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Screening local feed ingredients of Benin, West Africa, for fish feed formulation

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ABSTRACT

The cost of fish feed is a major constraint to fish farming in Sub-Sahara Africa. In the aquaculture value chain, feed is a determining factor and accounts for 60-75% of the total cost of fish production in many African countries. Therefore, 284 actors from all eight agro-ecological areas of Benin were interviewed and 28 local feed ingredients were collected as alternative ingredients for new fish feed formulations for, predominantly, *Clarias gariepinus and Tilapia niloticus*. Three categories of feeds were used, namely imported (84% of farmers), locally produced to complement imported feeds (76%) and natural ingredients (81%). The main imported feeds were from the Netherlands (59% of farmers), Ghana (52%) and France (15%). Natural ingredients were mostly *Moringa* leaves (52%), cassava leaves (26%) and maggots (43%). The best available ingredients were cereal bran, soybean meal, cottonseed meal, cassava chips, palm kernel cake, soybean and maize. Regarding proteins, the most promising ingredients were trash fish (680 g/kg), poultry viscera (590 g/kg), soybean meal (450 g/kg) and cottonseed meal (410 g/kg). Oyster shell had the highest ash content (960 g/kg), followed by whole garden snail meal (700 g/kg). The highest carbohydrate contents were for tapioca (890 g/kg), lafun (880 g/kg) and cassava chips (810 g/kg). Overall, this study revealed a diversity of local feed ingredients available in Benin to formulate fish feeds with adequate nutritional composition to enable efficient fish farming.

1. Introduction

The fisheries sector contributes significantly to the nutrition of millions of people around the world (Datta, 2011). In 2015 Fish and other aquatic products accounted for about 26 % of the animal proteins consumed in least developed countries against 11 % for developed countries (FAO, 2018). In Benin, fish provided about 38 % of animal protein intake in 2016 (FAO, 2019). Since fish is a source of proteins in the diet of poor-resource populations, further development of this sector could contribute to reducing food insecurity in developing countries.

In 2016, Aquaculture provided about 47 % of fish on the world market with Asia contributing about 89 % of global aquaculture production during the last 20 years. The contribution of Africa remains minor with 2.5 % in general and 0.9 % for low-income food-deficient countries in this period (FAO, 2018) despite its natural potential. Thus, there is a wide gap between fish demand and supply in developing countries. Indeed, in most African countries, local fish production remains marginal with low yields. The two major reasons identified are lack of adequate affordable fish feed and the poor availability of fingerlings of good quality (Sodjinou et al., 2016). Feeds play a key role in the development of fish farming. The major constraint to the emergence of aquaculture in developing countries is feed quality and its cost (Siddhuraju and Becker, 2003). For example, fish feed accounts for 60–75 % of the total cost of fish production in many African countries such as Nigeria (Babalola, 2010). The high cost of feed is due to the high cost of fishmeal, the main ingredient in the formulation of commercial feeds (Ye et al., 2011).

Fish require a high quality and nutritionally balanced diet for adequate growth within the shortest time. Therefore, local production of fish feed using locally available ingredients at low cost is crucial to the development and sustainability of aquaculture in Africa, especially in the rural areas. Affordable quality feed will make fish farming attractive to private investors and boost fish production. In evaluating ingredients

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for use in the aquaculture sector, several aspects merit attention. The ingredient availability, its accessibility and nutrient composition are of prime importance. Bhilave et al. (2012) indicated that the basic nutrient that cannot be compromised on in the choice of ingredients for feed formulation and production is protein. The present study screened local potential fish feed ingredients available in Benin for their nutritional quality, their availability and cost. The aim is to provide information that can help in incorporating any of these ingredients in the local production of formulated fish feed.

2. Materials and methods

2.1. Rapid appraisal investigation

A rapid appraisal investigation was conducted in three localities of Benin with a rich tradition in fish farming, namely Ouidah and Porto-Novo in the south and Parakou in the north. The aim was to identify the current understanding of fish farming and fish feeding practices. The appraisal was carried out by focus group discussions with 30 actors from different categories, i.e. farmers (10), feed retailers (10), and feed processors (10). The topics discussed related to fish feed, local ingredients and processing methods. The information was collected with a tape recorder. The results were used to design a questionnaire for a follow-up quantitative survey.

2.2. Study area and respondents

Respondents were sampled from a group of 1165 fish farmers previously involved in the Benin project for continental aquaculture extension, PROVAC-1 (MAEP, 2014), which was implemented in Benin during the period 2010–2014 and aimed to promote aquaculture in the country. Respondents were distributed over the eight agro-ecological zones of Benin. The following formula was used to determine the adequate number of respondents to be interviewed per agro-ecological area: $N_i = 4P_i\ (1\text{-}P_i)/d^2$, where ***Ni*** is the total number of fish farmers to be surveyed in agro-ecological area ***i***; ***Pi***, the proportion of fish farmers found in the agro-ecological area ***i***, and ***d*** the expected margin error, which was fixed at 0.1 (Dagnelie, 1998). Based on this formula, actors were randomly selected in each of the eight agro-ecological areas of Benin, as follows: 3 actors were selected in area I, 2 in area II, 8 in area III, 6 in area IV, 18 in area V, 100 in area VI, 26 in area VII and 91 in area VIII, giving a total of 254 respondents. In addition, two types of other actors, i.e. 19 animal feed-sellers and 11 by-products suppliers, were interviewed to assess price and availability of ingredients.

