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Growth performance, feed efficiency and carcass composition of African catfish, *Clarias gariepinus* (Picess: Clariidae) fingerlings fed diets composed of agricultural by-products

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Abstract

Four experimental diets were formulated to contain different ratios of animal protein to plant protein of 1:12 (diet F1), 1:9 (diet F2), 1:6 (diet F3) and 1:2 (diet F4).Diets F1 and F2 contained crude protein level of 35% at gross energy of 17 kJ/g providing protein to energy ratios (P/E) of 21 23 mg CP/kJ while diets F3 and F4 contained crude protein of 40% at gross energy level of 19 kJ/g providing P/E of 23 mg CP/kJ. The diets were fed to quadruplicate groups of African catfish *Clarias gariepinus* fingerlings (5.37 ± 0.23 g) for 12 weeks. The group of fish receiving the experimental diet F4 attained the highest ($P < 0.05$) final weight (31.25 g), weight gain (480.41%), specific growth rate (2.09 %/day), carcass nitrogen deposition (8.86 mg/day), apparent nitrogen utilization (28.81 %) and energy conversion efficiency (19.60 %). These results were followed by the fish group fed diet F3. The lowest ($P < 0.05$) results were attained by fish groups fed diets F1 and F2. The best ($P < 0.05$) feed conversion ratios were recorded in the groups of fish fed diets F3 and F4 and the poorest values were observed in the groups fed diets F1 and F2. Survival rates ranged between 86.67 and 93.33% and no significant differences ($P > 0.05$) were observed between the experimental groups. The highest ($P < 0.05$) body protein, lipid and energy content attained by the fish fed diet F4. These findings suggest that a diet containing a proportion of 1 : 2 animal protein to plant protein at protein level of 40%, gross energy of 19 kJ/g diet, and a protein to energy ratio of 23 mg CP/kJ could allow a complete replacement of commercial fish meal with agricultural by-products in diets of African catfish without negatively affecting its growth performance, feed utilization or carcass composition.

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Introduction

The shortage and rising cost of commercial fish meal, manufactured primarily from industrial fish such as menhaden, anchovy, sardines, mackerel and herring, have prompted the researchers to investigate the production of cost effective feed formulations for cultured fish species (Nyina-Wamwiza *et al.*, 2010). For African catfish, *Clarias gariepinus*, some efforts have concentrated on partial or total replacement of commercial fish meal in its diets with alternative sources of cheaper ingredients of animal and plant origins (de Graaf and Janssen, 1996; Ogunji *et al.*, 2008; Nyina-Wamwiza *et al.*, 2010). Among the potential animal protein sources is the large amount of tilapia processing by-products, amounting to approximately 64-69.5% of live fish harvested, which have become now available as an ingredient in commercial poultry feeds (Ponce and Gernat, 2002; Dale *et al.*, 2004). Poultry by-products meal, rendered from poultry processing plant offal, is the most common animal protein product used with success in fish feeds (Shapawi *et al.*, 2008; Rawles *et al.*, 2011). Among the plant proteins, soybean meal is considered, among all plant proteins, the best protein source for aquaculture feeds due to its nutritional value and cost effectiveness (Nguyen, 2008). Plant proteins at high percentage along with a small portion of animal protein were successfully used to replace the fish meal in the *C. griepinus* diets (Nyina-Wamwiza *et al.*, 2010). However, the plant proteins should be properly processed to rid or reduce the anti-nutritional factors usually present in plant materials such as trypsin inhibitor in soybean and tannins in sorghum (Kumar *et al.*, 2012) and cyanogenic glycosides present in the tuberous roots of cassava (Abu *et al.*, 2010).

On the other hand dietary protein is considered the main constituent in fish diets required to support growth but proportionally it increases the feed cost (Ahmad, 2008). African catfish has a relatively high protein requirements and the best growth rates and food conversions were achieved with diets containing 35-42% crude protein (Ogunji *et al.*, 2008). Dietary energy regulates metabolic activities and greatly affects the growth performance and feed utilization efficiency (Sweilum *et al*, 2005). Improper dietary protein and energy levels and their ratios may lead to lower fish performance, increase accumulation of lipids and glycogen in the somatic tissues and liver, increase undesirable nitrogenous waste output and an increase in production cost (Yousif *et al.*, 1996; Ahmad, 2008). Excessive dietary protein level in relation to energy can actually reduce growth due to the metabolic demands of nitrogen excretion. Several studies have been conducted to determine the optimum dietary protein and energy levels and their ratios for African catfish, *Clarias gariepinus* (Uys and Hecht, 1985; Degani *et al*, 1989; Eding *et al.*, 1993; Senger *et al.*, 1993; Ali and Jauncey, 2005; Ahmad, 2008; Nyina-Wamwiza *et al.*, 2010).

