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# Nutritional Evaluation of Some Locally Available Ingredients use for Least-cost Ration Formulation for African Catfish (*Clarias gariepinus*) in Nigeria

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## ABSTRACT

This experiment was conducted to evaluate the proximate composition and the digestibility of nutrients and energy in protein-rich (dried fish, duckweed meal, blood meal, shrimp waste meal) carbohydrate-rich (rice bran, wheat offal, cassava root meal, cocoyam root meal) and in oilseed cake (groundnut cake, soybean cake, sesame cake, cotton seed cake) feedstuffs to improve least-cost diet formulations and to allow effective substitution for fishmeal. The digestibility of various ingredients was measured by using an inert marker in the feed and by using the Guelph faeces collecting system. The Basal diet (B) was formulated to contain 273.84 g $kg^{-1}$ protein, 79.06 g $kg^{-1}$ lipid and 20.25 MJ $kg^{-1}$ DM gross energy. The test diets were composed of the ingredient of interest plus $Cr_2O_3$, making up 30% of the dietary Dry Matter (DM) and B making up 70% of the DM. ADC values of the ingredients tested were generally high especially for dried fish. It was found that dried fish (97.48%) among the protein-rich ingredients, cocoyam root meal (89.44%) among carbohydrate-rich ingredient and sesame cake (90.95%) among the oilseeds were the best ingredients tested. The ADC of energy in the test diets was high and ranged from 80.3 to 88.6% (average 83.3%, SD 2.3). African catfish has the digestive potentials to utilize all the ingredients tested effectively. This information will serve as baseline data in the selection of locally available ingredients for the formulation of more efficient, economical diets for *Clarias gariepinus*.

**Key words:** Digestibility, feedstuff, nutrient, energy, African catfish

## INTRODUCTION

Nigerian feed resources have been in the decline in recent years, because of the stagnant or diminishing output of certain traditional crops. Recent statistics demonstrate that the country increasingly relies on imports to meet the needs of an expanding livestock and aquaculture industry (FAO, 2008). This has culminated in the increase in prices of food and feed resources in the country which has aggravated the already precariously high cost of fish feed which has been a major problem to fish farmers in Nigeria. This high cost constitute 40-60% of the recurrent cost of most intensive fish farm ventures which negates the economic viability of the farm when cheaper alternatives are not available (Madu *et al*., 2003). In addition, there is a projected 128,559 tonnes of aquatic product production in Nigeria by 2015, requiring 44,947 tonnes of aquafeed-assuming an annual growth rate of 10% within the sector. This being the case, Nigeria's aquafeed requirement in 2015 will represent a mere 0.1% of that produced by their animal feed industry in 2000 (Shipton and Hecht, 2005). Thus, it is likely that in the foreseeable future, the Nigerian animal feed industry has the sufficient capacity to absorb the country's projected aquafeed production requirements.

Small-scale fish farmers account for over 70% of producers in Nigeria and this group is further divided into commercial and non-commercial (subsistence) farmers, most of whom are located in rural areas and with a limited knowledge-base on fish production. The African catfish (*Clarias gariepinus*) has been identified as one of the fish species with the greatest potential to contribute to fish production in Nigeria. In 2004, it contributed about 32% of the total production (Ayinla, 2007). This is so because the technologies available can be transferred to function profitably even in rural setting (Phonekhampheng *et al.*, 2008). However, the future development of small-scale aquaculture system depends on the use of available local ingredients which will reduce the feeding costs (Edwards and Allan, 2004).

However, for these ingredients to be incorporated into least-cost ration, nutritional assessment of nutrient contents presents several key facets for which various experimental approaches and methodologies can be employed (Udo *et al.*, 2011a). Also, more controlled and standardized conditions are called for concerning the systematic characterisation of the biological value of raw materials (Olele, 2011). Besides ingredient specification, ingredient digestibility, ingredient palatability and nutrient utilization are usually recognized as the most important areas of knowledge in order to enable the judicious use of a particular ingredient in feed formulation (Glencross *et al.*, 2007).

This study was conducted to establish some baseline data on the nutrient composition and digestibility of nutrients and energy in protein-rich, carbohydrate-rich and oil-seed cake feed resources that can be used to formulate least-cost ration for the African catfish (*Clarias gariepinus*) in Nigeria.

## MATERIALS AND METHODS

**Location and climate:** The study was carried out in facilities of the Institute of Oceanography (IOC), University of Calabar, Cross River State, located at the South-Eastern part of Nigeria (Latitude 4°25′-7°00′N; Longitude 7°15′-9°30′).

