

Full Length Research Paper

Development of fish feeds for African catfish (*Clarias gariepinus* Burchell 1822) farming in Sierra Leone, West Africa

Olapade O. J.* and Saboleh P.

Department of Aquaculture and Fisheries Management, School of Natural Resources Management Njala University, Njala, Sierra Leone.

Received 3 April 2022; Accepted 22 August 2022

This preliminary study was carried out to formulate high quality least-cost feed for the farming of African catfish (*Clarias gariepinus* Burchell 1822) in Sierra Leone. Locally sourced feed ingredients with vitamin premixes, lysine and methionine were used to formulate a 45% crude protein feeds for the African catfish. Proximate contents determined for the practical feed were compared with two imported commercially produced feeds (Ranaan feed and Aller Aqua). Mean proximate values for protein, moisture, fat, fibre, ash and dry matter were 40.59 ± 2.22 to $42.16 \pm 2.31\%$, 21.39 ± 0.23 to 22.77 ± 0.16 , 0.30 ± 0.07 to 1.07 ± 0.04 , 2.81 ± 0.14 to $3.28 \pm 0.15\%$, 16.62 ± 0.06 to $17.60 \pm 0.13\%$, and 77.22 ± 0.16 to $78.61 \pm 0.23\%$, respectively. P in $\mu\text{g/g}$, Na in $\mu\text{g/g}$ and percentage Ca were the minerals determined. Some of the values obtained, compared favourably with Ranaan and Aller Aqua at a cheaper cost. This study has shown that it is possible to develop a least-cost and nutrient rich feed for commercialization in Sierra Leone.

Key words: Amino acids, formulated diet, proximate analysis, nutrient-rich, least-cost, Sierra Leone.

INTRODUCTION

Fish is the most popular cheap animal protein that is consumed in Sierra Leone (Spring, 2015). Fish and other aquatic products contribute significantly to the economy of Sierra Leone through export earnings, job creation, as well as food security and nutrition. The government of Sierra Leone regards the fisheries sector as a pivot for development because of its socio-economic benefits (FAOSTAT. 2016 cited by Kassam et al., 2017). This sector is not only an important source of income and employment but also provides the most important animal-

source food in the diets of Sierra Leoneans, providing about 80% of animal protein intake. Sierra Leone fisheries sector is one of the main contributors to the national economy, making up about 10% of GDP. More than 80% of the fish consumed in the country comes principally from the marine fisheries, with insignificant proportion contributed by the inland freshwater environment. Little or nothing is contributed by the ill-developed aquaculture sector. With rising population coupled with increasing demand for fish, recent

*Corresponding author. E-mail: ojulius@njala.edu.sl. Tel: +23278507769.

assessment has indicated increased overfishing and a shortfall in landing from the marine environment (Hilborn et al., 2020); a pointer to the urgent imperative to develop the aquaculture sector, as an indisputable means to fill the gaps between demand and supply (WorldFish, 2016). It is believed that a sufficiently developed aquaculture sector will contribute to reducing the pressure on capture marine environments. Increased production from aquaculture is also expected to greatly complement current efforts aimed at achieving the United Nations Millennium Development Goals (MDGs), especially the eradication of extreme poverty and hunger, abatement of child mortality, improvement of maternal health, prevention of diseases, promotion of gender equity and women empowerment.

Sierra Leone, although blessed with abundant production resources, its aquaculture sector has been unfortunately dwarfed for many by the twin constraints of lack of improved fish seeds and affordable nutritionally balanced fish feed. In the recent years, Njala University has been leading the drive to solving the problems of African catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*) fingerlings production. Both fish species are also important in world aquaculture as good culture candidates, especially in Africa (FAO, 2018). It is unfortunately saddening to note that fish feed is still being imported at the cost that is beyond the reach of the ordinary poor farmers in Sierra Leone. The exorbitant cost of imported feed has forced fish farmers in the country to continue feeding their fish with rudimentary feed alternatives like termites, rice bran and household wastes. The result of this discordant feeding practice is the underperformance of the sector. The non-availability of cheaper and quality feeds, according to Siddhuraju and Becker (2003) is a major constraint to the development of aquaculture in developing countries. As noted by Babalola (2010), feed in fish production makes up between 60 and 75% in many African countries, which implies that would be investor has to plan diligently in order to succeed in the industry.

