BOLETIM DO INSTITUTO DE PESCA

ISSN 1678-2305 online version

Scientific Article

APPARENT DIGESTIBILITY COEFFICIENTS OF FEEDSTUFF USED IN TAMBAQUI DIETS*

Hellen BUZOLLO[1]

Thiago Matias Torres do NASCIMENTO[1]

Lidiane Cristina Gonçalves de SANDRE[1]

Ligia Maria NEIRA[1]

Rosângela Kiyoko JOMORI[2]

Dalton José CARNEIRO[1]

[1]Universidade Estadual Paulista – UNESP, Faculdade de Ciências Agrárias e Veterinárias, Via de Acesso Prof.Paulo Donato Castellane s/n, CEP 14884-900, Jaboticabal, SP, Brasil. E-mail: hellen_buzollo@yahoo.com.br (corresponding author).

[2]Faculdade Dr Francisco Maeda – FAFRAM, Fundação Educacional – FE, Rua Coronel Flauzino Barbosa Sandoval, 1259, Cidade Universitária, CEP 14500-000, Ituverava, SP, Brasil.

*Financial support: Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP

Received: October 11, 2017
Approved: January 31, 2018

ABSTRACT

Quality of fish diet can be evaluated by quantifying the ability of fish to digest food. Therefore, this study aimed to determine the apparent digestibility coefficients (ADC) for crude protein (CP), ether extract (EE) and gross energy (GE) in nine protein ingredients and seven energy ingredients most commonly used in commercial diets for tambaqui. In total, 510 tambaqui juveniles were fed test diets containing a reference diet supplemented with an inert digestibility marker (Cr_2O_3) and each ingredient tested. Digestibility analyses showed that corn gluten had the highest ADC_{CP} (98.09%) and ADC_{GE} (96.91%), whereas alcohol yeast had the lowest ADC_{CP} (63.17%) and ADC_{GE} (46.24%). Protein ingredients were revealed to be excellent sources of lipids (ADC_{EE} > 85.0%), with the exception of wheat gluten (ADC_{EE}: 63.73%). Corn (94.50%) and wheat bran (86.08%) showed the highest ADC_{CP} of all energy ingredients. No significant differences in ADC_{EE} were observed across the energy ingredients tested. Of the energy ingredients tested, corn oil (95.70%), fish oil (93.61%), soybean oil (93.31%) and corn (88.70%) had the highest ADC_{GE}. The use of protein ingredients and energy ingredients with high digestibility coefficients, such as the ones reported, can guide the formulation of top quality diets for tambaqui.

Key words: *Colossoma macropomum*; gross energy; ether extract; crude protein.

COEFICIENTE DE DIGESTIBILIDADE APARENTE DE ALIMENTOS UTILIZADOS EM DIETAS DE TAMBAQUI

RESUMO

A qualidade da dieta pode ser avaliada quantificando a habilidade dos peixes para digerir os alimentos. Portanto, este estudo teve como objetivo determinar os coeficientes de digestibilidade aparente (CDA) para proteína bruta (PB), extrato etéreo (EE) e energia bruta (EB) de nove ingredientes proteicos e sete ingredientes energéticos mais comumente usados em dietas comerciais para tambaqui. No total, 510 juvenis de tambaqui foram alimentados com dietas-teste contendo uma dieta de referência suplementada com um marcador de digestibilidade inerte (Cr_2O_3). As análises de digestibilidade mostraram que o glúten de milho apresentou o CDA_{PB} (98,09%) e CDA_{EB} (96,91%) mais alto, enquanto que a levedura de álcool apresentou o menor CDA_{PB} (63,17%) e CDA_{EB} (46,24%). Os ingredientes proteicos foram revelados como excelentes fontes de lipídios (CDA_{EE} > 85,0%), com exceção do glúten de trigo (CDA_{EE}: 63,73%). O milho (94,5%) e o farelo de trigo (86,08%) apresentaram o CDA_{PB} mais alto de todos os ingredientes energéticos. Não foram observadas diferenças significativas no CDA_{EE} dos ingredientes energéticos testados. Dos ingredientes energéticos testados, o óleo de milho (95,7%), óleo de peixe (93,61%), o óleo de soja (93,31%) e o milho (88,70%) apresentaram o CDA_{EB} mais alto. O uso de ingredientes proteicos e energéticos com altos coeficientes de digestibilidade, como os relatados, pode orientar a formulação de dietas de alta qualidade para tambaqui.

Palavras-chave: *Colossoma macropomum*; energia bruta; extrato etéreo; proteína bruta.

INTRODUCTION

In recent years, the preference for healthier foods has gained increasing attention. Fish is one of the most-traded food commodities worldwide. It is rich in protein, minerals, and vitamins, is low in fat content, and contains omega-3 fatty acids (FAO, 2014). Aquaculture has been responsible for the impressive growth in the supply of fish for human consumption (FAO, 2016) and studies on fish feeding and nutrition are crucial because feeding accounts for up to 70% of costs in the production cycle (MORO and RODRIGUES, 2015).