The present study was therefore conducted to evaluate the effect of complete replacement of commercial fish meal with lower-cost protein sources originating from animal and plant byproducts at two different levels of dietary protein and energy on the performance of African catfish, *Clarias gariepinus*.

Materials and methods

Experimental diets

Four experimental diets, composed of animal and plant byproducts, were formulated to contain two crude protein (CP) levels (35 and 40% dry weight) at two gross energy (GE) levels (17 and 19 kJ/g). Tilapia byproduct meal, poultry byproduct meal and soybean meal were the major protein sources in the experimental diets (Table 1).

The percentages of animal byproduct, of the total feedstuffs incorporated in the experimental diets, were designed to be 8% in diets F1, 10% in diet F2, 14% in diet F3 and 34% in diet F4 yielding ratios of 1:12, 1:9, 1:6 and 1:2 g/kg dry weight animal protein : plant protein in diets F1, F2, F3 and F4, respectively (Table 2). Soybean and sorghum meals were heated at 100 °C for one hour to destroy the anti-nutritional factors such as the trypsin inhibitor in soybean and tannis in sorghum. Fresh cassava roots were first blanched for 5 minutes in boiling water at 100 °C to rid the anti-nutrient cyanogenic glycosides present in the tuberous roots. All dry feed ingredients were finely ground and then thoroughly hand mixed for 10 minutes before the addition of oil. After the oil was dispersed and mixed, dissolved binder (carboxymethylcellulose) and water were added to form a dough-like which was then extruded using kitchen meat grinder fitted with 2 mm die. The resulting diet strands were subsequently oven dried at 55°C for 12 hours. After complete drying the strands were broken into crumbles and sieved into particles of 2 mm diameter. Crumble diets were then stored in freezer at -18°C in sealed plastic bags until fed. All experimental diets were analyzed for the proximate compositions according to standard methods (AOAC, 1990). The nitrogen-free extract (NFE) was calculated by difference [100 – (crude protein + crude lipid + crude fiber + ash)]. Gross energy was calculated based on the conversion factors: protein 23.51 kJ/g, lipid 39.75 kJ/g and carbohydrate (as NFE) 17.20 kJ/g (Shiau and Liang, 1994).

Experimental procedure

African catfish fingerlings averaging 5.37 ± 0.23 were randomly distributed among sixteen 128-L indoor plastic containers each filled with 100 L freshwater at a stocking rate of 15 fish per container. All fish were acclimated for a period of 1 week during which fish were fed twice daily *ad libitum* with 35% CP commercial diet. One day before the feeding trials, the experimental fish in all tanks were deprived of feed. Each of the four experimental diets was tested in quadruplicate for a period of 12 weeks. Fish in all treatments were hand fed 6 days a week at 5% body weight (BW) per day in the first 6 weeks and 4% BW during the rest of the experimental period. Water exchange was carried out once daily at a rate of 75% in the evening. Uneaten feed and waste excreta were siphoned out two times daily with minimal water waste. At fortnightly intervals the fish were bulk weighed and daily feed amounts were adjusted accordingly. Dead fish in each container were immediately removed and recorded. At the beginning and end of the experiment, samples of fish were retained from each treatment for subsequent proximate analysis. The water temperature and dissolved oxygen were monitored daily, pH, ammonia, nitrite and alkalinity were recorded biweekly. The water quality mean values (± SD) recorded were: water temperature 30.43 ± 1.01 °C, dissolved oxygen 6.75 ± 0.45 mg/l, pH 7.40 ± 0.21 , ammonia 0.06 ± 0.06 mg/l, nitrite 0.01 ± 0.00 mg/l and alkalinity 68.63 ± 13.75 mg $CaCO_3$/l.

Analytical methods

The growth performance and feed utilization efficiency of the fish were evaluated by determining the survival rate (%), weight gain (%), specific growth rate (SGR, %/day), feed conversion ratio (FCR), protein efficiency ratio (PER), condition factor (K), carcass nitrogen deposition (CND mg/day), apparent nitrogen utilization (ANU %) and energy conversion efficiency (ECE %) and were calculated as follows:

Survival (%) = 100 [(final no. fish – initial No. fish)/(initial no. fish)].

Weight gain (%) = 100 [(final fish wt – initial fish wt)/(initial fish wt)].

SGR (%/day) = 100 [($\log_e$ final wt $-\log_e$ initial wt)/(time, days)].