The quality fish feed plays a significant role in the growth, development and profitability of fish farming; and according to Tsevis and Azzaydi (2000), it is an important factor to be considered in both subsistent and commercial fish farming. Thus, the anticipated success desired for the sector will significantly depend on providing quality and least cost fish feed (Delgado and Minot, 2003). Glencross et al. (2020) cited by Hoerterer et al (2021) posited that the challenge of feeding farmed fish with diets that are nutritious but at the same time economically and environmentally sustainable is a major issue to ponder.

The effort to resolve this challenge can only be achieved by relying on the use of cheaper, locally available feed ingredients; integrating locally available feed ingredients in feed formulation in the right proportion supplemented with crystalline Essential Amino Acids (EAAs) based on the fish requirements (Tacon and

Metian, 2008; Macfadyen et al., 2012). Efforts have been made in recent years, through research to identify major nutritional requirements for important farmed fish (FAO, 2020; Naylor et al., 2021). Replacement of the expensive and high in demand fishmeal and fish oil in fish feed formulation is the focus of most fish feed researchers (Sattang et al., 2021).

The African catfish is native to tropical environment, preferred by farmers and easily cultured with fast growth potential when fed with nutritionally balanced diets. *Clarias spp.* command good price in Sierra Leone and is relished by consumers in the country because of its taste. The staffs of the Department of Aquaculture and Fisheries Management, Njala University has been working relentlessly for more than eight years to make the culture of African catfish and Nile tilapia easy for local farmers through research on improved fish strains and quality feeds. The objective of this study was therefore to develop least-cost and nutrient-rich fish feed for the farming of African catfish (*C. gariepinus*) in Sierra Leone. The developed feed was compared with two imported feed on the basis of their proximate contents as a way of determining the suitability of the developed feeds for farming of African catfish in Sierra Leone.

MATERIALS AND METHODS

Study area

This study was carried out at the Department of Aquaculture and Fisheries Management Njala University, Njala Campus, Njala, Kori chiefdom, Moyamba district, Southern Sierra Leone. Njala University is located on latitude 7.25, and longitude 11.2 with the GPS coordinates of 07° 15' 00.00" N and 11° 12' 00.00" W.

Constituents of diets

Feed ingredients for the formulation of 45% crude protein (CP) least-cost and nutrient-rich catfish feed for the use of farmers in Sierra Leone were purchased from local market in the country, while fish protein concentrate (FPC booster), vitamin premix, lysine and methionine were imported. Feed ingredients used were fish meal, palm kernel cake (PKC), rice bran, methionine, lysine, vitamin premix, Yeast, salt (NaCl), starch and FPC booster (Table 1).

Diet preparation

Feedstuff were measured out in predetermined proportion, ground finely and mixed thoroughly in a clean plastic basin. Warm water was added to the ingredients and mixed to form a dough. The dough was passed through a manual pelleting machine, which gave a spaghetti-like product. The pelleted products were covered with transparent polythene sheet and kept indoor for 30 min and later sundried to obtain a constant storage weight. The well dried formulated feeds were stored in air-tight transparent polythene bags and kept in a cool dry place prior to proximate determination.

Vitamin premix

Vitamin A: 12,000,000 IU, Vitamin D3: 4,000,000 IU, Riboflavin: 8 g,

Table 1. Ingredients used for diet formulation.

Feed ingredients	Percentage inclusion level				
	Diet 1 45% CP	Diet 2 45% CP	Diet 3 45% CP	Diet 4 45% CP	Diet 5 45% CP
Fish meal	49.3	47.4	46.2	44.9	43
PKC	2	2	2	2	2
Rice bran	29	27.9	27.1	26.4	25.3
Methionine	2	2	2	2	2
Lysine	4	4	4	4	4
Vitamin premix	0.5	0.5	0.5	0.5	0.5
Yeast	0	3	5	7	10
Salt	0.2	0.2	0.2	0.2	0.2
Starch	5	5	5	5	5
FPC booster	8	8	8	8	8
Total	100	100	100	100	100

Source: Primary data from the field; and from labels of Ranaan and Aller aqua feeds

d-Pantothenic acid: 24 g, Choline: 1,400 g, Niacin: 100 g, Vitamin E: 100 g, Vitamin K: 4 g, Vitamin C: 500 g, Folic acid: 1 g, Pyridoxine: 5 g, Thiamine: 5 g, BHT: 5 g.

Fish protein concentrate - liquid

Water max 65%; protein min 25%; Fat min 4%; Ash max 8% and phosphoric acid max 5%

Proximate determination of diets

Dry matter, moisture, crude protein, fat, crude fibre, ash and carbohydrate, calcium, potassium and sodium were determined for this study using procedures prescribed by AOAC (2000).