The mean ambient temperatures recorded were 28-32°C in the middle of the day during the study which started in February 2010.

### Collection and preparation of test feedstuffs

**Shrimp waste meal:** Shrimp head material was collected from the local markets, blanched in hot water and blended into paste. Two percent each of formic and ethanoic acids of the weight of the shrimp head paste were added to aid ensilage and to prevent the growth of spoilage organisms. Ensilage was carried out (1 kg bag$^{-1}$) in 10 air-tight polythene bags for 14 days at pH range of 3.6-4.7. The wet silage was co-dried with 15% of hydrolyzed feather meal (85: 15, w/w) as filler and oven dried at 60°C for 3 days. The dried product was blended into powder form stored at same temperature pending chemical analysis.

**Duckweed meal:** Duckweed (*Lemna pauciscostata*) were collected from the surface of each pond and reservoir with a plastic screen, dried at 50°C for 4 h, stored in plastic bags and cooled (-4°C) until proximate composition analyses were performed.

**Cocoyam and cassava root meal:** Cocoyam and cassava used for the research were purchased from local market in Calabar, Nigeria. They were peeled and sliced. The thin sliced cocoyam and cassava were parboiled for 3 min and then sun dried for 3-4 days. Samples of the boiled dried cocoyam and cassava slices were submitted for proximate analysis.

**Blood meal:** Fresh cow blood was purchased from slaughter house in Calabar, Nigeria, fried and spray dried for three days before grinding. Dried fish was cleaned with water before sun-drying and milling. Other feedstuffs were purchased from the market and milled to smaller particle sizes and submitted for proximate analysis.

**Experimental diets:** A Basal diet (B), composed of Fishmeal (FM), Dried Brewer's Grains with Solubles (DBGS), Palm Kernel Cake (PKC), White Corn Meal (WCM), palm oil, vegetable oil, vitamins and minerals premix, a binder (carboxy-methyl cellulose) and $Cr_2O_3$ as an indigestible marker was formulated (Table 1). Twelve test diets were formulated to determine the digestibility of dietary components in the following selected protein-rich ingredients; Dried Fish (DF), Duckweed Meal (DWM), Blood Meal (BM) and Shrimp Waste Meal (SWM); carbohydrate-rich ingredients; Rice Bran (RB), Wheat Offal (WO) Cassava Root Meal (CaRM) and Cocoyam Root Meal (CoRM) and oilseed cakes; Groundnut Oilcake (GOC), Soybean Oilcake (SOC), Sesame Oilcake (SEC) and Cotton Seed Cake (CSC). A batch of each ingredient was purchased from local markets and processed accordingly. All ingredients were ground to less than 0.5 mm in a pin mill (Alpine, Hosokawa Micron Powder Systems, Summit, NJ, USA), sized with a screener (Rotex, Cincinnati, OH, USA) and weighed to produce 80 kg batches of each diet. The B was formulated to contain 273.84 g $kg^{-1}$ protein and 79.06 g $kg^{-1}$ lipid and it composition were shown in Table 2. The diets were made into pellets (diameter: 2 mm) using manual pelleting machine The test diets were composed of the ingredient of interest plus $Cr_2O_3$, making up 30% of the dietary Dry Matter (DM)

Table 1: Formulation of basal diet for determination of apparent digestibility coefficients in African catfish (*Clarias gariepinus*)

| | Content (g $kg^{-1}$ diet) | |
|---|---|---|
| Ingredients | Basal diet | Test diet |
| Fish meal | 200.00 | 140.00 |
| Dried brewer's grains with solubles | 250.00 | 175.00 |
| White corn meal | 315.00 | 220.50 |
| Palm kernel cake | 200.00 | 140.00 |
| Palm oil | 5.00 | 3.50 |
| Vegetable oil | 5.00 | 3.50 |
| Mineral[1] and vitamin premix[2] | 10.00 | 7.00 |
| Carboxy-methyl cellulose | 10.00 | 7.00 |
| $Cr_2O_3$ | 5.00 | 3.50 |
| Test ingredient | | 300.00 |

[1]Vitamin premix (mg $kg^{-1}$ diet): Vitamin A 300,000 IU, Vitamin D3 150,000 IU, Vitamin E 3,000 mg, Vitamin K 3,250, Vitamin B1 500, Vitamin B2 400, Vitamin B6 400, Biotin 10, Folic acid 150, Pantothenic acid 1,500, Inositol 2,500, Taurine 2,000, Choline 5,000, [2]Mineral premix ($kg^{-1}$ diet): Fe 20 g , Cu 10 g, Zn 11 g, Co 120 mg, Se 100 mg, Ca 150 g, Mn 2 g

