Effects of dietary inclusions of oilseed meals on physical characteristics and feed intake of diets for the Nile Tilapia, Oreochromis niloticus

Obirikorang, Kwasi Adu; Amisah, Stephen; Fialor, Simon Cudjoe; Skov, Peter Vilhelm

Published in:
Aquaculture Reports

Link to article, DOI:
10.1016/j.aqrep.2015.01.002

Publication date:
2015

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

Aquaculture Reports 1 (2015) 43–49

Contents lists available at ScienceDirect

Aquaculture Reports

journal homepage: www.elsevier.com/locate/aqrep

Effects of dietary inclusions of oilseed meals on physical characteristics and feed intake of diets for the Nile Tilapia, *Oreochromis niloticus*

Kwasi Adu Obirikorang[a,*], Stephen Amisah[a], Simon Cudjoe Fialor[a], Peter Vilhelm Skov[b]

[a] *Kwame Nkrumah University of Science and Technology, Faculty of Agriculture and Renewable Natural Resources, Kumasi, Ghana*
[b] *Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, PO Box 101, DK-9850 Hirtshals, Denmark*

ARTICLE INFO

Article history:
Received 16 October 2014
Received in revised form 6 January 2015
Accepted 8 January 2015
Available online 7 February 2015

Keywords:
Oilseed byproducts
Water stability
Nutrient leaching
Feed intake
Nile Tilapia

ABSTRACT

The present study investigated the effects of the inclusion of three oilseed by-products (soybean, copra and palm kernel meals) on some physical characteristics of pelletized feeds as well as on voluntary feed intake and faecal matter production by the Nile tilapia, *Oreochromis niloticus*. The dietary inclusion of soybean meal resulted in a significantly higher feed bulk density relative to the fishmeal control diet. The inclusions of copra and palm kernel meals, however, resulted in lower feed bulk densities. Sinking rates, water stabilities and nutrient retention efficiencies of feed pellets were directly related to feed bulk densities. The soybean meal diet had the fastest sinking velocities, greatest water stability and highest nutrient retention rates. The dietary inclusion of soybean meal, however, significantly impaired feed intake compared to the other three diets. Mean daily feed intakes of the control, palm kernel meal and copra meal diets corresponded to 28.88, 27.01 and 28.31 g during the experimental period and varied significantly from the mean daily intake of the soybean meal diet which corresponded to 20.01 g. Faecal matter production (g dry mass kg^{-1} ingested feed) was significantly higher in the tilapia groups fed the copra and palm kernel meals. The results obtained from this study show that 30% inclusions of unrefined forms of copra and palm kernel meal in Nile tilapia diets is possible, without adversely affecting feed intake or pellet nutrient losses prior to ingestion.

1. Introduction

Fish feeds, according to Aarseth (2004) and Aarseth et al. (2006) should be resistant to mechanical stress such as handling and transportation. Pellets that break up into small particles and leach nutrients can reduce water quality of the culture environment and lead to poor animal growth, inefficient feed conversion, and low survival (Obaldo et al., 2002). Nutritional quality is also related to the physical quality of feed products, because formation of fragments and dust represents a direct loss of feed and feed conversion, thus increasing production cost (Thomas and van der Poel, 1996). Pellet water stability is an important quality parameter in the manufacture of aquaculture diets since feeds represent the single most expensive component in aquaculture. Pellets should be able to maintain their physical integrity with minimal disintegration and nutrient leaching while in the water until consumed by the animal (Obaldo et al., 2002; Halver and Hardy, 2002). Factors that affect the physical quality of feeds include the method of diet preparation and processing, types of ingredients and diet composition and types of binding agents (Obaldo et al., 1999; Aarseth, 2004). According to Thomas et al. (2001), the use of low-cost fishmeal replacers in diet formulations is an important factor that can significantly affect the physical qualities of the feed pellets, although the diet meets the nutritional requirements for the target species.

Nutritional studies aimed at replacing fishmeal in aquafeeds with more economical and environmentally sustainable alternatives have become increasingly common due to the stagnated global production and high cost of fishmeal. The low cost and wide-availability of oilseed meals, particularly copra and palm kernel meals in many tropical countries where aquaculture is practiced have generated much interest in their potential use in fish diets. The presence of high fibre contents and/or anti-nutritional factors (ANFs) in unrefined forms of these meals, however, limits their inclusion in aquafeeds to very low levels. The selected inclusion level for the oilseed meals in this study for example, is reflective of the possible presence of ANFs and the fact that very high fishmeal replacement on a weight-for-weight basis by these unrefined plant protein sources is not feasible because of

* Corresponding author. Tel.: +233 243561881.
E-mail address: quasiadu@gmail.com (K.A. Obirikorang).

http://dx.doi.org/10.1016/j.aqrep.2015.01.002
2352-5134/

Table 1
Proximate composition (% dwb) of the key raw materials used for the formulation of the different experimental diets.

Ingredients	DM	CP	CL	CF	Ash
Fishmeal[a]	90.73	72.30	11.28	1.00	13.00
Soybean meal[b]	89.40	50.00	2.01	3.82	5.89
Palm kernel meal[b]	91.20	17.81	13.24	18.41	3.30
Copra meal[b]	87.85	19.63	8.10	16.00	7.01

DM: dry matter; CP: crude protein; CL: crude lipid; CF: crude fibre.
[a] Danish fishmeal: FF Skagen A/S, Skagen, Denmark.
[b] Expeller-pressed oilseed meals sourced from Kumasi, Ghana.

Table 2
Diet formulation (g kg^{-1} as fed) and proximate composition (% dwb) of control and test diets used for the digestibility trial.

