 meters above sea level (See Fig. 1). The county receives an average rainfall of 1424mm and air temperatures fluctuate between26.1°C and 34.7°(Weather-Atlas (https://www.weather-atlas.com/en/liberia/bong-climate, 2023).

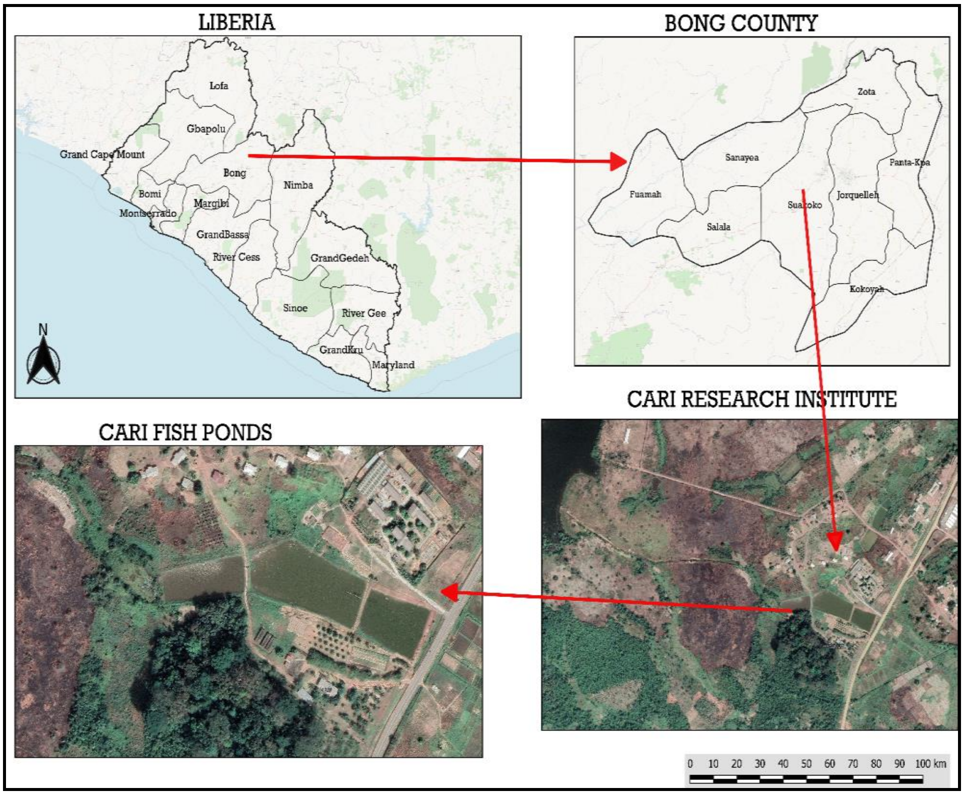

Figure 6: Experimental site where feed types were formulated and administered to O. niloticus
Source; Author

Experimental diets

Five fish feeds were used in the study. Two of the feeds were formulated on-farm by famers (FF1 and FF2), while two others (CF1 and CF) were sourced from local agro-dealers. The fifth feed (PF) was formulated under research project using local ingredients and used as a model feed equivalent to commercial feeds. The composition of the test feeds is presented in Table 1. Both farmers' feeds were formulated by combining different ingredients including wheat bran, rice bran and palm kernel cake, although, fish meal was added to FF1 as shown in *Table 2*. The feeds were given to the fish at 10% body weight per day, Dividing the fish twice (morning and evening) a day for a period of six months.

Feed proximate analysis

Feed proximate composition for all test feed types was determined using standard procedures of the (AOAC, 2006). The following nutrients were analyzed; feed moisture, crude protein (CP), crude lipids (CL), ash, and crude fiber (CF). Moisture content was determined by drying samples in an oven to constant weight at 105^{o}C and determining the loss in weight after cooling in a desiccator. Crude protein was estimated from Kjeldahl nitrogen after acid-sulpahate digestion and steam distillation of the sample, while crude lipid was determined by extraction of 5.0g of feed sample with low boiling point (40-60^{o}C) petroleum ether in soxhlet extraction unit. Ash content was determined by burning dry samples in a muffle furnace at 550 °C for 4 hours and weighing the residue. Crude fiber was determined by alkaline//acid digestion, followed by ashing of the dry residue at 550 °C in a muffle furnace for 4 hours and quantifying the loss in weight after cooling in a desiccator. All the results were expressed as percentages of dry weight of the sample.