2.3. Data collection

Surveys were conducted in June 2017 with fish farmers and fish feed producers. Information was collected using questionnaires developed for each type of actor and tested prior to the survey. The questionnaires included the following aspects: principal and secondary activities, experience in fish farming (year and educational background), fish species bred, type and form of fish feeds used, origin of fish feeds (local or imported), price of fish feeds, and the quality perception of diverse feeds/ingredients. The questionnaire for fish feed producers included the following additional aspects: ingredients used to produce fish feed, ingredients inducing floatability, price and availability of ingredients.

2.4. Sampling of ingredients and proximate composition analysis

Ingredients cited by farmers during the survey were collected for proximate analysis. Samples of each ingredient were collected in triplicate in three different areas either from the feed retailer shops or from industries as by-products or from fish feed producers. Moist samples like trash fish, leaves, garden snail, poultry viscera, brewers' yeast and Azolla were dried in an oven at 60 °C for 24 h, ground and kept in a freezer at −20 °C prior to analysis. Samples were analysed for dry matter, ash, crude lipid, crude proteins, crude fibre and total carbohydrates. Total ash, dry matter and fibre were determined according to AOAC (2000) methods. Crude protein and crude lipid contents were determined respectively by the Kjeldahl method and Soxhlet method. Total carbohydrate was calculated by subtracting crude protein, crude lipid and total ash from dry matter.

2.5. Statistical analysis

Sphinx Plus[2] software (Le Sphinx Développement, 74,650 Chavanod, France) was used to process the survey data. Microsoft EXCEL was used for descriptive statistics, generating averages with standard deviations. The mean values were compared using ANOVA (one way) followed by the Tukey's post-hoc test to generate homogenous subsets. Means were considered significant at $p < 0.05$. Principal Component Analysis (PCA) was performed to cluster the various ingredients on the basis of their proximate composition, availability and price using the statistical program Minitab 18 (Minitab LLC, Pennsylvania, USA).

3. Results and discussion

3.1. Socio-cultural characteristics of fish farmers in Benin

Fish farming in Benin is mainly carried out by men (92 %) aged between 22 and 72 years. The socio-cultural characteristics of fish farmers in Benin are presented in Table 1. Sixty percent of the respondents were 40 years and above. None of the actors was younger than 20 years. Young people may find it difficult to start fish farming activities because of the financial investment associated with this activity, particularly concerning the feed cost, which accounts for 60–75 % of the total cost of production (Babalola, 2010). Thus, young people without a substantial income and without bank support are not able to engage in such activity.

The majority of Beninese fish farmers are educated (83 %), 63 % percent has a high school level and 22 % a bachelor degree. Most fish farmers are retired persons from the public sector. Although the high

Table 1
Socio-cultural characteristics of fish farmers in Benin.

Variables	Modalities	Freq. %[a], (N = 254)
	20 < years old ≤ 40	31.1
	40 < years old < 60	40.0
	≥ 60 years old	12.2
Religion	Christian	60.2
	Muslim	12.6
	Animist	11.0
Level of education	Illiterate	15.3
	Primary	19.7
	Secondary	40.9
	University	22.0
Main activity	*Fish farming*	30.3
	Agriculture	29.1
	Public servant	11.0
	Commerce	09.8
Experience in *fish farming*	*< 2 years*	05.5
	2 ≤ years < 5	21.6
	5 ≤ year < 10	43.7
	≥ 10 years	29.1
Received training *in fish farming*	*Yes*	80.3
	No	19.7
Member of fish farming association	*Yes*	76.0
	No	24.0

[a] The sum of some percentages does not reach 100 because of the recorded non- responses.

level of education of the actors is an important asset, their advanced age may be a factor limiting further emergence of the sector. Only 30 % of the stakeholders interviewed are exclusively fish farmers. The other 70 % practice fish farming as a secondary activity. They are crop farmers (29 %), civil servants (11 %) and traders (10 %). Our results are in line with findings by Sodjinou et al. (2016) who reported that 18 % of fish farmers in Benin practice it as their main activity. This situation may be explained by the fact that the activity alone does not provide significant income to the stakeholders. In this respect, protein is the main factor that determines the high market price of fish feed (Shepherd and Jackson, 2013). This is partly due to the fact that some of the fish feed ingredients, especially fishmeal, compete with human consumption. Thus, alternative cheap sources of protein are needed to overcome the high cost of fish feed.

Currently, actors in the fish farming sector in Benin have several assets. First, 73 % have more than 5 years of experience in fish farming. Also, 80 % have been trained in fish farming and fish feed processing. They benefit from training provided by diverse projects and government organizations such as Vulgarization of Continental Aquaculture Project (41 % of respondents), Songhaï(12 %), Agricultural Productivity and Diversification Project (11 %), Regional agricultural centre for rural development (6%) and Bornefonden (6%). Finally, our survey revealed that 76 % of the respondents are members of fish farming associations, especially the Beninese Federation of Fish Farmers (24 % of the respondents), municipality or departmental associations (31 %) and cooperatives (19 %).

3.2. Quality of fish feeds used in Benin and actors' perception

Clarias gariepinus and *Tilapia niloticus* are the two main fish species farmed in Benin, farmed by 92 % and 89 % of the respondents, respectively. This finding confirms the results by Sodjinou et al. (2016), who reported that more than 77 % of fish farmers in Benin grow these two species.