	Control diet	Test diets		
		CM diet	PKM diet	SBM diet
Ingredients				
Fishmeal	425	298	298	298
Soybean meal	–	–	–	300
Copra meal	–	300	–	–
Palm kernel meal	–	–	300	–
Wheat bran	385	269	269	269
Palm oil	90	63	63	63
Vitamin premix	40	28	28	28
Diphosphate	30	21	21	21
Cassava starch (binder)	30	21	21	21
Proximate composition				
Dry matter	93.7	93.0	93.1	93.5
Crude protein	32.3	30.1	25.3	35.1
Crude lipid	14.6	10.8	15.2	13.9
Ash	10.9	10.4	8.5	9.7

CM diet: copra meal diet; PKM diet: palm kernel meal diet; SBM diet: soybean meal diet.

their relatively lower protein contents and unbalanced essential amino acid profiles. Despite the recommended maximum dietary inclusion levels of 15% for copra and palm kernel meals in fish diets (Jauncey, 1998; Hertrampf and Piedad-Pascual, 2000), some studies have demonstrated the possibility of including higher levels of these byproducts in tilapia diets without negatively affecting feed intake and growth performance. Copra inclusion levels beyond 30% significantly reduced feed conversion efficiencies of Nile tilapia (Santos et al., 2009). At up to 35% inclusion, Nile tilapia rations containing palm kernel meal did not depress growth performance (de Oliveira et al., 1997). Similarly, 30% dietary inclusions of palm kernel meal did not adversely affect growth performance and nutrient digestibility in *Oreochromis mossambicus* (Lim et al., 2001). Because of the negative synergistic effects of inherent ANFs coupled with generally poor essential amino acid profiles, most of the studies on copra, palm kernel and soybean meals as fishmeal replacers have been focused on their effects on diet digestibility (Mukhopadhyay and Ray, 1999; Ng and Chong, 2002; Köprücü and Özdemir, 2005; Mamun et al., 2007), as well as growth rate and survival in fishes (Jackson et al., 1982; Olude et al., 2008; Santos et al., 2009) with very little focus on their effects on the physical characteristic of feeds.

Studies on the effects of dietary inclusions of plants ingredients on feed physical characteristics are particularly important because the non-starch polysaccharide fractions of plant ingredients have the potential to reduce expansion and affect the hardness of feeds (Ainsworth et al., 2007). Hardness and water stability are important factors which determine nutrient retention capacity as well as the sinking velocity of pellets (Baeverfjord et al., 2006; Chevanan et al., 2009; Kraugerud et al., 2011). The hardness of pellets generally affects their preference and acceptability by fish, where softer pellets are usually preferred to harder pellets (Aas et al., 2011; Skoch et al., 1983). High water-stable diets are known to prolong digestion and intestinal absorption of nutrients in fish (Pillay and Kutty, 2005; Venou et al., 2009). Fish feed pellets should therefore aim to have physical properties that promote high feed intake and efficient digestion. Water stabilities as well as sinking velocities must be adjusted to the eating habits of the cultured fish species (Lovell, 1989; Baeverfjord et al., 2006; Sørensen, 2012). The aim of this study was thus to investigate the effects of the inclusion of three oilseed by-products, soybean, copra and palm kernel meals on some physical characteristics of pelletized feeds as well as on their intake by the Nile tilapia, *Oreochromis niloticus*.

2. Materials and methods

2.1. Diet formulation

Four diets including a fishmeal-based control diet were formulated for physical characteristics as well as the feed intake assessments. The proximate compositions of the key raw materials (Table 1) and formulations as well as nutritional compositions (% dry weight basis (dwb)) of the experimental diets (Table 2) are presented below. The control diet (CTRL) had fishmeal as the main protein source whiles the test diets contained the test ingredients at 30% inclusions. All the basal ingredients used in the feed formulation were finely-ground and sieved to obtain a homogenous mixture and weighed out according to their respective formulations. Mineral and vitamin premixes were added to each diet. Pre-gelatinised tapioca flour was used as the binder and the diets pelletized with a meat grinder fitted with a 2 mm die plate. The resulting pellets were oven-dried at 40 °C for 48 h.

2.2. Feed bulk densities and pellets sinking velocity measurements

Feed bulk densities were measured following the methods of Aarseth et al. (2006) by pouring feed samples through a funnel into tared 1000 ml measuring cylinders and weighing the content on a balance. The procedure was repeated 3 times for all the feed samples. Sinking velocities of the different feed pellets were measured in a 1.5 m high transparent plastic tube with a sealed bottom and a diameter of 15 cm. The tube was filled with municipal water of drinking quality heated up to 25 °C to simulate the temperature of the natural growing environment for tilapia. The sinking velocities of the pellets were measured by adapting the methods of Lekang et al. (1991). Sinking velocities of the various feed types were measured with a digital stop-watch over a distance of 100 cm between two points at the 10 and 110 cm marks after pellets were dropped from a height of 5 cm above the water surface. To ensure accurate depth recordings, a large-tipped marker was used to mark the 10 and 110 cm depths around the cylinder. The 10 cm marking from the top of the tube was to allow feed pellets to reach terminal or constant velocity before timing. Single pellets of around the same lengths (1 cm) were randomly selected for sinking velocity measurements and sinking velocities were recorded as cm s^{-1}. Thirty (30) pellets were randomly chosen for each diet for the test and feed pellets that came into contact with the tube wall during a fall were excluded.

2.3. Nutrient leaching rates and water stability of the feeds

The pellet water stability and nutrient leaching tests were based on modifications of the horizontal shaking methods employed by Obaldo et al. (2002) and Baeverfjord et al. (2006). One gram samples of each feed were weighed to the nearest 0.1 mg on an analytical balance (Mettler Toledo model XP204) into pre-weighed 3.5 cm × 2 cm × 0.5 cm histology casettes with 1 mm × 1 mm openings. Actual pellet movements within the plastic casings were not constrained by the casing covers. There were 5 replicates per diet for each trial run which covered 5, 10, 20 and 30 min. The replicates for each of the diets were collectively placed in separate 1000 ml beakers containing 300 ml of tap water and placed on a shaker (IKA model HS260) set at 60 cycles per minute for each time period. At the end of each set time, the cassettes were recovered and allowed to drain off excess water on paper tissues. All the cassettes along with their residual contents were transferred into an oven and dried at 80 °C for 48 h. The dry samples were cooled in a desiccator and weighed to determine the residual dry matter. The water stability of the pellets of the different dietary groups was calculated as a ratio of the dry matter recovered after each trial run and the dry matter of the original samples and expressed as a percentage. The dry samples of each of the diets for each time period were then analyzed for protein and lipid to determine nutrient contents relative to retained dry matter over the different time periods using the following equation:

$$\text{nutrient retained} = \frac{g\ \text{nutrient concentration remaining} \times g\ \text{dm pellets remaining}}{g\ \text{initial nutrient} \times g\ \text{initial pellets}}$$

