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Groundnut and Cottonseed Meals in Tilapia Juvenile Diets: Effects on Apparent Nutrient Digestibility, Short-Term Growth Performance, Feed Utilization and Carcass Composition

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Abstract

Oilseed by-products constitute a potential ingredient in fish feeds owing to their low cost, availability, and high protein contents. However, plant proteins tend to be deficient in essential amino acids limiting their utilization and incorporation in fish diets. This study evaluated the apparent nutrient digestibility, growth performance, feed utilization and whole-body composition of Nile tilapia fed diets containing 30% of cottonseed meal (CSM) or groundnut meal (GNM). The plant proteins corresponded to approximately 12% of dietary protein and replaced 42% to 46% of fish meal protein, respectively. The test diets; groundnut meal (GND30) and cottonseed meal (CSD30) were formulated to contain 32% crude protein and 14% crude lipid, with a gross energy density of 20 MJ/kg. A fish meal based diet served as a control (CD). Overall, the results showed that, with the exception of mean final body weight, weight gain (%), SGR and FCR did not differ among the diets but was highest in CD followed by GND30 and CSD30. The CSD30 resulted in significant reductions in protein and lipid digestibility, whereas nitrogen free extract digestibility was not affected in all diets. In general, 30% inclusion level of CSM and GNM are suitable replacements for fish meal in diets for Nile tilapia.

Keywords: Agro by-product; Nutrient digestibility; Nile tilapia; Oilseed meal

Introduction

The intensification, growth and development of aquaculture largely relies on the availability of high quality feed input, which also constitutes the major production cost in commercial fish farming [1]. Commercial fish feeds are formulated from a blend of terrestrial and marine ingredients, in which the use of fishmeal represents between 3% to 45% inclusion level depending on the age and type of species [2]. This is due to the advantageous characteristics such as high protein concentration, excellent amino acid profile and palatability which positively influence growth [3,4]. However, global fishmeal production has stabilized at 6 million tonnes to 7 million tonnes annually [5,6] and availability is limited. With no expected increases in fishmeal (FM) or fish oil (FO) production over the next decade, the incorporation of plant based raw materials in formulated feeds is expected to rise [7]. This has driven exploratory efforts into producing low-cost fish feeds from plant-based raw materials for certain finfish species, without compromising fish growth [8].

Many plant feed resources that could be used in feed production remain poorly utilised, undeveloped or even unexploited [9] despite being available in large quantities [10]. For example, in sub-Saharan Africa, by-products obtained from harvesting and or processing of agricultural commodities for human consumption is considered as waste with no economic use [11]. In view of the increasing demand for fish and fish products in most developed and developing countries, there is a need for better utilization of non-conventional feed resources [12]. Agro by-products such as groundnut meal/cake, sunflower, copra and palm kernel cakes, and cottonseed, canola and rapeseed meals [3,13] have been identified as cheaper and more readily available [3] protein sources to partially replace fishmeal in fish feeds [10]. These meals and cakes have potential use in fish feeds particularly for omnivorous warm water species like tilapia and the African catfish [2]. Nonetheless, an understanding of the potential nutritional limitations in their utilization is lacking, prohibiting their proper incorporation in fish diets.

Industrially produced groundnut meal/cake (GNM) in sub-Saharan Africa, is readily available for animal feed after oil extraction for human consumption whereas cottonseed meal (CSM) is available and usually less expensive than fishmeal, yet is hardly used in formulated feeds for tilapia, due to limited information on its nutritional value. Harnessing GNM and CSM in fish feeds could be beneficial in reducing feed cost for commercial fish farming while safeguarding the sustainability of the enterprise [14]. A major caveat in the use of plant-based raw materials is their lower crude protein level and often unbalanced amino acid profile compared to fish meal. The objective of the present study was to evaluate the apparent digestibility of nutrients as well as the short-term growth performance, feed utilization and whole-body composition of Nile tilapia fed diets in which cottonseed meal (CSM) and groundnut meal (GNM) were used to partially substitute fish meal (FM).

