Rev. Bras. Saúde Prod. Anim., Salvador, v.18, n.3, p.479-491 jul./set., 2017 ISSN 1519 9940
http://mc04.manuscriptcentral.com/rbspa-scielo http://dx.doi.org/10.1590/S1519-99402017000300008

Apparent digestibility of wheat and coproducts in extruded diets for the Nile tilapia, *Oreochromis niloticus*

Digestibilidade aparente do trigo e co-produtos em dietas extrusadas para juvenis de tilápias do Nilo "Oreochromis niloticus"

VIDAL, Luiz Vítor Oliveira[1*]; XAVIER, Tadeu Orlandi[2]; MOURA, Lorena Batista de[2]; MICHELATO, Mariana[3]; MARTINS, Elias Nunes[2]; FURUYA, Wilson Massamitu[3]

[1]Universidade Federal da Bahia, Escola de Medicina Veterinária e Zootecnia, Departamento de Zootecnia, Salvador Bahia, Brasil.
[2]Universidade Estadual de Maringá, Departamento de Zootecnia, Maringá, Paraná, Brasil.
[3]Universidade Estadual de Ponta Grossa, Departamento de Zootecnia, Ponta Grossa, Paraná, Brasil.
*Endereço para correspondência: vidal@ufba.br

SUMMARY

In the present study, we investigated the digestibility of wheat and its coproducts in extruded diets for juvenile Nile tilapia. Specifically, we evaluated the apparent digestibility coefficients (ADCs) of dry matter (ADCDM), gross energy (ADCGE), crude protein (ADCCP), essential amino acids (EAAs), and non-essential amino acids (NEAAs) in winter wheat, spring wheat, wheat middling, wheat bran, and wheat germ in a diet fed Nile tilapia. A reference diet and test diets were used, with 5.0g/kg chromic oxide (Cr_2O_3) as the external indicator. The ADCDM, ADCCP, and ADCGE were higher ($P< 0.05$) in winter wheat, spring wheat, and wheat germ than for wheat middling and wheat bran. The ADCs of all amino acids (AAs) were >80%, except for threonine in wheat middling and wheat bran, exceeding 90% for winter wheat and wheat germ. The values of all investigated ingredients were high for ADCCP, and the ADCs of EAAs and NEAAs. A strong negative correlation was detected for crude fiber and ash with the ADCs of dry matter, gross energy, and crude protein. In general, wheat ingredients have good digestibility of protein and amino acids, but high fiber content reduces CDAMS and CDAEB in extruded diets for Nile tilapia.

Keywords: amino acids, cereal, chemical composition, nutritional value, omnivorous fish

RESUMO

A digestibilidade do trigo e seus co-produtos foi avaliada em dietas extrusadas para juvenis de tilápia do Nilo. Foram avaliados os coeficientes de digestibilidade aparente (CDAs) de matéria seca (CDAMS), energia bruta (CDAEB), proteína bruta (CDAPB), aminoácidos essenciais (AAEs) e aminoácidos não essenciais (AANEs) do triguilho, trigo, farelo de trigo, fibra grossa de trigo e gérmen de trigo. Utilizou-se uma dieta de referência e dietas de teste, com 5,0g/kg de óxido crômico (Cr_2O_3) como indicador externo. O CDAMS, CDAPB e CDAEB foram maiores ($P< 0,05$) no triguilho, trigo e germen de trigo do que para farelo de trigo e fibra grossa de trigo. Os CDAs de todos os aminoácidos (AAs) foram maiores que 80%, exceto para treonina no farelo de trigo e fibra grossa de trigo, superior a 90% para triguilho e germen de trigo. Os valores de todos os ingredientes investigados foram elevados para CDAPB, e os CDAs de AAEs e AANEs. Uma forte correlação negativa foi detectada para fibra bruta e cinzas com os ADCs de matéria seca, energia bruta e proteína bruta. De maneira geral, os ingredientes provenientes do trigo possuem boa digestibilidade da proteína e aminoácidos, porém o alto conteúdo fibroso reduz os CDAMS e CDAEB, em dietas extrusadas para a tilápia do Nilo.

Palavras-chave: aminoácidos, cereais, composição química, valor nutricional, peixe onívoro

INTRODUCTION

Wheat is the world's most widely grown cereal, and is important for human nutrition. Wheat milling primarily produces flour, with co-products representing 25 % of the parent grain, which tend to be used in animal feeds (JONDREVILLE et al. 2000). Many agronomical parameters influence the proximate composition of wheat, while milling influences the composition of flour. Wheat, flour, and its coproducts are mainly used as energy sources because they have relatively low protein content and the proteins, in terms of amino acids, are not well balanced (HERTRAMPF & PIEDAD-PASCUAL, 2000).

Proximate composition of a dietary ingredient, as well as the variation in digestion and absorption of energy and nutrients among species is the primary information required to determine the potential use of a dietary ingredient (HEPHER, 1988). Consequently, it is important to determine the nutritional value of ingredients for farmed species to generate economically and environmentally effective diets (NRC, 2011). Furthermore, the extrusion of aquaculture diets is particularly beneficial for plant ingredients because it causes starch gelatinization, inactivates antinutritional factors and cell disruptors, and improves the accessibility of nutrients to digestive enzymes (ALONSO et al., 1998; ALONSO et al. 2000).

The nutritional value of wheat and its coproducts have previously been reported for Nile tilapia feed (FONTAÍNHAS-FERNANDES et al., 1999; FURUYA et al., 2001; BOSCOLO et al., 2002; SIGNOR et al., 2007; GONÇALVES et al., 2009); however, only one previous study has investigated this aspect in extruded diets, and only for wheat middlings (GUIMARÃES et al., 2008a). Therefore, further studies are required to understand the proximate composition and nutritional value of wheat and its coproducts.

