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Determination of Optimum Inclusion Level of Some Plant and Animal Protein-rich Feed Ingredients in Least-cost Ration for African Catfish (*Clarias gariepinus*) Fingerlings using Linear Programming Technique

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ABSTRACT

A 90 day study was undertaken to establish an optimum inclusion level of some plant and animal protein-rich feed resources in a formal least-cost diet for African catfish (*Clarias gariepinus*) fingerlings using linear programming technique. Five isonitrogenous (35% CP), isocaloric (3000 kcal kg^{-1}) and isolipidic (6.00% lipids) diets were formulated. The reference diet (DT01) was formulated using Fishmeal (FM), White Maize Meal (WMM), Dried Brewer's Grain (DBG), Palm Kernel Cake (PKC) and salt while Duck Weed Meal (DWM), Soybean Meal (SBM), Blood Meal (BM) and Shrimp Waste Meal (SWM) where included in diets DT02, DT03, DT04 and DT05, respectively. The formulated rations indicated that DWM, SBM, BM and SWM can be optimally included in a formal least-cost diet at 30.85, 30.75, 13.69 and 17.14% levels replacing 12.5, 72.14, 69.67 and 72.14% FM leading to 17.18, 23.00, 34.11 and 21.19% formula cost reduction. Ration formulated were tested on catfish fingerlings (20.15±3.50 g) twice daily for 6 days a week in triplicate groups of experiments earthen ponds for growth performance and feed utilization. Result show that growth performance and feed utilization parameters were not significantly ($p>0.05$) different from the RD and among the treatments. Carcass composition of the experimental fish showed that all the fish fed the experimental diets had higher carcass protein and lipid contents and lower ash and nitrogen free extract contents than the initial fish sample. These values are however similar for all treatments. These results show that locally available plant and animal protein-rich feed resources can be included in a formal catfish diet at cheaper costs without any negative effect on growth.

Key words: Fishmeal, inclusion, growth performance, carcass, nutrition

INTRODUCTION

The high quality and concentration of essential nutrients, especially of well-balanced amino acids, essential fatty acids and energy content makes fishmeal an indispensable ingredient in diets of most aquaculture species. Due to its nutrient content, high digestibility and palatability, fishmeal serves as the benchmark ingredient in aquaculture diets (Miles and Chapman, 2006). Aquafeed production on global scale has been rising steadily from 14.2 mmt in 1997 to 16.70 mmt in 2001

(Olele, 2011). As a consequence, a concomitant increase in the demand for fishmeal, fish oil and other feed ingredients commonly used in fish feeds is expected (Hashim, 2006). In addition, the growing trend towards the culture of premium valued carnivorous fish which require high portions of fishmeal in their diets, will mean further pressure on an already static supply of this ingredient. In the early 2002, aquaculture industry was using only 34% of the total global fish meal produced (Hardy, 2006) but by 2010, this value increased to 48% (Ayinla, 2007). This increase is expected to be at the expense of other animal feeds, indicating that technically, the impact of aquaculture expansion on the availability of fishmeal may be marginal and is expected to soar to 70% by 2015 (New and Wijkstrom, 2002). Consequently, the sustainability of feed-based production systems may be threatened by shortages and price rises of fishmeal and thus steps must be taken to reduce their inclusion levels in aquafeeds (Fagbenro and Adebayo, 2005).

Optimal use of fishmeal in practical aquaculture diets is necessary to minimize feeding costs which can account for 40% or more of operating expenses. Over the years, researchers have embarked on studies to search for possible replacements to fishmeal (Khan *et al.*, 2003; Sotolu, 2010). Among the many alternatives that have been examined, plant meals appear to have the most potential (Abdelghany, 2004; Ingweye *et al.*, 2010). Among the plant meals that have been investigated are soybean meal (Fafioye *et al.*, 2005; Hasanuzzaman *et al.*, 2009) and duckweed meal (Effiong *et al.*, 2009). The protein content of duckweeds is one of the highest (up to 45%, on DM basis) in the plant kingdom and has a better array of essential amino acids than most plant proteins and more closely resembles animal protein (Ekelemu, 2010). Further, its amino acid spectrum especially with regard to lysine (7.5% of total protein) and methionine (2.6% of total protein) is much higher as compared to other plant feed stuffs (Mishra, 2007). Duckweeds are highly variable in their composition and it depends on the nutrient status of the water on which they grow (Ansal *et al.*, 2010).

