BIO-ECONOMIC ASSESSMENT OF NOVEL FISH FEED FORMULATION SOFTWARE (FUTA AQUAFEEDAPP) FOR AFRICAN CATFISH *Clarias gariepinus*(Burchell 1822)RAISED IN RECIRCULATORY AQUACULTURE SYSTEM

ABSTRACT

In the current study, data on nutritional composition and cost of conventional and non-conventional fish feed ingredients were gathered, a spreadsheet was created to bank the data. Four fish feeds were formulated and produced using three conventional fish feed formulation methods and a developed software (AQUAFEED); the software was developed using data analytical tools: simple harmonic equation, linear programming and stochastic programming techniques. The nutrient composition of the four diets were evaluated in the laboratory. The result of the proximate analyses indicated that the four diets met the crude protein requirements for African Catfish fingerlings, the values ranged from 40.68±0.62(Pearson square) to 40.98±0.86(ALLIX). There were no significant differences in the moisture content, crude protein, crude fibre, crude lipid and NFE across all treatments, however there was significant difference in the ash content across the four diets.The result of the cost assessment across the four treatments were significantly different, it revealed that AQUAFEED had the lowest investment cost ($1/Kg) when compared with the three other treatments, while Pearson Square had the highest investment cost ($1.5/kg) due to the high inclusion of fishmeal in the diet.

Keywords: *Clarias gariepinus*, Data Analytics, AQUAFEEDAPP,fish feed, formulation.

1. INTRODUCTION

Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants. Aquaculture continues to be the fastest-growing food production system in the world after almost three decades. Over the past 35 years, aquaculture production in Nigeria has grown 12% a year (compared to the world average of 8%), from a little over 6000 metric tons in 1980 to nearly 307,000 metric tons in 2016. The country is the largest aquaculture fish producer in sub-Saharan Africa, accounting for 52% of the total farmed fish production in the region. Nigeria's aquaculture focuses mainly on freshwater fish, with catfish species accounting for 64% of aquaculture production in 2015 (World-Fish, 2018).

Feed accounts for at least 60% of the total cost of fish production in Aquaculture, which to a large extent determines the viability and profitability of fish farming enterprise (Ayinla, 2007). Good quality feed is key to fish production because it improves the yield or the quality of fish products, which in turn increases incomebecause feed has a direct impact on growth rate, productivity and animal health. Therefore, in order to meet the required dietary requirements of fish for increased production, careful selection and combination of various feed ingredients aimed at minimizing cost while meeting the nutritional requirements for fish growth is required (Fasakin, 1997). Hence, the use of data analytical approach.

Animal feed formulation can be defined as the process by which different feed ingredients are combined in a proportion necessary to provide the animal with proper amount of nutrients needed at a particular stage of production (Afolayan *et al*., 2008). Most feed formulation methods are based on trial by error, simultaneous equation, Pearson square, Linear Programming for feed formulation or Stochastic Programming techniques (Rahman *et al*., 2010), but they have quite a number of disadvantages (Adejoro, 2004; Afolayan and Afolayan, 2008 and Onwurah, 2005).Over time, many companies have developed several computer software packages for feed formulation, they include Window-based feed formulation program (WINFEED^{TM}), Animal feed formulating software (AFFOS), ALLIX, BESTMIX$^{®}$, MILAS$^{®}$, FEEDNETICS^{TM}. These packages vary from simple solutions to complex software packages designed for large feed manufacturers, however, they have limitations of application to tropical fish species, limited flexibility, cost and availability (Suresh, 2020).

A software that can combine both Linear Programming technique and Stochastic technique, a non-linear optimization program that will manage risk in ingredient variability (Rahman *et al*., 2010) and Big Data Analytical approach using Machine learning model (Suresh, 2020) is needed in aquafeed formulation and production. Machine learning tools features are novel in Aquafeed formulation, these tools are flexible and can optimize various factors in fish feed formulation which can help improve production indices in culturable fish species. African Catfish (*Clarias gariepinus*) is one of the major culturable aquaculture species in Nigeria (FAO, 2019). African Catfish production is considered to be the fastest growing segment of the Nigeria aquaculture industry over the last decade (FAO, 2019). Therefore, it is very important to develop feed formulation software that will help fish feed formulators design feeds that would meet the nutritional requirements of the fish species while minimizing cost and maximizing profit, hence advancing the bioeconomics of Aquafeed formulation in African Catfish using data analytical tools.