In the present study, were evaluated the apparent digestibility coefficients (ADCs) of dry matter (ADCDM), gross energy (ADCGE), crude protein (ADCCP), and essential amino acids (EAAs) and non-essential amino acids (NEAAs) in wheat and 4 of its coproducts in the extruded diet for Nile tilapia. Our results are expected to provide baseline information towards the development of more efficient diets of this economically important aquaculture species.

MATERIALS AND METHODS

A reference diet was formulated to meet the minimum dietary requirements of Nile tilapia as described by the NRC (2011) (Table 1 and 2). This diet contained 325.8 g/kg crude protein, 4613 kcal/kg digestible energy, and 5.0 g/kg chromic oxide (Cr_2O_3) as an inert external marker (Table 1). The macroingredients were thoroughly mixed and ground using a hammer mill (0.8mm screen). The 5 test diets included winter wheat, spring wheat, wheat middling, wheat bran, and wheat germ, all of which were provided by Moinho Toledense (Toledo, Paraná, Brazil).

Each test diet contained 70 % of the reference diet and 30 % of the test ingredients (GUIMARÃES et al., 2008b). All ingredients were ground and passed through a sieve (500-µm mesh). The test ingredients were mixed in a Y-mixer (TE 200/5, Tecnal,

Rev. Bras. Saúde Prod. Anim., Salvador, v.18, n.3, p.479-491 jul./set., 2017 ISSN 1519 9940
http://mc04.manuscriptcentral.com/rbspa-scielo http://dx.doi.org/10.1590/S1519-99402017000300008

Piracicaba, São Paulo, Brazil), passed through an experimental single-screw extruder (1-mm diameter; Extrutec®, Riberião Preto, São Paulo, Brazil), and dehydrated in a forced convection oven (TE 391-1, Tecnal) at 55 °C for 48 h. The feed was stored at 5 °C until use.

Table 1. Formulation and composition of the reference diet

Ingredient	g kg^{-1}
Poultry by-product meal[1]	220.0
Soybean meal	349.4
Corn flour	385.4
Dicalcium phosphate	15.0
Soybean oil	10.0
NaCl	5.0
Mineral and vitamin premix[2]	8.0
Ascorbic acid phosphate (350 g kg^{-1})[2]	1.0
Antioxidant[3]	0.2
Antifungal agent[4]	1.0
Chromic oxide (Cr_2O_3)	5.0

[1]Industry Farima, Tupãci, Paraná, Brazil. Composition: crude protein, 670 g kg^{-1}; dry matter, 948 g kg^{-1}; ash, 131 g kg^{-1}; gross energy, 4744 kcal kg^{-1}.
[2]Composition (IU or mg kg^{-1} of diet): Vitamin A (retinyl palmitate), 1,200,000 IU; vitamin D_3, (cholecalciferol), 200,000 IU; vitamin E (DL-α-tocopherol), 12,000 mg; vitamin K_3 (menadione), 2400 mg; vitamin B_1 (thiamine HCl), 4800 mg; vitamin B_2 (riboflavin), 4800 mg; vitamin B_6 (pyridoxine HCl), 4000 mg; vitamin B_{12} (cyanocobalamin), 4.8 mg; folic acid, 1200 mg; D-calcium pantothenate, 12,000 mg; vitamin C (ascorbic acid), 48,000 mg; D-biotin, 48 mg; choline chloride, 65,000 mg; niacin, 24,000 mg; ferrous sulfate ($FeSO_4 \cdot H_2O \cdot 7H_2O$), 10,000 mg; copper sulfate ($CuSO_4 \cdot 7H_2O$), 600 mg; manganous sulfate ($MnSO_4 \cdot H_2O$), 4000 mg; zinc sulfate ($ZnSO_4 \cdot 7H_2O$), 6000 mg; cobalt sulfate ($CoSO_4 \cdot 4H_2O$), 2 mg; sodium selenite (Na_2SeO_3), 20mg.
[3]Butylated hydroxytoluene (BHT), 15 mg.
[4]Butylated hydroxyanisole (BHA), 15 mg.

The digestibility assay was conducted at the Aquaculture Laboratory of the Universidade Estadual de Maringá (Maringá, Paraná, Brazil). Juvenile Nile tilapia (GIFT strain, *n* = 180; mean body weight = 30.4 ± 4.6 g) were obtained from the Aquaculture Laboratory, and were randomly assigned to 12 cylindrical fiberglass aquaria (120 L, 15 fish per aquarium). The aquaria were connected to a closed recirculation system consisting of three 500 L reservoir tanks. Oxygen was maintained at 5 ± 1 mg/L throughout the experiment by blowers and diffusers that supplied air to each aquarium and storage tank. A natural photoperiod of 12-h light: 12 h dark was provided.

Before the digestibility assay, fish were allowed to acclimate to the laboratory conditions for 4 weeks, and were fed a commercial extruded diet (320 g/kg crude protein; Pirá Ideal® Tilápias, Guabi, Campinas, São Paulo, Brazil) to apparent satiety.

Each of the 6 diets was initially assigned to one of the 12 aquaria. Fish were fed the experimental diets to apparent satiation twice daily for 7 days prior to feces collection. After this period, feces were collected once daily, using the modified Guelph system (GUIMARÃES et al., 2008b), for 7 days. Each aquarium was then assigned a different diet for a second trial period. To avoid contamination from the previous trial period, feces from the first 5 days of feeding the new diet were discarded (SUGIURA et al., 1998). This practice was followed for the third and final trial period. Feces were therefore collected during three periods (n = 3 replicates per diet), with each of these three replicates coming from a different trial period and a different aquarium.

