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Apparent Digestible Energy and Nutrient Digestibility Coefficients of Diet Ingredients for Pacu *Piaractus brachypomus*

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Abstract.—The digestible energy and apparent nutrient digestibility coefficients of common diet ingredients were determined for pacu *Piaractus brachypomus* (370.21 ± 17.56 g). Fish were fed with pelleted practical diets to apparent satiation and the feces were collected by siphoning. The digestibility value for each ingredient was determined by comparison of the digestibility of a test diet with a reference diet (24.5% crude protein and 1% chromic oxide). The digestible energy values of soybean meal (SBM), fish meal (FM), corn (CN), and wheat bran (WB) were 2382, 3826, 3353, and 1784 kcal/kg, respectively. The apparent dry matter digestibility coefficients were 83.72, 90.14, 89.13, and 82.05% for SBM, FM, CN, and WB, respectively. The apparent crude protein digestibility coefficients were 75.88, 90.49, 85.06, and 61.62% for SBM, FM, CN, and WB, respectively. The apparent lipid digestibility coefficients were 63.03, 77.00, 83.01, and 82.45% for SBM, FM, CN, and WB, respectively. The digestibility of protein, lipid, and energy from SBM were somewhat low compared to values for other warmwater omnivorous fishes, but similar to values reported for pacu-caranha *P. mesopotamicus*. Otherwise, the nutrient and energy availability of the ingredients to *P. brachypomus* was similar to that of other fish. This information will be useful in formulating nutritious, economical diets for pacus.

Aquaculture in South America has developed rapidly due to the increasing demand for fish products by a growing population, and to overfishing of native freshwater species. Some studies have addressed nutrition of South American species including pacu *Piaractus brachypomus* (Vásquez-Torres and Zacarias 1996), pacu-caranha *Piaractus mesopotamicus* (Fernandes et al. 2001), and tambaqui *Colossoma macropomum* (Saint-Paul 1985). The natural diets of these omnivorous species include leaves, fruits, tiny fish, and small crustaceans (Silva 1985). However, prepared diets based on research with individual species are still relatively rare. Pacu are cultured in many countries as ornamental fish, but in the Amazon basin of South America (especially in Brazil, Peru, and Columbia) the pacu is an important food fish (FAO 1994; INPA 1995). There are still impediments to expansion of pacu culture, however, as recent estimates for production of cultured pacu in Brazil (0 tons) and Peru (17 tons) were low compared to that of Columbia (15,000 tons) (FAO 2000). As pacu culture becomes more intensified, there is an increased dependence on nutritionally complete pelleted diets. Information on utilization of nutrients in common feedstuffs by pacu is needed to facilitate widespread culture of this species.

Most nutrition studies with this species have focused on the relative effectiveness of different protein sources for production, since proteins are usually the most expensive feed components. However, specific estimates of the availability of protein and other nutrients from individual feedstuffs are not available for most Characids (Menton 1989). This information is necessary to

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formulate nutritious, economical diets to maximize profits and preserve environmental quality by preventing indigestible ingredients from accumulating in the water.

Therefore, the goal of this study was to determine the apparent digestibility coefficients for dry matter, energy, protein, and lipid of some common diet ingredients (soybean meal, fish meal, corn, and wheat bran) for pacu. Previous work with a related species (*P. mesopotamicus*) showed that protein digestibility coefficients determined with feces collected using the Guelph and modified Guelph methods, dissection, or stripping were similar (Abimorad and Carneiro, in press). Therefore, feces were collected by siphoning in this study.

Materials and Methods

The pacu were obtained from the Instituto de Investigaciones de la Amazonia Peruana, Iquitos, Peru, and transported to the Aquaculture Research Center at the University of Arkansas at Pine Bluff, Pine Bluff, Arkansas, USA. The fish were fed a commercial catfish diet and maintained in tanks for 1 yr prior to use in digestibility trials.