The determination of apparent digestibility coefficients (ADC) is the first step in evaluating the nutritional quality and utilization efficiency of an ingredient in complete diets for animals. These coefficients provide an indication of the nutrient or energy fraction of the ingested feedstuff that is not excreted in the feces, but is used by the animal metabolism (NRC, 2011), thereby positively affecting production rates. Moreover, information on ADC can be useful to reduce excretion of nutrients in the production environment, contributing to sustainable fisheries and providing the basis for further studies on the nutritional needs of fish.

Brazil is known for its high freshwater species diversity. The tambaqui (*Colossoma macropomum*) is the most produced native species in continental aquaculture, with great growth in 2016 with 136.99 thousand tons (IBGE, 2016), due to its easy juvenile availability, fast growth, and excellent taste. Tambaqui is an omnivorous fish that adapts to a wide variety of sources of protein and energy in your diet. In fact, it can be fed commercial diets or take advantage of the primary productivity of the pond by utilizing plankton as a source of protein (GOMES and SILVA, 2009). Brazil produce a large amount of diversified feedstuff and the digestibility studies for this species are rare, and most studies have focused on the use of local alternative sources (SILVA *et al*., 2003, 2007; GUIMARAES *et al*., 2014), limiting the availability of data for the formulation of balanced diets that maximize production. Thus, this study aimed to determine the apparent digestibility coefficients (ADC) for crude protein, ether extract, and gross energy in nine protein ingredients and seven energy ingredients most commonly used in commercial tambaqui diets.

METHODS

The experiment was carried out in the Laboratory of Aquatic Organism Nutrition of the Aquaculture Center of São Paulo State University (Jaboticabal, São Paulo, Brazil). This study was conducted in accordance with the ethical principles for animal experimentation adopted by the Brazilian College of Animal Experimentation (COBEA) and was approved by the Ethics Committee on Animal Use (CEUA) at São Paulo State University, Faculty of Agricultural and Veterinarian Sciences, SP, Brazil, under protocol n. 015810/11.

A reference diet was formulated (Table 1) to determine the ADCs of each ingredient. In total, 16 ingredients were analyzed and divided into two groups: a) energy ingredient: broken rice, wheat bran, corn, sorghum, corn oil, soybean oil, and fish oil; b) protein ingredient: soybean meal, cottonseed meal, corn gluten meal, wheat gluten meal, alcohol yeast (spray-dried), salmon meal, tilapia processing residue meal, poultry by-product meal and feather meal. Ingredients were ground and analyzed (Table 2). 16 test diets containing 695 g kg^{-1} of the reference diet mixture, 5 g kg^{-1} of chromium-III oxide (Cr_2O_3) (used as the inert digestibility marker) and 300 g kg^{-1} of each ingredient tested (except for the oils and wheat gluten, 100 g kg^{-1}) were prepared. The inclusion of only 100 g kg^{-1} for wheat gluten meal was due to gluten's cohesive and visco-elastic properties that provide the binding needed for the pellet, but that may also result in a rubbery, dry pellet (DAY *et al*., 2006) and for the oils the inclusion of the 300 g kg^{-1} would cause an interference in the starch expansion (MOREIRA *et al*., 2015) and in the acceptability of the diets by the fish. For the preparation of diets, the ingredients were ground, manually mixed, and the diets were then extruded (Extecc® Maquinas, Ribeirão Preto, Brazil, model Ex Micro) into granules with diameter of approximately 5mm. The granules were dried in an oven with forced-air ventilation at 55 °C for 24 h.

The digestibility trial consisted of 17 treatments (16 test diets and one reference diet) and four replications arranged in a randomized entirely design. In total, 510 tambaqui (*Colossoma macropomum*) juveniles (mean initial weight: 70.0 ± 8.58 g) were used in the study. The animals were kept in 34 experimental tanks (430-L) provided with continuous aeration and water circulation. The physicochemical parameters of the water (mean ± standard deviation, pH: 7.85 ± 0.17; temperature: 29.72 ± 0.34 °C; dissolved oxygen: 5.71 ± 0.34 mg L^{-1}; and total ammonia: 189.17 ± 59.29 µg L^{-1}) in the tanks were within the acceptable range for the species (ARAUJO-LIMA and GOMES, 2010).

For fecal collection, 17 glass fiber (80-L) collectors provided with continuous aeration and water circulation were constructed

Table 1. Formulation and chemical composition of the reference diet (as fed basis).

Ingredient	g kg^{-1}
Tilapia processing residue meal	202.0
Soybean meal	88.9
Corn	335.1
Wheat bran	220.0
Broken rice	140.0
Dicalcium phosphate	8.0
Limestone	1.0
Mineral and vitamin supplement(1)	5.0
Composition (%)(2):	
Dry matter	885.4
Crude protein	237.0
Ether extract	60.1
Crude fiber	74.6
Mineral matter	81.4
Nitrogen-Free Extract(3)	432.3
Gross energy (MJ kg^{-1})	16.32
Calcium(4)	14.9
Phosphorus(4)	7.5

(1)Mineral mix (Premix Nutrifish Guabi®, Campinas, SP, Brazil) per kg of product: Fe, 15000 mg; Cu, 2500 mg; Zn, 12500 mg; I, 375 mg; Mn, 12500 mg; Se, 87.5 mg; Co, 125 mg; vitamin A, 2500000 IU; vitamin D3, 600000 IU; vitamin E, 37500 IU; vitamin K, 3750 mg; vitamin C, 50000 mg; vitamin B1, 4000 mg; vitamin B2, 4000 mg; vitamin B6, 4000 mg; vitamin B, 124000 lg; pantothenic acid, 12000 mg; biotin, 15 mg; folic acid, 1250 mg; and niacin, 22500 mg; (2)Composition calculated from the analyzed composition of ingredients; (3)NFE = DM - (CP + EE + MM + CF); (4)Values calculated according to Rostagno *et al*. (2011).

