Evaluation of locally-available agroindustrial byproducts as partial replacements to fishmeal in diets for Nile Tilapia (Oreochromis niloticus) production in Ghana

Obirikorang, Kwasi Adu; Amisah, Stephen; Agbo, Nelson Winston; Adjei-Boateng, Daniel; Adjei, Nathaniel Gyasi; Skov, Peter Vilhelm

Published in:
Journal of Animal Research and Nutrition

Publication date:
2015

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
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Abstract

Objective: This study assessed the potential of three widely-available local oilseed byproducts, soybean (SBM), copra (CM) and palm kernel meals (PKM) as partial replacements of fishmeal in Nile tilapia (O. niloticus) diets in terms of their digestibility and effects on growth and nutrient utilization.

Methods: Apparent digestibility coefficients (ADCs) were determined using chromic oxide as an inert marker in test diets formulated to contain 30% of each of the test ingredients by weight and 70% of a fishmeal-based reference diet. The 8-week growth trial evaluated the effects of partial replacements of fishmeal by the oilseed byproducts at different dietary inclusions. The soybean meal diets were formulated with the soybean meal contributing 25% (SBM25) and 50% (SBM50) of total dietary protein. Copra and palm kernel meals each contributed 10% (CM10 and PKM10) and 20% (CM20 and PKM20) of total dietary protein in their respective diets. The test diets were compared to a control diet with fishmeal as the sole protein source.

Results: Nutrient digestibilities of the test ingredients were generally significantly higher for the soybean meal than the copra and palm kernel meals. The ADCs of the soybean, copra and palm kernel meals were; protein, 90.57%, 69.36% and 61.12%; lipid, 96.14%, 95.64% and 95.85%; fibre, 96.74%, 77.61% and 55.07%; and energy, 91.99%, 73.61% and 75.14% respectively. All the dietary treatment groups recorded significant growth at the end of the trials with the fish in the control and SBM25 groups more than tripling their respective mean initial weights. All the other treatment groups more than doubled their mean initial body weights. Daily growth rates ranged from 1.40% day⁻¹ for the PKM20 group to 2.26% day⁻¹ for the control group.

Conclusion: The study has shown that the test ingredients can partially replace fishmeal in Nile tilapia diets without considerably compromising diet digestibility and carcass traits although higher dietary levels of the oilseed byproducts negatively affects growth.

Keywords: Oilseed byproducts; Fishmeal replacement; Digestibility; Growth; Oreochromis niloticus; Ghana

Introduction

The inability of Ghana’s fish output from capture fisheries to meet national demand has placed aquaculture in a central position to make up for the supply deficit. Factors such as high cost of commercial pelleted feed have, however, hindered the growth of the aquaculture sector in Ghana, especially among the small and medium-scale operators. It is estimated that feed constitutes

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between 60 and 70% of the total cost of producing tilapia [1], and with the average price per kilogram of imported formulated feed in Ghana around US$2.00, the culture of fish solely on commercial fish feeds is not feasible. Most farmers in Ghana thus produce supplementary fish feeds at the farm level usually as one, or a mixture of two or more feed ingredients. According to the estimates of Attipoe et al. [2], approximately 90% of the fish farmers in Ghana rely on mixtures of agro-industrial by-products such as maize bran, wheat bran, rice bran, groundnut bran, copra cake, soybean and fish meal as fish feeds. These feeds are largely supplementary and unbalanced in essential nutrients usually results in poor fish growth and low productivity.

