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Performance of sustainable fish feeds in Benin for *Clarias gariepinus* (Burchell 1822)

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ABSTRACT

Four sustainable feeds were formulated with locally available ingredients of Benin, produced by extrusion, chemically and physically characterized and their performance was explored. Formulated feeds (F1, F2, F3 and F4) and a Control Feed (CF) were fed to *Clarias gariepinus* juveniles for 16 weeks and fish growth parameters were monitored. Nutritional and sensorial qualities of the fresh and smoked fish were evaluated. Formulated feeds had the same levels of protein and carbohydrate contents and were similar to CF in this concern. The fat content of F2, F3 and F4 feeds was lower than that of the CF except for F1, which had similar fat content. All tested feeds had floatability rates exceeding 80%. The mean weight gain of the fish ranged from 168 g to 401 g. The best Feed Conversion Ratio was recorded with CF (1.01) followed by F2 (1.21). The Protein Efficiency Ratio of F2 (2.14) and CF (2.51) did not differ statistically. Fish fed with F2 had the best nutritional profile (protein: 682 g/kg, and fat: 231 g/kg) compared with fish fed on other feed formulas and the CF (protein: 634 g/kg, and fat: 274 g/kg). Smoked fish fed F2 and CF recorded similar acceptability from consumers.

Introduction

Feed remains the most expensive input in fish farming in most sub-Saharan African countries. It constitutes about 75% of the operating costs in aquaculture (Babalola, 2010). Presently, fish farming largely depends on imported feeds (Adéyèmi et al., 2020). One of the strategies to intensify fish farming in the region is to render available inexpensive and nutritive feed. In Benin, fish feed formulation is still in its infant stage. Most of the local attempts to design adequate fish feed failed because of the lack of information and skills.

Recently, Adéyèmi et al. (2020) surveyed various feed ingredients and identified soybean meal, cottonseed meal, brewer's yeast, trash fish and local fishmeal as promising protein sources for fish feed formulation. Soybean meal is by far the most used in animal feed and especially in aquaculture because of its permanent availability, affordable price and particularly good nutritional value with about 440 to 500 g/kg of protein. Its performance in feeding several species of fish is well established. Cottonseed meal (solvent-extracted), a by-product of cottonseed processing, has been used in diets for terrestrial animals for many years. Despite its high nutritional value, cottonseed meal contains gossypol, a polyphenolic compound, which is toxic to fish (Dharmakar et al., 2022), thus limiting its use. Yeast by-products from the brewing industry are natural diet additives that have been shown to positively influence non-specific immune responses as well as the growth (Andrews et al., 2011) of some fish species. In Benin, the brewing industry generates relatively large amounts of by-products like spent yeast, which can be readily recycled and reused. Trash fish are the residues of smoked fry sold in local markets in Benin. Because of their high nutritional quality containing a relatively high level of proteins (679 g/kg) and ash (243 g/kg), they are used by local feed producers in various feed formulas, especially those for fish (Adéyèmi et al., 2020). According to Rawles et al. (2011), combining various animal protein by-products as ingredients might be a way to formulate cost-effective yet highly nutritive fish feed.

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In the current study, predominantly local feed ingredients of Benin were used to formulate affordable fish feeds, produced by extrusion. These were physically and chemically characterized and their performance was explored using *Clarias gariepinus* juvenile, compared with an imported control feed. *Clarias gariepinus* grows fast, has a high market demand (Nurhayati et al., 2020) and is one of the most farmed fish in West Africa (Adéyèmi et al., 2020). It is often smoked and widely used in sauces because of the quality of its meat, which is well appreciated by consumers.

Materials and methods

Feed ingredients

Soybean meal, cottonseed meal, trash fish meal, cassava flour, premixed vitamins and minerals and methionine were purchased at local markets in Abomey-Calavi/Benin. Brewer's yeast slurry was obtained from SOBEBRA, a beer brewing company in Benin. Dried brewer's yeast was obtained by drying the brewer's yeast slurry at 70 °C to a water content of <100 g/kg. The proximate composition of the ingredients used is presented in Table 1.