2. MATERIALS AND METHODS

2.0 Study Area

The experiment was carried out in the Department of Fisheries and Aquaculture Technology, Federal University of Technology, Akure. The Data Analytics and application of Artificial Intelligence were done in the Department of Computer Science, Federal University of Technology, Akure.

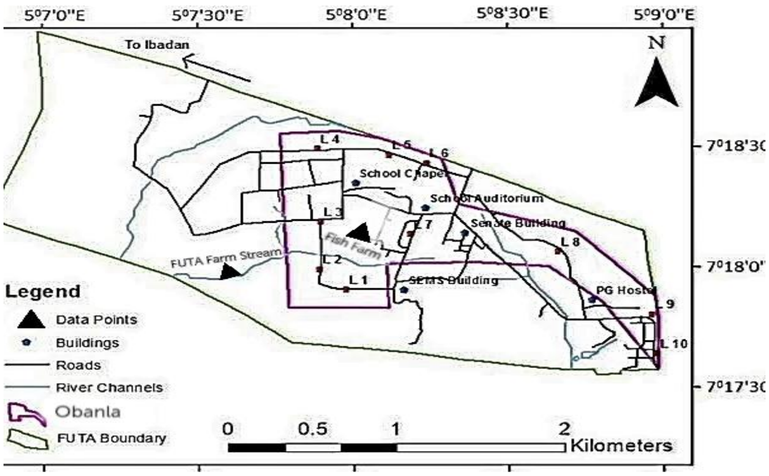

Figure 1: Map of FUTA.

2.1 Data Collection

Data on nutritional composition of fish feed ingredients, nutrient requirements and water quality parameters of African Catfish were gathered from literatures and secondary data websites (Feedipedia.com and Feedtables.com) and stored in a database using appropriate spreadsheets to bank the information.

2.2 Software Development

The software was developed at the Department of Computer Science. It is an hybrid of three models; Artificial Intelligence (AI) approach based on machine learning techniques, linear programming and stochastic programming.

2.3 Diet Preparation

Feed ingredients used for this experiment were yellow maize, fish meal, soyabean meal, groundnut cake, cassava starch, vitamin and mineral premix and groundnut oil (Table 1). The feed ingredients were purchased at Animal Concept Feedmill, Oyemekun, Akure. 10g of the each ingredient were analysed for proximate composition at the Federal University of Technology, Akure Biochemistry Laboratory.The newly developed Aquafeed software, Pearson Square feed formulation method and two other conventional fish feed softwares, WINFEED™ and ALLIX were used to formulate four experimental diets for African Catfish (*C. gariepinus*). All dietary ingredients were weighed using a sensitive chemical balance. The ingredients were grounded into fine particle size in a Henan milling machine (Henan Growing Mechanical Equipment Co., Ltd). The ingredients including protein sources (fish meal, soyabean meal, groundnut cake), groundnut oil, binder (cassava starch) and vitamin premix (Chemiconsult®) were thoroughly mixed in a Hobart A-2007 pelleting and mixing machine (Hobart Ltd, London, UK) to obtain a homogenous mass. The diets were all formulated to contain 40% protein. The mash was then pressed without steam through a mincer to obtain 2mm diameter sized pellets. The experimental diets were sundried immediately. After drying, the diets were stored in airtight, plastic containers. The diets wereanalysed at the Federal University of Technology, Akure Biochemistry Laboratory for proximate composition.

Table 1 Ingredients used for diet formulation

Ingredients	Control	Treatment 1	Treatment 2	Treatment 3
Fish meal	20.65	21.00	10.90	10.90
Soyabean meal	20.65	25.00	34.00	32.80
Groundnut cake	20.65	28.00	20.70	21.90
Yellow maize	28.05	16.00	24.40	24.40
Vegetable Oil	6.00	6.00	6.00	6.00
Vit/Min Premix	2.00	2.00	2.00	2.00
Starch	2.00	2.00	2.00	2.00

Premix manufactured by Chemiconsult International Limited, Ikeja, Lagos, Nigeria.