Table 2. Chemical and bromatological composition of ingredients used in the experimental diets (as fed basis).

Ingredient	DM[(1)] (g kg^{-1})	CP[(2)] (g kg^{-1})	EE[(3)] (g kg^{-1})	CF[(4)] (g kg^{-1})	MM[(5)] (g kg^{-1})	GE[(6)] (MJ kg^{-1})
Energy source:						
Broken rice	887.2	81.9	15.3	3.8	8.0	15.72
Wheat bran	900.7	165.9	39.6	101.9	50.8	16.28
Corn	881.6	81.6	36.1	26.5	12.4	16.20
Sorghum	891.4	92.4	39.6	21.8	12.9	16.47
Corn oil	1000.0	-	1000.0	-	-	39.43
Soybean oil	1000.0	-	1000.0	-	-	39.27
Fish oil	1000.0	-	1000.0	-	-	39.02
Protein source:						
Soybean meal	896.2	474.4	28.8	98.3	65.6	17.48
Cottonseed meal	913.7	446.1	18.2	140.8	57.1	16.95
Corn gluten meal	919.1	632.0	48.2	10.1	21.0	15.29
Wheat gluten meal	900.7	805.5	42.2		5.7	21.4
Alcohol yeast [(7)]	952.3	362.7	22.1	36.3	72.7	18.07
Salmon meal	919.1	663.5	83.4	1.8	150.0	18.38
Tilapia processing residue meal	980.3	602.4	104.8		252.0	17.87
Poultry by-product meal [(8)]	968.7	658.2	142.1	8.7	163.9	20.94
Feather meal	949.2	762.4	128.2		33.0	23.64

[(1)]DM = dry matter; [(2)]CP = crude protein; [(3)]EE = ether extract; [(4)]CF= crude fiber; [(5)] MM = mineral matter; [(6)]GE = gross energy; [(7)] spray dried; [(8)]hydrolyzed. The ingredients used in the experimental diets were obtained from four brazilian industries Guabi®, Coplana®, Agromix® and Grupo Ambar Amaral®, with exception of salmon meal that was imported from Chile.

according to the modified Guelph system described by ABIMORAD and CARNEIRO (2004). Fecal collection from the four replicates of the 17 treatments (16 test diets and 1 diet reference) was divided into two periods: 1st period - distribution of replicates 1 and 2 in 34 feeding tanks. The adaptation to the diets was carried out for seven days. On day 8, feces were collected from replicate 1 and on day 9 from replicate 2. 2nd period – redistribution of the diets of replicates 3 and 4 in 34 feed tanks. The adaptation to the diets was carried out for seven days. On day 8 feces were collected from replicate 3 and on day 9 from replicate 4. In both periods the fish from each replicate were fed to apparent satiation and transferred after the last feeding of the day (18:00 h) to the conical tanks and therefore, the collections were performed during the night. The feces were collected into Falcon conical tubes (kept on ice to reduce feces degradation), every three hours, for ease management of the animals, according to previous project, until 6:00 h of the next day. All feces collected from each replicate were lyophilized using a Thermo Electron Corporation Fisher® freeze dryer and analyzed.

Chromium-III oxide concentrations in diets and feces were determined by spectrophotometry following nitric-perchloric digestion according to the methodology described by FURUKAWA and TSUKAHARA (1966). Ether extract (EE) was determined by acid hydrolysis (AOAC, 2000). Crude protein (CP) was determined by automated combustion using a LECO FP 528 nitrogen analyzer (LECO Instruments, St Joseph, Michigan, USA). Gross energy (GE) was determined by bomb calorimetry (AOAC, 2000) using a C2000 basic IKA calorimeter. Apparent digestibility coefficients (ADC) of the nutrients in the diets were calculated according to the equation of NOSE (1960):

$$\text{ADC diet} = 1 - \left[\left(\frac{\%\text{mar kerin diet}}{\%\text{mar kerin feces}}\,\text{x}\,\frac{\%\text{nutrient in feces}}{\%\text{nutrient in diet}}\right)\right] \quad (1)$$

The ADC for a nutrient in a test ingredient was calculated from the digestibility coefficient for the reference diet and the test diets according to the following equation of FORSTER (1999):

$$\text{ADC ingredient} = \frac{\left[(a+b)\,\text{x}\,\text{ADC}_{\text{test diet}} - (a)\,\text{x}\,\text{ADC}_{\text{reference diet}}\right]}{b} \quad (2)$$

where: a = CP, EE, or GE contribution of the reference diet to the CP, EE, or GE content of the test dietm multiplied by 69.5%; b = CP, EE, or GE contribution of test ingredient to CP, EE, or GE content of the test diet, multiplied by 30%. For wheat oils and gluten: a = multiplied by 90% and b = multiplied by 10%.