Animal proteins can easily be combined with other feed ingredients with complementary amino acid profiles in order to match the nutritional requirements of a wide range of farmed species (Laporte *et al.*, 2009). Nutritional evaluations indicate that the utilisation of such blends in aquafeeds could help the aquaculture industry grow into a sustainable, ecological and ethical supplier of high quality food (Glencross *et al.*, 2007). In animal nutrition, Blood Meal (BM) is known to be one of the most efficiently used protein supplements. It is a sustainable source of protein and large quantities are available in abattoirs throughout the world. It is low in phosphorus which will please fish farmers from both an environmental and industrial perspective. Furthermore, it is uniquely rich in lysine, having twice the lysine content of white FM and almost thrice the level in dehulled SBM. Also, it is rich in leucine and valine and high in histidine and phenylalanine. As a result, BM quickly seems an alternative cheaper protein source that can replace costly FM produced from open sea fish products (Hertrampf and Piedad-Pascual, 2000; Agbebi *et al.*, 2009). Several studies have reported successful replacement of FM with BM without any adverse effect on growth and nutritional indices (Otubusin *et al.*, 2009). Similarly, continued production of the shrimp head waste without corresponding development of technology utilizing the waste has resulted in waste collection, disposal and pollution problems (Nwanna, 2003). Therefore, harnessing of these into fish feed production apart from minimizing the costs of fish production would serve as an excellent means of sanitizing the environment (Nwanna *et al.*, 2003).

Catfish feeds have generally been based on a fixed formula with little or no use of a linear programming technique as used in other animal industries (Robinson and Menghe, 2006). This has resulted in great disparity in terms of replacement level of fishmeal and the effect on other ingredient mixes in practical diets for catfish. Also in doing so, the cost of the diet which is paramount to the overall production process is ignored. To this end optimum replacement level of fishmeal by plant and animal protein-rich feed ingredients must be established in order to formulate nutritionally balanced diet for catfish based on their nutrient requirements while keeping the cost at the least (Olorunfemi *et al.*, 2001).

This study therefore, seek to use linear programming technique to establish an optimum replacement level of fishmeal with some plant and animal protein-rich feed ingredients in a formal diet for African catfish (*Clarias gariepinus*) fingerlings and test its effect on growth performance and feed utilization.

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- (NRCRI, 2000). The mean ambient temperatures recorded were 28-32°C in the middle of the day during the study which started in May and ended in to July 2010. The water source was a perennial water reservoir recycled through a network of pipes, filter tanks, into earthen ponds.

Collection and preparation of test feedstuffs: 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. Raw soybean seeds were procured from the local farmer in Calabar, Cross River State, Nigeria. They were washed, sun-dried and toasted before grinding to require sizes for diet formulation. Fresh cow blood was purchased from slaughter house in Calabar, Nigeria, fried and spray dried for three days before grinding. Shrimp head material was collected from the local markets, blanched in hot water and sun-dried before grinding. Other feedstuffs used in the reference diet were purchased from the market and milled to smaller particle sizes. All the feed ingredients were then submitted for proximate analysis.