Feeds used in fish farming in Benin are presented in Table 2. The majority of the farmers (84 %) stated that they use imported feeds. Local feeds (i.e. mixtures of ingredients or manufactured pellets) are used by 76 % of the farmers to complement imported feeds, thereby reducing the feeding costs. However, 22 % of the farmers exclusively use imported feeds while 13 % solely use local feeds. The most used imported feeds are from three companies, located in the Netherlands (59 %), Ghana (52 %) and France (15 %).

About 75 % of fish farmers declared that fish grows fast when fed with imported feeds while only 9.5 % give such an opinion for local feeds. Indeed, according to the stakeholders surveyed, to obtain 01 kg of African catfish, it takes an average of five months when using the imported feeds against ten months for local feeds. This is the main reason for the adoption of imported feeds by the majority of fish farmers despite of their high price (1.72 US/kg on average). The other reasons for not using local feeds, especially at the fingerling stage, are diverse. The stakeholders listed the high nutritional requirements of fish at the fingerling stage and the weak assimilation of the local granules by the fingerlings due to their small size. In addition, the inefficiency of local feeds in initiating significant growth was mentioned.

Apart from imported and locally manufactured feeds, fish farmers (81 %) use other ingredients as supplements to feed the fish. These include *Moringa oleifera* leaves (52 %), maggots (43 %), animal viscera (37 %), food left-overs (27 %), leaves of cassava (*Manihot esculenta*) (26 %), leaves of papaya (*Carica papaya*) (19 %) and poultry droppings (19 %), which are used as manure. Indeed, poultry manure is an efficient nitrogen source for plankton productivity, and this has prompted its use as a fertilizer in both intensive and semi-intensive aquaculture (Ocio and Vanaras, 1979). Also, fly larvae (maggots) produced during the decomposition of poultry manure provide feed for fish (Ruman and Singh, 1984) and are a rich source of protein and minerals (Aniebo et al., 2008). The supplement feeds are usually collected in the wild.

3.3. Current ingredients used in the local fish feed formulations in Benin

Table 3 presents the ingredients in the local fish feed formulations in Benin according to their origin, mode of procurement, cost and availability. There is a great diversity in local products and by-products used by producers in formulating fish feed in Benin. Ingredients are either of animal, plant or microbial origin. Ingredients of plant origin include maize grain, soybean grain, bran (from rice, maize, wheat and soybean), cottonseed meal, soybean meal, various leaves (*Moringa oleifera*, *Ceiba pentandra*, *Azolla* spp.), cassava flour (lafun, cassava chips, tapioca), and oil (palm fruit oil, palm kernel oil). Ingredients of animal origin include fishmeal, trash fish (waste of smoked/dried small fish), blood meal, poultry viscera and whole garden snails. From our investigation, it appears that fishmeals are used most (76 % of respondents) among the ingredients of animal origin. They are sufficiently available in Benin but vary greatly in terms of quality. These fish meals are imported from Senegal, Mauritania and Morocco and cost about 0.59 US$/kg. Trash fish ranked second in terms of use by farmers (42 % of respondents). The shortcoming of this ingredient is that it is

Table 2
Characteristics and actors' perception of various fish feeds used in Benin.

Feed type	Name/origin	Frequency of use (%, N = 254)	Cost (US $/Kg)	Protein content (g/kg)[a]	Perceived efficacy by farmers in terms of fish growing *(% of respondents, N = 254)* [b]		
					fast	*average*	*slow*
Locally produced fish feeds	Coarse flour	26.0	0.62 ± 0.20	nd	9.5	53.2	10.6
	Pellet	58.7	0.89 ± 0.34	nd			
	Manual granulated feed	0.8	nd	nd			
Imported fish feeds; from:	Netherlands	59.5	1.93 ± 0.20	420/450	74.8	10.6	0.4
	Ghana	52.4	1.71 ± 0.13	450			
	France	14.6	1.72 ± 0.12	420			
	Nigeria 1	9.5	1.71 ± 0.13	380			
	Nigeria 2	5.1	1.54 ± 0.15	–			
	Morocco	4.7	1.68 ± 0.19	450			
	Nigeria 3	4.3	1.74 ± 0.09	350			
	Danemark	3.5	1.67 ± 0.11	450			
	Mexico	3.2	1.71 ± 0.12	440			

1US$ = 580 Fcfa.
nd: not determined.
[a] Feed (3 mm) for juvenile *Clarias gariepinus*.
[b] The sum of some percentages does not reach 100 because of the recorded non- responses.

Table 3
Various fish feed ingredients available in Benin: their use, mode of procurement, availability and cost.