Determination of moisture content (%)

Feed samples (5 g each) were weighed into a clean pre-weighed crucible and dried in an oven at 105°C to constant weight. The moisture content was then calculated using this equation:

$$\text{Moisture \%} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Wet weight of sample}} \times 100$$

Determination of total ash (%)

Feed samples, 5 g each for the determination of total ash were weighed into clean pre-weighed crucibles and converted to ash in a furnace at 550°C to a constant weight. Total ash was then calculated as:

$$\text{Ash \%} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100$$

Determination of fat (%)

Feed sample (5 g) was massed into a polypropylene centrifuge bottle. Sodium acetate, aliquots of methanol, chloroform and water

was added into the bottle and shaken for 30 min. The content of the bottle were centrifuged at 2500 rpm for 10 min, after which it was set in 25°C water bath for 15 min. The samples was evaporated to dryness under nitrogen blanket, heated in a drying oven for 30 min, and cooled in a desiccator for 30 min. Fat content was then determined as:

$$\text{Fat\%} = \frac{(W_2 - W_1) \times V_c \times 100}{(V_A \times S_W)}$$

Where, W₂ was the weight of glass tube and dried extract (g), W₁ was the weight of empty dried glass tube (g), V_c was the total volume of chloroform (ml), V_A was the volume of extract dried (ml), and S_W was the weight of the sample in grammes.

Determination of protein (%)

Concentrated sulphuric acid (H₂SO₄) (20 ml) was carefully added into tube containing 1 g sample of feed and Cu (catalyst salt), and then shaken gently to aid digestion. Digested sample was cooled for 10 to 20 min. Distillation procedure was then performed using distillation unit and the distillate was titrated with 0.025N sulphuric acid (H₂SO₄) until the end point changed from green to pink. Volume of acid required in the titration was recorded. Blank was prepared with the exclusion of sample. The percentage of protein content was calculated using the equation below:

$$\% \text{ Nitrogen} = \frac{0.014 \times V_D \times N \times 100 \times T_V}{\text{Weight of sample} \times A_D}$$

$$\% \text{ Protein} = \% \text{ N} \times F$$

Where, V_D is the Volume of digest; N is the normality of acid; T_V is the titre value; A_D is the aliquot of digest and F is the conversion factor for nitrogen to protein.

Determination of fibre

Feed sample (5 g) was weighed into a litre conical flask containing 200 ml of boiling sulphuric acid and further boiled for 30 min over a burner. Swirling is done occasionally to remove solids from

adhering to the sides of the flask. The hot solution was decanted through Buchner funnel fitted with Whatman 52 filter paper. All residues were rinsed with boiling water until there was no colour change in litmus paper, an indication that acid has been completely removed from the residue. The residue was transferred into a 200 ml of 1.25% NaOH solution in a litre flask and brought to boil. The solution was thereafter maintained at a gentle ebullition for 30 min and subsequently filtered using rapid hardened filter paper. 1% HCl and distilled water, 15 ml of alcohol and 10 ml of diethyl ether were also added. The sample was dried in an oven at 100°C for 1 h and allowed to cool in a desiccator and weighed (W1). Sample was put in a crucible in a furnace at 55°C for 3 to 4 h; it was cooled in a desiccator and weighed again (W2). Fibre was calculated thus:

$$\% \text{ Fibre} = \frac{W1 - W2}{\text{Weight of the sample}} \times 100\%$$

Determination of carbohydrate (%)

Carbohydrate was determined as presented here:

$$\text{Carbohydrate} = 100\% - (\% \text{ moisture} + \% \text{ ash} + \% \text{ crude protein} + \% \text{ fat})$$

Statistical analysis

One-way ANOVA and simple statistical measure of mean, percentages and standard deviation were used to analyse the results of proximate determination.

RESULTS AND DISCUSSION

Proximate and chemical analysis of formulated feed

The highest mean percentage of crude protein obtained was higher at $44.48 \pm 0.40\%$ for Diet 5, while the least CP of $40.59 \pm 2.22\%$ was obtained for Diet 3. These figures were not significantly different ($P > 0.05$) from the 45% crude protein declared by Ranaan and Aller Aqua. The protein level obtained in this study agrees with the recommendation of National Research Council (NRC, 2011) of 35 to 40% for warm water fishes. According to Wilson (2000), most of the commercial fish feed, especially for catfish contain 32% CP. Boonyaratpalin (1988) estimated the protein requirement for tropical catfish to be 35 to 40, 25 to 35 and 28 to 32% for fry, grow-out and brood stock respectively. The result of this study agrees with that of Wantanabe et al. (1990) who reported that the utilization of protein of 35% and above inclusion in fish feed increase fish production. It has also been shown by various workers that fish growth performance is a function of the protein inclusion in the feed (Siddiqui et al., 1998; Giri et al., 2003; Ali and Jauncey, 2004a; Goda et al., 2007; Corn'elio et al. 2014; Keremah and Beregha, 2014; Olapade and Quinn, 2019).