Table 2: Proximate composition (g kg$^{-1}$ diet) and gross energy (MJ kg$^{-1}$ DM) of basal diet and test ingredients used in the determination of apparent digestibility coefficients for African catfish (*Clarias gariepinus*)

| Diet | DM | CP | CF | $CHO_T$ | EE | Ca | P | LS | MT | GE |
|---|---|---|---|---|---|---|---|---|---|---|
| Basal diet | 938.99 | 273.84 | 63.16 | 560.42 | 79.06 | 11.42 | 7.98 | 14.16 | 9.71 | 20.25 |
| Dried fish | 950.25 | 350.07 | 17.56 | 450.37 | 85.66 | 59.55 | 30.65 | 42.72 | 20.41 | 20.10 |
| Duckweed meal | 923.53 | 248.28 | 120.63 | 545.20 | 57.44 | 12.00 | 8.00 | 17.80 | 4.41 | 19.56 |
| Blood meal | 895.91 | 762.87 | 15.03 | 470.93 | 12.02 | 2.84 | 9.66 | 69.05 | 10.02 | 21.84 |
| Shrimp waste meal | 795.34 | 589.33 | 335.81 | 385.33 | 36.28 | 87.20 | 16.82 | 30.95 | 54.00 | 17.52 |
| Rice bran | 910.33 | 133.82 | 123.00 | 630.50 | 24.08 | 4.50 | 4.68 | 5.90 | 2.50 | 18.33 |
| Wheat offal | 880.50 | 190.50 | 105.70 | 714.34 | 45.52 | 1.30 | 18.90 | 7.10 | 5.65 | 16.56 |
| Cassava root meal | 882.80 | 285.50 | 36.87 | 910.30 | 33.60 | 8.98 | 2.18 | 7.22 | 3.12 | 17.24 |
| Cocoyam root meal | 870.21 | 251.62 | 28.56 | 886.34 | 6.80 | 1.03 | 5.66 | 7.56 | 3.67 | 17.21 |
| Groundnut oilcake | 900.20 | 453.65 | 50.05 | 427.20 | 110.50 | 2.60 | 8.90 | 18.75 | 6.60 | 18.31 |
| Soybean oilcake | 915.00 | 450.35 | 85.80 | 532.92 | 75.90 | 2.83 | 7.55 | 25.90 | 5.78 | 18.55 |
| Sesame oilcake | 850.25 | 386.81 | 78.35 | 358.98 | 155.76 | 25.55 | 12.10 | 10.36 | 23.81 | 17.21 |
| Cotton seed oilcake | 886.98 | 265.00 | 224.70 | 420.56 | 68.90 | 2.20 | 15.05 | 20.55 | 12.85 | 18.92 |

DM: Dry matter; CP: Crude protein; CF: Crude fibre; $CHO_T$: Total carbohydrate; EE: Ether extract; Ca: Calcium; P: Phosphorus; LS: Lysine; MT: Cysteine+Methionine; GE: Gross energy

and B making up 70% of the DM. Faeces were pooled within each treatment to obtain sufficient material for analysis which meant that no statistical analysis was possible to perform on the data presented.

**Fish and experimental design:** Juvenile African catfish (average body weight of 50±12 g) was obtained from the fish farm, Institute of Oceonography (IOC), University of Calabar, Calabar, Cross River State, Nigeria. Fish were acclimated to the concrete tanks and B at least for 2 weeks before the formal trial. Fish were randomly distributed into 39 cylindrical tanks of 120 l capacity half filled with stagnant water. Aeration was supplied to each tank 24 h day$^{-1}$. Three tanks were randomly assigned to each diet group. Each tank was stocked with 10 fingerlings of mixed sex. The digestibility study lasted for 14 days, comprising an adaptation period of 3-4 days followed by total faeces collection. Water quality parameters (temperature, pH, dissolved oxygen) were controlled during the experiment. The feeding level was approximately 5% of fish body weight and day. The daily feed allowance was divided into three equal meals which were fed at 8:00 14:00 and 17:00 respectively. Diets were placed in the water for 1 h, after which the tanks were cleaned from residual feed and feaces. The fish were not fed until the next morning and the feaces produced during that time was settled at the bottom of the conical tanks. Fresh faeces were collected daily after 1 h feeding from 07:00 to 13:00 from each tank and were frozen at -20°C. At the end of the collection period faecal matter were dried in an oven at 60°C ground and preserved in airtight containers pending analysis.