The dry matter and ash content of the ingredients, diets, and feces were analyzed using standard methods (AOAC, 2005). Moisture content was determined by drying samples at 105°C in an oven (TE-391-1, Tecnal) until a constant weight was obtained. Nitrogen content was determined using micro-Kjeldahl apparatus (Tecnal). Crude

Rev. Bras. Saúde Prod. Anim., Salvador, v.18, n.3, p.479-491 jul./set., 2017 ISSN 1519 9940
http://mc04.manuscriptcentral.com/rbspa-scielo http://dx.doi.org/10.1590/S1519-99402017000300008

protein content was estimated by multiplying the nitrogen content by 6.25 (SILVA & QUEIROZ 2002). Lipid content was determined by ether extraction in a multi-unit Soxhlet apparatus (TE-188/6, Tecnal) for 16 h. Ash content was determined by the combustion of dry samples in a muffle furnace (TE-1100-1P, Tecnal) at 550 °C for 6 h. Gross energy content was assessed using an adiabatic bomb calorimeter (Parr 1266, Parr Instruments Co., Moline, Illinois, USA). Amino acids were analyzed by Ajinomoto do Brasil Indústria e Comércio de Alimentos-Animal Nutrition Division (São Paulo, Brazil), by hydrolyzing 0.3 mg of sample in 1 mL of 6 N HCl for 22 h. The obtained sample was diluted in 0.02 N HCl and injected into an automatic AA analyzer (Hitachi L-888, Tokyo, Japan). Hydrolysis recovery was performed in 4 N methanesulfonic acid for the analysis of tryptophan and in performic acid for sulfur-containing AAs. Chromic oxide (Cr_2O_3) was determined using inductively coupled plasma-atomic emission spectrophotometry (ICP-AES; Vista-MPX, Varian, Palo Alto, California, USA) after perchloric acid digestion, following the modified technique described by Furukawa & Tsukahara (1966).

The ADCs of dry matter (DM), gross energy (GE), crude protein (CP), and EAAs and NEAAs were calculated according to the (NRC, 2011), in which: ADC (%) = (100 - [% chromium in feed/% chromium in feces] × [% crude protein or amino acid in feces/% crude protein or amino acids in feed] × 100). The ADC values in wheat and its coproducts were calculated according to the NRC (2011), in which: ADC of test ingredient (%) = $ADC_{test\ diet} + [(ADC_{test\ diet} - ADC_{reference\ diet}) \times (0.7 \times D_{reference}/0.3 \times D_{ingredient})]$, where $D_{reference}$ and $D_{ingredient}$ are the percentages of the nutrients or kcal g^{-1} gross energy in the reference diet and test ingredients, respectively.

All results were expressed as means. The data were subjected to one-way ANOVA analyses, followed by Duncan's multiple range tests. We used Pearson's correlation coefficients to assess how the chemical composition of the ingredients was correlated with ADCDM, ADCGE, and ADCCP. All statistical analyses were performed using SPSS 13.0 for Windows (SPSS Inc., Chicago, Il, USA). A significance level of 5 % was used for all comparisons.

RESULTS

The proximate compositions of wheat and its coproducts varied. Variation in EAA, NEAA, and crude protein content followed the same pattern (Table 2).

The ADCDM was significantly higher ($P< 0.05$) in winter wheat, spring wheat, and wheat germ than in the other ingredients (Table 3). The ADCGE was significantly higher ($P< 0.05$) in winter wheat, spring wheat, and wheat germ compared to wheat middling and wheat bran. Wheat middling had the lowest ADCGE value ($P< 0.05$), which significantly differed to the other 4 ingredients. Winter wheat, spring wheat, and wheat germ had significantly higher ADCCP than the other 2 ingredients ($P< 0.05$).

The ADCs of the EAAs and NEAAs did not reflect the ADCCP in any of the 5 ingredients, but a trend was observed. The ADCs of all EAAs and NEAAs were >80 % for most coproducts, with winter wheat and spring wheat having the highest values. Crude fiber and ash had a strong negative correlation with the ADCs of energy and nutrients (Table 4).

Rev. Bras. Saúde Prod. Anim., Salvador, v.18, n.3, p.479-491 jul./set., 2017 **ISSN 1519 9940**
http://mc04.manuscriptcentral.com/rbspa-scielo **http://dx.doi.org/10.1590/S1519-99402017000300008**

Table 2. Proximate composition (g/kg of dry matter), gross energy content (kcal/kg of dry matter), and amino acid profiles (g/kg of dry matter) of wheat and its coproducts, and the reference diet

Ingredient	Winter wheat	Spring wheat	Wheat middling	Wheat bran	Wheat germ	Reference diet
International feed number	4-05-268	4-05-258	4-05-205	4-05-190		
Crude protein	163.1	163.6	200.6	195.8	308.8	325.8
Crude fiber	31.2	22.8	85.1	87.5	27.2	35.4
Crude lipid	16.6	15.4	30.4	37.9	87.1	60.3
Ash	16.5	17.9	51.1	54.4	47.1	63.2
Gross energy	4423	4391	4506	4555	4837	4612
			Essential amino acids			
Arginine	7.4	7.1	12.6	12.2	22.9	27.2
Histidine	3.5	3.5	4.9	4.9	7.2	6.1
Isoleucine	5.5	5.4	5.9	5.7	9.3	13.2
Leucine	10.5	10.5	12.1	11.7	18.3	26.1
Lysine	4.3	4.0	7.2	7.5	17.2	19. 6
Methionine	2.6	2.5	3.1	2.8	5.1	5.9
Phenylalanine	7.4	7.2	7.8	7.6	10.8	15.5
Threonine	4.8	4.7	6.5	6.3	11.4	13.1
Tryptophan	4.5	1.8	2.6	2.5	3.2	3.6
Valine	6.6	6.5	8.4	8.5	13.8	15.0
Non-essential amino acids						
Alanine	7.7	7.8	13.1	13.1	23.5	19.0
Aspartic acid	5.4	5.4	8.7	8.8	16.7	32.4
Cystine	3.7	3.7	4.1	3.8	4.5	4.2
Glutamic acid	48.5	48.7	42.1	38.5	47.0	55.0
Glycine	6.5	6.4	9.9	9.7	15.9	22.53
Serine	7.5	7.5	8.9	8.3	12.7	15.5
Tyrosine	4.0	3.9	4.4	4.5	7.0	10.7