In this study, fishmeal, amino acids and FPC booster were the sources of protein; Ranaan utilized fishmeal and poultry waste meal; and Aller Aqua utilized the combination of animal and plant sources protein (fish

meal, soybean meal, feather meal, poultry meal, poultry blood meal and sunflower protein concentrate). The decision to utilize amino acids and FPC in this study is owing to the fact that some of the ingredients used by both Ranaan and Aller Aqua are not readily available in Sierra Leone. The use of animal blood in fish feed although is cheaper required some caution especially in a country like Sierra Leone where it may be impossible to gather sufficient quantity for commercial use. The inadequacy of appropriate technology to process animal blood into meal may dispose it to contamination, which will invariably render it unusable for the culture species. Groundnut oil cake (GNC) and soybean meal in combination with fishmeal is good in fish feed formulation (Audu et al., 2004), it is however important to mention that abnormal inclusion has been associated with reduced growth of fish as a result of poor feed utilization and digestion by the fish (NRC, 1993; Jauncey, 1998; Nyina-Wamwiza et al., 2007; Agbo et al., 2011; Olapade and Lombi, 2015; Olapade and Kargbo, 2015; Olapade and Quinn, 2019).

The result of this study showed that Diet 4 has the highest fibre value of 3.28 ± 0.15 and a least mean value of 2.81 ± 0.14 for Diet 1, slightly higher than for both Ranaan and Aller Aqua. Mean carbohydrate (CHO) value of 39.29 ± 2.24 was for Diet 3, while 36.76 ± 5.37 was the least obtained for Diet 5. These values far exceeded those of Ranaan and Aller Aqua and are beyond the recommended levels by NRC (2011). It is suggested, that a typical catfish feed should contain 25% or more soluble (digestible) carbohydrates, in addition to 3 to 6% more carbohydrates that are generally present as crude fibre (mainly cellulose). Fibre is a necessary component of plant ingredient, and they are useful in feed as binder. De Silva and Anderson (1995) opined that fibre contents of fish feed should not exceed 8 to 12%. Excess of fibre has been associated with reduced quality unusable nutrient in the diet, and has also been ascribed poor growth of *C. gariepinus* fingerlings (Adewolu et al., 2010; Agbabiaka et al., 2013). The implication of high level energy relative to protein in fish feed are lipid deposition, decreased feed intake and reduced weight gain and vice versa (Craig, 2017). Consequently, there is the need to balance the energy-to-protein ratio of the diets in this study, as this would help to reduce the carbohydrate and fibre level to acceptable level especially for African catfish which requires more protein than carbohydrate and fibre.

The highest fat obtained for Diet 5 ($3.16 \pm 0.01\%$), and a least value of $0.30 \pm 0.07\%$ recorded for Diet 2 in this research were significantly below those of Ranaan and Aller Aqua (Table 2). Fat values for Diet 1 ($0.30 \pm 0.07\%$), Diet 2 ($0.72 \pm 0.02\%$) and Diet 3 ($0.39 \pm 0.00\%$) are not significantly varied ($P > 0.05$). Diet 5 was however significantly higher ($P < 0.05$) (3.16 ± 0.01). The nature of fish tissue fatty acids is markedly influenced by dietary lipids. Fish can synthesize saturated fatty acids and members of the w9 and w7 families of unsaturated acids; however, a dietary source is required for the w3 (Alpha-

Table 2. The proximate composition of formulated diets (%) for African catfish, *Clarias gariepinus*.