**Chemical analysis:** Dry matter (DM), Crude Protein (CP), Crude Fiber (CF), Ether Extract (EE), total Carbohydrates ($CHO_T$), Phosphorus (P) and Calcium (Ca) content of the basal and test diets as well as that of the ingredients were determined according to the method of AOAC (1999). Amino acid profile of the feed ingredients analyzed includes sulphur amino acid (methionine + cystine) and lysine. These were determined using methods described by Shahidi *et al.* (1999). Details have been outlined by Adeyeye and Afolabi (2004). Chromic oxide content in diets and faeces was analyzed according to Furukawa and Tsukahara (1966). Gross Energy (GE) was determined based on the

Table 3: Apparent digestibility coefficient (%) of dietary components and gross energy in basal diet and test diets

| Diet | DM | CP | CF | $CHO_T$ | EE | Ca | P | LS | MT | GE |
|---|---|---|---|---|---|---|---|---|---|---|
| Basal diet | 90.58 | 95.55 | 86.37 | 86.48 | 72.574 | 78.48 | 75.28 | 84.58 | 79.27 | 85.36 |
| B+Dried fish | 92.60 | 95.34 | 81.63 | 75.46 | 75.89 | 90.56 | 73.56 | 82.74 | 80.44 | 88.63 |
| B+Duckweed meal | 90.85 | 92.45 | 85.05 | 77.46 | 76.26 | 83.08 | 80.07 | 87.80 | 82.49 | 84.57 |
| B+Blood meal | 91.67 | 97.29 | 84.31 | 70.16 | 71.36 | 79.84 | 79.94 | 79.35 | 80.05 | 83.62 |
| B+Shrimp waste | 89.13 | 84.35 | 83.87 | 72.89 | 69.73 | 82.27 | 81.28 | 73.07 | 75.06 | 82.11 |
| B+Rice bran | 87.45 | 84.17 | 89.88 | 83.22 | 74.28 | 80.48 | 74.67 | 85.98 | 80.54 | 86.21 |
| B+Wheat offal | 89.88 | 83.20 | 80.19 | 87.12 | 76.16 | 78.10 | 81.99 | 86.18 | 75.58 | 80.36 |
| B+Cassava root meal | 88.50 | 94.37 | 81.94 | 85.38 | 73.18 | 81.86 | 76.16 | 87.23 | 80.17 | 81.29 |
| B+Cocoyam meal | 90.25 | 95.62 | 83.67 | 91.24 | 73.20 | 78.69 | 75.66 | 86.57 | 76.36 | 84.90 |
| B+Groundnut cake | 86.08 | 85.56 | 85.43 | 74.23 | 77.56 | 79.68 | 78.08 | 80.71 | 81.08 | 82.66 |
| B+Soybean cake | 89.17 | 84.35 | 82.00 | 75.29 | 87.98 | 77.92 | 77.24 | 75.97 | 75.75 | 81.95 |
| B+Sesame cake | 90.68 | 86.57 | 88.73 | 73.85 | 85.56 | 85.57 | 82.14 | 81.35 | 82.37 | 83.20 |
| B+Cotton seed cake | 88.90 | 82.23 | 86.63 | 74.27 | 88.98 | 79.26 | 81.58 | 82.50 | 81.80 | 80.53 |

B: Basal diet; DM: Dry matter; CP: Crude protein; CF: Crude fibre; $CHO_T$: Total carbohydrate; Ca: Calcium; P: Phosphorus; LS: Lysine; MT: Cysteine+Methionine; GE: Gross energy

organic carbon content in the sample. Thirteen materials were used in calibration of the method with direct energy determination by bomb calorimetry. An average value of 47.08 kJ $g^{-1}$ organic carbon for the thirteen materials was considered as the future reference conversion factor.

**Calculations:** The equation of ADCs of nutrients and energy of the basal and test diets were calculated based on the formula used by Cho *et al*. (1982). The ADCs of the test ingredient were calculated based on the digestibility of the Basal diet and the test diets by a formula used by Bureau *et al*. (1999).