Ingredient	Frequency of use (%, N = 94)	Mode of procurement (%)			Place of procurement (%)			Availability	Cost (US $/kg)
		produced	bought	collected (free)	Animal feed shop	Open market	Private person	Ton/month	
Animal sources									
Fishmeal	76.6	0	100	0	91.7	01.4	05.6	8	0.59 ± 0.20
Trash fish	40.4	0	100	0	10.5	89.5	7.9	–	0.98 ± 0.56
Oyster shell	31.9	0	100	0	83.3	6.7	3.3	109	0.26 ± 0.23
Poultry viscera	18.1	41.2	47.1	5.9	0	29.4	11.7	–	0.37 ± 0.46
Earthworm	10.6	40	10	60	0	0	10	–	8.62 ± 0.00
Snail shell	3.2	33.3	66.7	0	33.3	33.3	0	–	0.07 ± 0.07
Blood meal	2.1	0	100	0	0	0	100	–	0.69 ± 0.00
Garden snail (*Limicolaria aurora)*	2.1	0	100	0	0	50	50	–	0.99 ± 1.04
Plant sources									
Palm oil	75.5	14.1	91.6	0	0	87.3	05.6	0.5	1.23 ± 0.22
Rice bran	72.3	4.4	95.6	1.5	80.9	2.9	14.7	14	0.18 ± 0.09
Soybean meal	62.8	0	98.3	0	88.1	5.1	5.1	6	0.67 ± 0.13
Wheat bran	61.7	0	100	0	96.6	1.72	3.5	5	0.27 ± 0.10
Cottonseed meal	56.4	0	100	0	94.3	1.89	3.8	11	0.39 ± 0.13
Maize bran	55.3	1.9	98.1	1.9	80.8	5.77	7.7	11	0.29 ± 0.09
Cassava ship flour	52.1	30.6	75.5	0	10.2	57.1	8.2	5	0.38 ± 0.21
Soyabean flour	49.0	13.0	89.1	0	37.0	63.0	0	5	0.61 ± 0.14
Maize flour	36.2	20.6	85.3	0	26. 5	64.7	0	11	0.37 ± 0.08
Moringa leaf	35.1	87.9	9.1	3.0	0	0	3.0[b]	–	1.49 ± 0.40
Peduncle of maize ear	33.0	32.3	35.5	32.3	0	3.2	32.3	–	0.05 ± 0.07
Palm kernel cake	29.8	0	100	0	78.6	10.7	14.3	24	0.28 ± 0.12
Soyabean bran	27.7	0	100	0	15.4	26.9	42.3	–	0.36 ± 0.29
Maize bran (Ogi processing waste)	19.2	16.7	66. 7	16.7	0	05.6	50	–	0.13 ± 0.07
Mud of palm oil	18.1	47. 1	41.2	23.5	0	11.8	17.7	–	0.34 ± 0.30
Azolla leaf	16. 0	86.7	13.3	0	0	0	6.7	–	0.52 ± 0.00
Brewer's spent grain	11.7	0	100	0	0	0	90.9	1	0.27 ± 0.06
Kapok-tree leaf	7.5	100	0	28.6[a]	0	0	0	–	00 ± 00
Cotton seed	4.3	0	100	0	75.0	0	25.0	–	0.33 ± 0.00
Peanut cake	3. 2	33.3	66.7	0	33.3	0	0	–	0.34 ± 0.00
Tapioca	2.1	0	100	0	0	100	0	1	0.52 ± 0.00
Spent wheat flour	2.1	0	100	0	100	0	0	–	0.17 ± 0.13
Palm kernel oil	2.1	0	100	0	0	100	50	–	0.71 ± 0.82
Brewer's spent grain (Tchoukoutou beer)	1.2	100	0	0	0	0	0	–	0.09 ± 0.00
Supplements									
Premix	37.2	0	100	0	91.4	5.7	0	0.5	2.59 ± 0.00
Lysine	36.2	0	100	0	91.2	2.9	2.9	0.5	4.71 ± 0.00
Methionine	33.0	0	100	0	90.3	3.2	3.2	0.5	6.90 ± 0.00
Salt	18.1	0	100	0	0	94.1	0	10	0.50 ± 0.20
Complex of Minerals and Vitamins (CMV)	8.5	0	100	0	100	0	0	–	3.90 ± 0.00

–: Availability < 0.1 ton/month.
[a] The sum of some percentages exceeds 100 because several answers were possible.
[b] The sum of certain percentages does not reach 100 because of non-responses among the respondents.

not sufficiently available. It is found in the local markets as a by-product of fish sellers. It is a mixture of heads and other fish waste. Poultry viscera are scarce but are the third most commonly used animal-based ingredient (18 % of respondents). With respect to the plant-based ingredients, palm oil, rice bran, soybean meal, wheat bran, cottonseed meal, corn bran, and cassava chips are the most commonly used as mentioned by more than 50 % of respondents. According to the stakeholders, ingredients such as rice bran, peduncles of maize ears, wheat bran, palm oil and mud of palm oil would be able to confer good floatability to fish feed. The listed ingredients listed are obtained from farmers' own production, bought or collected in the wild.

3.4. Nutrient composition of fish feed ingredients in Benin

The nutrient composition of the collected fish feed ingredients is presented in Table 4. The protein content of the ingredients ranged from 1.2 g/kg DM for tapioca, a cassava derived starch, to 788 g/kg DM for fishmeal from Denmark. The fat content varied from 2.0 g/kg DM for lafun, a dried cassava chip, to 282 g/kg DM for poultry viscera. The oyster shell recorded the highest ash content (955 g/kg DM) followed by whole garden snail meal (698 g/kg DM) and Senegal fishmeal (459 g/kg DM). The lowest ash value was recorded for lafun (3.0 g/kg DM). The carbohydrate content of the ingredients varied from 0.0 g/kg DM for Danish fishmeal to 893 g/kg DM for tapioca. The highest fibre content was for rice bran (248 g/kg DM) while the wheat flour had the lowest fibre content (0.2 g/kg DM).