Experimental design and fingerling sourcing

The study was conducted in three earthen fish ponds of size 1900 m^2. Five Hapas were installed in each of the three ponds, using the latter as blocks. Each Hapa measured 3.0 m × 2.0 m × 1m. The Hapas were stocked with *O. niloticus* fingerlings at stocking density of 15 fish per Hapa. The fingerlings were sourced from Central Agriculture Research Institute, (CARI). They were acclimatized under controlled conditions at temperature range 28-29°C and fed on CARI research fingerling feeds. After two weeks, the fingerlings were allotted randomly to Hapas and the five test feeds fed in three replicates. The feeds were coded as follows: PF, CF1, CF2, FF1 and FF2, where PF refers to project formulated feed, CF1 and CF2 refers to commercial feeds and FF1 and FF2 refers to farmer on-farm formulated feeds.

Fish growth performance indices

Fish performance was evaluated using the following indices: final mean weight, specific growth weight (SGR), percent weight gain (%WG), % survival, feed conversion ratio (FCR and Production Cost Index (PCI) and economic returns. All the parameters were calculated as outlined below.

$$\text{Mean weight} = \frac{\text{Total harvest weight}}{\text{Number of fish harvested}}$$

Percent Weight Gain (%WG) was calculated based on the formula below:

$$\textbf{\%WG} = \frac{100 * (\text{Final mean weight} - \text{Initial mean weight})}{\text{Initial mean weight}}$$

Specific Growth Rate

$$\textbf{SGR} = \frac{100 * [\ln(\text{final body weight}) - [\ln(\text{initial body weight})]}{\text{culture period in days}}$$

Percent Survival

$$\textbf{Survival Rate} = \frac{\text{Number of fish surving at end experiment)}}{\text{Number of fish at stocking}} \times 100$$

Feed Conversion Ratio (FCR)

FCR=Total feed fed (kg) ÷ Live weight gain by fish (kg) (Carter *et al*., 2021).

Production Cost index (PCI)

This index was derived from the least-cost best buy formula: That is the cost per kg of feed per unit percent protein content, which is equivalent to cost/kg protein per 100g feed. This value was divided by a factor of 10 to yield cost/kg protein/kg feed. If this result is multiplied by Food Conversion Ratio (FCR), the result is: [Cost/kg protein/kg feed] × [kg feed/kg fish] = cost/kg protein/kg fish. This can be translated to mean the cost of protein required to produce a kg of fish and can be taken as the economic value of feed in terms of the protein content.

Pond Water Quality

Pond water quality parameters including pH, dissolved oxygen and temperature were measured insitu daily in the morning and in the evening for the fish growth period.

Data Analysis

Data from the study was subjected to graphical evaluation using weight-time plots and Analysis of Variance (ANOVA) to determine growth trends and the overall significance among means. The differences between individual means were determined by using Duncan multiple range tests. Significance was declared at a probability level P≤0.05. Data curation was done in MS excel vesion 2019 and Genstat version 14.0 used for data analysis.

RESULTS

The percent inclusion of the ingredients in the test feeds are shown in Table 1, The composition of CF1 and CF2 were not listed on the bag and are, therefore, not included in the table.

The percent inclusion level of the ingredients in the test feeds are shown in **Table 1**, The composition of commercial feeds, CF1 and CF2 were not listed on the bag and, therefore are, not given in Table 1. Two of the listed test feeds (FF1 and PF) contain dietary fishmeal protein. PF contained both fishmeal and soybean meal, which are among the most expensive protein sources. These two inclusions pushed the cost per unit protein to be higher than those of the commercial feeds CF1 and CF2. Feeds formulated by farmers were of low cost compared to commercial feeds and that was formulated during project period.