Least-cost ration formulation using linear programming techniques: Data needed for least-cost feed formulation are: price of feed ingredients, nutrient concentrations in feedstuffs, nutrient requirements and nutrient availability from feedstuffs and nutritional and non nutritional restrictions. Ingredient market prices were obtained from Grain Silos and Flour Mills Organization and published Foreign Trade Statistics. These were compared with the local market prices in Nigeria that were obtained through survey, for harmonization (Table 1). Data on the nutrient requirements and nutritional and non-nutritional restrictions of catfish were collected from standard tables (NRC, 1993; Robinson and Menghe, 2006) and are presented on Table 1. The objective function was to minimize the cost of ingredient combination per unit of catfish feed subject to the following constraints: a minimum level 35% is placed on crude protein for fingerlings; maximum level of 6% on fat; maximum level of 7% on crude fiber; minimum level of 1.43% on lysine; minimum level 0.65 on methionine; minimum levels of 0.5% for phosphorus and sulphur, respectively and minimum of 3000 kcal g^{-1} protein for digestible energy. In the ingredient section; minimum level of 8% was placed on fishmeal; maximum of 20% for palm kernel cake and minimum

Table 1: Cost implications of raw materials and nutrient level of feed ingredients

		Content (%)								
Ingredients	Cost (N kg^{-1})*	DM	CP	CF	EE	Ca	P	LS	MT	ME (kcal kg^{-1})
FM	435.00	92.00	60.50	1.75	4.50	5.95	3.00	4.20	2.00	2860
WMM	140.00	88.00	10.50	2.00	3.20	0.01	0.09	0.30	0.18	3432
DBG	24.75	91.00	18.60	20.00	6.40	0.20	0.16	0.81	0.98	1980
PKC	15.50	91.60	20.40	9.00	8.20	0.30	0.60	0.75	0.94	3137
DWM	12.00	92.30	24.80	12.00	5.70	1.20	0.80	1.78	0.44	3450
SBM	165.00	88.50	45.30	6.50	3.50	0.20	0.20	2.80	0.60	2230
BM	110.50	89.50	76.20	1.50	1.20	0.28	0.09	6.90	1.00	3080
SWM	220.00	79.50	58.90	3.35	3.61	8.72	1.68	3.09	5.40	2100

FM: Fishmeal, WMM: White maize meal, DBG: Dried brewers' grain, PKC: Palm kernel meal, DWM: Duckweed meal, SBM: Soybean meal, BM: Blood meal, SWM: Shrimp waste meal, DM: Dry matter, CP: Crude protein, CF: Crude fibre, EE: Ether extract, Ca: Calcium, P: Phosphorus, LS: Lysine, MT: Methionine+cystine, ME: Metabolizable energy, *1US$ = N155.00

10% for soybean meal. Nutrients analyzed include: Dry Matter (DM), Crude Protein (CP), Crude Fibre (CF), Ether Extract (EE), Calcium (Ca), Phosphorus (P), Lysine (LS) and Methionine (MT) as presented on Table 1. This was done according to the methods of AOAC (1999). Estimation of the Metabolizable Energy (ME) of ingredient for the feed was calculated by converting the gross energy using the following equation as described by Miller and Payne (1959).

Mineral element analysis: Calcium and the phosphorus content of the ingredients were determined using a Perkin-Elmer Model 5000 Atomic Absorption Spectrophotometer (AOAC, 1999).

Amino acid profile determination: The amino acid profile of the ingredients was determined using methods described by Shahidi *et al.* (1999). Details have been outlined by Adeyeye and Afolabi (2004).

Data analysis: The method of data analysis employed in this study was linear programming model (LPM). All the data generated were computed in computer software with Simplex algorithm for linear and stochastic feed formulation-WINFEED 2.8 (Winfeed, 2006). The optimum feed formulated by this software is presented on Table 2.

Formulation of the research diets: Five isonitrogenous (35% CP), isolipidic (6.00% lipids) and isocaloric (3000 kcal g^{-1}) research diets were formulated for African catfish fingerlings using the result of the LP. The test diets were designated; DT01 (Reference diet), DT02 (RD+DWM), DT03 (RD+SBM), DT04 (RD+BM), DT05 (RD+SHW). The prices of these diets were calculated based on the weight of each ingredient used. The percentage ingredients were converted to weight based on the bag size of 50 kg. These were measured accordingly with a Camry Emperors kitchen balance into the feed mill for milling. The diets mixtures were then extruded through a 2 mm die ring to form noddle-like strands which was mechanically broken into pellets of suitable size for *C. gariepinus* fingerlings. The diets were sun-dried at 31-32°C and stored at -20°C in air-tight polythene bags prior to use.