There is thus an urgent need to develop low-cost but nutritionally balanced diets that can support increased intensive and semi-intensive systems using locally available and low-cost plant resources. At the global level, alternative protein sources for fish culture have been studied extensively during the last few decades because of the declining availability and high cost of fish meal [3-5]. A large number of plant products have been evaluated as potential protein sources in the diets for fish including cottonseed meal, sunflower meal and corn meal [6], soybean meal, cassava leaf meal, sweet potato leaf meal, groundnut cake [7], pea, horsebean and rapeseed plant protein concentrates [8], Jatropha kernel meal [9], cowpea [10] and lupin meal [11]. Despite the abundance of a large number agro-industrial by-product in Ghana, their potential as cheap ingredients for fish feed formulation remains to be fully exploited. Boateng et al. [12] attributed this failure to the lack of information on chemical compositions and nutritive values, improvement methods of the nutritional profile and feeding responses of animals to these agro-industrial by-products. Some studies have, however, shown that substantial amounts of these low-cost and readily-available feed ingredients can be fed to Nile tilapia (*Oreochromis niloticus*) without negative impacts on growth and feed utilisation. According to Omoregie et al. [13] *O. niloticus* fingerlings can be fed up to 30% palm kernel meal-based diets. Feeding Nile tilapia fingerlings a diet containing up to 35% palm kernel meal for 120 days had no adverse effects on growth [14]. Similarly, Oliveira et al. [14,15] fed *O. niloticus* fingerlings a diet containing up to 35% palm kernel meal with no adverse effects on growth or apparent digestibility, and with no pathological effects on viscera or intestinal epithelium.

The high price of fishmeal in Ghana has created a situation which warrants a thorough evaluation and improved use of alternative protein sources, particularly the locally-available plant by-products in aquafeed formulations at farm and commercial levels to boost fish production especially in small-scale farms. This study thus evaluated the effects of the inclusion of three widely-available local agro-industrial byproducts, soybean, copra and palm kernel meals in diets for the Nile tilapia (*O. niloticus*) on digestibility, growth and nutrient utilization.

### Materials and Methods

The soybean, copra and palm kernel meals used in this study were byproducts from the mechanical extraction of oil. Each ingredient was obtained as a single batch from an oil producing factory in Kumasi, Ghana. The test ingredients as well as all the other ingredients used in the formulation of the experimental diets were finely ground to obtain a homogeneous mixture and facilitate pelleting. The proximate composition of the test ingredients as well as the other major ingredient used in the diet formulations is presented in Table 1 below.

### Experiment I: Digestibility Trials

#### Experimental facilities

The digestibility experiment was conducted in an indoor flow-through system consisting of 20 rectangular transparent glass tank units, each with dimensions of 50 cm × 40 cm × 40 cm and a water-holding capacity of approximately 60 litres. The tanks are connected to a piping system that supplies water continuously through a 2-inch PVC pipe fitted overhead the experimental tanks. Water supply to the tanks was from a 1000-litre header tank through the common PVC inflow pipe. Water temperatures in the header tank and culture tanks ranged between 26 and 28°C during the study. Atmospheric air was supplied by a regenerative blower (Sweetwater S41) through air-supply valves fitted with tubes to each tank to maintain dissolved oxygen (DO) concentration of between 6.00 and 7.00 mgL⁻¹ throughout the experiment. During the trials, pH ranged between 6.8 and 8.00. A light:dark regime of 12 h:12 h was maintained using artificial light from fluorescent tubes. All-male Nile tilapia (mean weight 25.0 ± 1.0 g) were used for the digestibility experiment at a stocking density of 20 individuals per tank and acclimated for one week prior to the start of the experiment.

#### Diet formulation and preparation

The reference diet for the digestibility trial was formulated with the sole dietary protein source being fishmeal (aquaculture grade). The experimental diets were then prepared using 70% of the already formulated reference diet and 30% of each of the test ingredients (soybean, copra and palm kernel meals) as described in the materials and methods section. The soybean, copra and palm kernel meals were ground to obtain a homogeneous mixture and facilitate pelleting. The proximate composition of the ingredients used in the diet formulations is presented in Table 1 below.