## RESULTS

**Proximate composition of ingredient:** The proximate composition of the 12 ingredients considered in this study is presented on Table 2. DM ranged from 795.34 g $kg^{-1}$ diet in shrimp waste meal to 950.25 g $kg^{-1}$ diet in dried fish. The lowest value for CP (133.82 g $kg^{-1}$ diet) was recorded by rice bran while blood meal was observed to record the highest (762.87 g $kg^{-1}$ diet). At the same time, blood meal recorded the lowest CF (15.03 g $kg^{-1}$ diet) while the highest CF (335.81 g $kg^{-1}$ diet) content was observed in shrimp waste meal. Cottonseed oilcake contained the lowest $CHO_T$ (420.56 g $kg^{-1}$ diet) while Cassava root meal content the highest $CHO_T$ (910.30 g $kg^{-1}$ diet). The lowest EE (6.80 g $kg^{-1}$ diet) was observed in cocoyam root meal and the highest (155.76 g $kg^{-1}$ diet) was found in sesame oilcake. Cocoyam root meal was found to contain the lowest value (1.03 g $kg^{-1}$ diet) for Ca while shrimp waste meal contained the highest (87.20 g $kg^{-1}$ diet). Top on the list in terms of P was dried fish with the value of 30.65 g $kg^{-1}$ diet while cassava root meal had the least (2.18 g $kg^{-1}$ diet). The lowest value for LS was seen in rice bran (5.90 g $kg^{-1}$ diet) while blood meal had the highest (69.05 g $kg^{-1}$ diet). Rice bran had the lowest value for MT (2.50 g $kg^{-1}$ diet) while the highest value was found in shrimp waste meal (54.00 g $kg^{-1}$ diet). GE was high in blood meal (21.84 MJ $kg^{-1}$ DM) and low in wheat offal (16.56 MJ $kg^{-1}$ DM). Generally the ingredients were rich in nutrient composition.

Values for the ADC of dietary components and Gross energy in basal diet and test diets are presented on Table 3 and were used to calculate the ADC of the test ingredients used in the study. The calculated ADC values for the test ingredients are presented on Table 4. $ADC_{DM}$ ranged

Table 4: Apparent digestibility coefficient (%) of dietary components and gross energy in feed ingredients

| Ingredients | DM | CP | CF | $CHO_T$ | EE | Ca | P | LS | MT | GE |
|---|---|---|---|---|---|---|---|---|---|---|
| Dried fish | 97.48 | 94.94 | 43.30 | 43.50 | 82.86 | 95.82 | 72.48 | 81.35 | 81.73 | 96.36 |
| Duckweed meal | 91.56 | 84.44 | 83.43 | 55.80 | 88.04 | 93.21 | 91.18 | 93.77 | 96.90 | 82.56 |
| Blood meal | 94.39 | 98.63 | 64.70 | 24.95 | 52.87 | 87.81 | 89.63 | 76.86 | 81.81 | 79.93 |
| Shrimp waste meal | 85.20 | 72.20 | 58.60 | 26.70 | 55.36 | 83.38 | 87.80 | 60.36 | 73.24 | 73.47 |
| Rice bran | 79.90 | 29.95 | 93.97 | 76.58 | 87.26 | 91.00 | 72.36 | 93.52 | 92.29 | 88.52 |
| Wheat offal | 88.15 | 42.00 | 71.54 | 88.38 | 90.54 | 72.10 | 88.47 | 93.57 | 60.70 | 66.04 |
| Cassava root meal | 89.07 | 91.61 | 59.64 | 83.78 | 88.90 | 93.12 | 84.50 | 99.22 | 86.68 | 69.96 |
| Cocoyam root meal | 89.44 | 94.44 | 71.60 | 98.11 | 91.63 | 83.44 | 76.91 | 95.02 | 58.52 | 83.80 |
| Groundnut cake | 85.18 | 71.50 | 82.76 | 36.87 | 85.80 | 90.27 | 83.88 | 74.16 | 87.17 | 75.63 |
| Soybean cake | 85.88 | 68.40 | 77.70 | 47.76 | 91.02 | 72.47 | 82.06 | 65.06 | 62.02 | 73.24 |
| Sesame cake | 90.95 | 71.65 | 93.21 | 27.94 | 89.54 | 92.81 | 92.86 | 71.19 | 85.25 | 77.44 |
| Cotton seed cake | 84.96 | 51.88 | 86.80 | 36.38 | 92.15 | 89.84 | 89.84 | 77.63 | 86.33 | 68.51 |

DM: Dry matter; CP: Crude protein; CF: Crude fibre; $CHO_T$: Total carbohydrate; Ca: Calcium; P: Phosphorus; LS: Lysine; MT: Cysteine +Methionine; GE: Gross energy