Experimental feed production

Feed ingredients were used at different levels to formulate (by using the SOLVER function of Excel® spreadsheet software) and produce four floating extruded feeds (Table 2). Ingredients were ground with a hammer mill (1 mm screen aperture) and homogeneously blended using a mixer (MS-DM50A, China). They were pelletized with a locally constructed single-screw extruder (capillary die diameter of 3 mm), dried at 60 °C for 5 h, coated with red palm oil and dried again at 60 °C for 2 h before packaging in polythene bags. Le Gouessant (Le Gouessant Aquaculture, Lamballe-Armor, France) imported fish feed was used as a control.

Feeding trial

Nine hundred healthy juveniles of *C. gariepinus* were procured from a reputable commercial fish farm (TONON Foundation) at Abomey-Calavi (Lat. °N: 6° 26′, Long. °E: 2°21) - Benin. Fish were transported in an open 50-litre container to the experimental site at Porto-Novo (Lat. °N: 6° 29′, Long. °E: 2°36′) - Benin, and allowed to acclimatize for one week during which they were fed with the control feed. Five (05) concrete tanks (5 × 5 × 1.5 m) were used, for four formulated feeds and one for the control. After one week of fish acclimatization, they were starved overnight, weighed (≈ 7.3 g) and randomly dispatched (180 fish per tank). Tanks were supplied with fresh water and feeding was ad-libitum (3 times a day: 8:00, 12:00, and 17:00). The pool water was renewed every two weeks and the experiment continued for 16 weeks.

Measurement of growth parameters

Growth checks were carried out every two weeks by weighing a random sample of ninety (90) fish. This was done early in the morning between seven and ten o'clock to avoid the high ambient temperature during the day. During the trial, the pH was measured using a pH meter (WTW pH 3210); and dissolved oxygen (DO) and water temperature, by using a DO meter (HANNA HI 9146) twice a week (Monday and Friday) at 7 A.M., before feeding. Dead fish were removed and their number was recorded. The daily feed intake was measured per tank. The growth and feed utilization parameters were obtained using standard formulae according to Castel and Tiews (1980).

Measurement of physicochemical properties of feeds and fish

Samples of two different batches of each feed were analyzed in duplicate for their nutrient composition and physical properties. After 16 weeks, fish samples (5 per tank) were randomly collected, crushed, dried at 60 °C for 24 h and ground for analysis in triplicate. Dry matter was determined according to the AOAC (2005) method, and the ash was assessed by incineration at 550 °C for 24 h. Crude lipid content was determined by the Soxhlet method and crude protein by the Kjeldahl method applying a conversion factor of 6.25. Carbohydrate content was calculated by difference, while gross energy was estimated based on 1 g crude protein generating 23.65 kJ, 1 g crude fat generating 40 kJ, and 1 g carbohydrates generating 16.8 kJ. The bulk density and the rehydration rate of extrudates were determined according to Abubakar et al. (2016) and Guillaume et al. (2001), respectively. The percentage of floating extrudates was assessed by filling a cylinder with distilled water. One hundred extrudates were randomly selected and dropped into the water from 5 cm above the water surface. The number of floating extrudates was counted and expressed as a percentage of the total extrudates. The yield of granules was calculated from the total mass of the mixture and the mass of the regular-shaped granules obtained after extrusion. The essential amino acids and fatty acid composition of feeds were estimated based on literature data (National Research Council, 1993; Craig et al., 2017).

Sensorial evaluation of fish

A triangular test followed by a hedonic test was performed with thirty (30) panelists selected at the University of Abomey-Calavi based on their familiarity with smoked catfish. The aim was to, respectively, check whether there was a difference between pairs of smoked fish of different treatments and, in such case, which was preferred. The tests were conducted based on the smoked fish's sensory attributes such as the texture, appearance, taste and flavor. The hedonic test was carried out using the 9-point scale from 'like extremely' to 'dislike extremely'.

Table 1
Chemical composition (g/kg of Dry Matter) of the tested ingredients.