Vitamins supplied mg/100g diet: vitamin B_1 *(Thiamine) 1.2mg; vitamin* B_2 *(Riboflavine) 2.4mg; vitamin* B_3 *(Niacin) 10mg; vitamin* B_5 *(Pantothenic acid) 4.0mg; vitamin* B_6 *(Pyridoxine) 2.0mg; vitamin B7 (Biotin) 0.2mg; vitamin B9 (Folic acid) 0.4mg; vitamin K 2.0mg; vitamin B12 (Cyanocobalamin) 10.0mg; vitamin C (Ascorbic acid) 150mg, chlorine 160mg.*

Minerals: Manganese 4.8mg, Iron 150mg, Zinc 30mg, Copper 1.70mg, Iodine 0.50mg, Cobalt 0.3mg, Selenium 0.20mg.

2.4 Determination of Proximate Composition

The proximate composition of the feed ingredients and the diets were determined using analytical methods. All measurements were done in duplicatesand values presented in percentage.

2.4.1 Moisture Content

3g of each samples were weighed into petri dishes and oven-dried at 105^{O}C. The contents were removed and allowed to dry for 6 hours. The dishes were cooled in a desiccator for 30 minutes and reweighed.

$$\% \, moisture \, content = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

W_1 = Weight of petri dish

W_2 = Initial weight of feed sample and petri dish

W_3 = Final weight of feed sample and petri dish

2.4.2 Crude protein determination

Kjeldahl apparatus was used to determine the crude protein contents of the samples. 0.5g of each sample was placed into digestive tubes. 10ml of concentrated H_2SO_4 and 1.1 digestion mixture was added to the tubes. The tubes were placed in the digestion chambers at $420^{O}C$ for 45 minutes. They were allowed to cool and 5ml of sodium thio-sulphate ($Na_2S_2O_3$) and 30ml NaOH was added in the tubes. The distilled extraction was collected with 25ml Boric acid and titrated with standard Hcl (0.2N). The nitrogen values were converted into percentage of crude protein by multiplying it by 6.25.

% Nitrogen = $\frac{Vol \; of \; acid \; x \; molarity \;\; 0.014 \; x \; diluting \;\; factor}{Weight \; of \; samples \;\; (g)}$

% Crude protein = % Nitrogen x 6.25

2.4.3 Crude Lipid content

Crude lipid was determined by extracting 3g of samples with analytical grade acetone. Continuous extraction of lipid was done for 3 hours at $70^{O}C$ temperature until clear acetone was seen in siphon. The extract was transferred to a weighed beaker and the acetone was allowed to evaporate leaving the lipid in the container.

$$\% \, lipid \, content = \frac{W_2 - W1}{W3} \times 100$$

W_1 = Weight of beaker

W_2 = Weight of beaker with samples

W_3 = Weight of sample after extraction

2.4.4Crude Fibre content

Crude fiber determination was done by acid and alkaline digestion methods in which 2g of each sample were used with 0.128M H2SO4 and 0.223M KOH solution. The residual content was then dried in an oven at 105°C for a few hours and then ignited in muffle furnace at 550°C for 3 hours.

$$\% \, crude \, fibre = \frac{W_2 - W_3}{W_1} \times 100$$

W_1 = Weight of sample

W_2 = Weight of oven dried residue

W_3 = Weight of ash residue.

2.4.5 Ash content

Ashing was done using 1g of each sample in crucibles and transferred into a muffle furnace at 550^{O}C for 5 hours.After complete ashing, the crucibles were allowed to cool in a desiccator and then reweighed.

$$\% \, Ash \, content = \frac{W_2 - W_3}{W1} \times 100$$

W_1 = Weight of sample

W_2 = Weight of crucible with ash

W_3 = Weight of empty crucible

2.4.6 Nitrogen free extract

It was determined by subtracting the sum of the percentage contents of moisture, crude protein, lipid, ash and crude fibre from 100.

%NFE= {100 – (moisture+ crude protein+crude lipid+ash+crude fibre)**}**

3. RESULTS

3.1 Proximate composition of fish feed ingredients

The proximate compositions of the fish feed ingredients used in the experiment are shown in Table 2 containing protein sources (Fish meal, Groundnut cake, Soyabean meal) and energy sources (Yellow maize, vegetable oil).