Table 2: Ingredient composition, fishmeal substitutions and cost of least-cost ration formulated by computerized linear programming for African catfish (*C. gariepinus*) fingerlings

	Experimental diets (%)				
Ingredients	DT01	DT02	DT03	DT04	DT05
FM	28.72	25.13	8.00	8.71	8.00
WMM	34.42	24.02	32.70	40.71	40.07
DBG	16.86	0.00	8.57	16.90	14.74
PKC	20.00	20.00	20.00	20.00	20.00
DWM	-	30.85	-	-	-
SBM	-	-	30.75	-	-
BM	-	-	-	13.69	-
SWM	-	-	-	-	17.14
Salt	0.03	0.03	0.03	0.03	0.03
Total	100.03	100.03	100.05	100.04	99.90
Cost implication					
Bag size (kg)	50.00	50.00	50.00	50.00	50.00
Formula cost (N)	198.52	164.42	152.86	130.80	156.46
Cost bag^{-1} (N)	9926.00	8221.00	7643.00	6540.00	7821.00
% cost reduction	-	17.18	23.00	34.11	21.18

FM: Fishmeal, WMM: White maize meal, DBG: Dried brewers' grain, PKC: Palm kernel meal, DWM: Duckweed meal, SBM: Soybean meal, BM: Blood meal, SWM: Shrimp waste meal

Culture of African catfish

Experimental design: Five earthen ponds of 9×4×1.5 m dimensions were partitioned into triplicates with net and used for rearing the fish. The ponds were cleared, limed with CaO at the rate of 6 kg^{-1} pond and 500 g fermented chicken droppings applied.

Fish maintenance: Six hundred fingerlings of *C. gariepinus* (average weight; 20.15 g) were procured from the University of Calabar fish farm. This was done according to ADCP (1983).

Evaluation of fish performance: Data obtained were used for estimation of fish performance Specific Growth Rate (SGR); Daily Weight Gain (DWG), Apparent Food Conversion ratio (AFCR) and Protein Efficiency Ratio (PER) according to Cowey and Sargent (1972).

Water quality monitoring: Water parameters (Temperature, dissolved oxygen concentration, pH, turbidity, alkalinity and total ammonia concentration) recorded throughout the 90-day experimental period (APHA, 1995) were found to be within acceptable limit for fish growth and health (Boyd, 1990).

Statistical analyses: Data were analyzed by one-way ANOVA. The statistical package used for the analysis of data was SAS statistics, version 6.5.

RESULTS

The compounded reference diet: The optimal ingredient combinations of the diets for *C. gariepinus* fingerlings are shown in Table 2. In subjection to the constraints imposed on the ingredients, the Reference Diet (RD) for fingerlings (DT01) contained the highest value of WMM (34.42%) and the lowest value of DBG (16.86%). FM composition of DT01 (28.72%) was constrained by high cost (N435.00 kg^{-1}) as shown in Table 1. The formula cost for RD was 198.52 naira while those of DT02, DT03, DT04 and DT05 where 164.42, 152.86, 130.80 and 156.46 naira, respectively. The optimum inclusion levels for DWM, SBM, BM and SWM were 30.85, 30.75, 13.69 and 17.14%, respectively.

The nutrient content of RD for fingerlings shows that, DM, P, Ca, MT, LS and ME contents were, 90.340, 1.132, 1.964, 1.082, 1.742 and 3286.910, respectively (Table 3). Diets DT02 to DT05 were modification of RD through FM substitution. CP, CF and EE content were similar in all the diets. The highest value for DM was found in DT02 (91.081) while DT05 recorded the lowest (87.814). DT04 recorded the lowest p-value (0.500%) while DT02 recorded the highest (1.242%). In terms of Ca, DT05 contain the highest (2.500%) while DT03 contain the lowest (0.675%). DT03 has the lowest MT value (0.747%) while DT05 has the highest (1.785%). The LS content of the test diet was found to be lowest in DT05 (1.463%) and highest in DT02 (1.988%). ME ranges from 3169.803 in DT03 to 3558.061 kcal kg^{-1} in DT02. Meanwhile, CP was binding at the nutrient minimum limit with the shadow price of 7.44 naira while CF was binding at the nutrient maximum limit with the shadow price of 5.4 naira.