Crude protein = N × 6.25.

Rev. Bras. Saúde Prod. Anim., Salvador, v.18, n.3, p.479-491 jul./set., 2017 **ISSN 1519 9940**
http://mc04.manuscriptcentral.com/rbspa-scielo **http://dx.doi.org/10.1590/S1519-99402017000300008**

Table 3. Apparent digestibility coefficients (ADCs) of dry matter, gross energy, crude protein, and amino acids in wheat and its coproducts fed to Nile tilapia

Ingredient	Winter wheat	Spring wheat	Wheat middlings	Wheat bran	Wheat germ	*SEM*
Dry matter	91.6[a]	91.6[a]	55.9[b]	61.9[b]	87.2[a]	4.3
Gross energy	91.5[a]	91.6[a]	57.5[c]	66.1[b]	89.0[a]	4.0
Crude protein	96.3[a]	95.7[a]	84.2[b]	85.2[b]	93.7[a]	1.5
			Essential amino acids			
Arginine	96.1[a]	92.2[bc]	89.3[c]	85.5[d]	95.4[ab]	1.1
Histidine	92.2[bc]	96.0[ab]	87.1[d]	89.7[cd]	97.5[a]	1.2
Isoleucine	94.7[a]	96.3[a]	83.1[b]	82.7[b]	94.6[a]	1.7
Leucine	96.1[a]	96.7[a]	83.4[b]	82.8[b]	94.9[a]	1.7
Lysine	93.4[b]	93.9[ab]	85.1[c]	80.7[d]	96.4[a]	1.6
Methionine	96.3[a]	94.4[a]	84.5[b]	82.1[b]	94.4[a]	1.7
Phenylalanine	95.7[a]	96.6[a]	82.6[b]	82.8[b]	94.8[a]	1.8
Threonine	95.3[a]	89.1[b]	77.9[c]	78.8[c]	92.9[a]	2.0
Tryptophan	96.3[a]	98.5[a]	84.8[b]	87.8[b]	97.0[a]	1.5
Valine	96.5[a]	94.1[a]	80.7[b]	83.0[b]	94.4[a]	1.8
			Non-essential amino acids			
Alanine	98.9[a]	93.5[b]	82.7[c]	85.6[c]	93.9[b]	1.6
Aspartic acid	98.9[a]	96.4[a]	86.1[b]	83.4[c]	96.8[a]	1.7
Cystine	97.8[a]	97.3[a]	86.9[b]	88.7[b]	97.0[a]	1.3
Glutamic acid	99.0[a]	99.1[a]	94.7[d]	93.0[d]	97.7[c]	0.7
Glycine	107.6[a]	98.0[b]	86.7[c]	88.6[bc]	92.8[ab]	2.1
Serine	97.7[a]	96.8[a]	86.3[b]	85.7[b]	95.9[a]	1.5
Tyrosine	96.3[a]	97.4[a]	88.5[b]	84.4[b]	94.8[a]	1.5
Mean	97.0[a]	95.7[a]	85.3[b]	85.1[b]	95.4[a]	1.5

All values are the means of 3 replicates. Means in each column followed by different superscript letters differ significantly ($P < 0.05$); SEM = standard error of the mean.

Table 4. Correlation between the chemical components and apparent digestibility coefficients (ADC) of dry matter, gross energy, and crude protein

Variable	ADC of dry matter	ADC of gross energy	ADC of crude protein
Crude protein	0.016	0.050	-0.037
Crude fiber	-0.952**	-0.941**	-0.917**
Crude lipid	0.011	0.052	-0.049
Ash	-0.780**	-0.745**	-0.793**
Gross energy	-0.029	0.013	-0.086

Correlation** is significant at the 0.01 level (two-tailed).

DISCUSSION

The results demonstrate that the components of wheat and its coproducts vary depending on the parts of the wheat that are removed from the parent grain during processing, based on the analysis of proximate and AA compositions. Specifically, gross energy, crude protein, crude lipid, and AA content varied with respect to the 5 tested diets. These results support those obtained by previous studies (HERTRAMPF & PIEDAD-PASCUAL, 2000). Wheat middling and wheat bran are obtained by the wheat milling process (HUANG et al., 1999), resulting in their having the highest fiber content. Wheat germ is the reproductive part of the wheat grain (BEWLEY et al., 2006), and is removed during milling to improve the shelf life of flour (POMERANZ, 1987).