Materials and Method

Experimental ingredients

Screw-pressed cottonseed cake was acquired from Boris B Farms, a commercial agro-feed input dealer at Bantama and mechanically extracted groundnut meal from a local producer at Aboabo, all suburbs in Kumasi, Ghana. Fishmeal (LT SUPREME, FF Skagen A/S) and wheat bran (VALSEMØLLEN, Esbjerg, Denmark) were obtained from commercial sources in Denmark.

Diet formulation and preparation

Three iso-proteic (32% crude protein) and iso-lipidic (14% crude lipid) diets were prepared, to satisfy the nutritional requirements of tilapia using commercial software; (WINFEED V. 2.8, Cambridge, UK). The formulation was done such that the test ingredients contributed 12% of the total dietary protein content and replaced 42%-46% of fishmeal protein which corresponded to 30% inclusion level. The diets were designated as CSD30 and GND30 corresponding to cottonseed meal and groundnut meal respectively, whereas a fishmeal-based diet served as the control (CD). All ingredients were weighed out according to their respective formulations and were thoroughly mixed by hand until a homogenous mixture was obtained before adding pre-gelatinized tapioca starch and palm oil to obtain a dough-like mixture. The mixture was then pelleted with a meat grinder (KENWOOD MG470, UK) fitted with a 2.0 mm die plate. The pelletized diets were oven dried (MEMMERT UN110, Schwabach, Germany) at 40°C for 48 hours. The dried feeds were cooled, sealed in airtight polythene bags and stored at 4°C until feeding commenced.

Experimental design and facility

Due to the number of treatments applied in this study, nine tanks which formed the experimental units were used for the experiment which lasted for 12 days. The experimental diets applied were a control diet (CD) that contained fish meal as the main dietary protein source, cottonseed meal diet (CSD30) and groundnut meal diet (GND30), containing 30% inclusion level each of cottonseed meal and groundnut meal, respectively. The experimental diets were assigned to the tanks in triplicate groups using a complete randomized design. Fish growth and feed utilization recorded by measuring the weight gain (%), specific growth rate (% day^{-1}), feed conversion ratio, whereas the apparent digestibility coefficient and carcass composition of macronutrients of each diet was determined. The design of the tanks was the modified recirculating Guelph Digestibility System [15] located at the Technical University of Denmark at the North Sea Research Centre in Hirtshals. The system consisted of nine 150 L cylindro-conical PETG thermoplastic tanks with water flow rate of 2.5 L min^{-1}. Water temperature was thermostatically controlled at 25ºC using a relay-controlled 1.5 kW electric heater (JEVI A/S, Denmark) submerged in the reservoir tank. Dissolved oxygen concentration ranged between 5.73 mg/L and 6.38 mg/L during the experiment by an external air blower (HIBLOW, HP-40, Japan) connected to air stones in each tank. Illumination in the system was controlled at 12 hours of light and 12 hours of darkness by means of a 7W led lamp overhead each tank.

Fish stocking and feeding

All-male Nile tilapia (*Oreochromis niloticus*) were purchased from a commercial producer (TIL-AQUA INTERNATIONAL, Velden, The Netherlands) and were maintained on a commercial diet (EFICO ALPHA 845F, 32% protein, Biomar A/S, Denmark) until the experiments begun. At stocking, uniform-sized juvenile fish (35 g ± 0.7 g) were stocked at 15 individuals per tank and acclimated to the experimental facility for 7 days. During the experimental regime, fish were fed 3% of their body weight which was split over two feedings at 09:00 h and 15:00 h. Feeding was done carefully by giving small quantities at a time to avoid feed wastage. Before stocking, 15 fish were randomly selected from the population and an additional 3 fish were randomly selected from each tank at the end of the experiment for analysis of whole body composition. The selected fish were quickly euthanized by immersion into 2-Phenoxyethanol solution (0.6 mL/L) until fish were unconscious before an extra 0.1 mL/L was added until death (cessation of opercula movement) following procedures described in AVMA [16]. The dead fish were rinsed with freshwater, cut into smaller pieces, blended and frozen at −20°C; the samples were analysed for moisture content, crude protein, crude lipid and ash content.