Table 5: Estimated content of digestible energy (DE; MJ $kg^{-1}$ DM) and the crude protein (CP) and digestible CP (DCP) to energy ratio (g $MJ^{-1}$) in feed ingredients

| Ingredient | DE | CP/DE | DCP/DE |
|---|---|---|---|
| Dried fish | 19.6 | 17.9 | 17.1 |
| Duck weed meal | 16.6 | 15.0 | 12.6 |
| Blood meal | 17.5 | 42.6 | 43.0 |
| Shrimp waste meal | 12.9 | 45.7 | 33.0 |
| Rice bran | 16.2 | 8.2 | 2.5 |
| Wheat offal | 10.9 | 17.5 | 7.3 |
| Cassava root meal | 12.1 | 23.6 | 21.6 |
| Cocoyam root meal | 14.4 | 17.5 | 16.5 |
| Groundnut cake | 13.8 | 32.9 | 23.5 |
| Soybean cake | 13.6 | 33.1 | 22.7 |
| Sesame cake | 13.3 | 29.1 | 20.8 |
| Cotton seed cake | 13.0 | 20.4 | 10.6 |

from 79.90% in rice bran to 97.48% in dried fish (average 88.51; SD 4.54). The ADC value for CP ranged from 29.95% in rice bran to 98.63% in blood meal (average 72.64; SD 21.12). Dried fish had the lowest ADC value for CF (43.30%) while rice bran had the highest (93.97%) and was on average 73.94% (SD 14.71). The lowest ADC value for $CHO_T$ was recorded by blood meal (24.95%) while cocoyam root meal had the highest (98.11%) and was on average 59.90% (SD 25.08). $ADC_{EE}$ ranged from 52.87% in blood meal to 92.16% in cotton seed cake and was on average 83% (SD 13.17). The highest ADC value for Ca was seen in wheat offal (72.10%) while dried fish recorded the highest (95.82%) and was on average 87.11% (SD = 7.54). The $ADC_P$ was found to be very low in rice bran (72.34%) as compared to sesame cake which recorded the highest value (92.86%) and was on the average 84.33% (SD 6.78). Cassava root meal had the highest ADC value for LS (99.22%) as compared to sesame cake which recorded the lowest (71.19%) and was on average 81.81 (SD12.41). $ADC_{MT}$ was very low in cocoyam root meal (58.52%) and very high in duckweed meal (96.90%) and was on average 79.39% (SD 12.26). The highest ADC value for GE was seen in dried fish (96.38%) and the lowest was seen in wheat offal (66.04%) and was on the average 77.96% (SD 8.43).

The estimated content of Digestible Energy (DE) ranged from 10.9 MJ $kg^{-1}$ DM for wheat offal to 19.6 MJ $kg^{-1}$ DM for dried fish (Table 5). The value for P: E ranged from 8.2 g $MJ^{-1}$ in rice bran to 45.7 g $MJ^{-1}$ in shrimp waste meal while the DCP/DE value ranged from 2.5 g $MJ^{-1}$ in rice bran to 43.0 g $MJ^{-1}$ in blood meal.

## DISCUSSION

**Proximate composition of feed ingredients:** The proximate compositions of the studied feed ingredients were comparable to other published data (NRC, 1993; Phonekhampheng *et al*., 2008). Though some variations existed, this could be handled using stochastic programming (Udo *et al*., 2011b). In the more unconventional protein-rich feed ingredients, the chemical composition of ensiled SWM was almost similar to those reported by others (Nwanna *et al*., 2003; Nwanna, 2003) while that of DWM was different (Yilmaz *et al*., 2004; Tavares *et al*., 2008). In contrast, the chemical composition of dried fish and blood meal used in the present study differed from other published data (Laporte *et al*., 2008; Tibbetts *et al*., 2006). However, the CP of dried fish was similar to that reported by Phonekhampheng *et al*. (2008). The CP, lipid and GE content in dried fish were markedly lower and the content of DM markedly higher than in conventional fishmeal (NRC, 1993); This could be due to the use of small-sized trash fish which have a high proportion of bone to meat in their body.