The ADCDM, ADCGE, and ADCCP values obtained in the present study differ to those reported by previous studies on the wheat and coproducts used in Nile tilapia and hybrid tilapia diets. Fontaínhas-Fernandes et al. (1999) obtained 59.90 %, 82.60 %, and 88.60 % for the ADCDM, ADCGE, and ADCCP of winter wheat, respectively, in Nile tilapia diets. Vásquez-Torres et al. (2010) obtained 79.60 %, 85.40 %, and 59.20 % for the ADCDM, ADCGE, and ADCCP of winter wheat, respectively in hybrid red tilapia diets. Boscolo et al. (2002) obtained 86.51 %, 87.70 %, and 96.30 % for the ADCDM, ADCGE, and ADCCP of spring wheat, respectively, in Nile tilapia diets. (VÁSQUEZ-TORRES et al., 2010) obtained 66.00%, 83.50 %, and 61.40 % for the ADCDM, ADCGE, and ADCCP of spring wheat, respectively, for hybrid red tilapia diets.

In comparison with the present study, Guimarães et al. (2008a) obtained lower ADCDM (45.88 %), ADCGE (48.94 %), and ADCCP (66.04 %) for wheat middling used in Nile tilapia diets. In contrast, Boscolo et al. (2002) and Guimarães et al. (2008a) obtained higher wheat middling ADCDM (66.79 % and 70.37 %), ADCGE (68.81 % and 72.83 %), and ADCCP (91.00 % and 93.54 %) than the current study. In comparison, Rodrigues et al. (2012) obtained lower wheat bran ADCDM (40.10 %), ADCGE (40.30 %), and ADCCP (67.80 %) in Nile tilapia diets than the current study. Sklan *et al.* (2004) obtained lower wheat bran ADCGE (38.80%) but similar ADCCP (83.60%) to the current study.

We were unable to locate any published data about the energetics and digestibility of wheat germ nutrients for Nile tilapia or its hybrids. Compared to the current study, Takeuchi (1991) obtained lower ADCGE (77.0 %) and similar ADCCP (94.0 %) for defatted wheat germ used in the diet of common carp, *Cyprinus carpio* (Linnaeus, 1758), when reared at 25 °C.

With the exception of wheat middling, data about the ADC of AAs of wheat coproducts used for Nile tilapia diets are limited (FURUYA et al., 2001; GUIMARÃES et al., 2008a; GONÇALVES et al., 2009). The mean wheat middling ADC of AAs obtained in the present study (85.3 %) was higher than that reported by Guimarães et al. (2008a) (62.10 %) and Furuya et al. (2001) (77.40 %), but was similar to that reported by Gonçalves et al. (2009) (84.41 %).

Extrusion increases the ADCDM, ADCGE, and ADCCP of plant-based ingredients (HARDY & BARROWS, 2002; VENOU et al., 2003). Consequently, extrusion may have enhanced the nutritional value of wheat and its coproducts in this study compared to other studies where extrusion was not conducted for tilapia diets.

Here, we detected higher fiber content for wheat middling and wheat bran compared to the other ingredients. Variability in the ADCs of energy and nutrients of wheat and its coproducts may be influenced by differences in proximate composition. Similar results have been obtained for swine and poultry (NUNES et al., 2001; BORGES et al., 2003; WESENDONCK et al., 2013a; WESENDONCK et al., 2013b). Ingredients with higher fiber content had lower ADCs in the present study. Guimarães et al. (2008b) reported that high-fiber cottonseed meal fed to Nile tilapia has lower ADCCP and ADCs of AAs (78.6 % and 73.4 %, respectively) than low-fiber cottonseed meal (81.8 % and 80.7 %, respectively). Guimarães et al. (2008a) observed that broken rice fed to Nile tilapia had higher ADCs (62.23 %) than rice bran (59.50 %). Crude fiber cannot be digested by fish, and may cause differences in how fish utilize energy and nutrients (KRONTVEIT et al., 2014). The crude fiber decreases the ADCDM, and consequently the ingredient nutritional value decreases. As an indirect effect the speed of the bolus in the gastrointestinal tract increases, which decreases the action time of digestive enzymes and consequently all ADCs (LANNA et al., 2004; BAKKE et al. 2011). In the present study, dietary fiber had a stronger influence on ADCDM and ADCGE than ADCCP (BOOTH et al., 2001; KÖPRÜCÜ, 2012).

Consistent with our observations for fish, crude fiber has a negative correlation with the ADCs of energy and nutrients in plant ingredients fed to poultry (VILLAMIDE & FRAGA, 1998) and pigs (LEKULE et al., 1990). Ash is also negatively correlated with the digestibility of energy and nutrients. However, a biological explanation for the correlation between the ash and the ADCs of energy and nutrients in the plant ingredients of animal feeds was not found in the published literature. Yet, the correlation between the crude fiber and ash contents of the evaluated ingredients may explain this phenomenon (JONDREVILLE et al., 2000). Pearson's correlation estimates the linear relationship that may exist between two variables (BHUJEL, 2008). When the effects of more than one independent variable (chemical composition) are estimated on the dependent variable (ADCs), the consequence of the relationship between the independent variables may be inferred, in addition to how direct effects influence indirect effects (WRIGHT, 1921). Most of the ash obtained from wheat is on the fibrous part of the grain (WAN et al., 2009). Therefore, the correlation between ash and the ADCs of energy and nutrients for wheat and its coproducts may have an indirect effect on the effectiveness for Nile tilapia.

In the present study, dietary fiber had a stronger influence on ADCDM and ADCGE than ADCCP, supporting previous studies (BOOTH et al., 2001; KÖPRÜCÜ, 2012). Consistent with our observations for fish, crude fiber was also negatively correlated with the ADCs of energy and nutrients in plant ingredients fed to poultry (VILLAMIDE & FRAGA, 1998) and pigs (LEKULE et al., 1990).