FCR = Feed intake, g/fish wt gain, g.

PER = fish wt gain, g/protein intake, g.

K = 100 [(final body weight, g) / (L_s^3, cm)], where L_s = final standard body length.

CND (mg/day) = 1000 [(final fish wt X % final carcass protein) – initial fish wt X % initial carcass protein)] / (time, days) / (6.25).

ANU (%) = 100 (CND / nitrogen intake).

ECE (%) = 100 [(energy gain, kJ) / (energy intake, kJ)], where energy gain = (final body energy) – (initial body energy).

Statistical analysis

The data are presented as means ± SD of four replicates. All performance and body composition means were compared using PASW, Release 18 (SPSS Inc., 2009). Duncan's multiple range test was used to test for differences among treatment means at $P < 0.05$.

Results

The results of growth performance and feed utilization efficiency of African catfish *Clarias gariepinus* fed diets containing different animal and plant feedstuffs with different protein and energy levels for 12 weeks are displayed in Table 3. The group of fish receiving the experimental diet F4 composed of 1:2 animal protein : plant protein ratio and containing 41.11 % crude protein level at 19.02 kJ/g diet gross energy with 21.61 mg CP/kJ protein-to-energy ratio (P:E ratio) attained the highest ($P < 0.05$) final weight (31.25 g), weight gain (480.41%), specific growth rate (2.09 %/day), carcass nitrogen deposition (8.86 mg/day), apparent nitrogen utilization (28.81 %) and energy conversion efficiency (19.60 %). These results were followed by the fish group fed diet F3 composed of 1:6 animal protein : plant protein ratio and containing 39.49 % crude protein level at 15 kJ/g diet gross energy with 22.43 mg CP/kJ P:E ratio. The lowest ($P < 0.05$) results of final weight, weight gain, carcass nitrogen deposition, apparent nitrogen utilization and energy conversion efficiency were attained by fish groups fed diets F1 and F2 composed of 1:12 and 1:9 animal protein : plant protein ratio and containing 34.871 and 35.84 % crude protein levels at 16.87 and 19.18 kJ/g diet gross energy with 20.67 and 18:69 mg CP/kJ P:E ratios, respectively. The best ($P < 0.05$) feed conversion ratios were recorded in the groups of fish fed diets F3 and F4 and the poorest values were observed in the groups fed diets F1 and F2. The protein efficiency ratio values recorded in the groups fed diets F2, F3 and F4 were not significantly different ($P > 0.05$). No significant differences were observed between the condition factor and feed intake values in all treatments. Survival rates ranged between 86.67 and 93.33% and no significant differences ($P > 0.05$) were observed regardless of dietary treatment. Body composition of the fish fed the four experimental diets (Table 4) showed that the highest ($P < 0.05$) body protein, lipid and energy content were attained by the fish fed diet F4. The ash content was similar in all treatments. The lowest ($P < 0.05$) body lipid was attained by the fish group fed diet F1. The moisture content in all experimental groups was inversely related to the body lipid.

Table 1. Chemical composition of the major animal and plant ingredients incorporated in the experimental diets (% DM basis).

Ingredient	Dry Matter	Crude protein	Crude fat	Crude fiber	Ash	NFE
Tilapia byproduct meal	92.50	56.30	23.90	-	18.70	-
Poultry byproduct meal	91.20	61.40	29.70	-	6.80	-
Soybean meal	91.80	46.70	2.48	4.80	7.95	41.52

Discussion

The African catfish, *C. gariepinus* fry (5.37 ± 0.23 g) fed the experimental diet F4 containing high protein level of 41.11% with 1:2 animal to plant protein ratio at 19.02 (kJ/g diet) gross energy with 21.61 (mg CP/kJ) P:E ratio exhibited the highest ($P < 0.05$) growth performance, feed utilization efficiency and body compositional indices. Ali and Jauncey (2005) found that the best growth of *C. gariepinus* fingerlings (10.89 ± 0.04) was achieved at 430 g/kg protein, 21.2 kJ/g gross energy and P:E ratio of 20.5 mg crude protein/kJ gross energy. Despite the fish sizes, these results when related to protein level and P/E ratio are in some correspondence with the present study. However, these observations contradict the findings of many authors that the protein and P:E ratio are in general greater for the smaller than for larger fish (Winfree and Stickney, 1981;Yousif *et al.*, 1996). This may suggest that the quantitative protein requirement and the P/E ratio for the African catfish fry that support best growth and feed utilization are higher than the levels used in the present study. There are no significant differences ($P < 0.05$) between the feed intake of the four experimental groups. This may indicate that the inclusion of different levels of plant and animal by-products to replace the commercial fish meal did not affect the palatability and acceptance of the diets.