Sample	DM	Moisture	Ash	Protein	Fat	Fibre	CHO (NFE)
Diet 1	78.30 ± 0.20	21.70 ± 0.20	17.60 ± 0.13	41.51 ± 5.54	0.30 ± 0.07	2.81 ± 0.14	37.9 ± 5.63
Diet 2	78.61 ± 0.23	21.39 ± 0.23	16.64 ± 0.09	42.16 ± 2.31	0.72 ± 0.02	3.09 ± 0.06	37.38 ± 2.18
Diet 3	77.22 ± 0.16	22.77 ± 0.16	16.62 ± 0.06	40.59 ± 2.22	0.39 ± 0.00	3.21 ± 3.15	39.29 ± 2.24
Diet 4	78.01 ± 0.15	21.98 ± 0.15	17.26 ± 0.04	41.61 ± 5.57	1.07 ± 0.04	3.28 ± 0.15	36.76 ± 5.37
Diet 5	80.50 ± 0.29	19.49 ± 0.29	16.66 ± 0.40	44.48 ± 0.40	3.16 ± 0.01	3.01 ± 0.13	34.3 ± 1.65
Ranaan feed	ND	9.0	9.5	45.0	12.0	2.5	26.4
Aller aqua feed	ND	ND	6.0	45.0	12.0	2.6	ND

DM: Dry matter content; CHO: Carbohydrate; ND: Not declared; NFE: Non Fatty Extract.
Source: Primary data from the field; and from labels of Ranaan and Aller aqua

Table 3. Mineral contents of formulated diets for African catfish, *Clarias gariepinus*.

Sample	P µg/g (mean weight)	Na µg/g (mean weight)	Ca (%)
Diet 1	10,360.36 ± 1938.55	3,115.55 ± 43.74	2.84 ± 0.06
Diet 2	11,557.78 ± 283.37	3,117.79 ± 100.96	2.39 ± 0.03
Diet 3	11,075.78 ± 655.84	3,023.73 ± 87.11	2.41 ± 0.07
Diet 4	11,604.46 ± 1119.24	3,081.37 ± 174.00	2.26 ± 0.08
Diet 5	12,569.88 ± 1370.21	3,076.79 ± 62.29	2.27 ± 0.15
Ranaan Feed	1.3%	ND	ND
Aller Aqua Feed	1%	0.2%	0.5

µg/g: Microgram per gram; P: Phosphorus; Ca: Calcium; Na: Sodium.
Source: Primary data from the field; and from labels of Ranaan and Aller aqua feeds

linolenic acid - ALA, Eicosapentaenoic acid - EPA, and Docosahexaenoic acid - DHA) and w6 (Arachidonic and Linoleic acid) families to be present in fish tissues (NRC, 1977). Cowey and Sergent (1979) reported that 10 to 20% of lipid in most freshwater fish diets gives optimal growth rates without producing an excessively fatty carcass. Wilson (2000) reported that lipid level in catfish feeds should be 5.6%.

Yildirim-Aksoy (2009) noted that dietary lipids are important sources of highly digestible energy and according to him; it is the only source of the essential fatty acids needed by fish for normal growth and development. Thus, it can be said that lipids or fatty acids is good in the diet of fish at a certain level of inclusion. This study will strive to improve on the fatty acids level by reducing the non-fatty extract (NFE) and dry matter content of this test feed. The percentage moisture values obtained in this study, which ranged from 19.49 ± 0.29 to 21.98 ± 0.15 was higher than those of Ranaan feed and Aller Aqua feed. Moisture is of great importance in storage of feed. Improperly dried feed besides having a short shelf life will be infested by mould with possibility of developing mycotoxin.

Mineral contents of formulated diets

Aquatic animals need minerals for their physiological and

biochemical functions, and also to maintain their normal life processes (Lall and Kaushik, 2021). According to Craig (2017), minerals are inorganic elements that regulate osmotic balance and aid in bone formation and integrity. In this study, phosphorus (µg/g), sodium (µg/g) and calcium (%) were evaluated (Table 3). Phosphorus was determined for both Ranaan and Aller Aqua and the values of 1.3 and 1% reported respectively for the two feeds are below what was obtained in this study. Percentage of Na and Ca were only reported for Aller Aqua as 0.2 and 0.5%, respectively. The essentiality of macro-minerals (calcium, phosphorus, magnesium, sodium, potassium and chloride) has been confirmed in fish (NRC, 1993; NRC 2011). Lall and Kaushil (2021) however reported that gaps still exist in the knowledge of mineral nutrition of fish and shrimp with respect to their dietary requirements, physiological functions, and absorption from the gastrointestinal tract and bioavailability from feed ingredients. Even with the gaps, essential macro- and micro-minerals are required at optimum levels for growth and maintenance of normal health of farmed fish.