Fish were transferred to experimental tanks and allowed to acclimate to ambient conditions for 1 wk before initiating the trials. During acclimation fish were fed to satiation with a practical diet (standard reference diet) that was formulated according to Fernandes et al. (2001). Due to the small number of fish available for the trials, four separate digestibility trials were performed consecutively with the same fish. Prior to stocking fish were individually weighed (370.21 ± 17.56 g) and groups of five fish were randomly distributed into each of six 110-L tanks. Diets were randomly assigned to tanks in each trial. A diet containing one of the test ingredients was fed to fish in three tanks, and the reference diet was fed to fish in the remaining tanks. This sequence was repeated once for each test ingredient/reference diet pair, and the same reference diet was used in all trials. One week elapsed between trials, and the fish were fed the reference diet during this period. Each tank was supplied with dechlorinated municipal water in a flow-through system. Water temperature was monitored daily, and pH, dissolved oxygen (DO), and ammonia were monitored weekly in all trials.

The diet composition is presented in Table 1. The analyzed composition of the reference diet was: crude protein, 24.5%; crude lipid, 5.9%; dry matter, 81.1%; and gross energy, 4188 kcal/kg. All diets contained 1% chromic oxide as a digestibility marker. Each test diet was prepared with 70% of the standard reference diet and 30% of the test ingredient. The individual test ingredients evaluated were soybean meal,

TABLE 1. *Reference and test diet formulations for determination of apparent digestibility coefficients in pacu.*

Ingredients	Reference diet (g/kg diet as fed)	Test diet (g/kg diet as fed)
Fish meal	100.0	70.0
Soybean meal	260.0	182.0
Corn	300.0	210.0
Wheat bran	270.0	189.0
Vitamin mix[a]	10.0	10.0
Mineral mix[b]	10.0	10.0
Chromic oxide	10.0	10.0
Soybean oil	40.0	28.0
Test ingredient[c]		300.0
Total	1,000.0	1,000.0

[a] Vitamin mix (composition/kg): ascorbic acid = 50 g; D-calcium pantethenate = 5 g; choline chloride = 100 g; inositol = 5 g; menadione = 2 g; niacin = 5 g; Pyridoxine. HCl = 1 g; riboflavin = 3 g; thiamine. HCl = 0.5 g; DL-alpha-tocopherol acetate (250 IU/g) = 8 g; vitamin A acetate (2,000 IU/g) = 5 g; biotin = 0.5 g; cholecalciferol = 0.002 g; folic acid = 0.18 g; vitamin B_{12} = 0.002 g; cellulose = 806.48 g.

[b] Mineral mix (composition/kg): calcium phosphate monobasic = 136 g; calcium lactate = 349.49 g; ferrous sulfate = 5 g; magnesium sulfate = 132 g; potassium phosphate dibasic = 240 g; sodium phosphate monobasic = 88 g; sodium chloride = 45 g; aluminum chloride = 0.15 g; potassium iodide = 0.15 g; cupric sulfate = 0.5 g; manganese sulfate = 0.7 g; cobalt chloride = 1 g; zinc sulfate = 3 g; sodium selenite = 0.01 g.

[c] Soybean meal, fish meal, corn, or wheat bran.

fish meal, corn meal, and wheat bran. The dehulled solvent-extracted soybean meal (48% protein) was produced by Mountaire Feeds, Inc., North Little Rock, Arkansas, USA. Sea-Lac; TM ruminant grade menhaden fish meal was purchased from Omega Protein, Inc., Hammond, Louisiana, USA. Uncooked #2 corn (chops, steel cut) was obtained from Mountaire Feeds, Inc., North Little Rock, Arkansas, USA and cleaned prior to grinding at UAPB. The wheat bran was made from soft wheat that was dry-milled commercially without heat to obtain the bran (Siemer Milling Company, Hopkinsville, Kentucky, USA). All ingredients were finely ground (1–2 mm) in a Wiley mill at UAPB prior to inclusion in diets. Diets were prepared by slowly adding the micro-ingredients (vitamin and mineral premixes) to the macro-ingredients to ensure a homogenous mixture. Between 400 and 450 mL of distilled water were added per kilogram of diet to achieve a consistency that would produce stable pellets. A meat grinder fitted with a 3-mm die was used to produce the pellets, which were fan dried for 8 h and stored at −18 C until use.