Fishmeal is the main ingredient in the formulation of commercial feeds (Ye et al., 2011); it constitutes a substantial part of feeds formulated for diverse fish species that are commercially cultivated globally owing to its palatability and high nutritive value (Alceste and Jory, 2000). To assess the quality of the fishmeal sold in Benin, we collected samples from seven market points throughout the country and analysed them for proteins, fat and ash contents (Table 5). There is a great variability in the nutritional quality of the fishmeal with a coefficient of variation of 29.6 %, 55.5 % and 24.8 % for proteins, fat and ash, respectively. Overall, the marketed fishmeal in Benin is poor in

Table 4
Proximate composition (g/kg DM) of available fish feed ingredients in Benin.

Ingredients	Ingredients Code	Dry matter	Ash	Proteins	Fat	Fibre	Carbohydrate
Protein source							
Fishmeal Senegal	1	910.6 ± 29.3	458.8 ± 113.5	290.5 ± 85.8	77.2 ± 42.9	16.6 ± 7.6	84.1 ± 30.8
Fishmeal Danmark	2	854.6 ± 1.6	219.8 ± 2.6	788 ± 1.1	17.7 ± 0.4	7.3 ± 3.3	0.0
Trash fish	3	944.5 ± 3.4	242.7 ± 8.7	678.9 ± 7.8	78.8 ± 2.2	2.2 ± 5.4	0.0
Poultry viscera	5	837.3 ± 6.3	66.4 ± 1.0	586.0 ± 10.3	281.5 ± 6.5	5.5 ± 0.3	0.0
Dried brewer's yeast	7	735.8 ± 0.1	4.0 ± 0.4	515.1 ± 11.1	7.8 ± 0.0	1.7 ± 0.2	208.9 ± 11.8
Soybean flour	13	895.3 ± 19.0	53.1 ± 4.5	421.6 ± 10.6	108.6 ± 47.3	144.9 ± 15.3	312 ± 16.8
Industrial Soybean meal	15	894.9 ± 14.0	60.3 ± 5.6	447.1 ± 54.9	30.7 ± 40.1	118.8 ± 85.9	356.8 ± 66.2
Cottonseed meal	16	883.9 ± 17.2	66.7 ± 3.4	405.9 ± 23.9	14.9 ± 14.4	120.0 ± 1.6	396.4 ± 15.9
Cottonseed pellet	17	899.9 ± 4.8	66.7 ± 0.2	409.7 ± 07.7	32.1 ± 1.0	121.1 ± 9.2	391.4 ± 0.2
Moringa oleifera leaves meal	23	905.4 ± 0.2	83.3 ± 0.3	308.6 ± 3.2	44.6 ± 1.0	163.5 ± 5.6	468.9 ± 2.3
Mineral source							
Whole garden snail	4	970.6 ± 5.4	698.0 ± 75.1	171.3 ± 15.4	37.3 ± 17.6	3.2 ± 0.7	64 ± 41.5
Oyster shell	6	999.0 ± 16.9	955.1 ± 21.5	12.2 ± 0.7	0.6 ± 0.4	22.6 ± 3.4	31.1 ± 9.5
Carbohydrates source							
Wheat bran	8	881.8 ± 6.0	42.6 ± 2.4	15.6 ± 9.2	20.1 ± 2.8	71.5 ± 11.6	662.8 ± 18.7
Artisanal rice bran	9	905.3 ± 11.0	190.4 ± 54.6	73.9 ± 29.3	56.0 ± 47.4	247.9 ± 67.2	585 ± 63.6
Industrial rice bran	10	879.1 ± 9.0	76.2 ± 15.7	114.8 ± 9.8	108.9 ± 19.1	76.6 ± 43.4	579.2 ± 32.7
Artisanal maize bran	11	878.6 ± 13.5	26.8 ± 12.2	126.0 ± 12.3	83.4 ± 30.1	72.7 ± 4.1	642.4 ± 31.0
Industrial maize bran	12	858.5 ± 6.3	33.0 ± 0.0	120.4 ± 0.9	88.4 ± 1.1	71.2 ± 1.6	616.7 ± 6.1
Local soybean bran	14	904.8 ± 0.4	68.5 ± 17.8	245.5 ± 15.9	51.7 ± 1.4	150.1 ± 12.7	539.1 ± 9.4
Palm kernel Cake	18	915.4 ± 8.2	50.4 ± 10.2	165.5 ± 27.9	118.2 ± 38.6	125.3 ± 36.4	581.3 ± 34.9
Local brewer's spent grain	19	870.2 ± 0.2	123.9 ± 3.0	295.4 ± 0.4	47.8 ± 0.3	87.9 ± 4.4	403.1 ± 3.1
Industrial brewer's spent grain	20	869.1 ± 2.7	43.1 ± 8.7	273.2 ± 2.1	93.0 ± 3.9	162.5 ± 6	459.8 ± 6.7
Ceiba leaves meal	21	889.8 ± 0.5	97.5 ± 0.6	216.3 ± 4.3	25.0 ± 1.7	158.5 ± 0.8	551 ± 4.5
Azolla leaves meal	22	844.2 ± 2.3	137.7 ± 1.3	221.6 ± 1.1	11.9 ± 0.4	190.8 ± 3.0	473 ± 0.0
Cassava ships flour	24	864.8 ± 3.8	35.3 ± 0.1	14.6 ± 0.3	6.5 ± 3.6	30.9 ± 5.2	808.4 ± 3.6
Wheat flour	25	877.7 ± 0.9	6.5 ± 0.0	127.5 ± 5.4	10.6 ± 0.2	0.2 ± 0.0	733.1 ± 5.2
Tapioca	26	903.6 ± 0.1	6.5 ± 0.1	1.2 ± 0.3	2.7 ± 1.8	21.2 ± 7.4	893.2 ± 4.5
Lafun	27	896.6 ± 0.08	3.0 ± 0.5	13.9 ± 4.8	2.0 ± 1.4	31.1 ± 3.4	877.7 ± 6.2
Maize flour	28	882 ± 19.0	18.4 ± 0.5	89.1 ± 5.8	35.4 ± 3.3	56.2 ± 67.3	739.1 ± 69.2