Faecal collection for digestibility determination

A styrofoam jacket containing an ice slurry was wrapped around the settling column to reduce microbial degradation of the collected faecal matter [17] which were pooled every 3 days for 9 days. Faeces for determining apparent digestibility coefficients (ADCs) were collected every morning prior to feeding and frozen at −20°C.

Method for proximate and amino acid analysis of the basal ingredients, prepared diets, faecal matter and fish samples

Dry matter, crude protein crude lipid and ash contents of the ingredients, diets, faecal matter and fish carcasses were determined following the procedures of the Association of Official Analytical Chemists [18]. Dry matter was determined after oven drying for 24 hours at 105°C (MEMMERT UN110, Schwabach, Germany) and crude protein levels were determined from the Kjeldahl method (FOSS KJELTEC 2200, Denmark). Crude lipid contents were determined by the method of Bligh et al. [19] whereas ash contents were calculated from the weight loss after incineration of the samples for 6 hours at 550°C in a muffle furnace (HAREAUS INSTRUMENTS K1252, Germany). Phosphorus content in the samples was determined spectrophotometrically (HACH DR 2700 spectrophotometer) in accordance with IOS [20] standard method whereas amino acid profile of the ingredients and diets were determined in duplicates using the High Performance Liquid Chromatography (HPLC), following the method of Larsen et al. [21]. Gossypol and phytic acid contents were analyzed following the procedure described by Pons et al. [22], using a commercially available kit (MEGAZYME K-PHYT, Ireland) based on the method described by Fiske et al. [23], respectively.

Calculation of apparent digestibility coefficients (ADCs), growth performance and feed utilization

The calculation of ADCs of the macronutrients in the diets was done using the direct method as described by Jobling [24]. It is given as:

$$\mathrm{ADC_i} = ((C_i - F_i)/C_i) \times 100\%$$

Where i=The dietary macronutrients (i.e., protein, lipid, ash, carbohydrate dry matter), C=Consumed amount of i, and F=Faecal loss of i.

Growth performance and feed utilization were calculated using the following;

$$Weightgain(\%) = \frac{Finalweight(g) - Initial\ weight(g)}{Initialweight(g)} \times 100$$

$$Specificgrowthrate, SGR(\%/day) = \frac{[In(Finalweight)g - In(Initial\ weight)g]}{Numberofdays} \times 100$$

$$Feedintake,\ FI(g/fish) = \frac{totalfeed\ consumed}{Number\ of\ fish}$$

$$Feedconversion\ ratio,\ FCR = \frac{Dryweight\ of\ feed\ consumed(g)}{wetweight\ gain\ of\ fish(g)}$$

$$Survival(\%) = \frac{Final\ number\ of\ fish}{Initial\ number\ of\ fish} \times 100$$

Statistical analysis

Data for digestibility, fish growth, feed utilization and body composition were analysed by one-way analysis of variance (ANOVA) using GRAPHPAD PRISM 5.01 for windows (San Diego California, USA) followed by the Tukey's multiple comparison tests where significant differences ($p<0.05$) between treatment means were detected. Results for digestibility, fish growth performance and feed utilization are presented in Box and Whisker plots with individual data points shown whereas results for whole body composition are presented as means ± standard deviation (SD).

Results

Proximate composition (%) and amino acid profile of basal feed ingredients used in the preparation of experimental diets

The proximate composition (%) and amino acid profiles of the test ingredients and diets are shown in Table 1. Chemical analysis of the test ingredients showed that crude protein contents in cottonseed meal (CSM) and groundnut meal (GNM) were similar, but was approximately 52% to 54% of the protein content of the fish meal (FM) used. Groundnut meal was found to contain twice as much lipid as FM, whereas, the highest ash content was recorded in FM and the lowest in CSM.