Cost consideration of formulated diets

The costs of producing the 45% CP diets used in the study are presented in Table 4. The cost of producing a

Table 4. Cost of formulated diets for African catfish, *Clarias gariepinus*.

Feed type	Weight in kilogram (kg)	Price in Leones (Le)
Diet 1 - Formulated	15	128,168.20 (\$10.78)
Diet 2 - Formulated	15	149,387.80 (\$12.56)
Diet 3 - Formulated	15	163,529.40 (\$13.75)
Diet 4 - Formulated	15	177,671.00 (\$14.94)
Diet 5 - Formulated	15	198,883.4 (\$16.72)
Ranaan Feed	15	204,300.00 (\$17.18)
Aller Aqua Feed	15	279,226.59 (\$23.47)

Le - stands for Leone prefix for Sierra Leone currency.

Source: Primary data from the field; and from labels of Ranaan and Aller aqua feeds

15 kg feed was highest for Diet 5 - Le 198,883.4 (\$16.72) and lowest for Diet 1 - Le 128,168.20 (\$10.78). The cost of producing a 15 kg bag of Ranaan and Aller Aqua feed was Le 204,300.00 (\$17.18) and Le 297, 226.59 (\$23.47), respectively. It is evident that it is expensive to produce extruded feeds than local feeds, although the cost of producing Diet 5 - Le 198,883.4 (\$16.72) used in this study is not significantly different from the cost of producing a 15 kg Ranaan feed. Aller Aqua which is considered as the best fish feed by farmers in Ghana has a low FCR (feed conversion ratio) but more expensive than other feeds in the market.

Conclusion

It is evident from the preliminary results obtained in this study, that it is possible to formulate least-cost and nutrient rich feeds for the African catfish (*Clarias gariepinus*) using locally sourced feed ingredients. Availability of least-cost and nutrient rich fish feed is one of the major problems limiting aquaculture development in Sierra Leone. Using local agricultural by-products for fish feed development will not only reduce the cost of production, but would help to convert what is termed wastes to money, and thus improving the earnings of farmers who produces them. The use of local materials will also reduce capital flight on importation of commercially extruded feeds which often is beyond the reach of local farmers. The diets formulated in this study compared well with the imported Ranaan feed and Aller Aqua feed with respect to their respective proximate contents and costs of production. The researchers however have noted areas for improvement, and this will be worked on so that the diets can meet the recommended requirements of warmwater fishes as put forward by National Research Council (NRC, 2011). The final diets to be produced after the adjustment of the ingredients will be tried in the laboratory to determine its suitability for good growth performance of the African catfish. The diet level that furnishes good growth and FCR will be recommended for commercialization in Sierra

Leone. The knowledge of feed development exhibited in the department will not only help to promote local aquaculture development but will contribute significantly to the development of aquaculture in Africa, particularly in the Mano River basins country.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Alfred Seawright, Chief Executive Officer of Seawright Mining Company who provided the funding for the research. We are also thankful to the analytical laboratory of the University of Cape Coast (UCC) for helping with the chemical analysis.

REFERENCES

- Adewolu MA, Ikenweibe NB, Mulero SM (2010). Evaluation of an Animal Protein Mixture as a Replacement for Fishmeal in Practical Diets for Fingerlings of *Clarias gariepinus* (Burchell, 1822). *Israel Journal of Aquaculture-Bamidgeh* 62(4):237-244.
- Agbabiaka LA, Okorie KC, Ezeafulukwe CF (2013). Plantain peels as dietary supplement in practical diets for African catfish (*Clarias gariepinus* Burchell 1822) fingerlings. *Agriculture and Biology Journal of North America*, 4(2):155-159. DOI:10.5251/abjna.2013.4.2.155.159.
- Agbo NW, Adjei-Boateng D, Jauncey K (2011). The potential of groundnut (*Arachis hypogaea* L.) by-products as alternative protein sources in the diet of Nile tilapia (*Oreochromis niloticus*). *Journal of Applied Aquaculture* 23:367-378.
- Ali MZ, Jauncey K (2004a). Effect of feeding regime and dietary protein on growth and body composition of *Clarias gariepinus* (Burchell, 1822). *Indian Journal of Fisheries* 51(4):407-416.
- Association of Official Analytical Chemists (AOAC) (2000). *Official Methods of Analysis of AOAC International*, 17th ed.; AOAC International: Gaithersburg, MD, USA.
- Audu PA, Oniye SJ, Okechukwu PU (2004). Helminth parasites of domesticated pigeons (*Columba livia domestica*) in Zaria. *Nigeria. Journal of Pest and Disease Vector Management* 5:356-360.
- Babalola TOO (2010). Utilization of Dietary Animal Fats and Vegetable Oils by African Catfish (*Heterobranchius longifilis*) Fingerlings. PhD. Thesis. University of Ilorin, Nigeria.