Values are Means ± SD. Measurements are done in triplicate for each parameter.

Table 5
Nutritional composition (g/kg DM) of imported fishmeal commercialized in Benin.

Origin (Locality in Benin)	Ash	Fat	Proteins
Parakou	516.0 ± 6.3^{c}	81.2 ± 4.1^{b}	235.0 ± 7.3^{d}
Dogbo	359.7 ± 4.8^{e}	119.5 ± 0.5^{a}	350.3 ± 4.2^{bc}
Bohicon	355.4 ± 13.2^{e}	105.1 ± 1.6^{a}	339.0 ± 3.5^{c}
Pobè	633.7 ± 5.6^{a}	32.0 ± 7.2^{c}	174.0 ± 5.8^{f}
Tori-bossito	380.1 ± 0.5^{de}	116.8 ± 3.2^{a}	374.6 ± 5.6^{a}
Dangbo	571.8 ± 1.5^{b}	7.8 ± 0.0^{d}	195.6 ± 3.2^{e}
Abomey-Calavi	395.2 ± 6.0^{d}	78.0 ± 5.1^{b}	365.1 ± 1.5^{ab}
Average	458.8	70.5	290.5
Coefficient of variation (%)	24.75	55.49	29.55

Values are Mean ± SD. Means within a given column with different superscript letters are significantly different ($p < 0.05$).

proteins (main value 291 g/kg DM) but high in ash content (main value 459 g/kg DM). These results seem to indicate that these products are not derived from whole fish and might be mixed with other products. According to Guillaume et al. (1999), meals derived from whole fish are similar in chemical composition, i.e. 660 − 710 g/kg DM protein, 90 − 120 g/kg DM lipids and 120 − 150 g/kg DM ash. In the present study, we found ingredients such as Danish fishmeal (788 g/kg DM protein) and trash fish (679 g/kg DM protein) with nutritional characteristics in agreement with Guillaume et al. (1999). Our findings for the nutritional characteristics of fishmeal from trash fish are in line with data reported by Sotolu (2009) for this type of ingredient, namely protein: 616 g/kg DM, lipid: 96 g/kg DM, and ash: 224 g/kg DM.

The protein and ash contents found for poultry viscera in this study are of the same magnitude as data reported by Usman et al. (2007), even though the lipid content is higher than the 162 g/kg DM reported by the authors. The crude protein content (515 g/kg DM) found for the dried brewer's yeast meal in this work is higher than 438 g/kg DM reported by Hertrampf and Piedad-Pascual (2000) while the lipid value (8.0 g/kg DM) is in agreement with the data reported by these authors. The crude protein content recorded for *Moringa* leaf of 309 g/kg g DM is lower than the 438 g/kg DM reported by Kakengi et al., 2007), whereas the fibre and lipid contents of this product are similar for both studies. The proximate composition of cottonseed and soybean meals, two industrial by-products, is in line with the work of Toko et al. (2008) with the exception that their lipid levels are lower (15 and 31 g/kg DM, respectively, against 70 and 111 g/kg DM). These low lipid values could be due to the oil extraction techniques used. The agronomic environment as well as the seed varieties might be other determinants. Indeed, leaves are abundant in the tropics, growing freely without cultivation. All contain diverse levels of protein, which can produce an inexpensive source of nutrients for fish. Hence, the above described plant products with interesting nutritional value are cheap potential ingredients for fish feed formulation.

3.5. Clustering ingredients on the basis of their nutritional quality, cost and availability

Principal Component Analysis (PCA) performed on the generated data allowed grouping the ingredients on the basis of their protein, ash, fat, fibre and carbohydrate contents as well as their availability and cost. The 28 fish feed ingredients are positioned in Fig. 1 as a function of the two first components, which accounted for 56.7 % of the total variance in the initial data. In interpreting the rotated component pattern, we considered a parameter as a good contributor to the variation in the dataset when its component loading was greater than 0.3 (Table 6 and Fig. 1). Therefore, protein content and cost contribute positively with component 1, whereas carbohydrate content and availability related negatively with this component. Fibre and lipid