### Table 1 Proximate composition (gkg⁻¹ as-fed) and energy (kJ.g⁻¹) of the feed ingredients used for the formulation of the different experimental diets.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>DM</th>
<th>CP</th>
<th>CL</th>
<th>CF</th>
<th>Ash</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishmeal</td>
<td>974.3</td>
<td>703.3</td>
<td>112.8</td>
<td>6.5</td>
<td>131.1</td>
<td>218.5</td>
</tr>
<tr>
<td>Soybean Meal</td>
<td>894</td>
<td>500.3</td>
<td>10.1</td>
<td>38.2</td>
<td>58.9</td>
<td>189.6</td>
</tr>
<tr>
<td>Palm Kernel Meal</td>
<td>912</td>
<td>178.1</td>
<td>132.4</td>
<td>184.1</td>
<td>33</td>
<td>192.6</td>
</tr>
<tr>
<td>Copra Meal</td>
<td>878.5</td>
<td>196.3</td>
<td>81</td>
<td>160</td>
<td>70.1</td>
<td>141.8</td>
</tr>
<tr>
<td>Wheat Bran</td>
<td>875.3</td>
<td>151.4</td>
<td>14.9</td>
<td>78.7</td>
<td>46.8</td>
<td>178.3</td>
</tr>
<tr>
<td>Rice Bran</td>
<td>912.1</td>
<td>86.9</td>
<td>11.5</td>
<td>162.9</td>
<td>110.8</td>
<td>156.2</td>
</tr>
</tbody>
</table>

DM: Dry Matter; CP: Crude Protein; CL: Crude Lipid, CF: Crude Fibre
Calculations of the ADCs of the diets and test ingredients

The apparent digestibility coefficients of the nutrients and energy of the test and reference diets were calculated as follows:

$$ADC_{test \text{ diet}} = 100 \left( 1 - \left( \frac{D_{test \text{ diet}}}{D_{ref \text{ diet}}} \right) \frac{F_{test \text{ diet}}}{F_{ref \text{ diet}}} \right)$$ \[18,19\]

Where $D$=% nutrient of diet; $F$=% nutrient of faeces; $Di$=% $Cr_2O_3$ of diet; $Fi$=% $Cr_2O_3$ of faeces.

The apparent digestibility coefficients of the nutrients in the test ingredients were then calculated as follows:

$$ADC_{test \text{ ingredient}} = ADC_{kendall} + \left[ \left( ADC_{kendall} - ADC_{ref \text{ ingredient}} \right) \frac{0.7xD_{ref}}{0.3xD_{ref}} \right]$$ \[18\]

Where $D_{ref}$ = % nutrient (or kg$^{-1}$ gross energy) of reference diet (as fed); $D_{ref}$ = % nutrient (or kg$^{-1}$ gross energy) of test ingredient (as fed).

Experiment II: Growth Trial

Culture system and experimental species

The 56-day growth trials were conducted in hapas (1 × 1 × 1.5 m) set in an earthen pond at the fish production facility of the Faculty of Renewable Natural Resources (FRNR), Kwame Nkrumah University of Science and Technology in Ghana. This was to test the alternative feed ingredients under conditions that simulate commercial Ghanaian fish culture practices as closely as possible. The hapas were constructed using nylon mosquito netting with mesh openings of about 1.5 × 1.5 mm. The dietary treatments for each of the test ingredients were randomly assigned in triplicates to the hapas. Each hapa contained 20 homogeneous all-male Nile tilapia fingerlings with mean initial body weight of approximately 25 g. The fish were obtained from a commercial hatchery near Kumasi, Ghana for the growth trials and were acclimated for one week prior to the start of the experiment. During the acclimation period, fish were all fed a control diet containing none of the test ingredients.