Effect of dietary treatment on growth performance, feed utilization and carcass composition of *C. gariepinus*: There were no significance differences ($p>0.05$) observed in growth performance or nutrient utilization values among fish fed different diets. Generally, values for all the performance factors examined were high ranging from 3.02 in DT03 to 3.29 in DT05 for Daily Weight Gain (DWG); 3.04 in DT04 to 3.80 in DT01 for Specific Growth Rate (SGR). The values for feed utilization were also high ranging from 2.49 in DT04 to 2.62 in DT03 for apparent feed conversion ratio (apparent FCR) and from 1.09 in DT02 and DT03 to 1.15 in DT04 for Protein Efficiency Rate (PER) as presented in Table 4. Fish carcass composition is shown in Table 5. Whole body composition showed no differences among the groups of *C. gariepinus* fed different diets, the only exception being DT05, where higher CP (69.271%) was measured compared to the remaining diets. Body EE and ash contents (7.786 and 4.092%, respectively) were slightly higher in fish fed DT04 at the expense of CF, which indicated the lowest values. Differences for these parameters (CP, EE and ash) with those of other diets (DT01, DT02, DT03, DT05) were not significant ($p>0.05$).

Table 3: Nutrient composition of the least-cost ration produced by computerized linear programming for African catfish (*C. gariepinus*) fingerlings

	Experimental diets					
Nutrients (%)	DT01	DT02	DT03	DT04	DT05	*Nutrient requirements of *C. gariepinus*
DM	90.340	91.081	89.422	89.751	87.814	-
CP	35.000	35.000	35.000	35.000	35.000	≥35.00
EE	5.655	5.830	5.210	5.091	5.479	≤6.00
CF	7.000	7.000	7.000	7.000	7.000	≤7.00
MT	1.082	0.988	0.747	0.813	1.785	≥0.65
LS	1.742	1.988	1.620	1.906	1.463	≥1.43
Ca	1.964	2.094	0.675	0.713	2.500	≥0.45
P	1.132	1.242	0.510	0.500	0.821	≥0.45
ME (kcal kg^{-1})	3286.910	3558.061	3169.803	3381.845	3270.916	≥3000.00
ME/P	9.391	10.166	9.566	9.662	9.345	8.4-9.5

DM: Dry matter, CP: Crude protein, EE: Ether extract, CF: Crude fibre, MT: Methionine+cystine, LS: Lysine, Ca: Calcium, P: Phosphorus, ME: Metabolizable energy. *(NRC, 1993)

Table 4: Growth performance and feed utilization of *C.gariepinus* fed different diets of fishmeal substitution with conventional and nonconventional ingredients for 90 days

	Experimental diets				
Items	DT01	DT02	DT03	DT04	DT05
Growth performance					
Initial weight	20.05 ± 1.06	20.15 ± 2.22	20.12 ± 1.55	20.11 ± 2.21	20.13 ± 1.41
Final weight	305.21 ± 2.13^{a}	294.29 ± 2.29^{a}	291.85 ± 2.15^{a}	312.08 ± 6.12^{a}	316.37 ± 5.17^{a}
DWG (g fish^{-1})	3.17 ± 0.04^{a}	3.05 ± 0.96^{a}	3.02 ± 1.00^{a}	3.24 ± 0.66^{a}	3.29 ± 0.15^{a}
SGR	3.80 ± 0.67^{a}	2.98 ± 0.08^{a}	$2.98\pm.0.38^{a}$	3.04 ± 0.04^{a}	3.07 ± 0.32^{a}
Feed utilization					
FI (g fish^{-1})	730.01 ± 5.22	730.88 ± 1.29	730.18 ± 4.03	730.84 ± 2.28	730.66 ± 1.43
Apparent FCR	2.56 ± 0.52^{a}	2.61 ± 0.02^{a}	2.62 ± 1.06^{a}	2.49 ± 0.12^{a}	2.52 ± 0.24^{a}
PER	1.11 ± 0.06^{a}	1.09 ± 1.06^{a}	1.09 ± 0.52^{ac}	1.15 ± 0.08^{c}	1.14 ± 0.05^{a}