Raw materials	DM	Ash	Proteins	lipids	Fibres	Carbohydrates
Fishmeal (low quality)	890.0	375.2	410.8	78.0	19.4	26.0
Trash fish	945.0	242.7	679.0	88.8	2.2	25.4
Brewer's yeast slurry	125.0	12.0	–	–	–	–
Dried brewer's yeast	947.0	29.9	422.5	16.1	52.4	494.1
Cottonseed meal	880.0	66.7	436.7	14.9	120.0	461.7
Soybean meal	890.0	60.3	453.0	30.7	118.8	406.0
Cassava chip flour	860.0	35.3	16.4	6.5	30.9	80.84

* DM: Dry Matter.

Table 2
Feed formulas (g/kg wet basis).

Ingredients	Formula 1 (F1)	Formula 2 (F2)	Formula 3 (F3)	Formula 4 (F4)
Fishmeal	0	0	0	150
Trash fish	150	130	120	0
Brewer's yeast slurry	310	300	300	0
Dried brewer's yeastr's yeast	0	200	280	600
Soybean meal	35	120	50	0
Cottonseed meal	255	50	0	0
Cassava flour	200	150	200	200
Mineral and vitamins premix*	5	5	5	5
Methionine	2	2	2	2
Red palm oil	43	43	43	43

* Premix composition: iron: 45,000 mg/kg; copper: 5,000 mg/kg; manganese: 60,000 mg/kg; zinc: 70,000 mg/kg; iodine: 1,000 mg/kg; selenium: 400,000 mg/kg; silicic acid: 3,000 mg/kg and calcium: 24.51%.

Assessment of the fish fitness for smoking

Fish from two treatments (F2 and Control) were smoked by three local fish smokers to evaluate the fitness of fish for smoking using Productivity and Rate of moisture removal (drying rate) as criteria. Each smoker received three batches of 3 fish from each of the two treatments. Fish were hot-smoked for approximately 11 h over a gentle fire until they were perfectly dry. The drying rate was measured according to Ichsani and Dyah (2002) and the yield of smoked fish was calculated.

Statistical analysis

All data were expressed as mean ± standard deviation (SD). The effect of various treatments on different parameters was analyzed by one-way analysis of variance (ANOVA) using the Minitab18 computer software (Minitab LLC, Pennsylvania State University). Tukey's multiple range test was used to determine which pairs of the treatment means differed at $p < 0.05$. Tables for probability prepared by Roessler et al. (1948) were used for the analysis of triangular test data.

Results and discussion

Ingredients and feed formula

Most single protein sources cannot completely replace fishmeal. Rawles et al. (2011), suggested combining various protein by-products as a way to formulate cost-effective yet highly nutritious fish feeds. Thus, the objective of our study was to determine the best combination of brewer's yeast, trash fish, soybean meal and cottonseed meal to formulate multi-protein, affordable and nutritious fish feeds. In fact, brewer's yeast has been used in its wet form (slurry) and dried form in two formulas: F2 and F3. However, in F1 and F4 brewers' yeast was used only in wet form and dried form, respectively. The total amounts of brewer's yeast in the formulas were 310 g/kg (F1), 500 g/kg (F2), 580 g/kg (F3) and 600 g/kg (F4). The reason for using the wet form of brewer's yeast was to avoid adding water to the mixture before extrusion. Cottonseed meal was used in F1 to achieve the nutritional requirements of catfish. From F1 to F3, the reduction of the inclusion of trash fish and its total replacement in F4 by fishmeal (410 g/kg of protein, less expensive), is justified by the objective of obtaining a low cost of feed after formulation while adhering to the standard nutrients required for juvenile *Clarias gariepinus*. In the case of F4, we tested brewer's yeast as the only promising protein source. Finally, the reduction of the amount of cassava chips from 200 to 150 g/kg in F2 was necessary for technical reasons; jamming occurred during the extrusion of the mixture with 200 g/kg of cassava chips. The soybean meal amount, initially 70 g/kg in F2, was raised to 120 g/kg to fill the gap of the 50 g/kg caused by the reduction of the amount of cassava chips.

Nutrient composition and functional properties

The proximate composition and functional properties of the formulated feeds are presented in Table 3.