The ADCs of energy and nutrients in wheat coproducts have been determined for fish with different feeding habits, including some carnivorous species. For instance, compared to our results, Silva et al. (2013) obtained much lower ADCGE (40.45 %) and ADCCP (53.65 %) values for wheat bran in extruded diets fed to striped surubim, *Pseudoplatystoma reticulatum*. González-Félix et al. (2010) also obtained lower ADCGE values for whole wheat (55.4 %), wheat bran (44.9 %), and wheat middling (8.2 %) in pelleted diets fed to Florida pompano, *Trachinotus carolinus*, than what we obtained here. In contrast, Guimarães et al. (2014) obtained higher ADCDM (62.60 %), ADCGE (68.20 %), and ADCCP (84.40 %) for wheat middling in pelleted diets fed to tambaqui, *Colossoma macropomum*, which is omnivorous with herbivorous tendencies. Logically, carnivorous fish and omnivores with carnivorous tendencies have greater difficulty digesting plant-derived nutrients than herbivorous fish or omnivores with herbivorous tendencies (NRC, 2011; RODRIGUES et al., 2012). The level of amylolytic and proteolytic activity in the digestive tract varies widely among fish with different feeding habits (HIDALGO et al., 1999). This variation may reflects their differential ability to digest energy and nutrients from plant materials (BAKKE et al., 2011). Carbohydrates are the most abundant nutrients of vegetable origin, and may entrap other nutrients (NRC, 2011). Therefore, the ability of a given species to digest carbohydrates (RODRIGUES et al., 2012; GOMINHO-ROSA et al., 2015) may increase the utilization of carbohydrate and other nutrients in the diet. Such information helps researchers and managers determine the ability of different species with different habitats to process diets maximally (MA et al., 2016).

The ADC values for proteins are the fractional sums of the ADC values for AAs and other nitrogenous compounds in feed ingredients (NRC, 2011). Despite the ADCs of AAs being strongly correlated with ADCCP (GLENCROSS et al., 2008), the 2 components may not exactly match; thus, it is important to determine the individual AAs ADCs acids (GUIMARÃES et al., 2008b; GUIMARÃES et al., 2008a; GONÇALVES et al., 2009; DONG et al., 2010; RIBEIRO et al., 2011). However, a trend appeared to be present between these variables in the current study.

Overall wheat and its coproducts in extruded diets for Nile tilapia contain high ADCCP and ADCs of AAs. In contrast, the presence of high-fiber coproducts resulted in low ADCDM and ADCGE, which may limit the use of these ingredients in Nile tilapia feed. In conclusion, our results contribute important information towards enhancing the nutritional content of extruded diets for farmed Nile tilapia.

ACKNOWLEDGMENTS

Ajinomoto Animal Nutrition - Animal Nutrition Division, São Paulo, SP, Brazil assisted with the amino acid analyses. This study was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES, Brasília, DF, Brazil.

REFERENCES

ALONSO, R.; AGUIRRE, A.; MARZO, F. Effects of extrusion and traditional processing methods on antinutrients and in vitro digestibility of protein and starch in faba and kidney beans. **Food Chemistry**, v.68, n.2, p.159-165, 2000.

ALONSO, R.; ORÚE, E.; MARZO, F. Effects of extrusion and conventional processing methods on protein and antinutritional factor contents in pea seeds. **Food Chemistry**, v.63, n.4, p.505-512, 1998.

AOAC. **Official methods of analysis of AOAC International**. Gaithersburg, Md.: AOAC International, 2005.

BAKKE, A.M.; GLOVER, C.; KROGDAHL, A.; FARRELL, A.P.; BRAUNER, C.J. Feeding, digestion, and absorption of nutrients. In: GROSELL, M,; FARRELL, A.P.; BRAUNER, C.J. **The Multifunctional Gut of Fish**. London: Elsevier, 2011. p.57-110.

BEWLEY, J.D.; BLACK, M.; HALMER, P. **The Encyclopedia of Seeds: science, Technology and Uses**. Wallingford, UK: CABI International, 2006. 828p.

BHUJEL, R.C. **Statistics for Aquaculture**. Ames,:Wiley-Blackwell, 2008. p.240-240.

BOOTH, M.A.; ALLAN, G.L.; FRANCES, J.; PARKINSON, S. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus*. **Aquaculture**, v.196, n.1-2, p.67-85, 2001.

BORGES, F.M.O.; ROSTAGNO, H.S.; SAAD, C.E.P.; RODRIGUEZ, N.M.; TEIXEIRA, E.A.; LARA, L.B.; MENDES, W.S.; ARAÚJO, V.L. Avaliação dos coeficientes de digestibilidade dos aminoácidos do grão de trigo e seus subprodutos para frangos de corte utilizando diferentes metodologias. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v.55, n.6, p.722-733, 2003.

BOSCOLO, W.R.; HAYASHI, C.; MEURER, F. Digestibilidade Aparente da Energia e Nutrientes de Alimentos Convencionais e Alternativos para a Tilápia do Nilo (*Oreochromis niloticus*, L.). **Revista Brasileira de Zootecnia**, v.31, n.2, p.539-545, 2002.

DONG, X.H.; GUO, Y.X.; YE, J.D.; SONG, W.D.; HUANG, X.H.; WANG, H. Apparent digestibility of selected feed ingredients in diets for juvenile hybrid tilapia, *Oreochromis niloticus*×*Oreochromis aureus*. **Aquaculture Research**, v.41, n.9, p.1356-1364, 2010.

FONTAÍNHAS-FERNANDES, A.; GOMES, E.; REIS-HENRIQUES, M. A.; COIMBRA, J. Replacement of Fish Meal by Plant Proteins in the Diet of Nile Tilapia: Digestibility and Growth Performance. **Aquaculture International**, v.7, n.1, p.57-67, 1999.