	Test Ingredient		
Chemical composition	**Fish meal[*]**	**Cottonseed meal**	**Groundnut meal**
Dry matter	90.5 ± 0.0	90.4 ± 0.1	93.8 ± 0.1
Crude protein	72.0 ± 0.1	37.9 ± 0.6	39.0 ± 0.4
Crude lipid	11.6 ± 0.0	9.5 ± 0.0	25.9 ± 0.1
Ash	12.3 ± 0.1	7.3 ± 0.1	11.3 ± 0.0
Phosphorus	1.9 ± 0.0	1.2 ± 0.0	0.5 ± 0.0
Phytic acid	-	3.5 ± 0.2	1.3 ± 0.0
Gossypol	-	0.3 ± 0.0	-
Essential amino acid			
Arginine	4.8	3.3	4.2
Histidine	2.1	0.8	0.8
Isoleucine	3.9	0.9	1.3
Leucine	6.3	1.9	2.5
Lysine	6.6	1.2	0.9
Methionine	2.6	0.4	0.3
Phenylalanine	3.4	1.6	1.9
Threonine	3.6	1.1	1
Valine	4.8	1.3	1.5
TEAA	37.9	12.5	14.5

TEAA, total essential amino acid.

*Essential amino acid profile of fish meal was adapted from www.ffskagen.com.

Table 1: Mean proximate composition (% as fed), amino acid profile (% as fed), phytic acid (g/100 g as fed) and gossypol (g/100 gas fed) content of the test ingredients used in the formulation and preparation of test diets.

In general, both CSM and GNM had a lower essential amino acid (EAA) contents compared to the fishmeal (FM). Additionally, the fish meal had approximately three (3) times more total essential amino acids (TEAA) than the oilseed by-products and among the oilseed by-products, TEAAs was about 15% higher in GNM than CSM.

Formulation and nutritional composition of test diets

Chemical analysis of the test diets indicated that all diets were iso-proteic and lipidic (Table 2). Nitrogen free extract and gross energy contents were similar in all diets. Meanwhile, the minimum total essential amino acids (EAAs) were similar in all diets compared to the minimum requirement for tilapia although; the control diet was 4.0% slightly higher. While the arginine and threonine requirements were exceeded in all diets, lysine requirement was, however, limited in CSD30 and GND30 diets by 6.9% and 16.3%, respectively. Overall, the CSD30 diet had the lowest total EAAs whiles the highest total EAAs was recorded in diet CD.

Ingredient	Test diet			
	CD	CSD30	GND30	
Fish meal	299	172.4	160.5	
Wheat bran	556.8	386.7	444.5	
Cottonseed meal	-	300.2	-	
Groundnut meal	-	-	300	
Groundnut husk meal	-	-	-	
Tapioca flour (binder)	54.6	54.9	55.9	
Palm oil	74.7	70.2	24.4	
Vitamin and Mineral premix	15	15.5	14.7	
Proximate composition				
Dry Matter	96.5	95.7	97.4	
Crude Protein	32.8	31.7	32.6	
Crude Lipid	14.4	14.6	14.9	
Ash	7.5	7.3	8.7	
^{a}NFE	41.9	42.1	41.2	
Phosphorous	2.3	2.2	1.8	
^{b}Gross Energy	20.7	20.3	20.4	
Essential amino acid				EAA requirement*
Arginine	1.4	1.8	2.1	1.2
Histidine	0.6	0.6	0.6	1.1
Isoleucine	1.2	1	1	1.1
Leucine	1.9	1.7	1.7	1.9
Lysine	2	1.5	1.3	1.6
Methionine	0.8	0.6	0.5	0.7
Phenylalanine	1	1.1	1.1	1.1