ADCs of ingredients were analyzed separately according to the classification of ingredients (protein or energy). The data were analyzed using a parametric analysis of variance (ANOVA) and tested for error normality and homoscedasticity of variances. When significant differences were detected, the means of the variables were compared using the Tukey's test at the 5% significance level. All analyses were performed using SAS 9.1 software (SAS Inst. Inc., Cary, North Carolina, USA).

RESULTS

Protein ingredients

Mean ADC values of protein ingredients are presented in Table 3. Concerning crude protein digestibility, corn gluten meal had the highest ADC_{CP} (98.1%), but it was not significantly different from that of either soybean meal or wheat gluten meal (P>0.05). Additionally, alcohol yeast was less digestible protein ingredient. No significant differences in ADC_{CP} were found between salmon meal, poultry by-product meal, and feather meal (P>0.05). Of the protein ingredients analyzed, cottonseed meal (79.62%) and tilapia processing residue meal (78.46%) had intermediate ADC_{CP} values. Concerning ether extract, all protein ingredients had high ADC values ranging from 87.44 to 96.6%, except for wheat gluten (63.7%). Finally, in the case of gross energy, all protein ingredients had high ADC_{GE} values (>70%), except for cottonseed meal and alcohol yeast, which showed the lowest values, 50.15 and 46.24%, respectively. Corn gluten meal had the maximum value (96.9%).

Energy ingredients

Mean ADC values of energy ingredients are presented in Table 4. Regarding crude protein digestibility, wheat bran (86.1%) and corn (94.5%) had the highest ADC_{CP} values (P>0.05), whereas mean ADC_{CP} was around 71% for sorghum and broken rice and no significant difference was observed between the two ingredients. In the case of ether extracts, mean ADC_{EE} values were high (> 80%) for all energy ingredients. Concerning gross energy, oil

Table 3. Apparent digestibility coefficient (ADC) for crude protein (ADC_{CP}), ether extract (ADC_{EE}), and gross energy (ADC_{GE}) of protein ingredients fed to tambaqui (*Colossoma macropomum*).

Feedstuff	Protein		Ether Extract		Energy	
	ADC_{CP}	DP	ADC_{EE}	DEE	ADC_{GE}	DE
	%	g kg^{-1}	%	g kg^{-1}	%	MJ kg^{-1}
Soybean meal	95.08 ± 0.82^{a}	451.0	93.44 ± 1.2^{a}	26.9	76.82 ± 1.25^{cd}	13.42
Cottonseed meal	79.62 ± 1.16^{cd}	355.2	88.90 ± 6.11^{a}	16.2	50.15 ± 2.37^{e}	8.5
Corn gluten meal	98.09 ± 0.52^{a}	619.9	93.77 ± 2.29^{a}	45.2	96.91 ± 0.69^{a}	14.82
Wheat gluten meal	93.95 ± 0.08^{a}	756.8	63.73 ± 12.34^{b}	26.9	78.29 ± 3.84^{bcd}	16.75
Alcohol yeast	63.17 ± 1.37^{e}	229.1	91.41 ± 3.5^{a}	20.2	46.24 ± 1.14^{e}	8.36
Salmon meal	87.27 ± 0.73^{b}	579.0	92.28 ± 3.46^{a}	77.0	81.07 ± 0.7^{bc}	14.9
Tilapia processing residue meal	78.46 ± 0.43^{d}	472.6	90.53 ± 2.8^{a}	94.9	70.26 ± 0.33^{d}	12.56
Poultry by-product meal	86.02 ± 0.5^{b}	566.2	96.60 ± 3.07^{a}	137.3	83.83 ± 0.99^{b}	17.55
Feather meal	84.16 ± 0.52^{bc}	641.6	87.44 ± 4.03^{a}	112.1	77.26 ± 2.61^{bcd}	18.27
P value	< 0.001		0.01		< 0.001	
Coefficient of variation (%)	1.84		8.64		3.76	

Mean ± standard error of the mean (n=4). Values followed by the same letter in a column are not significantly different (Tukey's test, P > 0.05). DP: digestible protein; DEE: digestible ether extract; and DE: digestible energy.

Table 4. Apparent digestibility coefficient (ADC) for crude protein (ADC_{CP}), ether extract (ADC_{EE}), and gross energy (ADC_{GE}) of energy ingredients fed to tambaqui (*Colossoma macropomum*).

Feedstuff	Protein		Ether Extract		Energy	
	ADC_{CP}	DP	ADC_{EE}	DEE	ADC_{GE}	DE
	%	g kg^{-1}	%	g kg^{-1}	%	MJ Kg^{-1}
Broken rice	71.21 ± 2.55^{b}	58.3	99.26 ± 0.11	15.19	85.52 ± 0.38^{bc}	13.44
Wheat bran	86.08 ± 2.80^{a}	142.8	91.64 ± 7.41	36.29	68.23 ± 0.27^{d}	11.11
Corn	94.5 ± 3.18^{a}	77.1	80.18 ± 1.64	28.94	88.70 ± 1.83^{ab}	14.37
Sorghum	71.92 ± 1.49^{b}	66.4	96.78 ± 0.81	38.32	81.13 ± 0.5^{c}	13.36
Corn oil	-		85.76 ± 4.92	857.6	95.70 ± 1.87^{a}	37.73
Soybean oil	-		85.07 ± 9.75	850.7	93.31 ± 0.95^{a}	36.64
Fish oil	-		92.17 ± 2.59	921.7	93.61 ± 1.99^{a}	36.52
P value	< 0.001		0.11^{NS}		< 0.001	
Coefficient of variation (%)	6.14		9.38		2.88	