Experimental diets

A control diet was formulated with fishmeal (aquaculture grade) as the sole source of protein and this was replaced at the different inclusion levels with soybean, copra and palm kernel meals. Milled wheat and rice bran served as the carbohydrate source. The diet containing soybean meal was formulated with the soybean meal contributing 25% (SBM25) and 50% (SBM50) of total dietary protein. Copra and palm kernel meals each contributed 10% (CM10 and PKM10) and 20% (CM20 and PKM20) of total dietary protein in their respective diets. In all, 7 isonitrogenous (320 g.kg$^{-1}$ protein, crude protein), isolipidic (150 g.kg$^{-1}$ lipid) and isoenergetic (18 KJ.g$^{-1}$) diets were formulated for the experiment. These levels were based on requirements for Nile tilapia juveniles [17,20,21]. Proportions of all the ingredients used in the formulation of the different diets were computed and balanced using an Excel-Visual Basic Ration Formulator Spreadsheet. All ingredients used in the feed formulation were finely ground and sieved in order to obtain a homogenous mixture. Feeds were produced by thoroughly mixing all the dry ingredients together in a bowl, before adding water until a dough-like consistency was obtained.
Each experimental diet was pelletized and dried the same way as the diets for the digestibility trial. The formulations and proximate compositions of the experimental diets are presented in Table 3.

**Feeding and sampling**

During the trial all groups of fish were hand-fed at the same fixed rate (5% of total bulk weight), twice daily at 9:00 and 16:00 h. Data on weight gains were recorded every week and feeding rates were accordingly adjusted to compensate for growth. All fish were individually weighed at the beginning of the trial to ensure uniformity in the initial weights. For all the other weekly weight measurements, fish were bulked together, weighed to the nearest 0.01 g on an electronic top pan balance. Ten individuals from the initial fish stock and 5 from each of the hapas at the end of the trial were randomly sampled and stored at −20°C for subsequent whole-carcass proximate composition and calculations of hepatosomatic indices. Due to the practical limitations in conducting this trial in an earthen pond, it was not possible to ensure that all the fed experimental diets were ingested or to collect uneaten feed from the experimental hapas. Thus for all calculations dependent on feed intake such as the food conversion and protein efficiency ratios, the amount of feed fed instead of the exact feed consumed/intake was used without adjustments being made for any wastages.

**Calculations**

Growth and feed utilization parameters were calculated for the duration of the trial using the following equations:

- **Specific growth rate:** 
  \[ \text{SGR} = \frac{\ln W_1 - \ln W_0}{\text{Trial duration}} \times 100 \]

- **Weight gain:** 
  \[ \text{WG} = \frac{(W_1 - W_0)}{W_0} \times 100 \]

- **Feed conversion ratio:** 
  \[ \text{FCR} = \frac{(W_1 - W_0)}{\text{Feed fed}} \times 100 \]

- **Protein efficiency ratio:** 
  \[ \text{PER} = \frac{\text{Weight gain}}{\text{Crude protein fed}} \]

- **Hepatosomatic index:** 
  \[ \text{HSI} = \frac{\text{Liverweight}}{\text{Bodyweight}} \times 100 \]

- **Survival rate:** 
  \[ \text{Survival} \% = \frac{\text{Final number of fish}}{\text{Initial number of fish}} \times 100 \]

**Chemical Analysis**

Dry matter, crude protein, crude lipid, ash and fibre, gross energy contents of all the ingredients, diets, faeces and carcasses were determined following the procedures of the Association of Official Agricultural Chemists [22]. Dry matter was determined by the weight loss after a 24-hour drying at 105°C in an oven (Gallenkamp CHF097). The ash content was calculated from the weight loss after incineration of the samples for 6 hours at 550°C in a muffle furnace (Stuart Scientific S1203). The micro-Kjeldahl method (Gerhardt kjeldatherm system) was used for the determination of crude protein whiles crude lipid extraction and determination was done by solvent extraction using Soxhlet extraction. Crude fiber was determined using acid-base hydrolysis. The energy contents were determined using an Adiabatic Autobomb Calorimeter (Parr 6100) with benzoic acid as standard. Chromic oxide content of the test and reference diets as well as the faeces were determined by spectrophotometric methods (Spectronic 21). The differences in the ratios of the parameters of proximate composition and gross energy relative to chromic oxide in the feed and faeces in each treatment were calculated to determine the apparent digestibility.
Statistical Analysis

Data from the trials were expressed as mean ± standard deviation in tables. The data was subjected to one-way ANOVA to test for differences among dietary treatments and Tukey’s Multiple Comparison Test was further applied to evaluate differences between individual means. In all cases, differences were considered significant at p<0.05. All data were first tested for normality using the Kolmogorov-Smirnov test [23]. The descriptive statistics were executed using the GraphPad Prism (Version 5) statistical software.