In each trial, fish were fed their respective diets for a 5-d acclimation period followed by a 6-d fecal collection period. During the fecal collection period, fish were fed to apparent satiation once daily at 1830 h. Several hours after feeding, uneaten food was removed to prevent ingestion of feed that may have leached nutrients. All tank bottoms were siphoned in order to standardize the stress on the fish. The feces were collected by siphoning the following morning at 0800 h and separated from the water by sedimentation. Daily samples were pooled for each tank and dried in a conventional oven for 6 h at 65 C to reduce moisture, then stored frozen in airtight plastic bags. Feed and feces were analyzed for dry matter (135 C for 3 h), and the gross energy content was determined using an adiabatic bomb calorimeter) (ANSI/ASTM 1978) (Parr Instrument Co., Moline, Illinois, USA). Crude protein was quantified using the Kjeldahl method (AOAC 1984), and total lipid was analyzed using the Folch extraction method (Folch et al. 1957). Chromic oxide was determined by AOAC (1990) methods.

The digestibility coefficient for a nutrient in either the reference or test diet was calculated using the following expression:

$$[(\% \text{ nutrient in diet}/\% \ Cr_2O_3 \text{ in diet} - \% \text{ nutrient in feces}/\% \ Cr_2O_3 \text{ in feces}) \div (\% \text{ nutrient in diet}/\% \ Cr_2O_3 \text{ in diet})] \times 100$$

The digestibility coefficient for a nutrient in each test ingredient was calculated using the following expression:

$$\left(\frac{100}{30}\text{digestion coefficient of test diet} - \frac{70}{100}\text{digestion coefficient of reference diet}\right)$$

Data Analyses

Data are presented as means (± SD) of three replicates for each diet in each trial. Digestibility data derived from the reference and test diets were used to compute digestibility coefficients and apparent digestible energy within trials. Digestibility coefficients for different test ingredients were not compared statistically as the data was obtained in separate trials for each ingredient and the test ingredients were not experimental variables.

Results and Discussion

Water quality parameters (means ± SD) during the feeding trials were: temperature, 26.83 ± 0.60 C; pH, 7.19 ± 0.31; DO, 4.5 ± 0.98 mg/L; and ammonia, 0.51 ± 0.04 mg/L. These values are within acceptable limits for pacu.

Means of digestible energy (DE) and apparent digestibility coefficients (ADC) for dry matter (DM), crude protein (CP), and total lipid (TL) of soybean meal, fish meal,

TABLE 2. *Average percentage apparent digestibility coefficients of some ingredients for pacu. Means ± standard deviation (N = 3).*

Ingredient	Int. feed number[a]	Digestibility (%) Dry matter	Crude protein	Crude fat	ADE[b] (kcal/kg)
Soybean meal	5-04-604	83.72 ± 6.86	75.88 ± 7.95	63.03 ± 6.35	2,382
Fish meal	5-02-009	90.14 ± 5.78	90.49 ± 4.98	77.00 ± 7.64	3,826
Corn	4-02-935	89.13 ± 8.18	85.06 ± 2.37	83.01 ± 1.62	3,353
Wheat bran	4-05-205	82.05 ± 4.71	61.62 ± 4.37	82.45 ± 6.62	1,784

[a] International feed numbers (NRC 1993).
[b] ADE = Apparent digestible energy.