Mean ± standard error of the mean (n=4). Values followed by the same letter in a column are not significantly different (Tukey's test, P > 0.05). DP: digestible protein; DEE: digestible ether extract; and DE: digestible energy.

sources (corn, soybean, and fish) and corn had the highest ADC_{GE} values, but no significant differences were observed across the four ingredients (P>0.05). Additionally, no significant difference in mean ADC_{GE} was observed between broken rice (85.5%) and sorghum (81.1%, P>0.05). Wheat bran was the least digestible ingredient (68.23%).

DISCUSSION

Protein ingredients

The high ADC values of corn gluten meal observed in this study can be attributed to its high protein percentage (63%) and the low amount of fiber (1.01%) of this ingredient. The high ADC_{CP} and ADC_{GE} values of corn gluten meal was observed in omnivorous fish, such as pacu (*Piaractus mesopotamicus)* (ABIMORAD *et al*., 2008) and Nile tilapia *(Oreochromis niloticus)* (PEZZATO *et al*., 2002). However, there are a few drawbacks in using corn gluten meal, because its high carotenoid content imparts a yellow color to fillets (HU *et al*., 2012).

Our results for soybean meal are in line with the ones presented by ABIMORAD *et al*. (2008) for pacu, who found ADC_{CP} and ADC_{GE} values of 90.6% and 78.1%, respectively. This type of meal can be used in quantitative meal replacement studies as an alternative protein source for tambaqui because it contains most essential amino acids for fish (NRC, 2011) and is an affordable product, lowering production costs of diets (HERNÁNDEZ *et al*., 2007).

We observed a high protein digestibility of wheat gluten, even though it does not show efficient digestibility for ether extract and energy. Wheat gluten meal has low levels of important amino acids such as lysine and methionine (GATLIN *et al*., 2007), which may hinder its use and high cost. Despite being a good protein source, digestibility studies of wheat gluten in omnivorous species are rare (APPER-BOSSARD *et al*., 2013), but it is highly digestible for carnivorous species such as turbot *(Psetta maxima)* (BONALDO *et al*., 2011) and salmon (*Salmo salar*) (PRATOOMYOT, *et al*., 2010).

Two fish meal sources were evaluated in this study: one made from Nile tilapia filleting residue produced in Brazil and one made from salmon residue imported from Chile. Mean ADC_{CP} and ADC_{GE} of salmon meal were higher than those of Nile tilapia residue meal showing differences in the quality of by-products, and probably in their processing. Mean ADC_{CP} was similar to the value reported by PEZZATO *et al*. (2002) for Nile tilapia (78.55%) and lower than that obtained by ABIMORAD and CARNEIRO (2004) for juvenile pacu (88.4%). Mean digestibility coefficients of tilapia processing residue meal were slightly lower than those of the other protein ingredients tested, exception of alcohol yeast and cottonseed meal. The low ADC_{CP} of cottonseed meal may be related to its high fiber content, which is approximately 13.97% (ROSTAGNO *et al*., 2011). Also, this low digestibility coefficient may be due to high levels of gossypol, which is an antinutritional factor in cottonseed meal. Gossypol can be toxic to fish and accumulate in the liver and, if present in large amounts, may affect growth (PASTORE *et al*., 2013). Regarding cottonseed meal, we observed similar ADC_{CP} than reported by PEZZATO *et al*. (2002) for Nile tilapia (74.87%), and lower ADC_{CP} and ADC_{GE} than reported by ABIMORAD and CARNEIRO (2004) for pacu (86% and 59.55%, respectively).

Alcohol yeast did not classify as a good protein and energy source for juvenile tambaqui. The low ADC_{CP} of alcohol yeast may be related to the low digestibility of certain amino acids in yeast (HUYBEN *et al*., 2017). Other studies also reported low ADC_{CP} and ADC_{GE} for yeast: 34.70% and 86.20%, respectively, for Nile tilapia (HISANO *et al*., 2008) and 68.86% and 45.77%, respectively, for pacu (ABIMORAD and CARNEIRO, 2004). The high non-protein nitrogen and cell wall content in yeast, approximately 14% and 30%, respectively, hinder its use in animal feed (HAUPTMAN *et al*., 2014). Conversely, ether extract digestibility of yeast by juvenile tambaqui was remarkably high (91.41%).

Regarding poultry by-product and feather meals, mean ADC_{CP}, ADC_{GE}, and ADC_{EE} were greater than 80%. Similar values were reported by ABIMORAD and CARNEIRO (2004) for pacu (poultry by-product meal: ADC_{CP} = 83.4% and ADC_{GE} = 69.99%; feather meal: ADC_{CP} = 75.73% and ADC_{GE} = 79.52%).