Threonine	1.1	1	0.9	0.7
Valine	1.4	1.2	1.2	1.5
Total EAA	11.3	10.3	10.5	10.9
CD: Control Diet; CSD: Cottonseed Meal Diet; GND: Groundnut Meal Diet; NFE: Nitrogen Free Extract; EAA: Essential Amino Acid.				
*NRC, 1993.				
[a]NFE = 100–(%Moisture+%Crude Protein+%Crude Lipid+%Ash).				
[b]Gross Energy=((%Crude Protein x 23.6)+(%Crude Lipid×39.5)+(%NFE×17.2))/100.				

Table 2: Formulation (g/kg as fed), Proximate composition (%), Gross energy (MJ/kg) and Amino acid profile (% as fed) of test diets.

Apparent nutrient digestibility coefficient of *O. niloticus* juveniles fed diets containing oilseed by-products

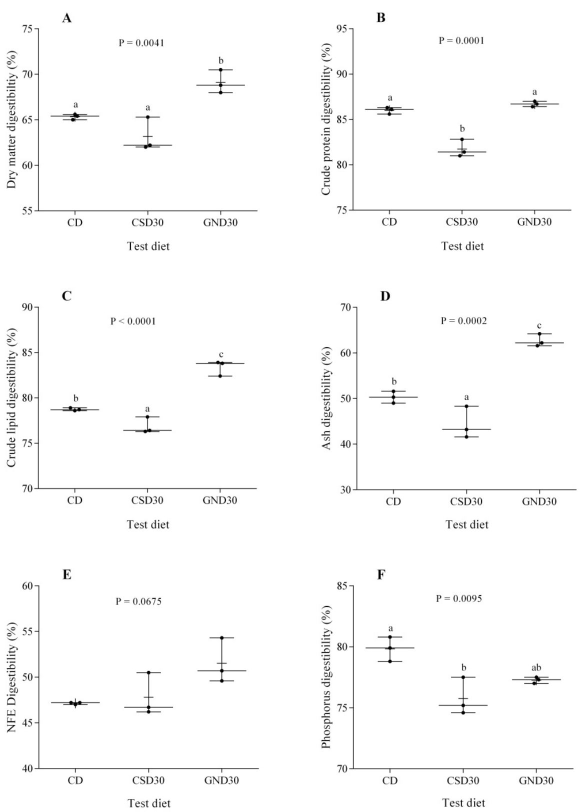

Figure 1: Apparent nutrient digestibility of (A) dry matter, (B) crude protein, (C) crude lipid, (D) ash, (E) nitrogen free extract (NFE) and (F) phosphorus of selected by oilseed meal in test diets for Nile tilapia juveniles. CD: Control diet; CSD: Cottonseed Meal Diet; GND: Groundnut Meal Diet. a,b,c Box plots within a part not sharing common lowercase letters are significantly different from each other (p<0.05, 1-Way ANOVA). Absence of lowercase letters indicates no significant difference.

The apparent digestibility coefficients (ADCs) of dry matter, crude protein, crude lipid, ash and phosphorus of the selected oilseed by-products for Nile tilapia are presented in Figure 1. Overall, GND30 had the best ADCs, followed by CD and then CSD30. Crude protein digestibility was significantly lower in CSD30 but above 80% for all diets (Figure 1B). Lipid digestibility was lowest for CSD30 and highest for GND30 (Figure 1C). Ash and NFE digestibility were lower for all diets and below 65%, whereas ADC of phosphorus ranged from 75.8% in CSD30 to 79.8% in CD.