The protein content of the four formulated feeds (F1, F2, F3 and F4) and the control feed (CF) ranged from 368 g/kg DM (F4) to 394 g/kg DM (CF) and were similar ($p > 0.05$). The carbohydrate content varied from 347 g/kg DM (CF) to 414 g/kg DM (F2). The protein values of the feeds were slightly lower than the required value (400 g/kg – 425 g/kg) as reported by Djissou et al. (2016) for *C. gariepinus* juveniles, but met the minimum required value of 38 g/kg reported by Jimoh et al. (2013). Also, several authors had recorded good growth performances in African catfish fed with feeds containing crude protein in the range of 250 g/kg to 380 g/kg (Taufek et al., 2016; Alegbeleye et al., 2012). Ultimately, the utilization of feed protein for growth depends on the quantity, quality as well as digestibility of the proteins (Gascoa et al., 2016). The carbohydrate values of all feeds were slightly higher than 270–380 g/kg (Muin et al., 2013) for a well-performing feed for *C. gariepinus*. Differences in feed ash, fat and gross energy contents were significant. The level of ash was highest in F4 (126 g/kg DM) and lowest in F1 and 2 (≈ 72 g/kg DM). F3 had a similar ash content (107 g/kg DM) compared to the control feed (86 g/kg DM). The highest fat content was recorded in the control feed (74 g/kg DM) and in F1 (67 g/kg DM), while F2 had the lowest fat content (48 g/kg DM). All the fat values recorded were below the fat requirement of juvenile catfish (100–110 g/kg) as reported by Jimoh et al. (2013), although Robinson and Li (1996) had reported that lipid levels in commercial catfish grow-out feeds rarely exceed 50 to 60 g/kg. Concerning the gross energy content, F1, F2 and CF exhibited the highest values (18 to 18.5 kJ/g) and F3 and F4 had the lowest energy content (≈ 17.5 kJ/g).

The calculated Essential Amino Acids (EAA) and Essential Fatty Acids (EFA) contents of the formulated feeds are given in Table 4.

Overall, the EAA content of all formulated feeds satisfied the requirements for adequate growth of *C. gariepinus* except for methionine and lysine. The methionine content of the F4 feed and the lysine content of F1, F2 and F3 feeds were lower than the minimum required value as reported by Alegbeleye et al. (2012) for the catfish species. The level of alpha-linolenic acid (18:3n-3), an important EFA for fish, averaged 1.2 g/kg in all formulated feeds, and was lower than the required values of 10 to 20 g/kg as reported by Robinson and Li (1996) for *C. gariepinus*. The linoleic acid (18:2n-6) was found in all formulated feeds at levels ranging from 6 g/kg to 16 g/kg of feed. The estimated Σn-3/Σn-6 ratios ranged from 0.37 to 0.68 and were relatively lower than the minimum value of 0.88 required for catfish as reported by Ng et al. (2003).

Table 3
Chemical (g/kg on DM basis) and physical properties of the experimental feeds.

Parameters	Formulated Feeds				Control Feed (CF)	p-value
	F1	F2	F3	F4		
Moisture	74.9 ± 13.0[a]	79.1 ± 10.3[a]	80.1 ± 7.40[a]	76.3 ± 17.6[a]	97.8 ± 0.00[a]	0.151
Ash	71.9 ± 21.7[b]	71.7 ± 20.0[b]	107 ± 1.90[ab]	126 ± 24.2[a]	86.4 ± 0.90[ab]	0.004
Protein	382 ± 7.40[a]	387 ± 13.7[a]	367 ± 30.1[a]	368 ± 13.1[a]	394 ± 0.20[a]	0.313
Fat	67.1 ± 2.40[a]	47.9 ± 0.20[c]	58.0 ± 0.80[b]	51.2 ± 5.50[c]	74.5 ± 2.10[a]	0.000
Carbohydrates	404 ± 31.2[a]	414 ± 33.9[a]	386 ± 21.4[a]	378 ± 22.5[a]	347 ± 3.20[a]	0.084
Gross energy (kJ/g)	18.5 ± 0.60[a]	18.0 ± 0.35[ab]	17.5 ± 0.32[bc]	17.1 ± 0.30[c]	18.1 ± 0.04[abc]	0.002
Density (g/L)	540 ± 2.04[b]	559 ± 10.51[a]	544 ± 11.1[ab]	464 ± 4.26[c]	485 ± 7.07[c]	0.000
Rehydration rate (%)	210 ± 4.08[ab]	195 ± 9.13[c]	201 ± 2.50[bc]	216 ± 4.79[a]	192 ± 3.54[c]	0.000
Floatability rate (%)	91.5 ± 2.38[ab]	83.0 ± 9.42[b]	96.5 ± 3.11[a]	92.0 ± 6.06[ab]	100 ± 0.00[a]	0.023
Yield (%)	58.1	60.9	59.5	79.0	na	na
Feed cost ($US/kg)	0.80	0.90	1.00	0.96	1.72	na