FURUKAWA, A.; TSUKAHARA, H. On the acid digestion method for the determination of chromic oxide as an index substance in the study of digestibility of fish feed. **Nippon Suisan Gakkaishi**, v.32, n.6, p.502-506, 1966.

FURUYA, W.M.; PEZZATO, L.E.; PEZZATO, A.C.; BARROS, M.M.; MIRANDA, E.C.D. Coeficientes de digestibilidade e valores de aminoácidos digestíveis de alguns ingredientes para tilápia do Nilo (*Oreochromis niloticus*). **Revista Brasileira de Zootecnia**, v.30, n.4, p.1143-1149, 2001.

GLENCROSS, B.; HAWKINS, W.; EVANS, D.; RUTHERFORD, N.; McCAFFERTY, P.; DODS, K.; KAROPOULOS, M.; VEITCH, C.; SIPSAS, S.; BUIRCHELL, B. Variability in the composition of lupin (*Lupinus angustifolius*) meals influences their digestible nutrient and energy value when fed to rainbow trout (*Oncorhynchus mykiss*). **Aquaculture**, v.277, n.3-4, p.220-230, 2008.

GOMINHO-ROSA, M.D.C.; RODRIGUES, A.P.O.; MATTIONI, B.; FRANCISCO, A. de.; MORAES, G.; FRACALOSSI, D.M. Comparison between the omnivorous jundiá catfish (*Rhamdia quelen*) and Nile tilapia (*Oreochromis niloticus*) on the utilization of dietary starch sources: Digestibility, enzyme activity and starch microstructure. **Aquaculture**, v.435, p.92-99, 2015.

GONÇALVES, G.S.; PEZZATO, L.E.; BARROS, M.M.; ROCHA, D.F.; KLEEMAN, G.K.; ROSA, M.J.S. Energia e nutrientes digestíveis de alimentos para a tilápia do nilo. **Boletim do Instituto de Pesca**, v.35, n.2, p.201-213, 2009.

GONZÁLEZ-FÉLIX, M.L.; DAVIS, D.A.; ROSSI, W.; PEREZ-VELAZQUEZ, M. Evaluation of apparent digestibility coefficient of energy of various vegetable feed ingredients in Florida pompano, *Trachinotus carolinus*. **Aquaculture**, v.310, n.1-2), p.240-243, 2010.

GUIMARÃES, I.G.; MIRANDA, E.C.; ARAÚJO, J.G. Coefficients of total tract apparent digestibility of some feedstuffs for Tambaqui (*Colossoma macropomum*). **Animal Feed Science and Technology**, v.188, p.150-155, 2014.

GUIMARÃES, I.G.; PEZZATO, L.E.; BARROS, M.M.; TACHIBANA, L. Nutrient Digestibility of Cereal Grain Products and By-products in Extruded Diets for Nile Tilapia. **Journal of the World Aquaculture Society**, v.39, n.6, p.781-789, 2008a.

GUIMARÃES, I.G.; PEZZATO, L.E.; BARROS, M.M. Amino acid availability and protein digestibility of several protein sources for Nile tilapia, *Oreochromis niloticus*. **Aquaculture Nutrition**, v.14, p.396-404, 2008b.

HARDY, R.W.; BARROWS, F.T. Diet Formulation and manufacture. In: HALVER, J.E.; HARDY, R.W. (Eds). **Fish Nutrition**. 3rd. San Diego: Academic Press, 2002. p.506-601.

HEPHER, B. **Nutrition of pond fishes**. Cambridge: Cambridge University Press, 1988.

HERTRAMPF, J. W.; PIEDAD-PASCUAL, F. **Handbook on Ingredients for Aquaculture Feeds**. Dordrecht: Kluwer Academic Publishers, 2000.

HIDALGO, M. C., UREA, E.; SANZ, A. Comparative study of digestive enzymes in fish with different nutritional habits. Proteolytic and amylase activities. **Aquaculture**, v.170, n.3-4, p.267-283, 1999.

HUANG, S.X.; SAUER, W.C.; MARTY, B.; HARDIN, R. T.. Amino acid digestibilities in different samples of wheat shorts for growing pigs. **Journal of Animal Science**, v.77, n.9, p.2469-2477, 1999.

JONDREVILLE, C.; van den BROECKE, J.; GROSJEAN, F.O.; CAUWENBERGHE, S.V.; GATEL, F.O. Ileal true digestibility of amino acids in wheat milling by-products for pigs. **Annales de Zootechnie**, v.49, n.1, p.55-65, 2000.

KÖPRÜCÜ, K. Variability in the chemical composition of different cottonseed and sunflower meals influences their digestibility when fed to grass carp (*Ctenopharyngodon idella*). **Aquaculture Nutrition**, v.18, n.6, p.662-672, 2012.

KRONTVEIT, R.I.; BENDIKSEN, E.Å.; AUNSMO, A. Field monitoring of feed digestibility in Atlantic salmon farming using crude fiber as an inert marker. **Aquaculture**, v.426-427, p.249-255, 2014.

LANNA, E.A.T.; PEZZATO, L.E.; CECON, P.R.; FURUYA, W.M.; BOMFIM, M.A.D. Digestibilidade aparente e trânsito gastrintestinal em tilápia do Nilo (*Oreochromis niloticus*), em função da fibra bruta da dieta. **Revista Brasileira de Zootecnia**, v.33, v.6, p.2186-2192, 2004.

LEKULE, F.P.; JØRGENSEN, H.; FERNÁNDEZ, J.; JUST, A. Nutritive value of some tropical feedstuffs for pigs. Chemical composition, digestibility and metabolizable energy content. **Animal Feed Science and Technology**, v.28, n.1-2, p.91-101, 1990.