corn, and wheat bran are shown in Table 2. One of the highest ADC's for dry matter in this study was for fish meal (90.1%). Khan (1994) also obtained a high ADC (97.0%) for DM of fish meal in tropical catfish *Mystus nemorus*, a euryphagous tropical species. Allen et al. (2000) obtained a wide range of values (76.8–93.9) for DM ADC's of different types of fish meal in Australian silver perch *Bidyanus bidyanus*. Digestibility of fish meal in different fish species varies with the quality of the fish meal, which depends largely on the starting products used to produce the meal. Sea-Lac® is produced from high-quality starting materials and is processed using a cold-temperature method, similar to Special Select® menhaden fish meal produced by the same company (Omega Protein, Inc., Hammond, Louisiana, USA). Sea-Lac® is designed for ruminants and contains less soluble protein than Special Select®, but the meals are nearly identical in proximate composition. We are not aware of comparative digestibility data for the two types of fish meal in any fish species, but the digestibility of Sea-Lac® menhaden fish meal was high in pacu in this study. The ADC of DM for corn (89.1%) was also high in pacu. Kirchgessner et al. (1986) and Barros et al. (1988) determined dry matter digestibility coefficients for corn of 90.0 and 86.9% in common carp *Cyprinus carpio* and Nile tilapia *Oreochromis niloticus*, respectively. The DM ADC of solvent-extracted soybean meal was 83.7 in pacu, which is higher than that reported for Australian silver perch (75.4%) (Allen et al. 2000). Differences in ADC's for dry matter and specific nutrients in different studies may be due to species differences, fecal collection method, or loss of water-soluble nutrients before evacuated feces are recovered from the water. Although different fecal collection methods did not affect digestibility results in a recent study with pacu-caranha (Abimorad and Carneiro, in press), the methodology does affect results in other species (NRC 1993).

The highest ADC's for crude protein in pacu were those of fish meal (90.5%) and corn (85.1%), confirming the capacity of pacu to digest both animal and vegetable foods. In its native lotic habitat, this species consumes either small fish or fruits according to season (Silva 1985). The ADC's of protein for menhaden fish meal in channel catfish and blue tilapia *Oreochromis aureus* were 88 and 85%, respectively (Wilson and Poe 1985; Popma 1985). However, the ADC for protein from soybean meal in pacu (75.9%) is lower than the value found by Khan (1994) for *Mystus nemorus* (86.0%). Values of 92.7–93.0% were determined for the ADC of protein from soybean meal for Nile tilapia (Sintayehu et al. 1996; Furuya et al. 2001). However, the ADC of protein for soybean meal in *Piaractus mesopotamicus* (70%) (Abimorad and Carneiro, in press) was similar to the value obtained in this study. The low values for soybean meal in pacu may reflect a species-specific response to anti-nutritional factors present in soybean meal, or differences in the way the soybean meal was processed in the different studies. Aside from the commercial procedure used to make the soybean meal in this study (solvent-extracted 48% protein dehulled product), no additional processing occurred before the meal was incorporated into the non-extruded diets. The moist heat used in extrusion cooking increases the digestible energy of feedstuffs containing starch (Bureau et al. 2002), which can affect the digestibility of non-carbohydrate components of the diet. In *P. mesopotamicus* dietary protein digestibility varied considerably depending on the ratio between dietary protein and total energy content (Carneiro et al. 1994). The digestibility of nutrients from soybean meal in *P. brachypomus* fed diets with different protein and energy levels should be examined in future studies.