Table 2: Proximate composition of selected feed ingredients in the Experimental diets (%DM)

INGREDIENTS	MC	CP	CF	CL	Ash	NFE
YM	10.01±0.19	10.09±0.53	2.62±0.87	4.87±0.35	3.02±0.66	69.40±0.26
FM	11.23±1.56	68.72±1.83	4.16±0.11	6.42±0.11	3.47±0.66	6.01±0.42
SBM	12.62±0.35	40.55±0.23	3.17±0.47	7.05±0.17	1.73±0.66	34.88±0.68

GNC	12.62±1.24	45.13±0.74	2.69±0.16	6.67±0.29	1.71±0.66	31.19±0.78

NFE (Nitrogen free extract): calculated as 100 – (moisture content + crude protein + crude fibre + crude lipid + ash).

MC: Moisture content, CP: Crude protein, CF: Crude fibre, CL: Crude Lipid, YM: Yellow Maize, FM: Fish meal, SBM: Soya bean meal, GNC: Groundnut cake.

3.2 Aquafeed software algorithm

Algorithm: AquaFeedApp

1. ***Set*** *the crude protein requirement of the feed, say CP_req*
2. *Assume* X_i *is the ingredients and* $i \dots n$ *is the number of ingredients selected for the mix.*
3. ***Initialize****n in order to obtain the grouping for protein supplement and basal feed list*
4. ***Initialize*** *protein supplement and basal feed lists to empty*
5. *If* $CP(X_i) > 20$
    1. *Add to protein supplement list*
6. *Else*
    1. *Add to basal feed list*
7. *Determine the length of protein supplement and basal feed list say nProteinSupp_list and nBasalfeed_list*
8. *If nProteinSupp_list == empty*
    1. *Print "Poor selection: Your mix must contain a least on protein source"*
9. *If nProteinSupp_list == 1*
    1. *Set protein_supp= CP of the ingredient*
10. *Else*
    1. *Set protein_supp = harmonic-mean ratio of CP for all the ingredients in nProteinSupp_list*
11. *If nBasalfeed_list == empty*
    1. *Print "Poor selection: Your mix must contain a least on energy source"*
12. *If nBasalfeed_list == 1*
    1. *Set basal_feed = CP of the ingredient*
13. *Else*
    1. *Set basal_feed = harmonic-mean ratio of CP for all the ingredients in nBasalfeed_list*
14. *If protein_supp>CP_req*
    1. *Resultant_basal=protein_supp – CP_req*
15. *Else*
    1. *Resultant_basal= CP_req – protein_supp*
16. *If basal_feed>CP_req*
    2. *Resultant_protein = basal_feed – CP_req*
17. *Else*
    2. *Resultant_protein= CP_req – basal_feed*
18. *Set aggre_mix= Resultant_basal + Resultant_protein*
19. *//Obtain gram mix per group based on 90% to create 10% allowance for oil and other additives*
20. *Gram_basal= Resultant_basal/agrre_mix*
21. *Gram_protein= Resultant_protein/agrre_mix*
22. *Obtain gram mix per ingredients using either CP ratio or high-low cost ratio of each mix*

3.3 Proximate composition of feed

The proximate compositions of the experimental feeds are shown in Table 3. The feed formulations were done using four different methods; Pearson square (control), ALLIX feed software as Treatment 1, WINFEED software as Treatment 2 and the developed software (AQUAFEED) as Treatment 3. Statistical analysis showed that there were no significant differences among the crude protein level, moisture content, crude fibre and crude lipid contents of the different treatments. However, there were significant differences in the ash content among the treatments.

Table 3: Proximate composition of experimental diet (%DM)

	Pearson Square	ALLIX	WINFEED	AQUAFEED
MC	12.71 ± 1.64^{a}	11.72 ± 1.77^{a}	10.18 ± 0.20^{a}	12.10 ± 1.03^{a}
CP	40.68 ± 0.62^{a}	40.98 ± 0.86^{a}	40.85 ± 0.63^{a}	40.89 ± 0.50^{a}
CF	1.97 ± 0.02^{a}	1.82 ± 0.03^{a}	1.99 ± 0.06^{a}	1.89 ± 0.05^{a}
CL	5.22 ± 0.02^{a}	5.15 ± 0.05^{a}	5.38 ± 2.20^{a}	6.89 ± 0.03^{a}
Ash	2.69 ± 0.07^{b}	1.51 ± 0.07^{a}	2.60 ± 0.48^{b}	2.81 ± 0.07^{b}
NFE	36.51 ± 2.25^{a}	38.82 ± 0.83^{a}	38.99 ± 2.49^{a}	36.31 ± 1.05^{a}

^{a,b} values in each row with different superscripts are significantly different ($p<0.05$).