Values are means ± SD, n = 4.
[abc] Mean values with in a row having different superscripts are different at $p < 0.05$.
DM: dry matter
na: data not available.
1 $US = 580 FCFA.

Table 4
Estimated essential amino acids and fatty acids of the formulated feeds in comparison to the minimum nutrient requirements of *C. gariepinus*.

Nutrient	Requirement	F1	F2	F3	F4	
Essential Amino Acids (% of Crude Protein)	Arginine	4.3	4.4	3.7	3.1	5.0
	Histidine	1.5	2.4	2.4	2.3	2.1
	Isoleucine	2.6	3.7	4.2	4.2	4.4
	Leucine	3.5	4.8	5.6	5.6	6.9
	Lysine	5.0	2.4	3.8	4.0	7.4
	Methionine	2.3	2.2	1.9	1.8	1.3
	Threonine	2.0	1.5	2.2	2.3	4.4
	Tryptophan	0.5	2.2	2.2	2.2	1.3
	Valine	3.0	3.3	3.9	4.0	5.4
Essential Fatty acids (g/kg of feed)	Alpha-linolenic acid (18:3n-3)	10	1.3	1.2	1.2	1.0
	Linoleic acid (18:2n-6)	–	16.0	9.8	7.1	6.0
	Ratio (Σn-3/Σn-6)	0.88	0.37	0.53	0.68	0.68

Feeds also differed in their density, rehydration and floatability rates (Table 3). Lower density rates were recorded in F4 (464 g/L) and control feed (485 g/L). F2, F3 and CF had lower but similar rehydration rates. Control feed had the highest floatability rate (100%) followed by F3 (96%) and F2 (83%). All these values conferred to the formulated feeds the best physical property (Vijayagopal, 2004; Guillaume et al., 2001).

Water quality and fish growth performance

The water quality parameters were monitored during the experiment. The pH ranged between 7.24 and 7.70, Dissolved Oxygen (DO) from 1.57 mg/L to 2.18 mg/L and temperature from 27.9 °C to 28.2 °C. The pH and temperature showed little variation during the experiment and were within the ranges recommended for the cultivation of *C. gariepinus*, which are 6.5–9 and 26 °C – 30 °C, respectively (Chabi et al., 2015). The DO values in our experimental tanks were lower than the recommended values (3 mg/L – 9 mg/L) probably because the water renewal was only every two weeks or per week (after 2 months) during the feeding trial (Okomoda et al., 2016). However, no sign of disease as a result of poor environmental conditions was observed in any of the treatments throughout the experimentation.

Final mean weight, daily weight gain, Specific Growth Rate (SGR), survival rate and production were all influenced ($p < 0.001$) by the experimental feeds (Table 5). These growth parameter values were close for the CF and F2 formula, and both were better than in the other treatments (F1, F3 and F4). The lowest growth parameter values were recorded in the F1 formula being respectively 175 g, 1.5 g, 2.83% and 46.6 kg/m^3 for final mean weight, daily weight gain, specific growth rate and production. The best growth response, notably the final mean weight (408 g) and SGR (3.59% per day) were obtained in the fish fed with the control feed followed by the fish fed with F2 for which the final mean weight and SGR were 350 g and 3.45% per day, respectively. On a weekly basis, the weight of the fish increased throughout the experiment period with the fish fed the control feed and F2 having the highest weekly weight gain (Fig. 1).