The DM, CF and EE content of rice and wheat bran used in this study were lower than those reported by Liti *et al*. (2006) while that of CP was higher. The high CP content may be due to the fact that the bran was collected fresh from the local farmers. Similarly, the CP content of cassava and cocoyam root meal was markedly higher than reported by others (Phonekhampheng *et al*., 2008; Aderolu and Sogbesan, 2010). In addition, the EE content was high while both the $CHO_T$ and CF contents were similar. This variation may be due to difference in variety or variation attributed to the laboratory procedure and human error (Divakaran, 2005). Among the oilcakes, the CP in GOC, SOC were higher than published data while others were either lower or similar (ADCP, 1983; Fagbenro, 1998). Plant proteins were especially deficient in the sulphur amino acids. These amino acids are also limiting in SOC. The leguminous seeds, quite surprisingly, were relatively rich in lysine, the amino acid that is most often the first to be limiting in compound feed.

**Digestibility of test diets and ingredients:** African catfish (*C. gariepinus*) has been described as an omnivorous scavenger (Clay, 1979). Considering this, it should be expected to have the potential to efficiently utilize a wide range of feed ingredients of both plant and animal origin. In general, this contention was supported by the high digestibility values of DM, CP, CF, EE and GE found for most dietary components in the present study for both the basal diet and the test diets. This was in agreement with other published data on catfish (Fagbenro, 1996, 1998). However, on average the carbohydrate-rich ingredients showed lower ADC values for DM and CP than the protein-rich ingredients (86.6 and 64.5 vs. 92.1 and 89.6%). This could partly be due to low CP content in the carbohydrate-rich feeds as compared with the protein-rich feeds. Moreover, this indicates that animal protein may be better utilized than plant protein by the African catfish (*Clarias gariepinus*). Generally, oilseed cakes were found to have the highest ADC value for CF (81.1% SD 5.7). Similar data has been reported by Fagbenro (1996, 1998). The ADC of $CHO_T$ in the diets and ingredients was lower than the ADC for CP and EE and varies greatly. However, despite a larger variation in the ADC between diets and ingredients, on average, about 80% of the $CHO_T$ were digested. This supports the presumed omnivorous nature of the African catfish

(Clay, 1979; Degani and Revach, 1991) and indicates a capacity to utilize carbohydrates to some extent in their diet. This is further supported by a recent study by Leenhouwers *et al.* (2007) and Phonekhampheng *et al.* (2008) who reported starch digestibility in the range of 80 to 97% in cereal-based diets fed to African catfish and total carbohydrate digestibility of 77.7% in protein-rich and carbohydrate-rich feedstuff, respectively.

The ADC of EE in the test diets indicates a high utilization of EE in most of the feed ingredients studied. Due to unexpectedly low ADC of EE in ensiled SWM and blood meal, the average ADC of EE in the protein-rich feeds was lower than in the carbohydrate-rich feeds and oilseed cakes. P. and Ca are the minerals that are required in largest amount by fish. On the average, the ADC value for P is lower than the ADC value for Ca. This is unexpected because unlike calcium, fish do not obtain a significant amount of phosphorus from the water (NRC, 1993). Studies with channel catfish have shown that if lysine and sulphur amino acid (methionine and cystine) requirement are met, then the requirements for other essential amino acids will be met (Lovell, 1989). Though the ADC value for MT was lower than that of LS, these two essential amino acids were well digested.

Energy is essential in that it contributes to the metabolic utilization of all nutrients in a diet. The ADC of energy in the test diets was generally high. This was in agreement with other published data on catfish (Fagbenro, 1996, 1998; Phonekhampheng *et al.*, 2008). However, the ADC of energy for the feed ingredients showed a wider range than that of test diets. On average, the ADC of energy for the carbohydrate-rich feed ingredients was lower (77.08%) and varied more (SD 9.3) between ingredients than the values for the protein-rich feed ingredients (83.08%; SD 8.4). On the whole, the oilseed cakes showed the lowest ADC value for energy (73.71%; SD 3.3). Similar findings were reported by Fagbenro (1996, 1998) and Phonekhampheng *et al.* (2008).

**Nutrient supply and Bioavailability from potential feedstuffs:** It has been well known that most plant-derived nutrient sources contain a wide variety of antinutritional substances (Francis *et al.*, 2001). Antinutrients are defined as substances which by themselves, or through their metabolic products arising in living systems, interfere with food utilization and affect the health and production of animals (Jayasuriya, 1993). This therefore creates a need for detoxification of such ingredients through processing before using in livestock feed (Ingweye *et al.*, 2010). One of such ingredients is duckweed meal. The $ADC_{CP}$ of this product was not low in this study (84.44%). Nutrients in this feed ingredient have been made available to fish by sun drying (Yilmaz *et al.*, 2004). Duckweed meal provides an easy, practical and cheaper fish feedstuff because it requires no processing to destroy any antinutrients. Current research findings show that utilization of diet containing 29.50% of duckweed is cost effective by reducing the cost of feed by 20.82% (Olorunfemi, 2006).