Mean followed by the same letters in each row for each treatment are not significantly different ($p<0.05$) DWG: Daily weight gain, SGR: Specific growth rate, FCR: Feed conversion rate, PER: Protein efficiency rate

Table 5: Effect of dietary treatment on carcass composition of *C. gariepinus* cultured in earthen ponds for 90 days

	Experimental diets (%)					
Parameter	DT01	DT02	DT03	DT04	DT05	Initial
Dry matter	82.613	86.316	79.209	81.314	87.349	86.855
CP	63.613	60.316	58.673	61.691	69.271	56.751
EE	7.371	5.366	6.270	7.786	5.437	3.746
CF	1.026	0.813	0.691	0.667	0.750	0.502
Ash	3.341	3.616	3.863	4.092	3.361	4.268
Moisture	45.044	30.113	36.163	41.263	35.312	25.044

CP: Crude protein, EE: Ether extract, CF: Crude fibre

DISCUSSION

Results show that DWM, SBM, BM and SWM can be used as a valuable protein sources for fish production. The crude protein contents of the dried DWM used in the present study (24.80%) is low compared to duckweed composition data determined by Tavares *et al.* (2008). According to these authors, the protein content ranged from 30 to 40% and the fiber content from 5 to 15 percent, when the duckweed was cultivated in nutrient rich media. Meanwhile, the fibre content of DWM in this study (12%) falls within the optimum range. However, the crude protein level in this study is higher than the level (18.34%) determined by Yilmaz *et al.* (2004). This shows that, nutrient content of duckweed varies according to the culture system. Generally, DWM holds immense potential for both nutrient recovery and utilization as fodder or feed for livestock including fish (Ansal *et al.*, 2010). SBM has good amino acid profile similar to FM and can replace FM in aquafeeds. Study shows that SBM has replaced FM up to 60%, particularly in feeds for omnivorous fish in spite of the presence of antinutritive factors such as trypsin inhibitor and phytate (Hashim, 2006). Meanwhile, SBM, BM and SWM used in this study had proximate composition similar to that of NRC (1993).

Results show that all nutrients were within the recommended nutrient requirements of *C. gariepinus* fingerlings (NRC, 1993). The optimum ingredient mixes is obtained at 30.85, 30.75, 13.69 and 17.14% inclusion level of DWM, SBM, BM and SWM, respectively thereby replacing 12.5, 72.14, 69.67 and 72.14% FM in their respective diets. The value for DWM is high as compared to the study of Robinnette *et al.* (1980) who substituted 10.0% DWM for fishmeal in the diet for channel catfish and lower than that of a more recent findings by Oyin and Agboola (2005) and Effiong *et al.* (2009) who substituted 25 and 20.0% DWM for fishmeal in the diet of African catfish (*C gariepinus* and *Heterobranchus longifilis*), respectively. However, the values for SBM, BM and SWM are virtually low as compared to the findings of Fafioye *et al.* (2005), Agbebi *et al.* (2009) and Nwanna (2003) who reported 62, 25 and 30% inclusion of SBM, BM and SWM, respectively in the diet for African catfish (*Clarias gariepinus*) fingerlings. These discrepancies are due to the fact that, when replacement is done in a least-cost diet using linear programming technique, not only FM that is replaced but also other ingredients since nutrient compositions vary. Feeding catfish with these diets could reduce feed costs by 17.18, 23.00, 34.11 and 21.19%, respectively. Meanwhile, application of LP technique in least-cost feed formulation for *C. gariepinus* has minimized the feed cost by 10.13% (Udo *et al.*, 2011a,b). Therefore, inclusion of these feedstuffs in least-cost ration will reduce feed cost by 27.31, 33.13, 44.24 and 31.32%. This value is higher than the findings of Olorunfemi (2006) who showed that, utilization of diet containing 29.50% DWM is cost-effective by reducing the cost of the feed by 20.8%. Therefore, the practical feasibility of such a feeding regime depends on duckweed production costs, which can vary depending on the resources available on each farm.