Table 1: **Percent inclusion of ingredients in test feeds**

Components	CF1	CF2	FF1	FF2	PF
All ingredients Inclusion	100%	100%	-	-	-
Corn	-	-	-	-	-
Fishmeal	-	-	5%	-	16%
Soybean	-	-	-	-	-
Wheat bran	-	-	15%	15%	14%
Rice bran	-	-	75%	75%	9.9%
Palm kernel cake	-	-	5%	10	30%
Soy bean meal	-	-	-	-	30%
Vitamin premix	-	-	-	-	0.1%
Total	100%	100%	100%	100%	100%
Cost (USD) of Ingredient per kg	0.6	0.6	0.175	0.14	0.968
Cost/kg Protein	0.188	0.202	0.145	0.156	0.319

Kg/Ing-kilogram per Ingredient *(Source; Author)*

Table 2 presents the proximate composition of the five tested feeds. The results indicate that the on-farm feeds formulated by farmers had markedly lower crude protein content compared to the commercial feeds, which was almost threefold lower than in the latter. Additionally, feeds formulated on-farm by farmers contained almost five times lower crude lipids than both the feed formulated during research period and commercial feeds. However, markedly higher levels in crude fiber were observed in the feeds that were formulated on-farm by farmers, which was almost three times that of the commercial feed brands. The higher crude fiber levels of feeds formulated by farmers were probably due to high inclusion levels of rice bran. Also, FF1 and FF2 contained higher levels of ash compared to other feeds. Feed CF1 had extremely very low ash content compared to the other test feeds.

Table 2: Proximate composition of test fish feeds that were used in the study

Test Feed	Crude Protein (%)	Moisture content	Dry matter	Crude fiber	Ash content	Lipids
PF	30.37	6.31	93.69	9.09	14.31	14.23
CF1	31.96	9.20	90.80	11.06	4.90	17.05
CF2	29.77	9.78	90.22	14.62	12.00	11.41
FF 1	12.00	5.77	94.23	22.35	19.6	2.14
FF2	9.00	2.91	97.09	16.00	22.00	3.91

PF-On-station Research formulated feed, CF1- commercially formulated feed 1, CF2-commercially formulated feed 2, FF1-farmer formulated feed 1, and FF2-farmer formulated feed 2 (Source; Author)

Table 3 presents the growth parameters of *O. niloticus* in response to the tested diets. The results indicate that the feed types had significant influence (P<0.05) on the growth of *O. niloticus*, with varying magnitudes. CF1 and PF were found to have significantly higher (P<0.05) harvest mean weight, relative gain weight, specific growth weight than the other test diets. CF1 and PF had also significantly lower (P<0.05) feed conversion ratios than the other test diets. Percent survival was not significantly different (P>0.05) among dietary treatments.

Table 3: Results of test feeds on growth parameters of *O. niloticus*

Parameters	CF1	CF2	FF1	FF2	PF
Initial mean weight (g)	13.00 ± 0.0^{a}	13.00 ± 0.0^{a}	13.00 ± 0.0^{a}	13.00 ± 0.0^{a}	13.00 ± 0.0^{a}
Final mean weight (g)	91.68 ± 2.21^{c}	36.20 ± 12.93^{b}	32.18 ± 1.25^{ab}	29.54 ± 6.0^{a}	86.28 ± 7.3^{c}
Mean Weight gain	78.68 ± 2.39^{c}	23.2 ± 5.30^{b}	19.18 ± 6.58^{ab}	16.54 ± 3.5^{a}	73.28 ± 7.3^{c}
Specific Growth Rate (SGR)	1.08 ± 0.63^{c}	0.58 ± 0.34^{b}	0.54 ± 0.25^{ab}	0.48 ± 0.2^{a}	1.05 ± 0.5^{c}
Survival Rate	100 ± 0.00^{a}	100 ± 0.00^{a}	100 ± 0.00^{a}	100 ± 0.0^{a}	100 ± 0.0^{a}
FCR	7.87 ± 2.9^{a}	14.34 ± 9.8^{b}	14.04 ± 9.1^{b}	14.29 ± 9.6^{b}	8.27 ± 23.1^{a}

(Source; Author)

The trends of specific growth rates are depicted in Fig, 2. Specific growth rate increased up to a maximum peak, 42 days after stocking for PF and CF1 and thereafter declined to value for the rest of the culture period. However, CF2 also reached some peak in SGR within 28 days after stocking but the peak was of lower magnitude compared to those of PF and CF1. SGR for feeds formulated by farmers (FF1 and FF2) did not display any significant peaks, but decreased for the rest of the culture period.