Growth performance, feed utilization and whole-body composition of *O. niloticus* juveniles fed oilseed by-product diets

The results on growth and feed utilization are given in Figure 2. No mortality was observed in any of the dietary treatments. Mean final weight was higher in CD than in GND30 and CSD30 (Figure 2B). Weight gain (%) and SGR did not differ among the dietary treatments but was highest in CD followed by GND30, then CSD30. Chemical analysis of the whole-body composition (Table 3) of experimental fish after the experiment did not show any differences (p>0.05) in moisture, crude protein, lipid and ash contents except phosphorus, which was highest in the cottonseed meal diet and lowest in the groundnut meal diet.

Test Diet				
Parameter	CD	CSD30	GND30	p value
Moisture content	74.7 ± 1.0	74.9 ± 0.1	74.6 ± 0.1	0.8218
Crude Protein	15.3 ± 0.2	15.2 ± 0.2	15.4 ± 0.2	0.7023
Crude lipid	6.5 ± 0.9	5.8 ± 0.2	6.6 ± 0.2	0.2307
Ash	4.1 ± 0.3	4.4 ± 0.2	3.9 ± 0.1	0.0553
Phosphorus	0.7 ± 0.0^{ab}	0.8 ± 0.0^{a}	0.6 ± 0.0^{b}	0.0281
CD: Control Diet; CSD: Cottonseed Meal Diet; GND: Groundnut Meal Diet;				
[a,b]Mean values within each row not sharing common superscripts are significantly different (p<0.05, 1-Way ANOVA). n=3.				

Table 3: Proximate composition (% wet basis) of Nile tilapia juveniles after being fed with diets containing plant proteins as a replacement for fish meal.

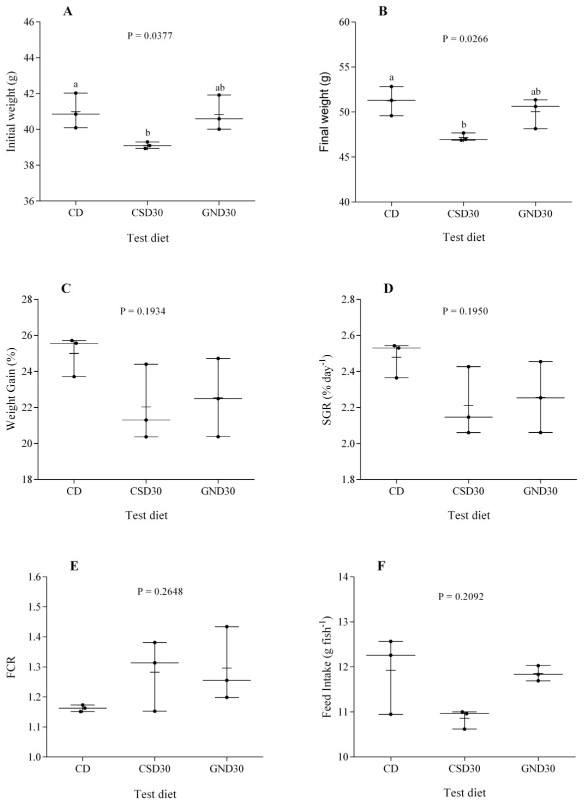

Figure 2: Growth performance (A-D) and feed utilization (E,F) of Nile tilapia juveniles after being fed with diets containing plant proteins as a replacement for fish meal. SGR: Specific Growth Rate; FCR: Feed Conversion Ratio; CD: Control Diet; CSD: Cottonseed Meal Diet; GND: Groundnut Meal Diet. a,b Box plots within a part not sharing common lowercase letters are significantly different from each other ($p<0.05$, 1-Way ANOVA). Absence of lowercase letters indicates no significant difference.