The use of cotton seed cake is limited by the low availability of lysine and the presence of gossypol-a yellowish pigment and a toxic phenolic compound confined to the genus of cotton, *Gossypium* (Berardi and Goldbatt, 1980). The use of good preparation condition has been proven to surmount such difficulty (Foline *et al.*, 2011). In this study, binding of gossypol in the oilcake rendered the product non-toxic and increased the lysine content. This was achieved by treating with water and cooking with steam, hence the $ADC_{CP}$ of 51.88% which is not below average.

Anti-nutritive factors in soybean products are principally urease and trypsin inhibitors present in the raw bean (Nwanna *et al.*, 2006). These are usually destroyed by heat during toasting and oil extraction process (Fafioye *et al.*, 2005). In this study, the ADC value for CP in soybean cake was 68.40% showing that more than 50% of the total CP was available to fish.

The general problem with shrimp waste meal is the present of exoskeleton (Nwanna *et al.*, 2006). Because shrimp exoskeleton is primarily chitin, an indigestible nitrogen-containing homopolysaccharide, the true CP content of shrimp meal made from freezing-plant wastes is only 50% of the value obtained by proximate analysis. This problem was solved by ensilage. This raised the $ADC_{CP}$ of this product to 72.20%.

Although sesame oilcake had higher CF content than groundnut oilcake (78.35 vs 50.05 g $kg^{-1}$ diet), the CP content of both feedstuffs were about the same (386.81 vs 453.65 g $kg^{-1}$ diet). Furthermore, sesame oilcake is very rich in methionine (23.81 g $kg^{-1}$ diet) in fact, the richest among oilcakes and meals. Its lysine content (10.36 g $kg^{-1}$ diet), on the other hand, is lower than that of groundnut oilcake. Sesame oilcake and groundnut oilcake used in combination can substitute for the more expensive animal proteins such as meat meal or fish meal.

Studies on *C. gariepinus* have shown that the CP level in the feed should be 300-350 g per $kg^{-1}$ diet to give a high growth rate (FAO, 1983). Granted, the CP requirement is around 400 g $kg^{-1}$ diet (Machiels and Henken, 1985; Degani *et al.*, 1989). Given the CP content of available ingredients in this study, diets for catfish have to be based on protein-rich feedstuffs and oilseed cakes to provide the protein needed to support a high growth rate. The only exception is if the CP supply in the diet was based on duck weed meal which depends on the culture system (Effiong *et al.*, 2009). In this case, around 30% of the dietary DM could come from low-protein feed ingredients.

On average, the DE content of the carbohydrate-rich feed ingredients was the same with that of the oilcakes and was lower than that of the protein-rich feed ingredients. This was mainly due to the lower ADC for energy, as the content of gross energy differed less between feed ingredients. The protein: energy ratio (P/E ratios) ranged from 17.9 to 45.7 g CP $MJ^{-1}$ DE for the protein-rich feed ingredients, from 8.2 to 23.6 g CP $MJ^{-1}$ DE for the carbohydrate-rich feed ingredients and from 20.4 to 33.1 g CP $MJ^{-1}$ DE in the oilseed cakes (Table 5). The optimum P/E ratio for growing *C. gariepinus* has been reported to be in the range of 25 to 30 g CP $MJ^{-1}$ DE (Ali, 2001; Ali *et al.*, 2008). Thus, to reach this level in the diet both the protein-rich feed ingredients and oilseed cakes studied have the potential to provide sufficient P/E ratios in catfish diets. These research findings were used to formulate least-cost ration using linear programming technique and the formula cost of the ration was reduced by 18.21 naira $kg^{-1}$ feed (Udo *et al.*, 2011a).

## CONCLUSION

The African catfish have digestive capacity to utilize all the studied feed ingredients reasonably well. Based on chemical composition and the digestibility data presented, it should be possible to formulate diets that better meet the nutrient needs of cultured African catfish in Nigeria. However, mainly the protein-rich feed ingredients and oilseed cakes are useful if the diet should reach a sufficient P: E ratio but in determining how best the available local ingredients can be combined effectively and efficiently to formulate least-cost ration for African catfish, linear programming technique should be applied.

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