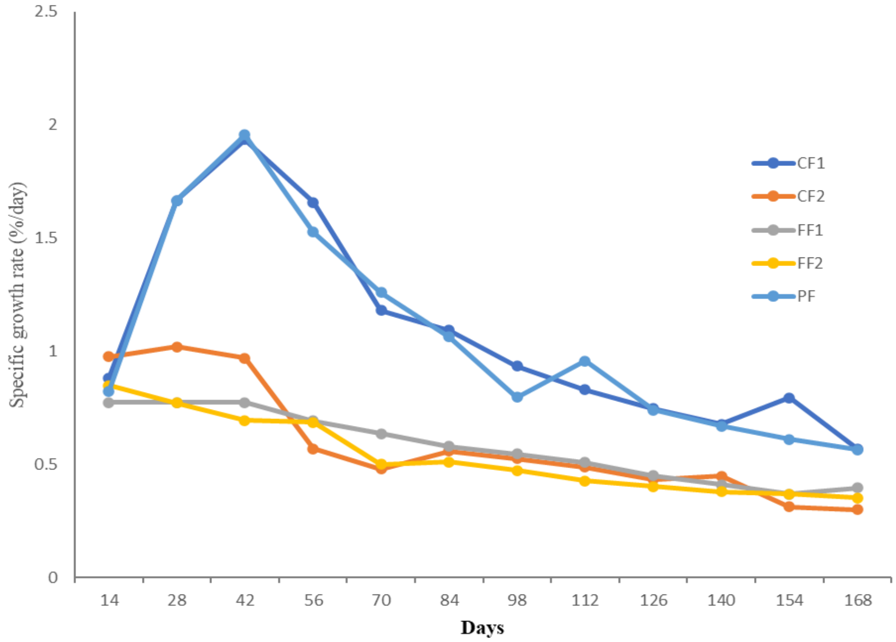

Figure 7. O. niloticus SGR changes over growth period under different feed types: CF1 and CF2 are the commercially formulated fish feed used by farmers who can afford them, FF1 and FF2 are farmer formulated using indigenous knowledge and experience and PF is research formulated feed by using locally accessible ingredients by farmers (Source; Author)

The trends in growth trajectories of mean weights-time plots are illustrated in Figure 3. The line graphs formed two clusters with CF1 and PF forming a cluster with higher growth trajectories compared to CF2, FF1 and FF2, which formed the second cluster with lower growth trajectories. This observation indicates that the critical standing crop for the two clusters had already been surpassed during the time of stocking.

The results for economic performance of the test feeds are shown in Table 5. The cost of protein producing a kg of fish was lowest in CF1 and highest in CF2. Test feed PF had the second highest cost of protein producing a kg of fish. The same costs were lower for the two feeds formulated by farmers. Consequently, CF1 had the highest while CF2 had the lowest returns per kg of fish. The former had a profitability of more than 2 US$ while the return for CF2 was only slightly higher than a dollar. PF had low returns per kg fish despite producing higher growth performance.

Table 5: Influence of feed types on economic performance of *O. niloticus* production

Feed source	CF1	CF2	FF1	FF2	PF
Cost of feed/kg	0.6	0.6	0.175	0.14	0.668
Cost/kg per unit protein	0.188	0.202	0.146	0.156	0.239
Feed Conversion Ratio (FCR)	7.87	14.34	14.04	14.29	8.27
Cost (USD) of unit protein/kg fish weight gain (CPI)	1.48	2.90	2.04	2.23	2.64
Net income/kg (USD)	2.52	1.10	1.79	1.77	1.36

** Average cost of a kg of fish in Liberia=4USD (Source; Author)*

In terms of environmental conditions, changes in water pH, temperature and dissolved oxygen did not vary significantly across the ponds ($p<0.05$), The parameters ranged, between 5.6-8.2, 24.0 - 31ºC, 5.23 - 6.45 mgL^{-1}, respectively. These values were in the range for optimal growth of *O. niloticus*.

DISCUSSION

The quality of feed is an important aspect in fish farming and it is the single most important factor in determining production, economics and sustainability of the aquaculture enterprise (Prabu *et al.*, 2017). The growth of *O. niloticus* under the five test feeds was influenced by the profile nutrients of the feeds and in particular the levels of crude protein and crude lipid. This influence was manifested in CF1 and PF, which had high levels of crude protein and lipid. One of the key determinants of a quality feed is the protein-energy ratio. This ratio determines the optimal performance of a dietary treatment (Jauncey and Ross, 1982). If protein is in excess of the non-protein energy in the diet, protein will be catabolized for energy purposes. If the protein is deficient and energy in excess, fish will stop feeding before it ingests enough protein for muscle construction because fish as in other animals eat to satisfy their energy requirements (Lee and Putman, 1973). Similar findings on *O. niloticus* growth performance as also found by (Abdel-Tawwab, 2012; Abdel-Tawwab and Ahmad, 2009), this result supports the view that high levels of crude protein in the two test feeds resulted to superior growth performance of the *O. niloticus*.