Energy ingredients

Energy ingredients showed high mean ADC values for protein, energy, and ether extract fractions, and thus can be included in commercial diets as less expensive energy sources. Mean ADC_{CP} of corn (94.5%) for juvenile tambaqui was very high in this study. GUIMARAES *et al*. (2014) obtained a lower ADC_{CP} (87.5%) for tambaqui, whereas ABIMORAD and CARNEIRO (2004) reported a lower ADC_{CP} (84.38%) for pacu, another omnivorous species with similar digestive tract morphology. Conversely, BOSCOLO *et al*. (2002) obtained a high ADC_{CP} of corn (93.4%) for Nile tilapia. Additionally, similar ADC_{GE} values of corn were reported by ABIMORAD and CARNEIRO (2004) for pacu (86.69%). Few studies have estimated ether extract digestibility in fish diets. PEZZATO *et al*. (2002) in a study with Nile tilapia found values of ADC_{EE} for corn (69.02%) lower than that observed in this study.

Similarly, to the results obtained with corn, protein and ether extract digestibility of wheat bran by tambaqui were high. Mean ADC_{CP} was similar to the values reported by GUIMARAES *et al*. (2014) and ABIMORAD *et al*. (2008) for tambaqui (84.4%) and pacu (87.7%), respectively, and lower than the values obtained by PEZZATO *et al*. (2002) and BOSCOLO *et al*. (2002) for Nile tilapia (91.13% and 91%, respectively). Mean ADC_{EE} in this study was higher than the value reported by PEZZATO *et al*. (2002) for Nile tilapia (67.37%). Conversely, energy digestibility of wheat bran by tambaqui was low (68.2%), similar to what was found by GUIMARAES *et al*. (2014). Wheat bran was the least digestible ingredient for ADC_{GE} (68.23%). The difference in energy digestibility of wheat bran compared to corn, sorghum, and broken rice, may be due to the high crude fiber content in wheat bran. The crude fiber, a component of the main feed ingredients, is indigestible to most fish species and should be avoided. High dietary crude fiber content shortens food transit time in the gut, affecting nutrient absorption (ENES *et al*., 2011).

Even though sorghum is a possible replacement for corn due to their similar chemical composition and nutritional value, mean ADC_{CP} of sorghum was significantly lower than of corn. The quality of the corn protein was higher, probably showing a better amino acid balance. GUIMARAES *et al*. (2014) and PEZZATO *et al*. (2002) also reported lower ADC_{CP} in sorghum than in corn for tambaqui (71.4%) and Nile tilapia (67.83%), respectively.

Mean ADC_{CP} of broken rice was similar to the value reported by GUIMARAES *et al*. (2014) for the same species (72.8%) and mean ADC_{GE} (85.52%) was higher than the value (80.7%) reported by GUIMARAES *et al*. (2014). Additionally, mean ADC_{EE} of broken rice was not significantly different from the ADC_{EE} of the other protein ingredients tested, evidencing that tambaqui can adjust its feeding behavior based on the availability of food during cultivation.

Oils are important energy sources used in fish diets. In this study, the three oil sources tested were well utilized by tambaqui. Fish oil was produced from Nile tilapia meal processing. Even though oils are commonly utilized in fish diets, few studies have evaluated the digestibility of oils by freshwater species. GUIMARAES *et al*. (2014) and BOSCOLO *et al*. (2002) observed ADC_{GE} values for soybean oil for tambaqui (89.85%) and Nile tilapia (92.7%) lower than the value observed in this study. Studies on corn oil are rare, but like soybean oil, it is a rich source of omega-6 polyunsaturated fatty acids and also a source of monounsaturated fatty acid, may be used as a replacement for animal oils to reduce production costs (PIEDECAUSA *et al*., 2007).

To our knowledge, this is the first study to evaluate a large number of feed ingredients commonly used in commercial diets for tambaqui. The apparent digestibility coefficients of the ingredients tested in this study will aid nutritionists in decision making regarding feed utilization parameters, which also include the quality of other nutrients, their pricing, availability, and seasonality.

CONCLUSION

In general, protein and energy ingredients are well utilized by juvenile tambaqui with high ADC values, except for alcohol yeast. The protein ingredients tested with better results were corn gluten meal and soybean meal, and among energy ingredients the better results were found with corn and oil sources. If inclusion limits are observed, the ingredients tested in this study can be used in commercial diets for tambaqui.

ACKNOWLEDGEMENTS

To Aquaculture Center at São Paulo State University (UNESP) for the experimental facilities and São Paulo Research Foundation (FAPESP) for financial support (process 2012/09126-4) and for the scholarship granted (process 2011/12963-2).

REFERENCES

ABIMORAD, E.G.; CARNEIRO, D.J. 2004 Fecal collection methods and determination of crude protein and of gross energy digestibility coefficients of feedstuffs for pacu, *Piaractus mesopotamicus* (Holmberg, 1887). *Revista Brasileira de Zootecnia*, *33*(5): 1101-1109. **http://dx.doi.org/10.1590/S1516-35982004000500001**.

ABIMORAD, E.G.; SQUASSONI, G.H.; CARNEIRO, D.J. 2008 Apparent digestibility of protein, energy, and amino acids in some selected feed ingredients for pacu *Piaractus mesopotamicus*. *Aquaculture Nutrition*, *14*(4): 374-380. **http://dx.doi.org/10.1111/j.1365-2095.2007.00544.x**.

AOAC – Association of Official Analytical Chemists. 2000 *Official methodsof analysis* (17th ed.). Gaithersburg: AOAC. p. 1219.