The mean values of FCR (2.61, 2.62, 2.49 and 2.52) obtained in this study for DWM, SBM, BM and SWM, respectively are comparable to those of other researchers (2.45, 18.45, 1.36 and 2.65) except those of SBM which is relatively better (Yilmaz *et al.*, 2004; Fafioye *et al.*, 2005; Agbebi *et al.*, 2009). The values of SGR, obtained in this study are better than the mean values of 2.16, 0.85, 1.01 and 1.79 reported by these authors for DWM, SBM, BM and SWM, respectively. Also the PER values observed in this study are better than 1.67, 0.40, 98.26 and 1.13 reported by these authours for DWM, SBM, BM and SWM, respectively. This discrepancy points to the fact that linear programming is the only technique for the formulation of nutritionally balanced diet that is well utilized by fish. One of the most commonly encountered difficulties, when alternative protein sources are used, is acceptability due to the palatability of the diets fed to fish (Rodriguez-Serna *et al.*, 1996). In this study, no palatability problem was encountered. All the diets were well utilized by catfish fingerlings.

Carcass composition of the experimental fishes showed that all the fishes fed the experimental diets had higher carcass protein and lipid contents and lower ash and nitrogen free extract contents than the initial fish sample. These values are however, similar for all treatments. This indicates that there was protein synthesis and increased tissue production in treated *C. gariepinus* and that fish growth was not due to the increase in weight alone (Koven *et al.*, 2001; Fountoulaki *et al.*, 2003). The moderately high level of carcass fat in diets DT01-05 indicated an enhanced production of lipids in the fish. Fountoulaki *et al.* (2003) observed in gilthead bream fingerlings that lipid was associated with increase efficiency of metabolism.

Concerning the prospect of these feedstuffs, DWM provides an easy, practical and cheaper fish feedstuff because it requires no processing to destroy any antinutrients (Nweke and Ugwumba, 2005). SBM has high nutritive and commercial value (Boonyaratpalin *et al.*, 1998). It is used as protein supplement and it constitutes the major fraction of the crude protein, with relatively high amount of lysine and essential amino acids and vitamins (i.e., thiamine, niacin, B-complex and carotene) (Martin and Ruberte, 1980). BM is low in P which will please fish farmers from both an environmental and industrial perspective. Agbebi *et al.* (2009) reported that FM can be replaced completely (100%) by BM with no adverse effects on growth, survival and feed conversion of

C. gariepinus. Such a replacement should be highly programmed in order to cater for other nutrients like calcium and methionine which are low in BM as compared to FM since fish requires high quality nutritionally balanced diet for growth and attainment of market size within the shortest possible time. Meyers (1986) reported that SWM contains a high amount of protein with excellent amino acid profile comparable to FM. Therefore, SWM can adequately substitute FM aqua-feeds as the later is scarce and expensive. Nevertheless, SWM contains high levels of chitin and ash which limit nutrient availability, utilization and digestibility in fishes. Hall and de Silva (1994) and Fox *et al.* (1994) noted that fermentation could reduce the chitin and ash content and consequently increase the protein, lipid and pigment concentration.

CONCLUSION

Generally, results show that protein-rich feed resources have the potentials to be optimally included in the formal least-cost diet for *C. gariepinus* fingerlings. This will replace FM and change the overall feed mixes, thereby formulating the same nutritionally balanced diets at a more reduced cost. This, However, does not cause any negative effect on the growth performance, feed and protein utilization and carcass composition of *C. gariepinus* fingerlings. Linear programming is the only means of achieving this.

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