2.4. Feed intake and faeces production assessment

The juvenile Nile Tilapia used for the feed intake and faecal production trials were obtained from a commercial supplier (Ekofisk, Sjöbo, Sweden) and transported to holding facilities at the Technical University of Denmark at the North Sea Research Centre in Hirtshals where they were quarantined for two-weeks. The intake assessment was performed in a modified Guelph System (Cho and Slinger, 1979) consisting of twelve 120 L, cylindro–conical PETG thermoplastic tanks. After the quarantine period, each tank was stocked with 1 kg fish (mean body mass ~50 g). The fish were acclimatized to the experimental facility and fed the experimental diets for 7 days prior to the start of the experiment. The faeces sedimentation column of each tank was enclosed by a Styrofoam jacket containing ice slurry to minimize microbial degradation of the collected faecal matter. Water supply to each tank was maintained at a flow rate of 100 L h^{-1}. Water temperature in the experimental system was maintained at 25 °C throughout the experiment by means of a relay-controlled 1.5 kW electric porcelain heater (Jevi, Denmark) submerged in the reservoir tank. Dissolved oxygen concentration in the tanks was maintained above 70% for the trial duration by two external air pumps (Resun LP-40).

Other water quality parameters such as pH and ammonia were monitored at regular intervals during the 10-day period. A 12 h light: 12 h dark photoperiod was maintained throughout the experiment by twelve 53 W soft tone incandescent light bulbs (Philips A19 EcoVantage) overhead each tank. To demonstrate the effects of the test ingredients on feed intake responses, the fish in all treatment groups were given the opportunity to refuse feed by feeding them just beyond apparent satiety as stipulated by Glencross et al. (2007) for 10 successive days. All uneaten feed was accounted for and feed intake was expressed in cumulative terms over the trial period. Fish were fed by hand twice a day at 9:00 and 16:00 h and each feeding period was recorded as a separate event. Faecal samples were collected daily prior to feeding over a period of 10 days and stored at −20 °C until analysis. Collected faecal matter were analyzed for dry matter and expressed as g DM kg^{-1} of ingested feed.

2.5. Proximate analyses

Dry matter of the test ingredients, experimental diets and faeces as well the crude protein, crude lipid and ash of the ingredients

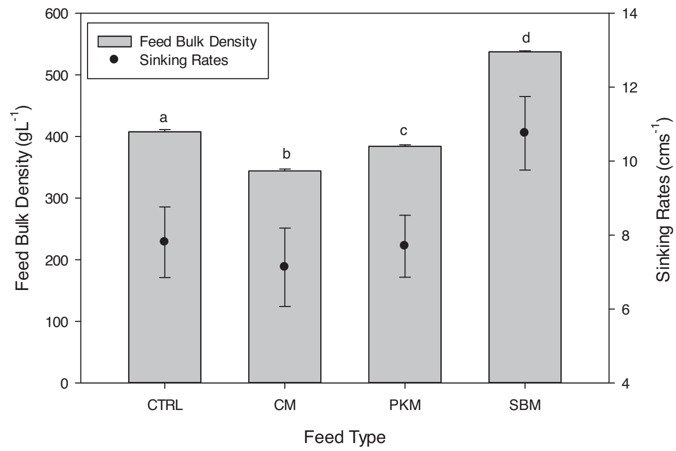

Fig. 1. Feed bulk densities (±SD) and pellet sinking rates (±SD) of the different experimental feeds (CTRL: control diet, CM: copra meal diet, PKM: palm kernel diet, SBM: soybean meal diet). Treatment means not sharing a common letter are significantly different (One-way ANOVA, $p < 0.05$).

and diets were determined following the procedures of the Association of Official Analytical Chemists (AOAC, 2005). Dry matter was determined after oven drying for 24 h at 105 °C (Memmert UN110). Ash contents were calculated from the weight loss after incineration of the samples for 6 h at 550 °C in a muffle furnace (Hareaus Instruments K1252). Crude protein levels were determined from the Kjeldahl method (Foss Kjeltec 2200) and crude lipid by the method of Bligh and Dyer (1959).

2.6. Statistical analyses

Data are presented as means ± standard deviations (SD). All data were subjected to one-way analysis of variance (ANOVA) and differences between the treatment means compared by the Tukey multiple comparison test. Differences were considered significant at $p < 0.05$. All graphs and statistical analyses were executed using SigmaPlot ver. 12.0 (Systat Software, Inc).

3. Results

3.1. Feed bulk densities and pellet sinking velocities

The bulk densities of all four feed types varied significantly ($p < 0.05$). The diet containing the soybean meal had the highest mean bulk density of 537.33 ± 1.80 g L^{-1}. The inclusions of the copra and palm kernel meals resulted in lower mean feed bulk densities of 344.26 ± 3.11 and 384.00 ± 2.92 g L^{-1} respectively. The control diet had a mean bulk density of 407.73 ± 3.49 g L^{-1}. Sinking velocities of the pellets were positively correlated ($p < 0.05$; $r^2 = 0.979$) with feed bulk densities. The pellets of the soybean meal diet recorded the highest mean sinking velocity of 10.75 ± 0.99 cm s^{-1} which was significantly higher ($p < 0.05$) than the pellet sinking velocities of the other three diets (Fig. 1). The palm kernel meal diet and the control diets recorded similar mean sinking velocities of 7.70 ± 0.84 and 7.80 ± 0.95 cm s^{-1} respectively. The 30% inclusion of copra meal to the diet reduced the mean sinking velocity of the resulting pellets to 7.13 ± 1.06 cm s^{-1} which was significantly lower ($p < 0.05$) than the other feed types.

3.2. Feed intake and faeces production

No mortalities were recorded during the trial period and the monitored water quality parameters did not vary significantly among the treatment groups. The control treatment recorded a

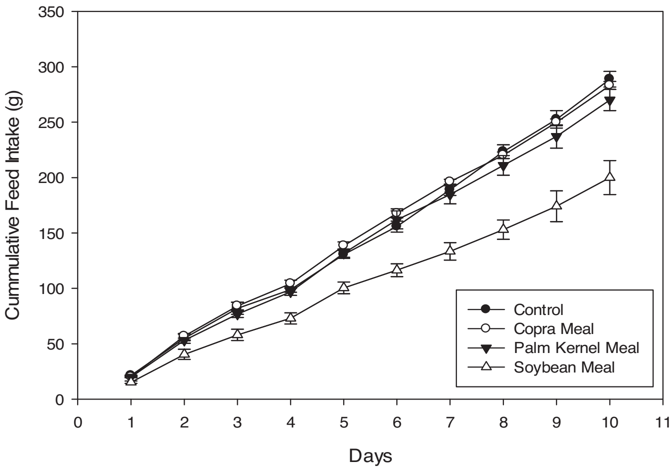

Fig. 2. Cumulative voluntary feed intake of the fish groups fed the different experimental diets.

pH range of 6.21–6.62 with the copra meal treatment recording a range of 6.23–6.62. The palm kernel and soybean meal treatments also recoded similar pH ranges of 6.22–6.62 and 6.21–6.74 respectively. Levels of total ammonia nitrogen in the different treatment tanks did not differ significantly and varied between 1 and 3 mg L^{-1} over the trial period for all the treatments. Acceptability of feed for the dietary treatments was observed to be very good after feeding *O. niloticus* juveniles under an apparent satiation regime over the 10-day period. The inclusion of soybean meal, however, significantly reduced ($p < 0.05$) the cumulative feed intake of the diet by 30.52% compared to that of the control diet. The mean cumulative feed intakes over the trial period for the soy and control diets were 200.10 ± 15.39 and 288.80 ± 7.08 g respectively. The *O. niloticus* fed the copra and palm kernel meal diets recorded total feed intakes of 283.10 ± 3.59 and 270.10 ± 9.51 g respectively, which were not significantly different from the control diet intake (Fig. 2). Mean daily intakes of the control, palm kernel meal and copra meal diets were ~3% of the estimated total fish biomass during the experimental period and varied significantly ($p < 0.05$) from the intake of the soybean meal diet which corresponded to ~2% of total fish biomass. Daily observations of fish gastrointestinal emptying patterns indicate that *O. niloticus* fed the copra and palm kernel meal diets had shorter gastric retention times and produced more faecal material relative to the groups fed the control and soy diets, although the former was not directly quantified. Faecal matter production (g DM kg^{-1} ingested feed) following the ingestion of the experimental diets was significantly different ($p < 0.05$) among the dietary treatments. Faecal production in the *O. niloticus* groups fed the copra meal and palm kernel meal diets were 358.08 ± 7.35 and 372.60 ± 10.19 g DM kg^{-1} ingested feed respectively, which were significantly higher than the control (274.79 ± 5.44 g DM kg^{-1} ingested feed) and soybean meal diets (239.49 g DM kg^{-1} ingested feed) (Fig. 3).

3.3. Water stability and nutrient leaching rates of the feeds

Diets differed significantly in terms of their water stabilities and dry matter retention (Fig. 4). Dry matter loss occurred in a linear fashion over time for all the diets. The soy diet exhibited the best maintenance of pellet structural integrity with dry matter retention of 93.96 ± 0.45% compared to 91.86 ± 0.75% for the control diet after 5 min. The copra and palm kernel meal diets recorded dry matter retentions of 90.22 ± 0.85 and 90.39 ± 0.47% respectively after 5 min (Fig. 4). After the 30th minute, 89.60 ± 0.48% of dry matter was recovered for the soybean meal diet which was

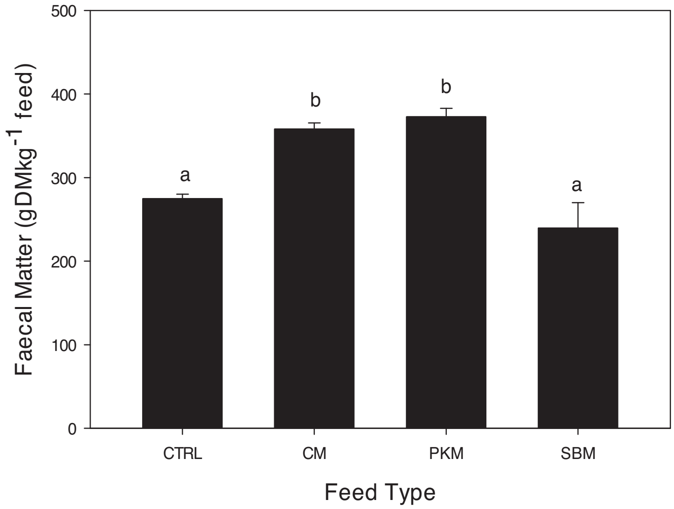

Fig. 3. Faecal matter production (±SD) of Nile Tilapia fed the different experimental diets (CTRL: control diet, CM: copra meal diet, PKM: palm kernel diet, SBM: soybean meal diet). Treatment means not sharing a common letter are significantly different (One-way ANOVA, $p < 0.05$).

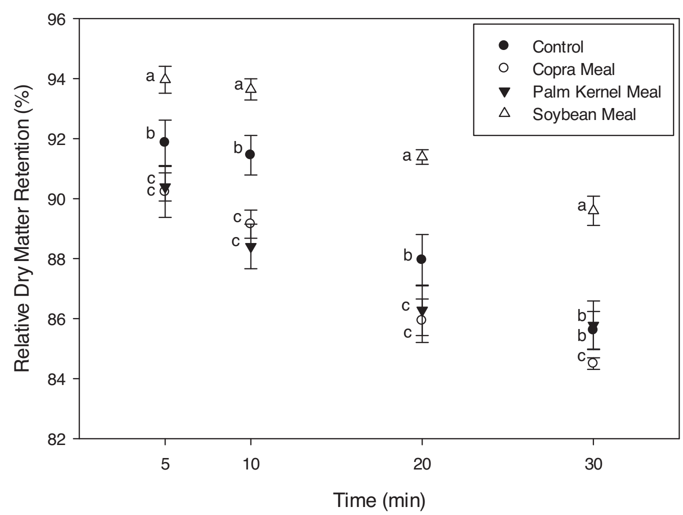

Fig. 4. Pellet dry matter retention of the experimental feeds after 30 min immersion in water. Treatment means in each time interval with different letters are significantly different from each other (One-way ANOVA, $p < 0.05$).

significantly higher ($p < 0.05$) than the dry matter retained for the control (85.61 ± 0.63%) after the same period. The copra and palm kernel meal diets recorded dry matter retentions of 84.50 ± 0.19 and 85.78 ± 0.81% respectively after 30 min.

After the 30-min cycle, protein retention in the residual dry matter of the various feed pellets varied significantly ($p < 0.05$). Crude protein recoveries after 30 min varied from a 95.43 ± 0.94% for the soybean meal diet and 78.75 ± 1.49% for the palm kernel meal diet. The recorded crude protein contents in the retained dry matter of the control and copra diets after 30 min immersion were 89.01 ± 1.41 and 87.27 ± 0.35% respectively (Fig. 5).

With the exception of the pellets of the palm kernel meal diet, lipid was well retained in the pellets of the other diets relative to the dry matter retentions after each immersion time cycle. Signs of lipid leakage from the pellets of these three diets were mostly evident at the 30th minute following significant breakdown of pellet structure. The considerably higher pellet dry matter losses relative to lipid loss of the diets resulted in progressively higher relative lipid contents after each time cycle. The crude lipid content in the

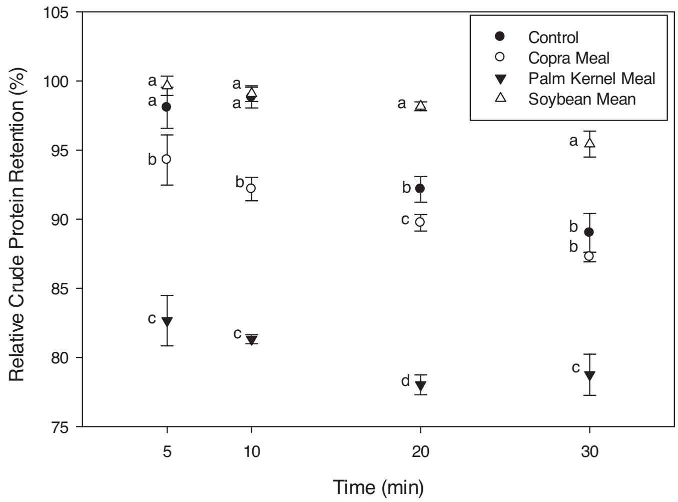

Fig. 5. Pellet crude protein retention of the experimental feeds after 30 min immersion in water. Treatment means in each time interval with different letters are significantly different from each other (One-way ANOVA, $p < 0.05$).

residual dry matter was highest for the control diet and lowest for the palm kernel meal diet (Fig. 6).

4. Discussion

Based on the general pellet physical qualities as well as feed intake observed in the present study, copra and palm kernel meals showed promising prospects as partial protein sources in *O. niloticus* diets. Water stabilities of the pellets in terms of dry matter and nutrient retention were significantly affected by the inclusions of the oilseed byproducts into the experimental diets. The different inherent binding characteristics of the different oilseed meals, which according to Sørensen et al. (2009) and Kraugerud and Svihus (2011) is dependent on their chemical constituents and functional properties, is likely to have caused the differences in pellet quality and stability. The physical qualities of feed pellets depend largely on how well particles of the individual ingredients bond together (Behnke, 1996). Based on inherent binding capabilities, MacMahon and Payne (1991) assigned pelletability indices to different ingredients to indicate the effects of their inclusions on pellets qualities. Their study rated the pelleting qualities of expeller-pressed soybean, copra and palm kernel meals on a scale of 0–10, 7, 7 and 6 respectively, where 0 is poor and 10 is excellent, which appears to be in agreement with the findings of this study as far as pellet water stability is concerned.

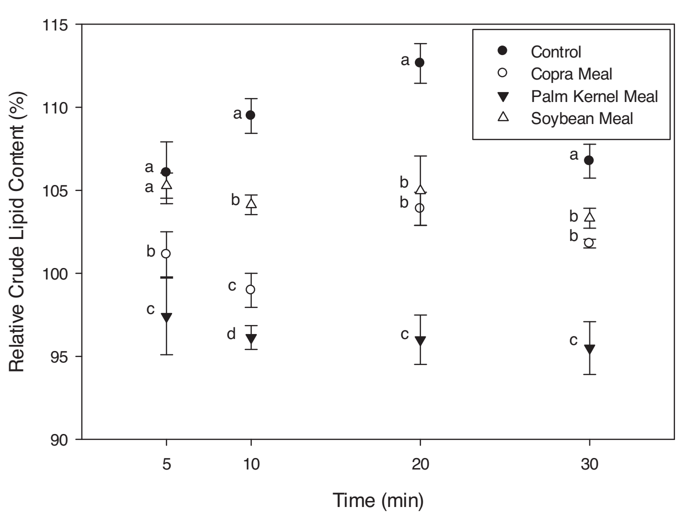

Fig. 6. Pellet crude lipid retention of the experimental feeds after 30 min immersion in water. Treatment means in each time interval with different letters are significantly different from each other (One-way ANOVA, $p < 0.05$).

More specifically, ingredient nutritional properties and compositions have been reported to play significant roles in the physical qualities of feed pellets. High lipid and fibre contents of ingredients are generally known to negatively affect pellet physical properties (Rumpf, 1962; Thomas et al., 1998; Kaliyan and Morey, 2009). The high fibre and residual lipid contents of the copra and palm kernel meals used in this trial may have negatively affected pellet structural integrity and nutrient retentions of their respective diets. Proteins can also induce binding functionalities in an ingredient (Thomas et al., 1998). Soy protein for example is known to generally improve the quality and stability of feed pellets (Sørensen et al., 2009). The adhesiveness of soy protein is caused by intermolecular forces (electrostatic and covalent disulphide bonding) in unfolded proteins (Kumar et al., 2002). The pellet nutrient retention capacities of the different experimental feeds were directly related to their respective water stabilities. The selective retention of lipid in the residual dry matter of the different feeds is comparable to the findings of Baeverfjord et al. (2006) although in their study retention was slightly higher for low water-stable diets than in high water-stable diets. Although after half-an-hour, there were significant pellet dry matter loss and nutrient leaching for all the experimental diets, tilapias are adapted to picking up feed pellets from the water surface or within the water column immediately after feed administration. It is thus unlikely that the feed pellets used in this study will significantly leach out the nutrients intended for the target species before ingestion since the sinking velocities of all the different feed pellets were well-suited to the feeding habits of Nile tilapia.

The slightly lower feed intake of the fish groups fed the palm kernel meal diet relative to the control and copra meal diets could have been as a direct result of lower growth rates due to the lower dietary protein content. This is because aside the high non-starch polysaccharide fraction which impairs digestibility, palm kernel meal contains no known ANFs which negatively affects feed intake in fish (Lim et al., 2001; Ng and Chong, 2002; Ng et al., 2002). The significantly lower feed intake of the soy diet by *O. niloticus* could well be as a result of the general palatability problems associated with the soy protein sources because of the presence of anti-nutritional factors. The replacement of fishmeal with unrefined soybean products quite often negatively affects the palatability of fish diets. The reduced feed intake reported for soybean meal in this study is similar to the findings of other authors who tested different soy products in Chinook salmon (Fowler, 1980; Hajen et al., 1993), Atlantic salmon (Refstie et al., 1998), the red snapper (Davis et al., 2005). Fowler (1980) hypothesized that the reduced palatability of the soy diets were due to the presence of unpalatable compounds in soybean meal.

It is, however, important not to discount the possibility of the feed acceptability and intake by *O. niloticus* also being influenced by pellet structural integrity and hardness. Pellets with very high water stability are generally known to affect preference and acceptability by animals with softer pellets usually being preferred to harder pellets (Skoch et al., 1983). In agreement with the findings of this study, diets with lower water stabilities have been reported by some studies to increase feed intake and gastrointestinal evacuation of ingested feed (g DM kg^{-1} ingested feed) in the target fish species (Adamidou et al., 2009; Aas et al., 2011). Aas et al. (2011) observed a 23% increase in feed intake when rainbow trout were fed a diet with relatively lower pellet water stability compared to a diet with higher water stability. The dietary inclusion of high water-stable soybean meal diet resulted in a 30.52% reduction in total feed intake relative to the control diet, which possibly suggests that a prolonged digestion process following ingestion and slower gastric evacuation rates could have resulted in reduced feed intake in the *O. niloticus* fed this diet. Aside gastric retention times, the higher feed intake of the relatively lower water stable diets possibly implies that *O. niloticus* are able to easily crush and handle these pellets more effectively in their buccal cavity during feeding.

Fish faeces are the major source of solid waste in aquaculture systems (Franco-Nava et al., 2004). It is thus important that dietary formulation result in reduced faecal matter production relative to feed intake. In this study, the additions of copra and palm kernel meals to the experimental diets resulted in significantly higher faeces production (g DM kg^{-1} feed). High feacal matter productions are often related to inefficient digestion of dietary components. In this case high dietary levels of indigestible fibre appear to be the main factor influencing faecal production rates in the tilapia groups fed these two diets. The 30.31 and 35.59% respective increases in faecal matter production of the tilapia groups fed the copra and palm kernel diets relative to the control group could represent significant water quality concerns especially in pond culture. Faecal matter productions expressed as a proportion of feed consumed of the fish groups fed the copra and palm kernel meal diets (35.8 and 37.3% respectively) are well above the 15–25% reported by Cho and Bureau (2001) in typical fish production systems. The high faecal matter production following the ingestion of diets containing 30% of the two oilseed meals can have negative implications for culture water quality since fish faecal fractions are mainly constituted of particulate organic substances, including particulate forms of nitrogen and phosphorus as well as urea (Wallace et al., 1991; Bureau and Cho, 1999). The leaching of carbon and nitrogen from faeces into the culture environment as dissolved organic carbon and nitrogen can potentially lead to nutrient enrichment of the culture environment (Chen et al., 2003). This coupled with the high faecal particulate matter loading can have even greater negative water quality implications for non-aerated pond environments. Even though tilapia production in Ghana has entered a steady phase of expansion, it is still dominated by non-aerated earthen ponds, with over 4500 operational ponds in the main aquaculture regions of the country (Frimpong et al., 2011). The negative influence of the diets containing unprocessed forms of copra and palm kernel meals on faeces production can thus result in nutrient enrichment and an increased demand for and reduced levels of dissolved oxygen in these culture environments leading to poor fish growth and mortalities.

5. Conclusion

The results obtained from this study have shown that 30% inclusions of unrefined forms of copra and palm kernel meals do not negatively affect the feed intake of *O. niloticus*. The addition of 30% soybean meal, however, significantly reduced feed intake. Similarly, water stabilities and dry matter as well as nutrient retentions were significantly affected by the inclusions of the oilseed meals. The inclusion of the soybean meal resulted in pellets with significantly higher bulk density, sinking rate and water stability compared to the other experimental diets. Nutrient retention efficiencies were also affected by the inclusion of the oilseed meals. The PKM diet resulted in lower protein and lipid retentions relative to the fishmeal-based control diet. Prior treatments of copra and palm kernel meal may be necessary to reduce their high crude fibre contents which appeared to negatively affect pellet water stability and faecal matter production.

Acknowledgements

The authors would like to thank the technical and laboratory staff of the Section for Aquaculture, DTU Aqua, Hirtshals, Denmark for their assistance with the experimentation and laboratory analyses. The present study is part of KAO's PhD which was supported by a Danish International Development Agency (DANIDA) fellowship.

References

Aarseth, K.A., 2004. Attrition of feed pellets during pneumatic conveying: the influence of velocity and bend radius. Biosyst. Eng. 89, 197–213.

Aarseth, K.A., Perez, V., Bøe, J.K., Jeksrud, W.K., 2006. Reliable pneumatic conveying of fish feed. Aquac. Eng. 35, 14–25.

Aas, T.S., Terjesen, B.F., Sigholt, T., Hillestad, M., Holm, J., Restfie, S., Baeverfjord, G., Rørvik, K.-A., Sørensen, M., Oehme, M., Åsgård, T., 2011. Nutritional responses in rainbow trout (*Oncorhynchus mykiss*) fed diets with different physical qualities at stable or variable environmental conditions. Aquac. Nutr. 17, 657–670.

Adamidou, S., Nengas, J., Alexis, M., Foundoulaki, E., Nikolopoulou, D., Campell, P., Karacostas, J., Rigos, G., Bell, G.J., Jauncey, K., 2009. Apparent nutrient digestibility and gastrointestinal evacuation time in European seabass (*Dicentrarchus labrax*) fed diets containing different levels of legumes. Aquaculture 289, 106–112.

Ainsworth, P., Ibanoglu, S., Plunkett, A., Ibanoglu, E., Stojceska, V., 2007. Effect of brewers spent grain addition and screw speed on the selected physical and nutritional properties of an extruded snack. J. Food Eng. 81, 702–709.

AOAC (Association of Official Analytical Chemists), 2005. Official Methods of Analysis of the Official Association of Analytical Chemists, 18th ed. Association of the Official Analytical Chemists, Arlington, VA, USA.

Baeverfjord, G., Refstie, S., Krogedal, P., Åsgård, T., 2006. Low feed pellet water stability and fluctuating water salinity cause separation and accumulation of dietary oil in the stomach of rainbow trout (*Oncorhynchus mykiss*). Aquaculture 261, 1335–1345.

Behnke, K.C., 1996. Feed manufacturing technology: current issues and challenges. Anim. Feed Sci. Technol. 62, 49–57.

Bligh, E.G., Dyer, W.J., 1959. A rapid method for total lipid extraction and purification. Can. J. Biochem. Physiol. 37, 911–917.

Bureau, D.P., Cho, C.Y., 1999. Phosphorus utilization by rainbow trout (*Oncorhynchus mykiss*): estimation of dissolved phosphorus waste output. Aquaculture 179, 127–140.

Chen, Y.S., Beveridge, M.C.M., Telfer, T.C., Roy, W.J., 2003. Nutrient leaching and settling rate characteristics of the faeces of Atlantic salmon (*Salmo salar* L.) and the implications for modelling of solid waste dispersion. J. Appl. Ichthyol. 19, 114–117.

Chevanan, N., Muthukumarappan, K., Rosentrater, K.A., 2009. Extrusion studies of aquaculture feed using distillers dried grains with solubles and whey. Food Bioprocess Technol. 2, 177–185.

Cho, C.Y., Bureau, D.P., 2001. A review of diet formulation strategies and feeding systems to reduce excretory and feed wastes in aquaculture. Aquac. Res. 32, 349–360.

Cho, C.Y., Slinger, S.J., 1979. Apparent digestibility measurement in feedstuffs for rainbow trout. In: Halver, J., Tiews, K. (Eds.), Proc. World Symp. on Finfish Nutrition and Fishfeed Technology, vol. II. Heenemann, Berlin, pp. 239–247.

Davis, D.A., Miller, C.L., Phelps, R.P., 2005. Replacement of fish meal with soybean meal in the production diets of juvenile red snapper, *Lutjunus cumpechunus*. J. World Aquac. Soc. 36 (1), 114–119.

de Oliveira, A.C.B., Pezzato, L.E., Barros, M.M., Pezzato, A.C., Silveira, A.C., 1997. African palm kernel meal on Nile tilapia production performance. Pesqui. Agropecu. Bras. 32 (4), 443–449.

Fowler, L.G., 1980. Substitution of soybean and cottonseed products for fish meal in diets fed to chinook and coho salmon. Prog. Fish Cult. 42 (2), 87–91.

Franco-Nava, M.A., Blancheton, J.P., Deviller, G., Le-Gall, J.Y., 2004. Particulate matter dynamics and transformations in a recirculating aquaculture system: application of stable isotope tracers in sea bass rearing. Aquac. Eng. 31, 135–155.

Frimpong, E.A., Quagrainie, K.K., Amisah, S., Agbo, N.W., Anane-Taabeah, G., 2011. Harnessing the Opportunities and Overcoming the Constraints to Widespread Adoption of Cage Aquaculture in Ghana. Final Project Report Submitted to United States Agency for International Development Aquaculture and Fisheries Collaborative Research Support Program Corvallis, Oregon.

Glencross, B.D., Booth, M., Allan, G.L., 2007. A feed is only as good as its ingredients: a review of ingredient evaluation for aquaculture feeds. Aquac. Nutr. 13, 17–34.

Hajen, W.E., Higgs, D.A., Beames, R.M., Dosanjh, B.S., 1993. Digestibility of various feedstuffs by post juvenile chinook salmon (*Oncorhynchus tshawytscha*) in sea water: measurement of digestibility. Aquaculture 112, 333–348.

Halver, J.E., Hardy, R.W., 2002. Fish Nutrition, 3rd ed. Academic Press, CA, USA.

Hertrampf, J.W., Piedad-Pascual, F., 2000. Handbook on Ingredients for Aquaculture Feeds. Kluwer, The Netherlands.

Jackson, A.J., Capper, B.S., Matty, A.J., 1982. Evaluation of some plant proteins in complete diets for the tilapia *Sarotherodon mossambicus*. Aquaculture 27, 97–109.

Jauncey, K., 1998. Tilapia Feeds and Feeding. Pisces Press Ltd., Stirling, Scotland, pp. 241.

Kaliyan, N., Morey, R.V., 2009. Factors affecting strength and durability of densified biomass products. Biomass Bioenergy 33 (3), 337–359.

Köprücü, K., Özdemir, Y., 2005. Apparent digestibility of selected feed ingredients for Nile tilapia (*Oreochromis niloticus*). Aquaculture 250, 308–316.
Kraugerud, O.F., Svihus, B., 2011. Effects of online pretreatment of plant ingredients on processing responses and physical properties in extruded fish feed. Anim. Feed Sci. Technol. 168, 250–256.
Kraugerud, O.F., Jørgensen, H.Y., Svihus, B., 2011. Physical properties of extruded fish feed with inclusion of different plant (legumes, oilseeds, or cereals) meals. Anim. Feed Sci. Technol. 163, 244–254.
Kumar, R., Choudhary, V., Mishra, S., Varma, I.K., Mattiason, B., 2002. Adhesives and plastics based on soy protein products. Ind. Crops Prod. 6, 155–172.
Lekang, O.I., Andersen, J., Bøe, J.K., Berre, B., 1991. Utstyr og metoder for måling av fysiske egenskaper ved partikkelmateriale (Devices and Methods for Measuring Physical Properties of Particulate Material. Technical note 106/91). Department of Mathematical Sciences and Technology, The Norwegian University of Life Sciences, Ås, Norway (in Norwegian).
Lim, H.A., Ng, W.K., Lim, S.L., Ibrahim, C.O., 2001. Contamination of palm kernel meal with *Aspergillus flavus* affects its nutritive value in pelleted feed for tilapia, *Oreochromis mossambicus*. Aquac. Res. 32, 895–906.
Lovell, T., 1989. Feed formulation and processing. In: Lovell, T. (Ed.), Nutrition and Feeding of Fish. Van Nostrand Reinhold, New York, pp. 107–127.
MacMahon, M.J., Payne, J.D., 1991. The Pelleting Handbook. Borregaard Lignotech, Norway, 72 pp.
Mamun, S.M., Focken, U., Becker, K., 2007. Comparative digestion efficiencies in conventional, genetically improved and genetically male Nile tilapia, *Oreochromis niloticus* (L.). Aquac. Res. 38, 381–387.
Mukhopadhyay, N., Ray, A.K., 1999. Utilization of copra meal in the formulation of compound diets for rohu *Labeo rohita* fingerlings. J. Appl. Ichthyol. 15, 127–131.
Ng, W.-K., Chong, K.K., 2002. The nutritive value of palm kernel meal and the effect of enzyme supplementation in practical diets for red hybrid tilapia *(Oreochromis* sp.). Asian Fish. Sci. 15 (2), 167–176.
Ng, W.-K., Lim, H.-A., Lim, S.-L., Ibrahim, C.-O., 2002. Nutritive value of palm kernel meal pretreated with enzyme or fermented with *Trichoderma koningii* (Oudemans) as dietary ingredient for hybrid tilapia (*Oreochromis* sp.). Aquac. Res. 33, 1199–1207.
Obaldo, L.G., Divakaran, S., Albert Tacon, G., 2002. Method for determining the physical stability of shrimp feeds in water. Aquac. Res. 33, 369–377.
Obaldo, L.G., Dominy, W.G., Ryu, G.H., 1999. Growth, survival, and diet utilization of Pacific white shrimp, *Penaeus vannamei*, fed dry extruded diets with different levels of shear and moisture. J. Appl. Aquac. 9, 47–57.
Olude, O.O., Alegbeleye, W.O.A., Obasa, S.O., 2008. The use of soaked copra meal as a partial substitute for soybean meal in the diet of Nile tilapia (*Oreochromis niloticus*) fingerlings. Livest. Res. Rural Dev. 20 (10), 169–170.
Pillay, T.V.R., Kutty, M.N., 2005. Feed and nutrition. In: Aquaculture: Principles and Practices, 2nd ed. Blackwell Publishing, Oxford, pp. 105–173.
Refstie, S., Storebakken, T., Roem, A.J., 1998. Feed consumption and conversion in Atlantic salmon (*Salmo salar*) fed diets with fish meal, extracted soybean meal or soybean meal with reduced content of oligosaccharides, trypsin inhibitors, lectins and soya antigens. Aquaculture 162, 301–312.
Rumpf, H., 1962. The strength of granules and agglomeration. In: Knepper, W.A. (Ed.), Agglomeration. John Wiley, New York, pp. 379–418.
Santos, E.L., Ludke, M.C.M.M., Barbosa, J.M., Rabello, C.B.V., Ludke, J.V., Winterli, W.M.C., Silva, E.G., 2009. Coconut meal levels in ration for fingerling Nile tilapia. Rev. Bras. Saúde Prod. Anim. 10 (2), 390–397.
Skoch, E.R., Binder, S.F., Deyoe, C.W., Allee, G.L., Behnke, K.C., 1983. Effects of pelleting conditions on performance of pigs fed a corn-soybean meal diet. J. Anim. Sci. 57 (4), 922–928.
Sørensen, M., 2012. A review of the effects of ingredient composition and processing conditions on the physical qualities of extruded high-energy fish feeds as measured by prevailing methods. Aquac. Nutr. 18, 233–248.
Sørensen, M., Stjepanovic, N., Romarheim, O.H., Krekling, T., Storebakken, T., 2009. Soybean meal improves the physical quality of extruded fish feed. Anim. Feed Sci. Technol. 149, 149–161.
Thomas, M., Rijm, W., van der Poel, A.F.B., 2001. Functionality of raw materials and feed composition. In: Brufau, J. (Ed.), Feed Manufacturing in the Mediterranean Region. Improving Safety: From Feed to Food. CIHEAM, Zaragoza, pp. 87–102 (Cahiers Options Méditerranéennes; n. 54).
Thomas, M., van Vliet, T., van der Poel, A.F.B., 1998. Physical quality of pelleted animal feed. 3. Contribution of feedstuff components. Anim. Feed Sci. Technol. 76, 59–78.
Thomas, M., van der Poel, A.F.B., 1996. Physical quality of pelted animal feed. 1. Criteria for pellet quality. Anim. Feed Sci. Technol. 61, 89–112.
Venou, B., Alexis, M.N., Fountoulaki, E., Haralabous, J., 2009. Performance factors, body composition and digestion characteristics of gilthead sea bream (*Sparus aurata*) fed pelleted or extruded diets. Aquac. Nutr. 15, 390–401.
Wallace, R.A., Sanders, G.P., Ferl, R.J., 1991. Biology: The Science of Life, 3rd ed. Harper Collins Publishers, New York.