Results

Diets digestibility

The apparent digestibility coefficients of dry matter, crude protein, crude lipid, crude fibre and gross energy of the diets are shown in Table 4 below. The dry matter digestibility of the test diet containing the SBM (71.94%) did not vary significantly (p>0.05) from that of the reference diet (72.75%). The dry matter digestibility of the diets containing CM and PKM on the other hand were 69.95% and 65.31% respectively and varied significantly (p<0.05) from the dry matter digestibility of the reference and SBM diets. The crude protein digestibility of the reference and test diets were generally high ranging from 89.67% (PKM) to 96.48% (reference diet). There were, however, significant differences (p<0.05) in the crude protein digestibilities among all the diets, except between CM and PKM diets. No significant differences (p>0.05) were found in the lipid digestibility of the diets. There were reduced crude fibre digestibility of the diets containing CM (82.72%) and PKM (74.46%) compared to the reference diet (94.49%) and the diet containing SBM (96.55%). Trends in gross energy digestibility of the diets were similar to the crude protein digestibility with the reference and PKM diets recording the highest and lowest gross energy digestibilities of 95.50% and 89.14% respectively.

Table 4

<table>
<thead>
<tr>
<th>Reference SBM CM PKM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet Digestibility</td>
</tr>
<tr>
<td>Dry Matter (%)</td>
</tr>
<tr>
<td>Crude Protein (%)</td>
</tr>
<tr>
<td>Crude Lipid (%)</td>
</tr>
<tr>
<td>Crude Fibre (%)</td>
</tr>
<tr>
<td>Gross Energy (%)</td>
</tr>
<tr>
<td>Ingredient Digestibility</td>
</tr>
<tr>
<td>Dry Matter (%)</td>
</tr>
<tr>
<td>Crude Protein (%)</td>
</tr>
<tr>
<td>Crude Lipid (%)</td>
</tr>
<tr>
<td>Crude Fibre (%)</td>
</tr>
<tr>
<td>Gross Energy (%)</td>
</tr>
<tr>
<td>Digestible Nutrients</td>
</tr>
<tr>
<td>Crude Protein (gkg⁻¹)</td>
</tr>
<tr>
<td>Gross Energy (kJg⁻¹)</td>
</tr>
</tbody>
</table>

Test ingredient digestibilities

The apparent digestibility coefficients of dry matter, crude protein, crude lipid, crude fibre and gross energy of the test ingredients are shown in Table 4 below. Generally, nutrient and energy digestibilities were highest in the SBM and there were significant differences (p<0.05) among all three ingredients with the exception of crude lipid digestibility. There were significant variations (p<0.05) among all three test ingredients in terms of dry matter digestibility with SBM recording the highest of 69.97% and PKC recording the lowest of 39.89%. The protein digestibilities of CM (69.35%) and PKC (61.12%) were relatively lower than that of SBM (90.57%) and there were significant differences (p<0.05) among all the test ingredients. Similar to the diets, there were no significant differences (p>0.05) in lipid digestibilities among the 3 test ingredients. Crude fibre digestibility was significantly different among the three test ingredients with PKC recording the lowest digestibility of 55.07% and SBM recording the highest of 96.74%. The crude fibre digestibility of CM was 73.61%. Gross energy digestibilities were similar for CM (73.61%) and PKM (75.14%) but significantly different (p<0.05) from SBM (91.99%).