The inclusion of animal and plant proteins at a ratio of 1 : 2 in diet F4 demonstrated the best growth performance while the medium results were obtained by diet F3 in which the inclusion was at a ratio of 1 : 6 (animal protein : plant protein). The lowest performance was recorded for diets F1 and F2 in which the animal protein : plant protein ratios were 1 : 12 and 1 : 9, respectively The poor growth performance rates and feed utilization efficiency of fish as a function of high inclusions of plant protein versus animal protein in diets F1 and F2 could be attributed to the deficiency of essential amino acids required for growth. Another factor that may have affected the quality of plant proteins is the heat treatment of the plant ingredients applied in the present study to rid the anti-nutritional factors might have affected the protein quality of these ingredients. Many studies have indicated that heat treatment have caused deficiency and imbalance in the protein quality of plant proteins (Viola *et al.*, 1983; Bressani *et al.*, 1987; Ogunji *et al.*, 2008).

Table 2. Ingredients (% DM) and chemical composition of the experimental feeds F1, F2, F3 and F4.

Ingredients	Experimental diets (animal protein : plant protein)			
	F1 (1:12)	F2 (1:9)	F3 (1:6)	F4 (1:2)
Tilapia byproduct meal	5.0	6.0	8.0	17.0
Poultry byproduct meal	2.0	3.0	6.0	1.5
Soybean meal	44.5	44.5	44.5	32.5
Sorghum meal	1.5	1.5	1.5	1.5
Alfalfa meal	33.5	33.0	33.0	23.0
Wheat bran	3.5	3.5	3.5	3.5
Cassava root meal	1.5	0.5	0.5	1.5
Sunflower oil	-	5.0	-	1.0
Vitamin-mineral mix[1]	1.5	1.5	1.5	1.5
Binder (carboxymethylcellulose)	1.0	1.0	1.0	1.0
α-cellulose	6.0	0.5	0.5	3.0
Chemical analysis (g/kg dry weight)				
Dry matter	91.14	91.35	92.81	91.81
Crude protein	34.87	35.84	39.49	41.11
animal protein	2.68	3.51	5.70	14.07
plant protein	32.19	32.33	33.79	27.04
Crude fat	4.50	8.91	4.82	8.44
Crude fiber	8.44	2.30	7.08	3.01
Ash	12.18	11.03	11.42	12.54
NFE	40.01	41.92	37.19	34.90
GE (kJ/g diet)	16.87	19.18	17.60	19.02
P/E ratio (mg CP/kJ)	20.67	18.69	22.43	21.61

[1] Vitamin-mineral premix: Vitalyte Plus, Anglian Nutrition Products Co., UK (A 15,000,000 IU; D3 4,400,000 IU, E 1,350 mg, K 4,350 mg, B24,350 mg, B6 2,350 mg, B12 11,350 mg, C 1,000 mg, Nicotinamide 16,700 mg, Calcium pantothenate 5,350 mg, Potassium chloride 87,000 mg Sodium sulphate 212,000 mg, Sodium chloride 50,000 mg, Magnisium sulphate 12,000 mg, Copper sulphate 12,000 mg, Zinc sulphate 12,000 mg, Manganese sulphate 12,000 mg, Lysine 15,000 mg, Methionine 10,000 mg, Lactobacillus species (as probiotic) $1x10^9$ cfu/g).

Data from the present study demonstrated that plant protein could be used to completely replace fish meal (menhaden) in African catfish provided that it is combined with an animal protein source and that the adequate proportions between the two sources is maintained. Attempts to completely replace commercial fish meal with animal or plant protein sources in fish diets have provided equivocal results (Robinson and Li, 1993). Some researchers indicated that commercial fish meal may be superior to other feed ingredients in terms of amino acid composition, availability and palatability (Hardy and Barrows, 2002; Sink *et al.*, 2010) and that feed devoid of commercial fish meal depressed weight gain of fish (Lovell,1992). On the contrary, Robinson and Li (1994) proved that soybean meal or a combination of soybean meal, cottonseed meal and supplemental lysine could be used to replace commercial fish meal in feeds for grow-out of channel catfish without detrimental effects (Robinson and Li, 1993, 1994). Furthermore, Sink *et al.* (2010) indicated that the growth is not limited in channel catfish fry fed all plant protein diets, and that there is no apparent advantage to the inclusion of animal protein in diets for this species fry. Nyina-Wamwiza *et al.* (2010) examined the partial or total replacement of menhaden fish meal (MFM) by agricultural by-products in diets of juvenile African catfish (7.49 ± 0.09 g) and concluded that MFM can be totally replaced by plant feedstuffs in African catfish, assuming that a proper balance of different plant ingredients is ensured and that the diet should contain a proportion of animal protein such as blood meal and chicken viscera meal.