No difference was observed in these parameter values between fish fed with F3 and F4. The differences in growth response observed between feeds are attributable to the feed nutritional composition and the variation in the feed utilization by fish. Feeds were not equally accepted by fish, since the values of feed intake per fish ranged from 153 g (F1) to 382 g (Control), and consequently, the protein intake varied from 58.8 g (F1) to 151 g (Control) throughout the experimentation. Among the formulated feeds, F2 had the highest carbohydrate content and was also the richest source of protein. The Feed Conversion Ratios (FCRs) of F1, F3 and F4 were similar, while the control feed exhibited the best value (1.01) followed by the F2 formula for which FCR was 1.21. However, the conversion ratio recorded for all formulated feeds was in accordance with the range (1.2–1.8) reported by Tacon and Metian (2008) for commercial catfish feed. FCR value of F2 feed was especially similar to that reported by Alofa et al. (2016) (1.17) for *C. gariepinus* fed with Coppens, a reputable commercial feed.

In addition, it was better than 2.31, 2.32 and 2.71 reported by Goda et al. (2007), testing feeds containing 260 g/kg of poultry by-product, 260 g/kg of meat and bone meals and 310 g/kg of soybean meal, respectively. F4 feed exhibited the lowest Protein Effi-

Table 5
Growth performance and feed utilization of *C. gariepinus* fed experimental feeds.

Parameters	Experimental feeds					p-value
	F1	F2	F3	F4	CF	
Initial mean weight (g/fish)	7.33	7.33	7.33	7.33	7.33	
Fish survival rate (%)	65.6 ± 4.19[c]	83.3 ± 1.67[ab]	75.0 ± 2.89[bc]	67.2 ± 11.1[c]	94.4 ± 1.92[a]	0.000
Final mean weight (g/fish)	175 ± 11.4[d]	350 ± 28.5[b]	266 ± 11.5[c]	235 ± 9.29[c]	408 ± 15.2[a]	0.000
Feed intake (g/fish)	154 ± 2.53[d]	344 ± 21.3[b]	284 ± 2.49[c]	256 ± 5.95[c]	382 ± 11.7[a]	0.000
Mean weight gain (g/fish)	168 ± 11.4[d]	342 ± 28.5[b]	259 ± 11.5[c]	228 ± 9.30[c]	401 ± 15.2[a]	0.000
Weight gain (g/day)	1.50 ± 0.10[d]	3.06 ± 0.26[b]	2.31 ± 0.10[c]	2.03 ± 0.08[c]	3.58 ± 0.14[a]	0.000
Specific Growth Rate (%/day)$^{\alpha}$	2.83 ± 0.06[d]	3.45 ± 0.07[b]	3.21 ± 0.04[c]	3.10 ± 0.04[c]	3.59 ± 0.03[a]	0.000
Production (kg/m^3/year)	46.7 ± 5.12[d]	123 ± 12.6[b]	83.4 ± 3.04[c]	65.2 ± 11.3 [cd]	164 ± 7.1[a]	0.000
Feed Conversion Ratio $^{\beta}$	1.44 ± 0.15[ab]	1.21 ± 0.05[bc]	1.48 ± 0.04[ab]	1.73 ± 0.26[a]	1.01 ± 0.01[c]	0.001
Protein intake (g/fish) $^{\mu}$	58.8 ± 0.97[d]	133 ± 8.25[b]	105 ± 0.92[c]	94.1 ± 2.19[c]	151 ± 4.61[a]	0.000
Protein Efficiency Ratio$^{\pi}$	1.83 ± 0.18[bc]	2.14 ± 0.09[ab]	1.84 ± 0.05[bc]	1.60 ± 0.24[c]	2.51 ± 0.03[a]	0.000

[abcd] Mean values within a row having different superscripts are different at $p < 0.05$. $^{\alpha}$ Specific Growth Rate = [(log Wf – log Wi)/days of feeding] × 100; $^{\beta}$ Feed Conversion Ratio = Feed intake (g)/Total fish weight gain (g); $^{\mu}$ Protein intake (g) = (Feed intake (g) × Feed protein content (%))/100; $^{\pi}$ Protein Efficiency Ratio = Fish weight gain (g)/ Protein intake (g).