APPER-BOSSARD, E.; FENEUIL, A.; WAGNER, A.; RESPONDEK, F. 2013 Use of vital wheat gluten in aquaculture feeds. *Aquatic Biosystems*, *9*: 21. PMid:24237766.

ARAUJO-LIMA, C.A.R.; GOMES, L.C. 2010 Tambaqui. In: BALDISSEROTO, B; GOMES, L.C. *Espécies nativas para piscicultura no Brasil* (2. ed.). Santa Maria: MS. p. 175-204.

BONALDO, A.; PARMA, L.; MANDRIOLI, L.; SIRRI, R.; FONTANILLAS, R.; BADIANI, A.; GATTA, P.P. 2011 Increasing dietary plant proteins affects growth performance and ammonia excretion but not digestibility and gut histology in turbot (*Psetta maxima*) juveniles. *Aquaculture (Amsterdam, Netherlands)*, *318*(1-2): 101-108. **http://dx.doi.org/10.1016/j.aquaculture.2011.05.003**.

BOSCOLO, W.R.; HAYASHI, C.; MEURER, F. 2002 Apparent digestibility of the energy and nutrients of conventional and alternatives foods for Nile Tilapia *(Oreochromis niloticus)*. *Revista Brasileira de Zootecnia*, *31*(2): 539-545. **http://dx.doi.org/10.1590/S1516-35982002000300001**.

DAY, L.; AUGUSTIN, M.A.; BATEY, I.L.; WRIGLEY, C.W. 2006 Wheat-gluten uses and industry needs. *Trends in Food Science & Technology*, *17*(2): 82-90. **http://dx.doi.org/10.1016/j.tifs.2005.10.003**.

ENES, P.; PANSERAT, S.; KAUSHIK, S.; OLIVA-TELES, A. 2011 Dietary carbohydrate utilization by European sea bass (*Dicentrarchus labrax* L.) and gilthead sea bream (*Sparus aurata* L.) juveniles. *Reviews in Fisheries Science*, *19*(3): 201-215. **http://dx.doi.org/10.1080/10641262.2011.579363**.

FAO – Food and Agriculture Organization of The United Nations. 2014 *The state of world fisheries and aquaculture 2014*. Rome: FAO. 223p.

FAO – Food and Agriculture Organization of The United Nations. 2016 *The state of world fisheries and aquaculture 2016.* Rome: FAO. 253p.

FORSTER, I. 1999 A note on the method of calculating digestibility coefficients of nutrients provided by single ingredients to feeds of aquatic animals. *Aquaculture Nutrition*, *5*(2): 143-145. **http://dx.doi.org/10.1046/j.1365-2095.1999.00082.x**.

FURUKAWA, A.; TSUKAHARA, H. 1966 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*, *32*(6): 502-506. **http://dx.doi.org/10.2331/suisan.32.502**.

GATLIN, D.M.; BARROWS, F.T.; BROWN, P.; DABROWSKI, K.; GAYLORD, T.G.; HARDY, R.W.; HERMAN, E.; HU, G.; KROGDAHL, Å.; NELSON, R.; OVERTURF, K.; RUST, M.; SEALEY, W.; SKONBERG, D.; SOUZA, E.J.; STONE, D.; WILSON, R.; WURTELE, E. 2007 Expanding the utilization of sustainable plant products in aquafeeds: a review. *Aquaculture Research*, *38*(6): 551-579. **http://dx.doi.org/10.1111/j.1365-2109.2007.01704.x**.

GOMES, L.C.; SILVA, C.R. 2009 Impacto f pond management on tambaqui, *Colossoma macropomum* (Cuvier), production during growth-out phase. *Aquaculture Research*, *40*(7): 825-832. **http://dx.doi.org/10.1111/j.1365-2109.2009.02170.x**.

GUIMARAES, I.G.; MIRANDA, E.C.; ARAUJO, J.G. 2014 Coefficients of total tract apparent digestibility of some feedstuffs for Tambaqui (*Colossoma macropomum). Animal Feed Science and Technology*, *188*(1): 150-155. **http://dx.doi.org/10.1016/j.anifeedsci.2013.11.007**.

HAUPTMAN, B.S.; BARROWS, F.T.; BLOCK, S.S.; GAYLORD, T.G; PATERSON, J.A.; RAWLES, S.D.; SEALEY, W.M. 2014 Evaluation of grain distillers dried yeast as a fish meal substitute in practical-type diets of juvenile rainbow trout, *Oncorhynchus mykiss. Aquaculture (Amsterdam, Netherlands)*, *432*(1): 7-14. **http://dx.doi.org/10.1016/j.aquaculture.2014.03.026**.

HERNÁNDEZ, M.D.; MARTÍNEZ, F.J.; JOVER, M.; GARCÍA, B. G. 2007 Effects of partial replacement of fish meal by soybean meal in sharpsnout seabream *(Diplodus puntazzo)* diet. *Aquaculture (Amsterdam, Netherlands)*, *263*(1-4): 159-167. **http://dx.doi.org/10.1016/j.aquaculture.2006.07.040**.

HISANO, H.; SAMPAIO, F.G.; BARROS, M.M.; PEZZATO, L.E. 2008 Composição nutricional e digestibilidade aparente da levedura íntegra, da levedura autolisada e da parede celular pela tilápia-do-nilo. *Ciência Animal Brasileira*, *9*(1): 43-49.