MA, F.; LI, X.Q.; LI, B.A.; LENG, X.J. Effects of extruded and pelleted diets with differing lipid levels on growth, nutrient retention and serum biochemical indices of tilapia (*Oreochromis aureus* × *Tilapia nilotica*). **Aquaculture Nutrition**, v.22, n.1, p.61-71, 2016.

NATIONAL RESEARCH COUNCIL - NRC. **Nutrient Requirements of fish and shrimp**. Washington: National Academy Press, 2011. p.376-376.

NUNES, R.V.; ROSTAGNO, H.S.; ALBINO, L.F.T.; GOMES, P.C.; NASCIMENTO, A.H.D. Valores de aminoácidos digestíveis verdadeiros e equações de predição dos aminoácidos digestíveis do grão e de subprodutos do trigo para aves. **Revista Brasileira de Zootecnia**, v.30, n.3, p.774-784, 2001.

POMERANZ, Y. **Modern cereal science and technology**. Weinheim: VCH Publishers, 1987.

RIBEIRO, F.B.; LANNA, E.A.T.; BOMFIM, M.A.D.; DONZELE, J.L.; QUADROS, M.; CUNHA, P.D.S.L. True and apparent digestibility of protein and amino acids of feed in Nile tilapia. **Revista Brasileira de Zootecnia**, v.40, p.939-946, 2011.

RODRIGUES, A.P.O.; GOMINHO-ROSA, M.D.C.; CARGNIN-FERREIRA, E.; FRANCISCO, A. de; FRACALOSSI, D.M. Different utilization of plant sources by the omnivores jundiá catfish (*Rhamdia quelen*) and Nile tilapia (*Oreochromis niloticus*). **Aquaculture Nutrition**, v.18, n.1, p.65-72, 2012.

SIGNOR, A.A.; BOSCOLO, W.R.; FEIDEN, A.; SIGNOR, A.;. REIDEL, A. Triguilho na alimentação da tilápia do nilo (*Oreochromis niloticus* L.): digestibilidade e desempenho. **Ciência Rural**, v.37, n.4, p.1116-1121, 2007.

SILVA, D.J.; QUEIROZ, A.C. **Análise de Alimentos**: métodos químicos e biológicos. Viçosa, MG: Universidade Federal de Viçosa, 2002. 235p.

SILVA, T.S.C.; MORO, G.V.; SILVA, T.B.A.; DAIRIKI, J.K.; CYRINO, J.E.P. Digestibility of feed ingredients for the striped surubim *Pseudoplatystoma reticulatum*. **Aquaculture Nutrition**, v.19, n.4, p.491-498, 2013.

SKLAN, D.; PRAG, T.; LUPATSCH, I. Apparent digestibility coefficients of feed ingredients and their prediction in diets for tilapia *Oreochromis niloticus* x *Oreochromis aureus* (Teleostei, Cichlidae). **Aquaculture Research**, v.35, n.4, p.358-364, 2004.

SUGIURA, S.H.; DONG, F.M.; RATHBONE, C.K.; HARDY, R.W. Apparent protein digestibility and mineral availabilities in various feed ingredients for salmonid feeds. **Aquaculture**, v.159, n.3-4, p.177-202, 1998.

TAKEUCHI, T. Digestion and nutrition. In: ITAZAWA, Y.; HANYU, I. (Eds.). **Fish Physiology**. Tokyo: Kouseisha-Kouseikaku, 1991. p.67-101.

VÁSQUEZ-TORRES, W.; YOSSA PERDOMO, M.I.; HERNÁNDEZ ARÉVALO, G.; GUTIÉRREZ ESPINOSA, M.C. Apparent digestibility of feed ingredients of common use in the balanced diets for tilapia red hybrid (*Oreochromis sp*.). **Revista Colombiana de Ciencias Pecuarias**, v.23, p.207-216, 2010.

VENOU, B.; ALEXIS M.N.; FOUNTOULAKI, E.; NENGAS, I.; APOSTOLOPOULOU, M.; CASTRITSI-CATHARIOU, I. Effect of extrusion of wheat and corn on gilthead sea bream (*Sparus aurata*) growth, nutrient utilization efficiency, rates of gastric evacuation and digestive enzyme activities. **Aquaculture**, v.225, n.1-4, p.207-223, 2003.

VILLAMIDE, M.J.; FRAGA, M.J. Prediction of the digestible crude protein and protein digestibility of feed ingredients for rabbits from chemical analysis. **Animal Feed Science and Technology**, v.70, n.3,:p.211-224, 1998.

WAN, H.F.; CHEN, W.; QI, Z.L.; PENG, P.; PENG, J. Prediction of true metabolizable energy from chemical composition of wheat milling by-products for ducks. **Poultry science**, v.88, n.1, p.92-97, 2009.

WESENDONCK, W.R.; KESSLER, A.D.M.; RIBEIRO, A.M.L; SOMENSI, M.L.; BOCKOR, L.; DADALT, J.C.; MONTEIRO, A.N.T.R.; MARX, F.R. Valor nutricional e energia metabolizável de subprodutos do trigo utilizados para alimentação de suínos em crescimento. **Pesquisa Agropecuária Brasileira**, v.48, p.203-210, 2013a.

WESENDONCK, W.R.; OLIVEIRA, V.; GEWEHR, C.E.; SILVA, Y.L.; BORDIGNON, L.A.F. Composição química e valores energéticos de alimentos alternativos para leitões. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v.65, n.1, p.198-202, 2013b.

WRIGHT, S. Correlation and causation. **Journal of Agricultural Research**, v.20, n.7, p.557-557, 1921.

Data de recebimento: 08/02/2017
Data de aprovação: 11/07/2017