Growth and feed utilisation

Table 5 details the growth and feed utilisation parameters of the fish groups fed the different experimental diets. Although all the dietary treatments resulted in appreciable fish growth at the end of the trial, the inclusions of the oilseed byproducts as protein sources in the tilapia diets significantly reduced fish growth and feed utilization and efficiency compared to the control diet. Feed intake was also significantly reduced in the fish groups fed the oilseed meal diets compared to the control diet group. At the end of the 8-week period, the control group and the SBM25 groups more than tripled in their respective initial weights. All the other treatment groups recorded mean final weights which were more than double their mean initial body weights. The final mean...
Table 5 Growth and feed utilization of Oreochromis niloticus fingerlings fed different inclusion levels of soybean meal (SBM), palm kernel cake (PKM) and copra meal diets over a 56-day period.

<table>
<thead>
<tr>
<th>Diets</th>
<th>Control</th>
<th>SBM25</th>
<th>SBM50</th>
<th>PKM10</th>
<th>PKM20</th>
<th>CM10</th>
<th>CM20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IBW (g)</td>
<td>25.93 ± 0.38</td>
<td>25.50 ± 0.36</td>
<td>25.47 ± 0.32</td>
<td>25.50 ± 0.10</td>
<td>25.43 ± 0.12</td>
<td>25.00 ± 0.36</td>
<td>25.07 ± 0.32</td>
</tr>
<tr>
<td>FBW (g)</td>
<td>88.60 ± 1.15</td>
<td>82.60 ± 0.36</td>
<td>70.60 ± 0.53</td>
<td>68.07 ± 0.55</td>
<td>55.87 ± 0.55</td>
<td>75.93 ± 0.38</td>
<td>58.30 ± 0.45</td>
</tr>
<tr>
<td>WG</td>
<td>255.44 ± 6.93</td>
<td>224.23 ± 4.43</td>
<td>176.56 ± 1.40</td>
<td>166.93 ± 1.92</td>
<td>119.67 ± 3.06</td>
<td>206.04 ± 6.23</td>
<td>132.59 ± 1.74</td>
</tr>
<tr>
<td>SGR</td>
<td>2.26 ± 0.03</td>
<td>2.00 ± 0.25</td>
<td>1.82 ± 0.01</td>
<td>1.76 ± 0.20</td>
<td>1.40 ± 0.03</td>
<td>1.98 ± 0.02</td>
<td>1.50 ± 0.02</td>
</tr>
<tr>
<td>SR</td>
<td>100.00 ± 0.00</td>
<td>93.33 ± 5.77</td>
<td>90.00 ± 0.00</td>
<td>86.87 ± 5.77</td>
<td>93.33 ± 5.77</td>
<td>93.33 ± 5.77</td>
<td>93.33 ± 5.77</td>
</tr>
<tr>
<td>FCR</td>
<td>2.74 ± 0.05</td>
<td>2.88 ± 0.02</td>
<td>3.28 ± 0.07</td>
<td>3.45 ± 0.02</td>
<td>4.18 ± 0.05</td>
<td>2.97 ± 0.01</td>
<td>3.81 ± 0.01</td>
</tr>
<tr>
<td>FI</td>
<td>174.36 ± 0.64</td>
<td>164.25 ± 1.01</td>
<td>144.85 ± 2.25</td>
<td>147.13 ± 2.16</td>
<td>127.20 ± 1.38</td>
<td>150.60 ± 0.61</td>
<td>126.37 ± 0.57</td>
</tr>
<tr>
<td>PER</td>
<td>1.14 ± 0.02</td>
<td>1.09 ± 0.01</td>
<td>0.97 ± 0.02</td>
<td>0.83 ± 0.01</td>
<td>0.68 ± 0.01</td>
<td>1.03 ± 0.06</td>
<td>0.82 ± 0.00</td>
</tr>
<tr>
<td>HSI</td>
<td>1.00 ± 0.09</td>
<td>0.98 ± 0.19</td>
<td>0.97 ± 0.13</td>
<td>0.99 ± 0.08</td>
<td>1.03 ± 0.04</td>
<td>1.01.09</td>
<td>0.94 ± 0.06</td>
</tr>
</tbody>
</table>

**FBW (g):** Initial body weight, **WBW (g):** Final body weight, **WG (%):** Weight gain, **SGR (%/day):** Specific growth rate, **SR:** Survival rate (%), **FCR:** Feed conversion ratio, **FI (g dry diet fish⁻¹ 56 days⁻¹):** Feed intake, **PER:** Protein efficiency ratio.