Discussion

Apparent nutrient digestibility of the selected oilseed meals

Oilseed meals though important protein sources in animal diets are generally low in protein content and nutritional quality compared to fishmeal. This is largely attributed to the imbalance and lower levels of essential amino acids contained therein. However, legumes like groundnuts and soybeans, and majority of oilseeds are exceptions; they are considered to be good substitutes for animal proteins. Nonetheless, the extent of their nutrient digestibility is important to determine their actual nutritional value as feed ingredients for fish. Our data show that, the ADC of dry matter (DM) for all diets was moderately low. The inclusion of about 30% CSM coupled with the high inclusion level (38% to 55%) of wheat bran in CSD30 and CD is likely to have raised the crude fibre level in these diets resulting in increased rate of gastrointestinal ejection and decreased digestive enzyme activity time which reduced DM absorption [17,25]. Similarly, Chu et al. [26] reported lower ADC of DM for soybean meal (57.3%) and rapeseed meal (50.4%) when fed to loach *Misgurnus anguillicaudatus*. Obirikorang et al. [17] also reported reduced dry matter digestibility for copra and palm kernel meals when fed to Nile tilapia and attributed it to the high fibre content or the presence of high amounts of non-starch polysaccharides [27] in the diets. On the other hand, DM digestibility for GND30 was significantly higher than the control diet, and much better than those reported by Obirikorang et al. [17,26]. The improved DM digestibility for GND30 also resulted in better digestibility of the other ADCs.

ADC of protein was high in all diets (>80%). Although protein digestibility for both GND30 and CD was higher, it was slightly better in GND30, suggesting a more digestible groundnut meal protein which could replace fish meal protein in Nile tilapia diets at 30% or higher without compromising growth and health. However, it is worth noting that the slightly lower ADC of protein for the control diet might have been influenced by the higher level of wheat bran included in the diet compared to the other diets and not the quality of fish meal protein. According to Koprucu et al. [28] good growth performance in fish generally is dependent on the protein quality; specifically the amino acid profile of the dietary ingredients. A previous work by Duodu et al. [29] to determine the influence of yeast fermentation on the AA profile of groundnut and cottonseed meals showed that, although, lysine and methionine levels did not meet the requirement for tilapia their concentrations in the raw state were adequate to promote growth. The ADC of protein in the CSD30 and GND30 diets present better prospects for their use in aquafeeds, barring the presence of any substances that may inhibit or slow down digestibility. In general, ADCs of protein in the test diets for tilapia were within the 75%-95% range reported by Koprucu et al. [28] for protein-rich feed ingredients.

Lipids are necessary for fish growth and development because they play important physiological roles in providing energy, essential fatty acids and fat soluble nutrients [30]. The main sources of energy in fish diets are from lipids and carbohydrates, but sometimes proteins are used in cases where the dietary lipid and carbohydrate are deficient. However, most diets are formulated to meet the minimum nutrient requirements of the target species in order to enable protein sparing. The groundnut meal diet tested resulted in higher lipid and NFE digestibility compared to the control and cottonseed meal diets. It could be deduced that tilapia fed the GND30 diet relied mostly on the dietary lipid and carbohydrate as energy sources. Nonetheless, lipid digestibility for all the test ingredients were generally good suggesting that sufficient amount of lipases were available to promote efficient lipid digestion [31]. According to Sklan et al. [31] ADC for lipid for tilapia normally ranges from 72% to 90%, which is in agreement with what was we found. Chu et al. [26] reported slightly lower ADCs of lipid for fermented soybean meal (66.4%), soybean meal (65.5%) and rapeseed meal (64.0%) when fed to loach, and attributed this to the relatively short intestines of loach to their body length which might have caused a shorter feed retention time in the fish's digestive system resulting in reduced digestibility. Lech et al. [32] reported that nutrient digestion and absorption is maximized only when the diet is retained for a longer period in the gastrointestinal tract for assimilation to occur. The reduced NFE digestibility of the CSD30 diet was possibly due to the stronger cell walls and high fibre content of the cottonseed meal which might have restricted digestive enzymes penetration and breakdown. Ash digestibility was generally low for all diets. This could have resulted from phytate-mineral complexes which hinder digestibility and bioavailability of minerals as well as the general absorption of nutrients [33].