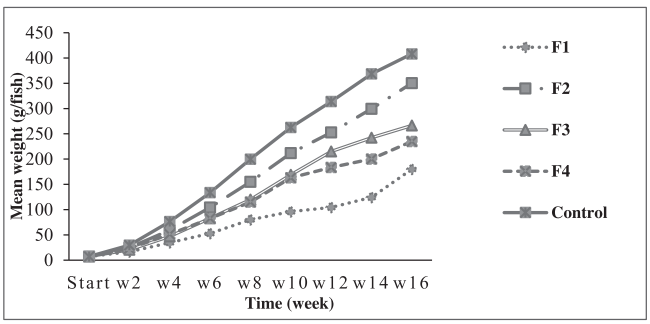

Fig. 1. Comparative weekly weight gain of fish fed experimental feeds.

ciency Ratio (PER) (1.60). The PER of the F2 feed (2.14) and control feed (2.51) were similar. PER recorded for F2 feed was slightly lower than 2.56 reported by Taufek et al. (2016), but higher than 1.67 reported by Adewolu et al. (2010), and 1.70, 1.17, and 1.47 from Goda et al. (2007) performing feed trial on *C. gariepinus***.**

The mortality rate recorded in the experiment ranged from 6% (Control feed) to 34% (F1). The phenomenon of cannibalism (Mukai et al., 2013; Solomon and Okomoda, 2012) and the low dissolved oxygen level recorded during the feeding trial might be the reasons for this mortality. Indeed, fish starts to lose appetite when the dissolved oxygen level is low (Eriegha and Ekokotu, 2017), and this can reduce growth and raise the mortality rate of *C. gariepinus* fingerlings reared in a static system (Okomoda et al., 2016). However, the fish survival rate was the best and similar for the control and F2 feeds, with an average value of 89%. Thus, the high mortality rate recorded could not be specifically attributed to the low dissolved oxygen level since the frequency of water renewal was every two weeks in F2 as well as in the control feed.

Based on the FCR and PER recorded for F1, which were found acceptable, it could be deduced that the low survival rate and poor growth of fish fed with F1 were caused by poor feed intake and should be largely attributed to the feed composition. The F1 formula incorporated up to 255 g/kg of cottonseed meal, which might restrict feed intake by the fish as suggested by Ashiru et al. (2015). Indeed, cottonseed meal contains gossypol and phytic acid (Xu et al., 2022) and its toxicity to fish (Dharmakar et al., 2022) could have led to restriction of feed use. The overall growth performance and high survival rate with F2 suggested that this feed was suitable for fish and met its nutritional requirement. In the F2 feed, cottonseed meal was used in a relatively low quantity (50 g/kg) compared to F1 (255 g/kg). Moreover, the high amount of soybean meal (120 g/kg) in F2 combined with a high level of brewer's yeast (500 g/kg) might have contributed strongly to this performance. The lower weight gains and poor FCR with F4 indicated that using yeast powder as the only source of protein in this feed could not satisfy the protein requirement of *C. gariepinus*.

Overall, the good performances obtained with the F2 formula, suggested that the optimum combination of trash fish meal, brewer's yeast, soybean meal and cottonseed meal as protein sources could generate adequate feed for the breeding of the African catfish as an alternative to imported feeds.

Nutritional quality of fish

Fish whole-body proximate composition at the end of the sixteen-week feeding trial is shown in Table 6. Crude protein ($p = 0.002$) and crude fat ($p < 0.001$) contents were different. Fish fed F2 exhibited the highest crude protein content (682 g/kg DM) compared to the other formulated feeds. The protein content of the fish fed the control feed (634 g/kg DM) was similar to that of fish fed F2. Fish fed F2 had the lowest fat content (231 g/kg DM), while the highest was recorded in fish fed F1 (351 g/kg DM).

The ash contents of the various fish were similar and averaged 129 ± 6 g/kg DM. The protein content of F2-fed fish was higher than reported by Aremu et al. (2013), (599 g/kg); Dada and Olugbemi (2013), (600–620 g/kg) and Soltan et al. (2008), (640 g/kg) on dried fish whole-body of *C. gariepinus*. Furthermore, the fat content of F2-fish was higher than the values of 90 g/kg, 70 g/kg and 132 g/kg reported by Dada and Olugbemi (2013), Sotolu (2009) and Aremu et al. (2013), respectively. Soltan et al. (2008) reported a similar level of fat (210 g/kg) in *C. gariepinus* whole-body.