Each value is the mean ± SD of data from triplicate groups. Within a row, means with the same letters are not significantly different (P>0.05). Absence of letters indicates no significant difference between all the treatments.

Whole body proximate composition

The whole body proximate compositions of the fish groups fed the different dietary treatments are outlined in Table 6. With the exception of crude lipid, the whole body proximate composition (expressed on a wet weight basis) were not significantly affected (P>0.05) by additions of the different plant protein ingredients or their inclusion levels. There was a significant effect of the dietary manipulations with the test ingredients on the lipid contents of the fish flesh at the end of the growth trials despite the isosidipnic nature of the experimental diets. Lipid retention in the tissues of the fish fed the control and soy-based diets were significantly lower (P<0.05) than that of the fish fed the copra and palm kernel diets at the end of the trial.

Discussion

The additions of copra and palm kernel meals significantly reduced nutrient dry matter, protein, fibre and energy digestibilities of their respective diets mainly due to their high crude fibre contents. Fibre is usually indigestible to most cichlids mainly because they do not possess the required enzymes for fibre digestion. Anderson et al. [24] recommended that for maximum fish growth, crude fibre levels in tilapia diets should not exceed 5%. The copra and palm kernel meal diets used for the digestibility trials had fibre contents of 9.5 and 11.7% respectively compared to 3.4% for the control diet and 4.7% for the soybean meal diet. The fibre of copra is high in the polymer mannan, which has a low digestibility and often has a laxative effect in animals and increases the rates of gastrointestinal transit of ingested feeds [21]. The presence of a high level of non-starch polysaccharides (NSPs) in palm kernel meal impairs the digestibility and utilization of nutrients present in them either by direct encapsulation of the nutrients or by increasing the viscosity of the intestinal content, thereby reducing the rate of hydrolysis and absorption of nutrients [25]. The ADCs of protein (90.57%), lipid (96.14%), fibre (96.74%) and energy (95.50%) recorded for soybean meal in this study compared fairly favourably to the protein (87.40%), lipid (92.10%), fibre (95.20%) and energy (83.70%) ADCs of soybean meal in O. niloticus reported by Köprüçi and Özdemir [26]. Agbo [17] also recorded fairly similar nutrients and energy ADCs for soybean meal (dry matter: 77.47%; protein: 94.50%; lipid: 96.84% and energy: 85.99%) for Nile tilapia juveniles. The high protein digestibility of soy recorded in this study is supported by the findings of other works on soy digestibility by the Nile tilapia which include 92.72% [27], 91.56% [28], 89.28% [29] and 94.50% [17]. The dry matter digestibility for soybean for this study also compares favourably to the dry matter ADC of 71.04% reported by Pezzato et al. [28]. Boscolo et al. [30] observed that the addition of PKM in the diets of red tilapia resulted in significantly lower dry matter, protein, and lipid digestibilities, similar to what was found in this study. They recorded dry matter, protein and lipid ADCs of 30.3, 80.1 and 87.1% respectively. The digestible
The protein quality of copra meal is poor due to the reduction in protein quality with increasing inclusion levels. Despite the isonitrogeneous nature of all the diets used in the growth trials, a critical factor which could have affected fish growth is the presence of antinutritional factors. Treating these test ingredients could have improved their nutritional values and reduced the levels of antinutritional factors [35] and the presence of a number of antinutritional factors [36]. Although this study did not identify and quantify the levels of antinutritional factors in the test ingredients it is highly likely they contained substantial levels which depressed fish growth. Condensed tannins present in copra meal at a level of approximately 2.4% have been reported as possibly causing growth depression in tilapia (Sarotherodon mossambicus) and rohu (Labeo rohita) fingerlings at inclusion levels of 20 and 25% respectively [32,36]. Soaking defatted CM in water can significantly reduce tannin levels and increase feed intake responses of fish. The copra meal as well as all the other test ingredients used in this study were not soaked in water or heat-treated prior to their inclusion in the diets used for the digestibility and growth trials. Treating these test ingredients could have improved their nutritional values and reduced the levels of antinutritional factors as have been reported in some nutritional studies. Mukhopadhyay and Ray [36], for example observed reductions in tannin levels from 2.4 to 0.9% after soaking copra meal in water for 16 hours and fish fed diets containing the pre-soaked copra meal compared favourably with the fishmeal-based control group in terms of growth response, food conversion ratio and protein efficiency ratio. The nutritional potential of soybean meal has also been reported to increase after appropriate treatment to remove or inactivate the antinutritional factors present in them [37,38]. Similar to the findings of Rumsey et al. and Krogdahl et al. [39,40] it was observed at the end of the growth trials that fish fed diets high in SBM generally exhibit progressive impairment of growth and increased feed conversion ratios.