Table 3. Growth performance and feed utilization of fish fed the experimental diets F1, F2, F3, F4[1] (mean ± SD, n = 4 replicates).

Variable[2]	F1	F2	F3	F4
Initial wt (g)	5.38 ± 0.26	5.35 ± 0.25	5.37 ± 0.26	5.38 ± 0.27
Final wt (g)	17.02 ± 2.19^{c}	19.69 ± 2.44^{c}	24.82 ± 1.19^{b}	31.25 ± 2.35^{a}
Survival (%)	86.67 ± 5.44^{a}	88.33 ± 6.38^{a}	91.67 ± 6.38^{a}	93.33 ± 5.44^{a}
Wt gain (%)	216.36 ± 38.67^{c}	267.58 ± 35.54^{c}	363.29 ± 33.31^{b}	480.41 ± 30.14^{a}
SGR (% day^{-1})	1.36 ± 0.14^{d}	1.55 ± 0.12^{c}	1.82 ± 0.08^{b}	2.09 ± 0.06^{a}
K	0.73 ± 0.09^{a}	0.75 ± 0.03^{a}	0.78 ± 0.04^{a}	0.83 ± 0.03^{a}
Feed intake (g/day)	0.32 ± 0.025^{a}	0.37 ± 0.022^{a}	0.43 ± 0.037^{a}	0.49 ± 0.045^{a}
FCR	2.38 ± 0.39^{a}	2.20 ± 0.24^{a}	1.87 ± 0.24^{b}	1.58 ± 0.06^{b}
PER	1.23 ± 0.22^{ab}	1.28 ± 0.13^{a}	1.34 ± 0.17^{a}	1.52 ± 0.21^{a}
CND (mg/day)	3.58 ± 0.66^{c}	4.48 ± 0.71^{c}	6.31 ± 0.41^{b}	8.86 ± 0.74^{a}
ANU (%)	19.90 ± 3.52^{b}	21.03 ± 2.14^{b}	22.76 ± 2.90^{b}	28.81 ± 1.18^{a}
ECE (%)	8.84 ± 0.68^{d}	13.11 ± 0.83^{c}	15.68 ± 1.28^{b}	19.60 ± 1.85^{a}

[1] Means in the same row sharing the same superscript are not significantly different (P > 0.05).

[2] As defined in text.

The body contents of protein, lipid and energy content were observed to increase with increasing protein to energy ratio. It was also observed that as the carcass moisture content decreased, the fat content appeared to increase. These findings are consistent with the results of many studies such as studies on blue tilapia *Oreochromis aureus* (Alhadhrami and Yousif, 1994), Nile tilapia *Oreochromis niloticus* (Ali *et al.*, 2008), Asian seabass *Lates calcarifer* (Catacutan and Coloso, 1995, the rabbitfish *Siganus canaliculatus* (Osman *et al.*, 1996; Yousif *et al*, 2005), African catfish *Clarias gariepinus* (Ali and Jauncey, 2005).

Table 4. Body composition (% wet body weight) of catfish fed experimental feeds F1, F2, F3 and F4[1].

Variable	Initial	F1	F2	F3	F4	± SEM
Moisture (%)	77.73	75.81^{a}	75.76^{a}	74.88^{a}	73.94^{b}	0.417
Crude protein (%)	15.68	16.15^{b}	16.39^{b}	17.04^{ab}	17.98^{a}	0.172
Crude lipid (%)	3.03	3.85^{c}	4.76^{b}	4.83^{b}	5.84^{a}	0.208
Ash (%)	4.07	4.41^{a}	4.54^{a}	4.65^{a}	4.7	0.338
Energy content (kJg^{-1})	4.89	5.33^{c}	5.75^{c}	5.93^{ab}	6.55	0.111

[1] Means in the same row sharing the same superscript are not significantly different (P > 0.05).

In conclusion, the findings of the present study indicate that the level of inclusion of agricultural by-products is dependent on the levels of crude protein, gross energy in the diet and on the protein to energy ratio. This study suggests that if the proportions of animal protein and plant protein are maintained within 1 : 2 at a protein level of 40%, gross energy of 19 kJ/g diet, and a protein to energy ratio of 23 mg CP/kJ, then the expensive commercial fish meal could be completely replaced with agricultural by-products in the diets of African catfish without any apparent detrimental effects on the growth performance, feed utilization or body composition.

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