Fitness for smoking and sensorial quality

The fish fed F2 and fish fed control feed were subjected to the smoking process and evaluated for their sensorial quality. Table 7 shows fish yields and the rate of fluid loss (water and fat) during smoking.

Fish yields and fluid loss were similar for the two types of fishes. However, fish fed F2 dried faster and could be removed from the smoking oven sooner, thus, saving energy. F2-fed fish contained less fat than CF-fed fish. F2 would fit better with the processors' preferences, who prefer faster drying fish to save energy and get a higher dry matter yield of smoked fish. This may increase their profitability in the fish market. From the nutritional point of view, the "lean" low-fat nature of fish is preferable and the potential presence of essential fatty acids in fish can provide additional health benefits for consumers (Carlucci et al., 2014). Therefore, we consider the fish fed F2 desirable.

Table 6
Chemical composition (g/kg Dry Matter) of the whole body of *C. gariepinus* fed experimental feeds.

Nutrient	*C. gariepinus* fed experimental feeds					p-value
	Fish/F1	Fish/F2	Fish/F3	Fish/F4	Fish/CF	
Dry matter	906 ± 6.90[a]	901 ± 11.4[a]	911 ± 7.60[a]	913 ± 9.0[a]	911 ± 2.30[a]	0.411
Protein	530 ± 30.5[c]	682 ± 46.3[a]	589 ± 13.2[bc]	576 ± 19.0[bc]	634 ± 41.2[ab]	0.002
Fat	351 ± 10.8[a]	231 ± 6.50[c]	285 ± 8.40[b]	301 ± 20.5[b]	274 ± 19.4[b]	0.000
Ash	123 ± 11.7[a]	137 ± 18.8[a]	132 ± 7.20[a]	124 ± 18.9[a]	130 ± 4.70[a]	0.689

Values are means ± SD, n = 3; [abc] Mean values within a row having different superscripts are different at $p < 0.05$.

Table 7
Smoking suitability of experimentally produced *C. gariepinus*.

Parameters	Smoked-dried fish		p-value
	Fish/F2	Fish/CF	
Total time of smoking (h)	11.1	11.1	–
Initial mass (kg)	1.32 ± 0.25[a]	1.81 ± 0.37[a]	0.135
Final mass (kg)	0.390 ± 0.09[a]	0.579 ± 0.13[a]	0.109
Drying rate (kg/h)	0.084 ± 0,01[a]	0.111 ± 0,02[a]	0.142
Yield of smoked fish (%)	29.3 ± 2.77[a]	32.0 ± 3.43[a]	0.347

Values are means ± SD, n = 3. Mean values within a row having the same superscript ([a]) are not different ($p > 0.05$). Drying rate = (Initial mass- Final mass)/(Total time of smoking). Yield of smoked fish = [(Final mass/Initial mass) × 100].

Table 8
Sensory quality of fish.

Tests (n = 30)	Fish/F2	Fish/CF	p-value
Global acceptability (*Appearance, texture, flavor/savor)*	6.60[a]	7.03[a]	0.301
Triangular Test (*Good response*)	19/30		0.001

[a] Mean values in the same row and with the same superscript are not different ($p > 0.05$).

The sensory qualities of smoked catfish are shown in Table 8. Panelists' acceptability for both F2 and CF smoked fish was similar ($p = 0.301$), and the fishes were liked moderately (≈7.00). However, the triangular test on both types of smoked fish indicated that the fishes were different in terms of texture with fish fed F2 being drier than the other.

Conclusion

The study showed that the formulated F2 feed, based on the combination of the fish waste meal, brewer's yeast, soybean meal and cottonseed meal as protein sources, can be a good substitute for imported feeds for African catfish feeding. From a nutritional point of view, F2 increased the level of protein and decreased the level of fat in *C. gariepinus*. This study demonstrated that it is possible to produce affordable feed with adequate floatability for catfish breeding in developing countries by using locally available feed ingredients. Further studies will be required to increase the appeal of the feed to increase its consumption.

Ethical clearance

All applicable international, national, and/or institutional guidelines for the care and the use of animals were followed.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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