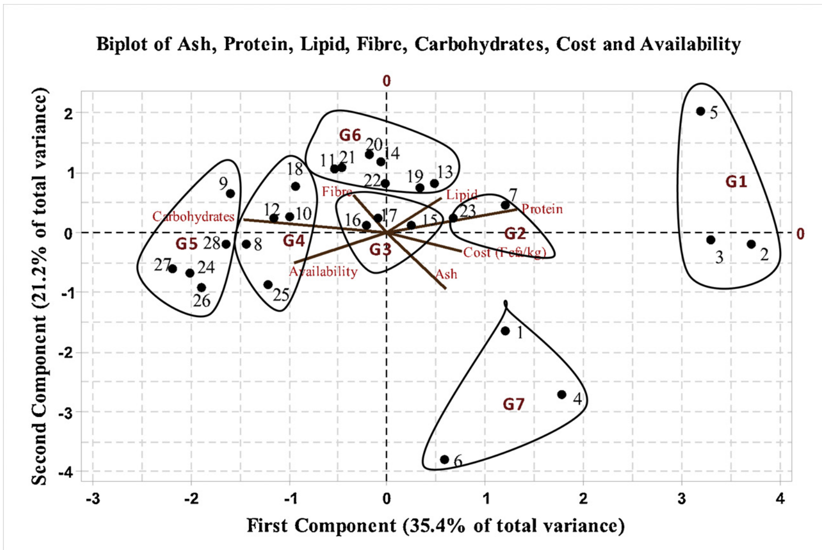

Fig. 1. PCA clustering of ingredients based on their nutritional quality, cost and availability.

Table 6
Pattern matrix.

Variables	Principal components	
	Component 1	Component 2
Ash	+ 0.243	−0.631[^]
Protein	+ 0.536[^]	+ 0.269
Lipid	+ 0.228	+ 0.40[^]
Fibre	−0.134	+ 0.424[^]
Carbohydrates	−0.588[^]	+ 0.152
Cost (US$/kg)	+0.307[^]	−0.217
Availability	−0.379[^]	−0.344[^]

[^] Values greater than 0.30.

contents correlated positively with component 2 and ash content linked negatively to it. The PCA allowed clustering the ingredients in seven groups. Ingredients in Group 1 (G1), including fishmeal from Denmark, fish offal and poultry viscera showed a high positive correlation with component 1 and are rich in protein, but less available. They are expensive and very poor in carbohydrates. Ingredients of G2, i.e. dried brewer's yeast and *Moringa* leaf meals, are also a good source of protein with the advantage that they are relatively affordable and contain more carbohydrates compared to ingredients in G1. Soybean and cottonseed meals pertain to G3, correlating poorly with component 1 and component 2. They are rich in protein, carbohydrates, fibre and have a low fat content. They are constantly available and accessible throughout the year. Ingredients in G4 showed a negative correlation with component 1 and incorporated wheat bran, industrial maize bran, rice bran and wheat flour. They are high in carbohydrate content and are available and accessible. Their protein content is on average 120 g/kg DM. Ingredients in G5 presented a high negative correlation with component 1. This group contains cassava chips flour, tapioca, lafun (dried cassava chips) and maize flour. These ingredients have the highest carbohydrate content and are highly available and accessible but poor in protein and fibre. They would be excellent sources of starch (binder) in fish feed formulation. Ingredients in G6 showed a low positive correlation with component 2. They consist of local soy bran (residues of soybean-cheese production), local maize bran (residues of mawè production), palm kernel cake, local brewer's spent grain (from local Tchoukoutou beer), *Ceiba pentandra* leaf, Azolla leaf, industrial brewer's spent grain and soya grain. These ingredients contain more fibre than ingredients in G3. Except the palm kernel cake and soya grain, they contain just a little lipid, are not available in industrial quantities and also contain less protein compared to those in G3. G7 showed high negative correlation with component 2, and contains fishmeal from Senegal, whole garden snails and oyster shells. Although the Senegalese fishmeal is relatively high in proteins, their common characteristic is a high ash content. They are low in carbohydrates and fibre and relatively easily available.

4. Conclusion

The present study characterized the local fish feed ingredients in Benin for their nutrient composition, availability and cost. The survey demonstrated that fish farming in Benin depends on imported feeds despite their high price. Locally produced feeds are of poor quality and take more time to grow the fish. For local fish feed formulation, the study identified promising ingredients in the category of plant-based materials, which include maize, soya, brans, cottonseed meal, soybean meal, leaves (from *Moringa oleifera, Ceiba* spp.*, Azolla* spp.), a root crop (lafun, cassava chips, tapioca), and an oil crop (palm oil, palm kernel oil). Ingredients of animal origin identified are fishmeal, trash fish, blood meal, poultry viscera and whole garden snails. Among all ingredients, soybean meal and cottonseed meal are rich in proteins and carbohydrates and are available and accessible for industrial fish feed production. Trash fish has interesting protein levels, but adequate collection strategies need to be developed to ascertain its availability. Through this study, it appears that it is possible to use local fish feed ingredients available in Benin to formulate fish feeds with a satisfactory nutritional composition to ascertain adequate fish growth.

Author statement

The following tasks were accomplished by the different co-authors.

Adékambi Désiré Adéyèmi: Field investigation, data analysis and paper drafting.

Oloudé B. Oscar Odouaro: Field investigation and laboratory analysis.

Ifagbemi Bienvenue Chabi: Field and laboratory works monitoring, reviewing.

Adéchola P. Polycarpe Kayodé: Fund sourcing, experiment designing, conceptualization, supervision, reviewing, project administration.

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R. Anita Linnemann: Funds sourcing, experiment designing, conceptualization, supervision, reviewing.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aqrep.2020.100386.