NFE (Nitrogen free extract): calculated as 100 – (moisture content + crude protein + crude fibre + crude lipid + ash).

MC: Moisture content, CP: Crude protein, CF: Crude fibre, CL: Crude Lipid.

3.4 Amino acid profile of fish feed

Tables 4 and 5 below show the levels of essential and non-essential amino acids present in the fish feed produced during the experiment; Pearson square as control, ALLIX feed software as treatment 1, WINFEED software as treatment 2 and the developed software (Aquafeed) as treatment 3. NIRvascan smart spectrometer was used to determine the amino acid levels of the ingredients.

Table 4: Essential Amino acid profiles of the diets

EAA	Pearson Square	ALLIX	WINFEED	AQUAFEED
Arginine	13.65	16.17	10.56	12.10
Histidine	8.38	9.75	7.16	7.57
Isoleucine	9.76	8.82	9.75	9.73
Leucine	24.95	23.59	26.15	26.97
Lysine	15.14	19.11	15.13	15.51

Methionine	11.16	14.22	10.23	10.55
Threonine	12.02	11.99	12.35	12.31
Tryptophan	21.15	23.34	18.95	20.55
Valine	13.82	15.51	12.83	12.76
Phenylalanine	9.24	12.28	8.17	8.08

EAA: Essential Amino Acids.

Table 5: Non- essential Amino acid profiles of the diets

NEAA	Pearson Square	ALLIX	WINFEED	AQUAFEED
Alanine	21.91	16.61	23.08	22.68
Aspartic acid	26.81	22.18	28.11	27.15
Cystine	2.37	4.50	2.29	1.48
Glutamic acid	31.18	30.77	30.78	29.47
Glycine	20.30	17.96	20.56	21.87
Proline	14.68	16.11	12.03	13.50
Serine	12.29	10.40	12.40	12.03
Tyrosine	9.30	8.50	8.09	8.04

NEAA: Non- essential Amino Acids.

3.5 COST ASSESSMENT

3.5.1 Cost of ingredients

Table 6 shows the cost of ingredients per treatment. The mean total cost of feed ingredients (TFI) per treatment are significantly different (P>0.05), the highest (122.88±23.94) was found in the control (Pearson square) while the lowest total cost of feed ingredients (95.06±14.75) was found in Treatment 3 (AQUAFEED).

Table 6: Cost of ingredients per treatment

Ingredients	Pearson Square(₦)	ALLIX(₦)	WINFEED(₦)	AQUAFEED(₦)
FM	465.75±135.51^{b}	439.65±126.02^{b}	228.90±65.40^{a}	228.90±65.40^{a}
SBM	92.40±15.60^{a}	96.25±16.25^{ab}	130.90±22.10^{b}	126.28±21.32^{ab}
GNC	72.60±15.40^{a}	92.40±19.60^{a}	68.31±14.49^{a}	72.27±15.33^{a}
YM	63.43±1.08^{b}	47.20±0.80^{a}	71.98±1.22^{c}	71.98±1.22^{c}
Veg. Oil	96.00±0.00^{a}	96.00±0.00^{a}	96.00±0.00^{a}	96.00±0.00^{a}
Vit/Min P.	50.00±0.00 ^{a}	50.00±0.00^{a}	50.00±0.00^{a}	50.00±0.00^{a}
Starch	20.00±0.00 ^{a}	20.00±0.00^{a}	20.00±0.00^{a}	20.00±0.00^{a}
TOTAL (TFI)	122.88±23.94^{b}	120.21±23.24^{b}	95.16±14.74^{a}	95.06±14.75^{a}

Mean values in each column with different superscripts are significantly different ($p<0.05$).

3.5.2 Cost of feed preparation

Table 7 shows the cost of feed preparation.