Despite the isonitrogenous nature of all the diets used in the growth trial, a critical factor which could have affected fish growth is the reduction in protein quality with increasing inclusion levels of the test ingredients. The protein quality of copra meal is poor both in terms of its amino acid balance and digestibility [41]. It is deficient in important essential amino acids such as lysine, methionine, threonine and histidine but high in arginine, which is known to have antagonistic effect on lysine utilization [41]. Soybean meal although has one of the best amino acid profiles as far as plant aquafeed ingredients are concerned are usually deficient in methionine. All the diets used in the digestibility and growth trials were not supplemented with their respective deficient amino acids. Deficiencies in the essential amino acids profile of a feed can lead to poor utilization of the dietary protein and consequently reduces growth and decreases feed efficiency [42]. The positive effects of amino acid-supplementation of plant-based diets have been highlighted by some studies. The amino acid composition of diets is generally considered to affect the efficiency of protein utilization. Mukhopadhyay [43], for example reported that fish fingerlings can effectively utilise copra meal supplemented with the inherent lacking amino acids up to 50% replacement of fishmeal protein without significantly reducing growth if the meal is properly fermented. Aside the possible presence of ANFs and the poor amino acid profiles, the low nutrient digestibilities particularly of copra and palm kernel meal is a major factor that might have resulted in the lower fish growth rates and nutrient utilizations in the growth trials. There was a link between the nutrient ADCs of the test ingredients and the growth rates and feed utilisations recorded for their respective diets.

**Conclusion**

Although the inclusion of the oilseed byproducts in the *O. niloticus* diets resulted in significant differences in terms of growth and feed utilization and efficiency compared to the control diet, all the dietary treatment groups more than doubled their mean initial body weights over the 8-week period and recorded appreciable growth rates of between 1.40 and 2.00% day⁻¹. The study has also shown that the test ingredients can partially replace fishmeal in Nile tilapia diets without considerably compromising diet digestibility and carcass traits. High inclusions of copra and palm kernel meals can, however, have a deleterious effect on general fish growth because of their high fibre contents and low dry matter and fibre digestibilities. In other to get full acceptance into the Ghanaian aquaculture sector as low-cost aquafeed ingredients it might be necessary to treat these by-products to reduce their levels of crude fibre and anti-nutritional factors. Natural and/or chemical supplementation of their respective deficient amino acids can also enhance their effects on fish growth.

**Acknowledgement**

The first author is grateful for the Danish International Development Agency (DANIDA)-sponsored PhD fellowship at the Section for Aquaculture of the Technical University of Denmark (DTU) at the North Sea Research Centre in Hirtshals, Denmark.
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