The source of protein also influenced the growth of *O. niloticus*, for instance, famer feed one (FF1) formulated feed with fish meal was found to promote better growth performance compared to the feed FF2 containing solely plant protein sources. The second commercial feed did not have labeling of its ingredient composition and it performed so poorly and thus presenting itself as an inferior diet. It is more likely than not that the dietary protein was of plant origin. This argument is reinforced by the low ash content in the feed and corroborates with poor performance of *O. niloticus*. These findings are consistent to the findings Aragão *et al.* (2022) who reported that use of plant sources as the sole protein supply negatively impact fish gut health leading to depressed growth and development (Glencross *et al.*, 2020; Hardy, 2010). Plant protein sources have also been found to have high amount of anti-nutritional properties which are known to depress fish growth performance (Houlihan *et al.*, 2001; Roques *et al.*, 2018).

Fish obtain essential nutrients from supplied feeds for their growth and development. However, the rate at which it converts the given feed to growth depends on several factors including; growth stanza of the fish (Ssepuuya *et al.*, 2019; Stankus, 2021), environmental factors (Kamalam *et al.*, 2017) and the quality characteristics of the feeds (Houlihan *et al.*, 2001). This study established that subjecting *O. niloticus* fingerlings to high quality feeds results to steady weight gain as observed under PF and CF1. However, growth performance and feed conversion ratio were not at the level expected for feeds with such level of protein. Although water quality was suitable for better growth of *O. niloticus* fish in Hapas were subjected to a crowded conditions which led to stress and, therefore, poor growth. Also, it is well established that growth of fish is proportional to the size of the culture facility, (Hinneh *et al.*, 2022). Low quality feeds on the other hand were observed to depress growth in the present study over the culture period of the fish. Houlihan *et al.* (2001) and Roques *et al.* (2018) attributed such observation to other feed qualities such as high anti-nutrient properties, poor digestibility and feed utilization. Although, this study did not evaluate the aforementioned feed properties, it is likely that feeds that led to poor fish performance contained significant amounts of the antinutritional properties. The feeds FF1 and FF2 contained high levels of crude fibre, which may have also contributed to their marginal performance, Crude fibre is known the adversely affect fish growth (Kamarudin *et al.*, 2018; Li *et al.*, 2012). This is because fibre increases gastric evacuation and therefore reduces retention time of the diet and thus nutrient retention for absorption.

Ranking feeds in terms of fish growth and conversion efficient is common method of assessing feed performance (Boyd, 2021). However, such parameters do not take into consideration the economic performance of the feed which is an essential tool for evaluation of an aquaculture enterprise. The normal procedure to evaluate the economic performance of a feed is through development of an enterprise budget, which is tedious and lengthy (Rahman *et al.*, 2020). A simple index for assessing the cost-effectiveness of essential components of feed, which combines fish growth and the cost of feed is needed. One of the most important essential nutrients in promoting fish growth is protein content in a feed (Davidson *et al.*, 2016). The cost effectiveness of a feed is evaluated by determining the cost per unit protein in one kg of feed required to produce one kg of fish. This index is determined by dividing the cost of a kg of feed by the percent protein in the feed (Jauncey and Ross, 1982). If this value is multiplied by a factor of 10, the index is converted into cost / kg protein/ kg feed. Feed Conversion Ratio (FCR) on the other hand given by the total amount of feed/weight gain. If these two indices are multiplied together, the result is the cost of protein needed to produce a kg fish. If the cost of fish per kg is known, return per unit of production can be worked out, while holding the other costs of operations constant.

CONCLUSION AND RECOMMEDATION

The findings of the present study reveal that feed quality is one of the most important variables responsible for the low production of *O. niloticus* in Liberia. The study also revealed that the labels on feed packs may not necessarily implicate feed quality and performance. To improve fish productivity without necessarily increasing costs of production, it is recommended that feed-fertilizer combination be adopted, where the low-quality feeds will nutritionally be supported by natural food items (Diana *et al.*, 1991). A further recommendation is that by feeding half satiation in fertilized ponds, the cost of feeding can be significantly reduced and improves water quality as well.

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Conflicts of Interest

The authors declare no conflict of interest

Data Availability Statement: The data collected under this research are available from the corresponding author upon request.

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