HU, B.; FERRELL, M.; LIM, C.E.; DAVIS, D. 2012 Evaluation of traditional diet and corn gluten feed substituted alternative diet for pond-raised hybrid catfish on production and xanthophyll level. *Aquaculture (Amsterdam, Netherlands)*, *354–355*(1): 22-26. **http://dx.doi.org/10.1016/j.aquaculture.2012.04.038**.

HUYBEN, D.; VIDAKOVIĆ, A.; LANGELAND, M.; NYMAN, A.; LUND, T.; KIESSLING, A. 2017 Effects of dietary yeast inclusion and acute stress on postprandial plasma free amino acid profiles of dorsal aorta-cannulated rainbow trout. *Aquaculture Nutrition*, *00*: 1-11.

IBGE – Instituto Brasileiro de Geografia e Estatística. 2016 *Produção da pecuária municipal 2016*. Available from:<https://www.ibge.gov.br/media/com_materialdeapoio/arquivos/ea77821e06cad1457f9b35c1abe2137f.pdf>. Access on: 28 de jan. 2018.

MOREIRA, P.O.; ROCHA, J.D.M.; SILVA, T.C.; BITTENCOURT, F.; NEU, D.H.; BOSCOLO, W.R. 2015 Óleo de soja utilizado pré e pós-processamento de rações para tilápia do nilo. *Boletim do Instituto de Pesca, Sao Paulo*, *41*(3): 547-555.

MORO, G.V.; RODRIGUES, A.P.O. 2015 *Rações para organismos aquáticos: tipos e formas de processamento*. Palmas: Embrapa Pesca e Aquicultura. (Documentos 14).

NOSE, T. 1960 On the digestion of food protein by gold-fish (*Carassius auratus L.)* and rainbow trout *(Salmo irideus* G.). *Bulletin of Freshwater Fisheries Research Laboratory*, *10*(1): 11-22.

NRC – NationaL Research Council. 2011 *Nutrient requirements of warmwater fishes and shellfishes*. Washington: National Academy Press. 376p.

PASTORE, S. C G.; GAIOTTO, J.R.; RIBEIRO, F.A.S.; NUNES, A.J.P. 2013 Formulação de rações e boas práticas de fabricação. In: FRACALOSSI, D.M.; CYRINO, J.E.P. *Nutriaqua: nutrição e alimentação de espécies de interesse para a aquicultura brasileira*. Florianópolis: Sociedade Brasileira de Aquicultura Aquática. p. 295-345.

PEZZATO, L.E.; MIRANDA, E.C.; BARROS, M.M.; PINTO, L.G.Q.; FURUYA, W.M.; PEZZATO, A.C. 2002 Apparent digestibility of feedstuffs by Nile tilapia *(Oreochromis niloticus)*. *Revista Brasileira de Zootecnia*, *31*(4): 1595-1604. **http://dx.doi.org/10.1590/S1516-35982002000700001**.

PIEDECAUSA, M.A.; MAZÓN, M.J.; GARCÍA GARCÍA, B.; HERNÁNDEZ, M.D. 2007 Effects of total replacement of fish oil by vegetable oils in the diets of sharpsnout seabream (*Diplodus puntazzo*). *Aquaculture (Amsterdam, Netherlands)*, *263*(1-4): 211-219. **http://dx.doi.org/10.1016/j.aquaculture.2006.09.039**.

PRATOOMYOT, J.; BENDIKSEN, E.Å.; BELL, J.G.; TOCHER, D.R. 2010 Effects of increasing replacement of dietary fishmeal with plant protein sources on growth performance and body lipid composition of Atlantic salmon (*Salmo salar* L.). *Aquaculture (Amsterdam, Netherlands)*, *305*(1-4): 124-132. **http://dx.doi.org/10.1016/j.aquaculture.2010.04.019**.

ROSTAGNO, H.S.; ALBINO, L.F.T.; DONZELE, J.L.; GOMES, P.C.; OLIVEIRA, R.F.; LOPES, D.C.; FERREIRA, A.S. BARRETO, S.L.T.; EUCLIDES, R.F. 2011 *Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais*. Viçosa: Universidade Federal de Viçosa. 252p.

SILVA, J.A.M.; PEREIRA FILHO, M.; OLIVEIRA-PEREIRA, M.I. 2003 Frutos e Sementes Consumidos pelo Tambaqui, *Colossoma macrompum* (Cuvier, 1818) Incorporados em Rações. Digestibilidade e Velocidade de Trânsito pelo Trato Gastrointestinal. *Revista Brasileira de Zootecnia*, *32*(6): 1815-1824. **http://dx.doi.org/10.1590/S1516-35982003000800003**.

SILVA, J.A.M.; PEREIRA-FILHO, M.; CAVERO, B.A.S.; OLIVEIRA-PEREIRA, M.I. 2007 Digestibilidade aparente dos nutrientes e energia de ração suplementada com enzimas digestivas exógenas para juvenis de tambaqui (*Colosssoma macropomum*) Cuvier, 1818). *Acta Amazonica*, *37*(1): 157-164. **http://dx.doi.org/10.1590/S0044-59672007000100021**.