The ADC of protein from corn in *P. brachypomus* (85.1%) was lower than the values found for hybrid tilapia *Oreochromis niloticus* × *O. aureus* (97.9%) (Takeuchi et al. 1994) and common carp (93.3%) (Degani et al. 1997), but similar to that obtained for Nile tilapia (87.1%) (Furuya et al. 2001). Crude protein digestibility coefficients for wheat bran in pacu (61.6%) were notably lower than those of the other ingredients. Fairly low values were also observed for wheat in channel catfish (72%) (Cruz 1975) and Nile tilapia (78.2%) (Furuya et al. 2001). However, values exceeding 99% were reported for protein digestibility of two types of wheat in Australian silver perch (Allen et al. 2000). There is not sufficient detail in all of these studies to determine the reasons for the differences in results. Low protein digestibility of wheat products has been attributed to their high crude fiber content (about 10%) (NRC 1993). Wheat bran also has a high level of phytate phosphorus (8.8 g/kg). Phytate-protein complexes can reduce the utilization of proteins and amino acids by altering protein structure, resulting in decreased solubility, digestibility, and function (Camus and Laporte 1976; Cheryan 1980).

The lipid digestibility coefficient of soybean meal (63.0%) in *P. brachypomus* was low compared to values for the other ingredients and to values reported for soybean meal in Nile tilapia (78.2–94.6%) (Sintayehu et al. 1996; Furuya et al. 2001). Differences in the properties of the soybean meals used and other methodological differences could explain differences in results between studies. However, the lipid content of solvent-extracted soybean meal is typically less than 4%, so its contribution to the total available energy in soybean meal is minor. The reference diet in this study contained about 6% total lipid. The ADC for lipid from fish meal in pacu (77.0%) was similar to that reported for Nile tilapia (80.1%) (Pezzato et al. 2002). In contrast, the value for blue tilapia was higher (98.0%) (Popma 1982). The ADC's for lipid from corn and wheat bran in pacu were higher (83.0% and 82.5%, respectively) than those for soybean meal or fish meal. The ADC's of lipid from corn (94.4%) and wheat (87.1%) in Nile tilapia (Furuya et al. 2001) indicated a strong ability to utilize the lipid component of plant feedstuffs, similar to *P. brachypomus*.

The digestible energy values of diet ingredients for pacu are shown in Table 2. Values for fish meal and corn (3,826 kcal/kg and 3,353 kcal/kg, respectively) were higher than those for soybean meal or wheat bran. Similar results were obtained for corn and fish meal in channel catfish (Wilson and Poe 1985) and Nile tilapia (Furuya et al. 2001). Fish meal has a higher lipid content than the other ingredients. Lipid oxidation yields approximately twice as much energy as either carbohydrates or protein. Also crude fiber (indigestible matter) is lower in fish meal than in the other ingredients. However, the natural diets of pacu are rich in plant matter and they appear to use the soluble carbohydrate in corn efficiently as an energy source. Pacu derived less energy from soybean meal (2,382 kcal/kg) than other omnivorous fishes such as channel catfish (3,010 kcal/kg) (Wilson and Poe 1985), and Nile tilapia (3,064 kcal/kg) (Pezzato et al. 2002). Wheat bran contained only 1,784 kcal/kg digestible energy for pacu compared to 1,863 kcal/kg for wheat in channel catfish (Wilson and Poe 1985) and 2,701 kcal/kg in Nile tilapia (Furuya et al. 2001). The digestibility of energy from wheats was also low compared to that in fish meals and solvent-extracted soybean meal in Australian silver perch (Allen et al. 2000). Again, the crude fiber content of this ingredient was considerably higher than that of the other ingredients tested. Wheat bran and other wheat products contain polysaccharides, such as pentosans, and oligosaccharides, such as stachyose and raffinose, which are all poorly digested by monogastric species.

Neither the corn nor the wheat bran were subjected to high temperatures during commercial processing prior to inclusion in the diets in this study. The digestible energy content of cooked feedstuffs is generally higher due to increased starch gelatinization, which renders carbohydrates more accessible to amylase (Bureau et al. 2002). Although the ADE of corn and wheat were high and low, respectively, in pacu, the ADE's of both ingredients might differ if extruded ingredients or diets are used. Both extruded and raw diet ingredients and diets are used in areas where *P. brachypomus* is cultured. