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Research Article

Replacement of soybean meal by peanut meal in diets for juvenile Nile tilapia, *Oreochromis niloticus*

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ABSTRACT. The use of alternative feeds aims to maintain productivity and reduce animal production costs. This objective of this study was to determine the nutritional value of peanut meal (PNM), as well as replacement of soybean meal (SBM) by PNM in diets for Nile tilapia, *Oreochromis niloticus*. To determine the apparent digestibility coefficients (ADC) of nutrients from the PNM, 40 fish (100 ± 4.3 g) were randomly distributed in four 250 L tanks and fed reference and test diets (50% PNM) plus 0.1% chromic oxide. Feces were collected by modified Guelph system. For the growth performance trial, 180 fish (13.4 ± 0.2 g) were randomly distributed in 30 200 L tanks and fed during 90 days with isoproteic (26.8% digestible protein) and isoenergetic (17.6 kJ g^{-1} digestible energy) diets containing replacement levels of 0, 25, 50, 75 and 100% of SBM digestible protein by PNM digestible protein. The experimental design was completely randomized with five treatments and six replicates. The ADC for protein from PNM was 90.9% whereas the ADCs for essential amino acids ranged from 88.7% for lysine to 97.6% for arginine. The feed conversion ratio was significantly affected when the SBM was totally replaced by PNM. The protein efficiency ratio, protein retention and whole-body protein content significantly decreased in fish fed diets containing PNM levels above 25% of PNM. Therefore, PNM can replace up to 25% of SBM without impairing juvenile Nile tilapia growth performance, feed efficiency, and body composition.

Keywords: *Oreochromis niloticus***,** *Arachis hypogaea*, aquafeeds, digestibility, growth performance.

INTRODUCTION

Soybean meal (SBM) is currently the most common plant protein source used in feeds for freshwater species, due to its high protein content, balanced amino acid profile, consistent quality and abundant supply (Trosvik *et al*., 2012). SBM is generally included to a 20-60% of total formulation in diets for Nile tilapia, *Oreochromis niloticus* (Fernandes Jr. *et al*., 2016; Koch *et al*., 2016). Due to its high demand as a protein source for feedstock animals, the SBM is a competitive ingredient and, consequently, its cost increased significantly (Hossain *et al*., 2012). Therefore, alternative sustainable plant-based protein sources must be identified without compromising fish growth rates (Barros *et al*., 2002). SBM has been successfully replaced by cheaper plant-based protein ingredients in feeds for Nile tilapia, including cottonseed meal (Yue & Zhou, 2008; Kleemann *et al*., 2011), canola meal (Soares *et al*., 2001; Zhou & Yue, 2010), and sesame meal (Guo *et al*., 2011).

The peanut *Arachis hypogaea* L. is the fourth largest oilseed crop in the world (Yildirim *et al*., 2014), with an approximate total global production of 45.6 million ton. Peanut meal (PNM) is a by-product obtained from oil extraction of the whole or broken peanut seeds. Due to its high protein content (40.1-50.9%) (Batal *et al*., 2005), and lower cost than SBM per unit of protein (Goes *et al*., 2004), PNM can be used as a protein source typically to replace SBM. However, PNM has some restrictions related to an imbalance of some essential amino acids, especially arginine and lysine, and its protein quality is considered to be inferior to SBM (Batal *et al*., 2005). Nevertheless, other feedstuffs

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complementing the amino acid profile of PNM, as well as crystalline amino acids supplement, can be included to improve feed formulation.

The apparent digestibility coefficients (ADCs) of dry matter, energy and nutrients of PNM has been evaluated for several fish species such as channel catfish, *Ictalurus punctatus* (Wilson *et al*., 1981), rainbow trout, *Oncorhynchus mykiss* (Riche & Brown, 1996), silver perch, *Bidyanus bidyanus* (Allan *et al*., 2000), cobia, *Rachycentron canadum* (Zhou *et al*., 2004), hybrid catfish, *Clarias macrocephalus* × *C. gariepinus*, and Nile tilapia (Tram *et al*., 2011). However, more studies are needed regarding the potential effects of PNM as a protein source in fish feed. Generally, it has been reported that the amount of PNM that can be included in feeds depends on the dietary protein and available amino acids levels (lysine, methionine, and threonine), as well as anti-nutritional factors (Jackson *et al*., 1982; Hasan *et al*., 1997). Therefore, this study was undertaken to evaluate the ADCs of PNM and, afterward, the effect on growth performance of Nile tilapia fed diets containing graded levels of PNM in replacement of SBM.

MATERIALS AND METHODS

This research was divided into two studies. In Study I, the chemical composition and ADCs of dry matter, energy and nutrients of PNM were determined. In Study II, the effects of replacing SBM digestible protein with PNM digestible protein on the growth performance, feed intake, feed utilization and body composition of juvenile Nile tilapia were evaluated.

All experimental procedures were approved by the Animal Ethics Committee of the Veterinary and Animal Science College, São Paulo State University (protocol 190/2011 - CEUA).

Digestibility assay

The PNM ADC analysis was performed by an indirect method, using chromic oxide (Cr_2O_3) as an inert marker (0.1%) (Bremer-Neto *et al*., 2003). A practical feed was formulated to meet the nutritional requirements of Nile tilapia (Furuya *et al*., 2010) and used as the reference diet (RD) (Table 1). Soybean meal was used as dietary protein source. The test diet (TD) was obtained by replacing 50% of the RD by PNM.

Juvenile Nile tilapia (100 ± 4.3 g) were stocked in four cylindrical plastic cages (120 L; 10 fish per cage), housed in four 250 L circular feeding tanks. In addition, four 300 L cylindrical, conical-bottomed tanks were used for feces collection. Both systems were connected to a biological filter and an electronic thermostat (26.6 ± 0.5ºC). The dissolved oxygen levels (6.5 ± 0.3 mg L^{-1}) of the feeding and collecting tanks were maintained by porous diffusers coupled to a central air blower.

Table 1. Ingredient composition of the reference diet. a) Vitamin and mineral premix (kg of product): vitamin A, 1200000 UI; vitamin D3, 200000 UI; vitamin E, 12000 mg; vitamin K3, 2400 mg; vitamin B1, 4800 mg; vitamin B2, 4800 mg; vitamin B6, 4000 mg; vitamin B12, 4800 mcg; folic acid, 1200 mg; D-calcium pantothenate, 12000 mg; ascorbic acid, 48000 mg; biotin, 48 mg; choline, 65000 mg; nicotinic acid, 24000 mg; iron, 10000 mg; cooper sulphate, 600 mg; manganese sulphate, 4000 mg; zinc sulphate, 6000 mg; potassium iodide, 20 mg; cobalt, 2 mg; selenium, 20 mg, b) Vitamin C Rovimix® Stay-35, DSBM, Heerlen, The Netherlands, c) Butylated hydroxytoluene - Antioxidant, d) Vetec Química Fina Ltda., Duque de Caxias, RJ, Brazil.

Ingredients	%
Soybean meal	60.34
Cornmeal	33.63
Soybean oil	2.44
DL-Methionine	0.20
L-Threonine	0.21
Dicalcium phosphate	2.11
Vit/Min premix[a]	0.80
NaCl	0.10
Vitamin C[b]	0.05
BHT[c]	0.02
Chromic oxide[d]	0.10

Diets were randomly assigned to tanks (n = 2), and fish were fed seven days prior to the fecal collection (acclimatization period). During the trial period, fish were fed to apparent satiation from 08:00 to 17:00 h. At 18:00 h, the cages were transferred to the collecting feces tanks. In the morning of the following day (06:00 h), fish were returned to their respective feeding tanks, and feces were collected with sampling vials (200 mL) connected to the bottom of the collection tanks. This procedure was carried out until a representative volume of feces was collected for chemical analysis. Feces were oven-dried (50ºC, 24 h), powdered and stored under refrigeration (-20ºC) for posterior analysis.

The chemical composition of diets, PNM and feces were determined in duplicates samples according to standard procedures (AOAC, 1995). Dry matter was analyzed via oven-drying at 105ºC for 24 h. Total nitrogen content was determined by the micro-Kjeldahl method, and crude protein was then calculated as %N × 6.25. Crude lipid concentration was determined by Soxhlet extraction with petroleum ether. Crude fiber was determined by the Weende method. Ash content was determined by burning samples to 550ºC for 24 h, and gross energy was assessed using an adiabatic bomb

calorimeter (C200, IKA, Staufen, BW, Germany). Total phosphorus concentration was analyzed by a colorimetric process, using the vanado-molybdate reagent (Williams, 1979), and amino acid content was determined by high-performance liquid chromatography (HPLC) in an auto-analyzer after hydrolysis of samples with 6 N HCl for 22 h at 110ºC (Moore & Stein, 1963). The Cr_2O_3 content of diets and feces were determined according to Bremer-Neto *et al*. (2005).

The dry matter (ADC_{DM}), gross energy (ADC_{GE}), crude protein (ADC_{CP}), crude lipid (ADC_{CL}), phosphorus (ADC_P) and amino acid (ADC_{AA}) digestibility values were calculated for the RD and TD according to Cho *et al*. (1982): $ADC_n = 1 - [(\%Cr_2O_{3d} / \%Cr_2O_{3f}) \times (\%N_f / \%N_d)]$, where ADC_n = the apparent digestibility coefficients of a nutrient, $\%Cr_2O_{3d}$ = % chromic oxide of the diet, $\%Cr_2O_{3f}$ = % chromic oxide of the feces, $\%N_f$ = % of nutrients (or kJ g^{-1} gross energy) in feces and $\%N_d$ = % of nutrients (or kJ g^{-1} gross energy) in the test diet. The ADC of PNM was calculated as described by Bureau *et al*. (1999): $ADC_{test\ ingredient} = ADC_{test\ diet} + [(ADC_{test\ diet} - ADC_{ref.\ diet}) \times (0.5 \times D_{ref} / 0.5 \times D_{ingr})]$, where D_{ref} = % of nutrients (or kJ g^{-1} gross energy) in the reference diet mash (as is) and D_{ingr} = % of nutrients (or kJ g^{-1} gross energy) in the test ingredient (as is). The chemical compositions and ADCs of the RD and PNM are presented in Table 2.

Table 2. Proximate composition (% dry matter) and apparent digestibility coefficients (%) of energy and nutrients in reference diet and peanut meal fed to Nile tilapia.

	Reference diet	Peanut meal
Proximate composition		
Dry matter	93.7 (73.2)	93.75 (69.7)
Gross energy (kJ g^{-1})	18.8 (77.8)	19.2 (74.7)
Crude protein	31.09 (93)	50.72 (90.9)
Crude lipid	4.78 (85.7)	3.27 (84.5)
Crude fiber	4.70	10.27
NFE	45.72	22.97
Ash	7.41	6.52
Phosphorus	1.02 (52.8)	0.34 (41.5)
Essential amino acids		
Arginine	2.35 (98.4)	6.38 (97.6)
Histidine	1.07 (96.8)	1.43 (93)
Isoleucine	1.09 (93.2)	1.39 (89.9)
Leucine	2.44 (95.3)	3.03 (91.9)
Lysine	2.53 (96.5)	2.35 (88.7)
Methionine	1.33 (98.5)	0.50 (95.5)
Phenylalanine	1.46 (96.3)	2.24 (94.0)
Threonine	1.42 (95.2)	1.08 (88.8)
Valine	1.15 (92.3)	1.62 (89.6)
Non-essential amino acids		
Alanine	1.34 (91.5)	1.80 (89.4)
Aspartic acid	3.12 (97.4)	5.12 (94.5)
Glutamic acid	5.47 (98.0)	8.52 (95.3)
Cystine	0.82 (99.0)	0.89 (97.5)
Glycine	1.26 (95.2)	2.91 (88.8)
Proline	1.66 (95.2)	2.07 (91.2)
Serine	1.53 (95.9)	2.15 (92.7)
Tyrosine	0.86 (95.7)	1.65 (94.1)

Study II. Growth Performance

Five isoproteic (26.8% digestible protein) and isoenergetic (17.6 kJ g^{-1} digestible energy) diets were formulated based on the data collected in the digestibility trial and the plant feedstuff values reported for Nile tilapia (Furuya *et al*., 2010). The same level of digestible lysine (1.53%), methionine (0.52%), threonine (1.18%), tryptophan (0.30%) and available phosphorus (0.51%) was maintained for all experimental diets. The replacement levels of SBM digestible protein by PNM digestible protein were 0, 25, 50, 75 and 100%, representing the treatments in this study.

Feed ingredients were ground in a laboratory grinder to achieve 0.5 mm particle size, weighed, mixed in a Y vertical mixer, moistened (25% water, v:v) and processed into 4.0 mm pellets in a meat grinder. Diets were oven dried (50ºC, 24 h) and stored under refrigeration (4ºC) until its use. At the beginning of the experiment, diets were ground and sieved to obtain feed particles with size according to fish size. The gross energy, crude protein, crude lipid, crude fiber, and ash of the experimental diets were analyzed in duplicate, according to standard methods (AOAC, 1995). The compositions and chemical analysis of the experimental diets are shown in Table 3, and the corresponding amino acid profiles are shown in Table 4.

Six hundred fish were purchased from a commercial fish farm (Piscicultura Fernandes, Palmital, SP, Brazil) and transferred to the laboratory (AquaNutri, FMVZ, Botucatu, SP, Brazil). The fish were acclimated and fed a commercial diet for two weeks prior to the feeding trial. Then, a homogenous group of 180 fish was selected by weight (13.4 ± 0.2 g) and randomly stocked into 30, 200-L tanks (six fish per tank). The experimental diets (treatments) were randomly distributed among the tanks and their weights were recorded for further calculations. The experimental design was completely randomized and consisted of five treatments and six replicates.

The tanks were supplied with 6 L min^{-1} dechlorinated tap water that passed through a biological filter to reduce impurities and ammonia concentration. The tanks were cleaned as required. The recirculated system was supplied with a heater. The water temperature, dissolved oxygen concentration, and pH level were maintained at 26.0 ± 0.4ºC, 7.2 ± 0.4 mg L^{-1}, and 7.0 ±

Table 3. Ingredients (%) and proximate composition (% dry matter) of the experimental diets. [1]Percent soybean meal digestible protein replaced by peanut meal digestible protein. [2]Analyzed values. a) Vitamin and mineral premix (kg of product): vitamin A, 1200000 UI; vitamin D3, 200000 UI; vitamin E, 12000 mg; vitamin K3, 2400 mg; vitamin B1, 4800 mg; vitamin B2, 4800 mg; vitamin B6, 4000 mg; vitamin B12, 4800 mcg; folic acid, 1200 mg; D-calcium pantothenate, 12000 mg; ascorbic acid, 48000 mg; biotin, 48 mg; choline, 65000 mg; nicotinic acid, 24000 mg; iron, 10000 mg; copper sulphate, 600 mg; manganese sulphate, 4000 mg; zinc sulphate, 6000 mg; potassium iodide, 20 mg; cobalt, 2 mg; selenium, 20 mg, b) Vitamin C Rovimix® Stay-35, DSBM, Heerlen, The Netherlands. cButylated hydroxytoluene - antioxidant.

	Diets[1] (%)				
	0	25	50	75	100
Ingredients					
Soybean meal	46.87	34.71	22.55	10.45	-
Peanut meal	-	11.72	23.44	35.15	45.39
Corn gluten	6.45	6.45	6.45	6.45	6.45
Cornmeal	35.91	36.85	37.82	38.47	38.34
Wheat middlings	4.0	4.0	4.0	4.0	4.0
Soybean oil	1.55	1.35	1.14	1.02	1.11
L-Lysine	0.01	0.17	0.33	0.5	0.63
DL-Methionine	0.19	0.19	0.19	0.2	0.2
L-Threonine	0.3	0.37	0.44	0.52	0.58
L-Tryptophan	0.05	0.11	0.17	0.23	0.28
Dicalcium phosphate	2.03	2.04	2.04	2.04	2.05
Cellulose	1.67	1.07	0.46	-	-
Vit/Min premix[a]	0.8	0.8	0.8	0.8	0.8
NaCl	0.1	0.1	0.1	0.1	0.1
Vitamin C[b]	0.05	0.05	0.05	0.05	0.05
BHT[c]	0.02	0.02	0.02	0.02	0.02
Proximate composition[2]					
Gross energy (kJ g^{-1})	19.1	19.	18.9	18.8	18.8
Crude protein	33.15	33.28	33.44	33.6	33.69
Crude lipid	4.16	4.2	4.23	4.35	4.65
Crude fiber	5.61	5.57	5.54	5.63	6.01
Ash	6.8	6.64	6.47	6.31	6.18

0.5, respectively. The water quality parameters were monitored once per week using a YSI 556® multi-probe (YSI Environmental, Yellow Spring, OH, USA). The total ammonia concentration (0.11 ± 0.07 mg L^{-1}) was determined using a commercial test kit (Alcon®, Camboríu, SC, Brazil). The photoperiod was maintained at a 12:12 h light:dark schedule.

Fish were fed the experimental diets until apparent satiation in four daily meals (08:00, 11:00, 14:00, and 17:00 h) for 90 days. At the end of the feeding period, fish were fasted for 24 h, anesthetized (benzocaine, 67 mg L^{-1}) and weighed. Growth performance and feed efficiency were evaluated by estimating the following parameters: weight gain (WG) = final body weight (g $fish^{-1}$) - initial body weight (g $fish^{-1}$), feed intake (FI, g $fish^{-1}$) = total feed consumed (g) / number of fish per replicate, feed conversion ratio (FCR) = FI / WG, protein efficiency ratio (PER) (%) = 100 × WG / protein intake (PI, g kg^{-1} dry weight basis) and protein retention (PR, %) = 100 × [(FBW × final whole body protein) - (IBW × initial whole-body protein) / PI].

An initial pooled sample of ten fish from the original population and three fish per tank (18 fish from each diet group) at the end were euthanized by anesthetic overdose (benzocaine, 300 mg L^{-1}) to evaluate their centesimal compositions. The fish samples were frozen (-20ºC) before further homogenization and analysis. The moisture, protein, lipid and ash contents were evaluated according to AOAC procedures (1995).

The growth performance and feeding efficiency data were analyzed using a one-way ANOVA ($P < 0.05$). The Tukey multiple range test was used to identify differences among normally distributed means. The analysis was conducted using the statistical software package Minitab version 16 (Minitab Inc., State College, PA, USA).

Table 4. Amino acid composition (% dry matter) of the experimental diets. [1]Percent soybean meal digestible protein replaced by peanut meal digestible protein. [2]Calculated based on the data collected in the digestibility trial and the plant feedstuff values reported for Nile tilapia (Furuya *et al*., 2010).

	Diets[1] (%)				
	0	25	50	75	100
Essential amino acids[2]					
Arginine	2.07	2.39	2.70	3.01	3.28
Histidine	0.81	0.82	0.84	0.85	0.86
Isoleucine	1.45	1.31	1.18	1.06	0.95
Leucine	3.11	2.98	2.84	2.71	2.59
Lysine	1.82	1.82	1.82	1.83	1.82
Methionine	0.62	0.61	0.60	0.60	0.59
Phenylalanine	1.64	1.61	1.57	1.54	1.51
Threonine	1.47	1.44	1.42	1.41	1.39
Valine	1.52	1.41	1.30	1.19	1.10
Non-essential amino acids[2]					
Alanine	1.58	1.53	1.48	1.43	1.39
Aspartic acid	3.17	3.08	2.99	2.90	2.82
Glutamic acid	6.10	5.94	5.79	5.64	5.51
Cystine	0.31	0.36	0.41	0.46	0.51
Glycine	1.22	1.32	1.41	1.50	1.58
Proline	1.91	1.83	1.75	1.68	1.61
Serine	1.50	1.46	1.42	1.38	1.35
Tyrosine	1.06	1.06	1.07	1.08	1.09

RESULTS

Digestibility

Arginine presented the highest ADC among essential amino acids, whereas lysine displayed the lowest value. Methionine exhibited a high availability despite its low content in PNM (Table 2).

Growth performance

The replacement of more than 25% of SBM digestible protein with PNM digestible protein significantly impaired the growth performance of Nile tilapia. The feed conversion ratio was significantly affected when SBM was totally replaced by PNM. However, no significant FI, HSI or survival differences were observed among the treatments. Replacing up to 25% of SBM digestible protein with PNM digestible protein did not significantly affect the FBW, WG, PER, and PR of the fish (Table 5).

Replacing 50%, 75% and 100% of SBM with PNM significantly decreased the carcass protein contents of the fish. However, no significant differences among treatments were detected in moisture, lipid or ash content in whole-body samples (Table 6).

DISCUSSION

Digestibility

Low ADC_{DM} values were recorded for PNM in this study, which may be related to the fiber content of the feed. Dietary fiber is not entirely digested by most fish species (NRC 2011) and studies have reported that the dietary fiber content and ADC_{DM} are related (Allan *et al*., 2000; Guimarães *et al*., 2012). The ADC_{DM} value determined in this study is similar to values reported for the other fish species, such as silver perch, *Bidyanus bidyanus* (74.2%) (Allan *et al*., 2000); yellowfin seabream, *Sparus latus* (70.6%) (Wu *et al*., 2006); and hybrid tilapia, *O. niloticus* × *O. aureus* (66.6%) (Zhou & Yue, 2012).

The dietary fiber content also affected the ADC_{GE}. This correlation has been reported in other studies (Guimarães *et al*., 2012; Vidal *et al*., 2015). The GE digestibility observed in this study was similar to values reported for silver perch (77%) (Allan *et al*., 2000) but lower than values reported for hybrid tilapia, *O. niloticus* × *O. aureus* (81.5%) (Zhou & Yue, 2012).

The obtained ADC_{CP} value was similar to those reported for silver barb, *Puntius gonionotus* (88.6%) (Mohanta *et al*., 2006), and hybrid catfish, *Clarias macrocephalus* × *C. gariepinus*, and Nile tilapia (93.4% and 94.2%, respectively) (Tram *et al*., 2011) but

Table 5. Growth performance and feed utilization of juvenile Nile tilapia fed the experimental diets. [1]Mean values ± standard deviation (n = 6). Values in the same row with different superscript letters are significantly different (Tukey test). [2]Percent soybean meal digestible protein replaced by peanut meal digestible protein. a) FBW, final body weight = g fish-1, b) WG, weight gain = FBW (g) - IBW (g), c) FI, feed intake, d) FCR, feed conversion rate = FI (g) / WG (g), e) PER, protein efficiency ratio = 100 × WG (g) / protein intake (g kg^{-1}, dry weight); fPR, protein retention = 100 × [(FBW × final whole-body CP) - (IBW × initial whole-body CP) / protein intake (g kg^{-1}, dry weight)], gSUR, survival rate = 100 × (final fish number / initial fish number).

	Diets[2] (%)					*P*-value
	0	25	50	75	100	
FBW (g)[a]	105.2 ± 3.6^{a}	101.4 ± 2.6^{ab}	96.1 ± 6^{bc}	97.4 ± 3.4^{bc}	91.3 ± 4.9^{c}	≤ 0.0001
WG (g)[b]	91.6 ± 3.5^{a}	88 ± 2.8^{ab}	82.7 ± 5.9^{bc}	84 ± 3.5^{bc}	77.9 ± 4.9^{c}	≤ 0.0001
FI (g)[c]	102.6 ± 2.3^{a}	105.7 ± 2.2^{a}	104.1 ± 4.4^{a}	100.7 ± 4.7^{a}	100.7 ± 8.8^{a}	> 0.563
FCR[d]	1.1 ± 0.03^{b}	1.2 ± 0.1^{ab}	1.2 ± 0.1^{ab}	1.2 ± 0.1^{ab}	1.3 ± 0.04^{a}	> 0.008
PER (%)[e]	2.7 ± 0.1^{a}	2.5 ± 0.1^{ab}	2.4 ± 0.1^{bc}	2.5 ± 0.1^{b}	2.3 ± 0.1^{c}	≤ 0.0001
PR (%)[f]	37.8 ± 1.2^{a}	36.1 ± 1.7^{ab}	30.8 ± 3^{c}	32.9 ± 0.8^{bc}	29.8 ± 1.7^{c}	≤ 0.0001
SUR (%)[g]	97.2 ± 6.8^{a}	100^{a}	100^{a}	100^{a}	94.4 ± 8.6^{a}	> 0.220

Table 6. Whole-body composition (wet weight basis) of juvenile Nile tilapia fed experimental diets for 90 days[1]. a) Mean values ± standard deviation (n = 6). Values in the same row with different superscript letters are significantly different (Tukey test), b) Percent soybean meal digestible protein replaced by peanut meal digestible protein.

Composition	Initial values	Diets[2] (%)					*P*-value
		0	25	50	75	100	
Moisture	82.2	76.3 ± 0.8^{a}	77.1 ± 0.5^{a}	77.6 ± 0.2^{a}	77.2 ± 0.3^{a}	77.3 ± 0.7^{a}	> 0.150
Protein	11.3	14 ± 0.4^{a}	13.7 ± 0.2^{ab}	12.8 ± 0.3^{c}	13 ± 0.2^{bc}	12.7 ± 0.2^{c}	≤ 0.0001
Lipid	1.4	7.1 ± 0.4^{a}	6.9 ± 0.4^{a}	7.4 ± 0.3^{a}	7.3 ± 0.2^{a}	7.1 ± 0.2^{a}	> 0.416
Ash	3.9	2.3 ± 0.2^{a}	2.3 ± 0.1^{a}	2.3 ± 0.1^{a}	2.3 ± 0.1^{a}	2.5 ± 0.1^{a}	> 0.366

higher than that of hybrid tilapia, *O. niloticus* × *O. aureus* (77.6%) (Zhou & Yue, 2012). Tilapia exhibited a high protein digestibility, which is likely related to the high proteolytic enzyme activity (Tengjaroenkul *et al*., 2000).

The average amino acid ADCs obtained from PNM were higher than the protein ADC in this study. This result suggests that the ADC_{CP} of PNM cannot be used as an indicator of amino acid digestibility, as was reported by Wilson *et al*. (1981), Gaylord *et al*. (2004) and Zhou & Yue (2012). Therefore, the ADCs of individual amino acids should be taken into account when formulating diets to avoid deficiencies.

Arginine exhibited the highest ADC among essential amino acids. This result is similar to those obtained with channel catfish (96.6%) (Wilson *et al*., 1981); hybrid tilapia, *O. niloticus* × *O. aureus* (94.7%) (Zhou & Yue, 2012); and striped catfish, *Pangasianodon hypophthalmus* (98.3%) (Da *et al*., 2013). Some essential amino acids exhibited below-average ADCs, including isoleucine, leucine, lysine, threonine, and valine. Lysine displayed the lowest ADC value. Similar results were observed for silver perch (89.5%) (Allan *et al*., 2000) and striped catfish (86.7%) (Da *et al*., 2013). According to Kaushik *et al*. (1988), excess dietary arginine may decrease the lysine digestibility, because these two amino acids share the same carrier system in the intestines (Berge *et al*., 1999).

Methionine exhibited a high availability in this study despite its low content in PNM. Similar values were observed for silver perch (97.8%) (Allan *et al*., 2000); hybrid striped bass, *Morone chrysops* × *M. saxatilis* (94%) (Gaylord *et al*., 2004); and hybrid catfish and Nile tilapia (96.3% and 96.2%, respectively) (Tram *et al*., 2011).

The ADC_P obtained in this study was higher than the value reported for rainbow trout (22.1%) (Riche & Brown, 1996), but lower than the value reported for hybrid tilapia, *O. niloticus* × *O. aureus* (53.1%) (Zhou & Yue, 2012). Differences in digestive anatomy and physiology may affect phosphorus digestion and absorption in different fish species (Hua & Bureau, 2010). These differences in phosphorus digestibility among fish species have been reported in various studies (Ellestad *et al*., 2002; Hua & Bureau, 2010),

which have suggested that cichlids may be able to digest approximately 27% of phytate-P from plant ingredients, whereas cyprinids and salmonids lack this capability.

Growth performance

Replacing more than 25% of SBM with PNM impair various Nile tilapia growth parameters, such as FBW and WG. Replacing SBM with other plant ingredients can decrease or inhibit the feed intake and impair fish growth (Adebayo *et al*., 2004; Azaza *et al*., 2009; Zhou & Yue, 2010). However, FI was not affected by replacing SBM digestible protein with PNM digestible protein in the present study. Thus, the palatability of PNM may be similar to that of SBM. Therefore, the negative effects of PNM digestible protein levels above 25% may be due to decreasing the DM and/or CP digestibility compared to fish fed diets without PNM. Plant feedstuffs used in the fish feed may influence the digestive process due to the presence of anti-nutritional factors (Francis *et al*., 2001). Moreover, proteases activities in the intestine and hepatopancreas may be affected by the plant protein source (Lin *et al*., 2010), potentially inhibiting the growth and feed utilization of Nile tilapia.

The replacement of SBM digestible protein by PNM digestible protein impaired the utilization of dietary protein for protein deposition. This effect is demonstrated by the low PER and PR values exhibited by the fish fed diets containing above 25% of PNM digestible protein. Low dietary protein utilization is generally attributed to essential amino acids deficiency (Azaza *et al*., 2008, 2009). However, all experimental diets in this study were supplemented with crystalline amino acids (L-Lysine, DL-Methionine, L-Threonine, and L-Tryptophan). According to NRC (2011), an imbalance in any essential dietary amino acid may impair protein deposition and amino acid retention and result in amino acid deamination and catabolism. The dietary arginine concentrations in diets containing greater than 25% of PNM were 31.6% to 58.6% higher than a diet without PNM. Therefore, the low PER and PR exhibited by the fish fed diets with above to 25% of PNM may be associated with high dietary arginine levels, potentially impacting the arginine:lysine ratio. The high arginine concentration may result in a lower lysine uptake (Berge *et al*., 1999) because these two amino acids display an antagonistic behavior and compete for the same absorption sites (Berge *et al*., 2002). Thus, the interaction between arginine and lysine may affect the biological value of the dietary protein (Goytortúa-Bores *et al*., 2006). Imbalanced arginine and lysine in fish diets may consequently impair the utilization of dietary protein. This relationship has also been reported for other fish species, such as rohu, *Labeo rohita* (Abidi & Khan, 2009); black sea bream, *Acanthopagrus schlegelii* (Zhou *et al*., 2011); and cobia (Van Nguyen *et al*., 2014).

The protein content in Nile tilapia bodies exhibited a negative relationship with increasing PNM levels in the diets. This result agrees with the PER and PR values described above, which demonstrates that higher arginine levels impaired protein utilization. The excess dietary arginine affected protein deposition in the fish, which was also observed in Indian major carp, *Cirrhinus mrigala* (Ahmed & Khan, 2004); hybrid Clarias, *Clarias gariepinus* × *C. macrocephalus* (Singh & Khan, 2007); and cobia (Ren *et al*., 2014). Therefore, these results highlight the importance of establishing the optimal balance of essential amino acids, which should optimize dietary protein utilization. Although arginine supplementation is not necessary for fish diets, the antagonistic relationship between arginine and lysine should be assessed when developing practical diets for Nile tilapia.

In conclusion, the PNM may be added to up to 11.72% in the Nile tilapia diet, which corresponds to 25% of SBM digestible protein, without affecting growth performance, feed efficiency, and body composition, since the amino acids requirement is considered.

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