- Boonyaratpalin M, Suraneiranat P, Tunpibal T (1998). Replacement of fish meal with various types of soybean products in diets for Asian seabass, *Lates calcarifer*. *Aquaculture* 161(1-4):67-78.
- Corn'elio FHG, Cunha DA, Silveira J, Alexandre D, Silva C, Fracalossi DM (2014). Dietary protein requirement of juvenile Cachara Catfish, *Pseudoplatystoma reticulatum*. *Journal of the World Aquaculture Society* 45(1):45-54. DOI: 10.1111/jwas.12090.
- Cowey CB, Sargent JR (1979). Nutrition. In: W.S. Hoar, D.J. Randall and J.R. Brett, eds. *Fish physiology* 8:1-69. New York, Academic Press.
- Craig S (2017). *Understanding Fish Nutrition, Feeds, and Feeding*. Virginia Cooperative Extension Publication pp. 420-256. Accessed May 22, 2022 from FST-269.pdf (tamu.edu)
- Delgado CL, Minot N (2003). "GRP27 Proposal Participation in High-Value Agricultural Markets" Presented at IFPRI.
- De Silva SS, Anderson TA (1995). *Fish Nutrition in Aquaculture*. Chapman & Hall, 2-6 Boundary Row, London SE1 8HN P 319.
- EI-Sayed AFM (1999). Alternative dietary protein sources for farmed tilapia, *Oreochromis sp.* *Aquaculture* 179(1/4):149-168.
- Food and Agricultural Organization of the United Nations (FAO) (2018). *The State of World Fisheries and Aquaculture 2018—Meeting the Sustainable Development Goals*; FAO: Rome, Italy.
- Food and Agricultural Organization of the United Nations (FAO) (2020). *The State of World Fisheries and Aquaculture. Sustainability in action*. Rome, Italy.
- Giri SS, Sahoo SK, Sahu AK, Meher PK (2003). Effect of dietary protein level on growth, survival, feed utilization and body composition of hybrid *Clarias* catfish (*Clarias betrachus* x *Clarias gariepinus*). *Animal Feed Science and Technology* 104(1-4):169-178.
- Goda AM, El-Haroun ER, Chowdhury MA (2007). Effect of totally or partially replacing fish meal by alternative protein sources on growth of African catfish *Clarias gariepinus* (Burchell, 1822) reared in concrete tanks. *Aquaculture Research* 38(3):279-287. DOI: 10.1111/j.1365-2109.2007.01663.x
- Hardy RW, Barrows FT (2003). Diet formulation and manufacture. In: Halver JE, Hardy RW (eds) *Fish Nutrition*. Academic Press, San Diego pp. 505-600.
- Hilborn R, Amoroso RO, Anderson CM, Ye Y (2020). Effective fisheries management instrumental in improving fish stock status. *PNAS* 117(4):2218-2224 <https://doi.org/10.1073/pnas.1909726116>
- Hoerterer C, Peterreit J, Lsnig G, Johsndrn J, Pereira GV, Conceição LEC, Pastres R, Buck BH (2021). Sustainable fish feeds: potential of emerging protein sources in diets for juvenile turbot (*Scophthalmus maximus*) in RAS. *Aquaculture International* 30:1481-1504 <https://doi.org/10.1007/s10499-022-00859-x>.
- Jauncey K (1998). *Tilapia Feeds and Feeding*. Pisces Press Ltd., Sterling, Scotland, ISBN-13:978-0952119845 241 p.
- Kassam L, Lakoh K, Longley C, Phillips MJ, Siriwardena SN (2017). *Sierra Leone fish value chain with special emphasis on Tonkolili District*. Penang, Malaysia: WorldFish. Program Report: 33.
- Keremah RI, Beregha O (2014). Effect of varying dietary protein levels on growth and nutrient utilization of African catfish *Clarias gariepinus* fingerlings. *Journal of Experimental Biology and Agricultural Sciences* 2(1):13-18.
- Lall SP, Kaushik SJ (2021). Nutrition and Metabolism of Minerals in Fish. *Animals* 11:2711. <https://doi.org/10.3390/ani11092711>.
- Macfadyen G, Nasr-Alla AM, Al-Kenawy D, Mohamed MF, Hebicha H, Diab AM, Hussein SM, Abou-Zeid RM, El-Naggar G (2012). Value-chain analysis—an assessment methodology to estimate Egyptian aquaculture sector performance. *Aquaculture* 362:18-27.