References

Alceste, C., Jory, D.E., 2000. Tilapia alternative protein sources in Tilapia feed formulation. Aquaculture Magazine-Arkansas 26. pp. 70–75.

Aniebo, A.O., Erondu, E.S., Owen, O.J., 2008. Proximate composition of housefly larvae (Musca domestica) meal generated from mixture of cattle blood and wheat bran. Livestock Research for Rural Development 20 12.

AOAC, 2000. Official Methods of Analysis, 17th ed. Washington, DC, USA.

Babalola, T.O.O., 2010. Utilization of Dietary Animal Fats and Vegetable Oils by African Catfish (*Heterobranchus longifilis*) Fingerlings. PhD. Thesis. University of Ilorin, Nigeria.

Bhilave, M.P., Bhosale, S.V., Nadaf, S.B., 2012. Protein efficiency ratio (PER) of Ctenopharengedon idella fed on soyabean formualted feed. Biol. Forum 4 (1), 79–81.

Dagnelie, P., 1998. Statistique théorique et appliquée vol. 2 Paris. De Boeck & Larcier, Paris and Belgique.

Datta, S.N., 2011. Culture of Azolla and its efficacy in diet of Labeo rohita. Aquaculture. 310, 376–379. https://doi.org/10.1016/j.aquaculture.2010.11.008.

FAO, 2018. La situation mondiale des pêches et de l'aquaculture. Atteindre les objectifs de développement durable, Rome 2018. [Online] http://www.fao.org/3/i9540fr/i9540fr.pdf (Accessed 10 January 2020).

FAO, 2019. FAO Yearbook. Fishery and Aquaculture Statistics 2017, Rome [Online] http://www.fao.org/3/i9942t/I9942T.pdf (Accessed 10 January 2020).

Guillaume, J., Kaushik, S., Bergot, P., Métailler, R., 1999. Nutrition and Feeding of Fish and Crustaceans. Springer-Paraxis Books in aquaculture and fisheries.

Hertrampf, J.W., Piedad-Pascual, F., 2000. Handbook on Ingredients for Aquaculture Feeds. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Kakengi, A.V.M., Kaijage, J.T., Sarwatt, S.V., Mutayoba, S.K., Shem, M.N., Fujihara, T., 2007. Effect of *Moringa oleifera* leaf meal as a substitute for sunflower seed meal on performance of laying hens in Tanzania. Livest. Res. Rural Dev. 19 (8).

MAEP (Ministère de l'Agriculture, de l'Elevage et de la Pêche), 2014. Projet de vulgarisation de l'aquaculture continentale en République du Bénin. Rapport final, JICA Library [Online] http://open_jicareport.jica.go.jp/pdf/12236519_01.pdf (Accessed 10 January 2020).

Ocio, E., Vanaras, R., 1979. Housefly larvae meal grown on municipal organic waste as a source or protein in poultry diets. Anim. Food Sci. Technol. 4 (3), 227–231. https://doi.org/10.1016/0377-8401(79)90016-6.

Ruman, O., Singh, P.K., 1984. Utilization of Azolla in poultry feed. Indian Farm. 27, 37–39.

Shepherd, C.J., Jackson, A.J., 2013. Global fishmeal and fish-oil supply: inputs, outputs and markets. J. Fish Biol. 83, 1046–1066. https://doi.org/10.1111/jfb.12224.

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.). Aquacult. Res. 34, 487–500. https://doi.org/10.1046/j.1365-2109.2003.00836.x.

Sodjinou, E., d'Almeida, A.F.M., Mensah, G.A., Hessavi, P., Adjile, A., Chikou, A., Ahounenou, J., Mongbo, R.L., Houssou, P., Adegbola, P.Y., 2016. Aliments, ressources alimentaires et pratiques de nourrissage dans les exploitations piscicoles du Sud-Bénin. [Online] https://www.researchgate.net/profile/Epiphane_Sodjinou/publication/311965354_Aliments_ressources_alimentaires_et_pratiques_de_nourrissage_dans_les_exploitations_piscicoles_du_Sud-Benin/links/5865638008aebf17d397f486/Aliments-ressources-alimentaires-et-pratiques-de-nourrissage-dans-les-exploitations-piscicoles-du-Sud-Benin.pdf (Accessed 10 January 2020). .

Sotolu, A.O., 2009. Comparative utilizations of fish waste meal with imported fishmeal by african catfish (*Clarias gariepinus*). Am.-Euras. J. Sci. Res. 4, 285–289.

Toko, I.I., Fiogbe, E.D., Kestemont, P., 2008. Mineral status of African catfish (*Clarias gariepinus*) fed diets containing graded levels of soybean or cottonseed meals. Aquaculture. 275, 298–305. https://doi.org/10.1016/j.aquaculture.2007.11.038.

Usman, R., Palinggi, N.N., Ahmad, T., 2007. Utilisation of local feed ingredients in tiger grouper grow out moist diets. Aquaculture Asia Magazine 12. pp. 33–36.

Ye, J., Liu, X., Wang, Z., Wang, K., 2011. Effect of partial fishmeal replacement by soybean meal on the growth performance and biochemical indices of juvenile Japanese flounder Paralichthys olivaceus. Aquac. Int. 19 (1), 143–153. https://doi.org/10.1007/s10499-010-9348-1.