Overall, phosphorus digestibility was identical in the plant protein diets but significantly lower than the control diet between 3.2%-5.2%. They were only less digestible by one-quarter of the total dietary phosphorus which was better than Chu et al. [26,34] who reported 56.3%-69.8% (for juvenile cobia) and 25.1%-44.0% (for loach), respectively. They indicated that plant-based feedstuffs have lower phosphorus ADCs than feedstuffs from animal sources. The high capacity shown by Nile tilapia to utilize phosphorus is partly due to their higher digestive ability for acidic proteolytic digestion [35]. In our opinion, the high phosphorus digestibility of the plant proteins by tilapia is an indication that use of these diets would result in reduced eutrophication in culture systems. However, any attempt to reduce phosphorus levels in plant protein ingredients to meet the nutritional requirement of tilapia and or increase their bioavailability is necessary to achieve not only an improved culture effluent and minimize carbon foot prints but also contribute to the overall health and productivity of the farm [36].

Growth performance, feed utilization and whole-body composition of *O. niloticus* juveniles the selected oilseed meals

Aside water quality, good growth in fish is promoted by the quality of diet fed to the fish. Preliminary growth data we found suggests the possibility of replacing up to 30% of fishmeal (FM) protein in the diets of Nile tilapia with Groundnut meal (GNM) and Cottonseed meal (CSM). Percentage weight gain, SGR and FCR at the end of the experiment were comparable between all diets. Similar observations were reported by Obirikorang et al. [17] for copra and palm kernel meals. Although, initial fish weight in GND30 and CSD30 diets were lower than CD, their slightly reduced growth could be related to possible deficiencies in their essential amino acid composition especially in lysine and methionine (Table 2). Nonetheless, fish fed diet CD may have had a comparative genetic advantage which favoured their growth, although they were pooled from the same population as that of GND30 and CSD30. Overall, there is a need to deal with the negative attributes associated with these oilseed by-products i.e. nutrient deficiencies, the presence of ANFs, and high fiber contents [32] that reduce their value as potential protein replacers for fish meal.

Regarding whole body composition, none of the parameters assessed were significantly influenced by the dietary protein source except phosphorus content which was found to be lower in fish fed GND30 compared to CD and CSD30. A possible reason for the lower carcass phosphorus content in GND30 could be attributed to the fact that although, fish in all treatments might have attained the juvenile-adult transition stage where the fish reaches chemical maturity [37] and weight (muscle mass) increases faster than length (bone mass) leading to a decline in calcium and phosphorus concentrations [38], this process may have occurred more rapidly in GND30 than in CD and CSD30; or probably due to the low level of dietary phosphorus in GND30 (Table 2). In a report by Shearer et al. [39] the proximate composition of cultured fish is highly influenced by size, life cycle stage, energy intake and metabolic energy demands. Our data show that, although final body weight in the control diet was significantly higher than in CSD30, the differential magnitude in fish size between treatments was not large enough to cause any differences in whole body composition. Secondly, the final weight of fish in all treatments could be classified as still juveniles with similar energy intake and energy metabolic demands; which explains the similarity in the whole body composition of fish from the different treatments. Furthermore, we found that, an inverse relationship existed between whole body moisture and whole body lipid and this is in agreement with [39].

Conclusion

Our findings indicate that GNM and CSM proteins can be digested by Nile tilapia juveniles. Crude lipid and ash digestibility were best in GND30 whereas NFE digestibility was generally low in all diets. Growth performance and feed utilization were not compromised by the inclusion of the CSM and GNM. This suggests that raw CSM and GNM could be used to replace up to 30% fish meal protein in Nile tilapia diets. In order to enhance the prospects of using the oilseed by-products tested in fish diets, it would be prudent to explore safe ways of processing these ingredients to improve their nutritional value, eliminate or reduce anti-nutrients to reasonable levels, improve phosphorus digestibility and facilitate higher inclusion levels either by boosting their amino acid contents or blending the different raw materials at different protein ratios.

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