- National Research Council (NRC) (1993). *Nutrient Requirements of Fish*. National Academies Press: Washington, DC, USA.
- National Research Council (NRC) (2011). *Nutrient Requirements of Fish and Shrimp*. National Academic Press, Washington, DC, USA.
- National Research Council (NRC) (1977). *Nutrient Requirements of Warmwater Fishes*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/20664>.
- Naylor RL, Hardy RW, Buschmann AH, Bush SR, Cao L, Klinger DH, Little DC, Lubchenco J, Shumway SE, Troell M (2021) A 20-year retrospective review of global aquaculture. *Nature* 591(7851):551-563. <https://doi.org/10.1038/s41586-021-03308-6>.
- Nyina-Wamwiza L, Wathelet B, Kestemont P (2007). Potential of local agricultural by-products for the rearing of African catfish *Clarias gariepinus* in Rwanda: Effects on growth, feed utilization and body composition. *Aquaculture Research* 38(2):206-214.
- Olapade OJ, Quinn PG (2019). Nutritional evaluation of defatted groundnut cake meal with amino acid as protein supplement in African catfish (*Clarias gariepinus* Burchell, 1822) juvenile diet. *Journal of Fish and Aquatic Science* 14:7-14.
- Olapade OJ, Kargbo M (2015). Effect of *Terminalia catappa* on growth and haematology of *Clarias gariepinus* juveniles. *Journal of Aquaculture, Feed Science Nutrition* 7:1-5.
- Olapade OJ, Lombi GAG (2015). Growth performance and haematology of the African catfish (*Clarias gariepinus* Burchell, 1822) juveniles fed graded level of *Anisophyllea laurina* R. Br. Ex. Sabine (Monkey plum) seed meal. *Asian Journal of Agriculture and Food Science* 3(2):133-140.
- Sattang S, Amornlerdpison D, Tongsiri S, Palić D, Mengumphan K (2021). Effect of freshwater fish oil feed supplementation on the reproductive condition and production parameters of hybrid catfish (*Pangasius larnaudii* x *Pangasianodon hypophthalmus*, Sauvage, 1878) broodstock. *Aquaculture Reports* 20:100598.
- Siddhuraju P, Becker K (2003). Comparative nutritional evolution of differentially processed mucuna seeds (*Mucuna pruriens* L.) DC. Var. utilis (Wall ex Wight) (Baker ex Burck) on growth performance, feed utilization and body composition in Nile tilapia (*Oreochromis niloticus* L.). *Aquaculture Research* 34(6):487-500. <https://doi.org/10.1046/j.1365-2109.2003.00836.x>.
- Siddiqui AQ, Howlander MS, Adam AA (1988). Effects of dietary protein levels on growth, feed conversion and protein utilization in fry and young Nile tilapia, *Oreochromis niloticus*. *Aquaculture* 70(1-2):63-73. DOI:10.1016/0044-8486(88)90007-5.
- SPRING (2015). *Integrated Nutrition and Agriculture Needs Assessment for Sierra Leone*. Arlington, VA: USAID Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) project.
- Tacon AGJ, Metian M (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Elsevier Journal* 285(1-4):146-158. <https://doi.org/10.1016/j.aquaculture.2008.08.015>.
- Tsevis AA, Azzaydi TA (2000). Effect of feeding regime on selected species of fish. Article publication of FISON, Feb., 2000. Agora.
- Wantanabe WO, Clark JH, Dunham JB, Wicklund RI, Olla BL (1990). Culture of Florida red tilapia in marine cages: The effects of stocking and dietary protein on growth. *Aquaculture* 90(2):123-134.
- Wilson RP (2000). *Channel Catfish, Ictalurus punctatus*. In: *Handbook of Nutrient Requirement of Finfish*, Wilson, R.P. (Ed.). CRC Press, Boca Raton, USA pp. 35-53.
- WorldFish (2016). *Feed the Future Sierra Leone Scaling Up Aquaculture Project: Implementation Strategies and Management*. Working Document. Penang WorldFish.
- Yildirim-Aksoy M (2009). Lipid, fatty acid requirements of tilapia. Retrieved on April 2, 2022 from <https://www.globalseafood.org/advocate/lipid-fatty-acid-requirements-of-tilapia/>