Table 7: Cost of feed preparation

Preparation	Locations	Cost (₦)
	Animal Concept, Oyemekun	350
Transportation	Oja oba	150
	Isinkan market	250

Grinding	1000
Workmanship	1500
TOTAL (TFP)	3250

TFP= Total cost of feed preparation

3.5.3 Cost of feed

Cost of feed is the addition of the cost of fish feed ingredients and the total cost of feed preparation. Table 8 shows the cost of feed.

Table8: Cost of feed

Ingredients	Pearson Square(₦)	ALLIX(₦)	WINFEED(₦)	AQUAFEED(₦)
Fish meal	465.75	439.65	228.90	228.90
Soyabeanmeal	92.40	96.25	130.90	126.28
Groundnut cake	72.60	92.40	68.31	72.27
Yellow maize	63.43	47.20	71.98	71.98
Vegetable Oil	96.00	96.00	96.00	96.00
Vit/Min Premix	50.00	50.00	50.00	50.00
Starch	20.00	20.00	20.00	20.00
TFP	3250.00	3250.00	3250.00	3250.00
TOTAL (CF)	4110.18	4091.50	3916.09	3915.43

TFP= Total cost of feed preparation

CF= Cost of feed

4.DISCUSSION

Crude protein in yellow maize, fishmeal, groundnut cake and soyabean meal agreed with the reports of Ndukwe *et al*., (2015), Shepherd and Jackson (2013), Isikwenu (2011) and Eshun (2012) studies on analytical composition of feed ingredients, the moisture content values of the fish feed ingredients recorded herein align with studies of X, Y, Z above. However, Datti *et al*., (2019) and Ogbemudia *et al*., (2017) recorded slightly lower moisture content in Soyabean meal which is not in agreement with this study SBM moisture content.Percentage crude fibre values recorded in the present study are in agreement with previous literatures. Although, Eshun (2012) and Preston (2012) recorded slightly lower crude fibre values in Soyabean meal and fishmeal respectively.

In Table 3, there was no significant difference (p>0.05) in moisture content with the values ranging from 10.18±0.20 in WINFEED to 12.10±1.64 in AQUAFEED are slightly lower than values (19.49±0.29 - 21.98±0.15) recorded by Olapade and Saboleh (2022). Crude protein values were not significantly different (p>0.05), the values are within the recommended range for African Catfish fingerlings (FAO, 2023).

The crude lipid values were not significantly different (p>0.05), AQUAFEED value (6.89±0.03) is in sync with ranges (6.45%-6.81%) reported by Oyekanmi*et al*., (2013). There was no significant difference (p>0.05) in the percentage crude fibre content of all the feed formulation methods with values ranging from 1.82±0.03 (ALLIX) to 1.99±0.06 (WINFEED). Orire et al., (2013) proximate composition study recorded 1.84% crude fibre content as the optimum value and this aligns with (1.89±0.05) recorded in AQUAFEED formulation method.

As seen above in Table 4, the essential amino acid profile revealed that the feed formulated using Aquafeed compete favourably with other feed formulation methods.Of note, are lysine, leucine, phenylalanine, threonine which are required for physiological activities at early growth stages of *Clarias gariepinus*.

There were no significant differences (p>0.05) in the costs of groundnut cake, vegetable oil, vitamin/mineral premix and starch across the feed formulation methods; However, there were significant differences (p<0.05) in the costs of fishmeal, yellow maize and soyabean meal due to exchange rate fluctuations during the acquisition period;

The highest cost of ingredient (122.88±23.94) was recorded in Pearson square, while the lowest ingredient cost (95.06±14.75) was recorded in AQUAFEED.There were significant differences in the total cost of ingredients across the formulation methods.

In the present study, the highest investment cost (₦4110.18) was recorded in Pearson square, followed by ALLIX while the lowest investment cost (₦3915.43) was recorded in AQUAFEED.

Cost of feed across all treatments were significantly different. Estimated investment cost decreased across different feed formulation methods in the current study probably because of the differences in feed ingredients present.

Fish meal is the most expensive source of protein in this study, however AQUAFEED and WINFEED had the lowest investment cost because fish meal was reduced when compared to Pearson square and ALLIX which had the higher inclusion of fish meal present and thus leading to high investment cost.

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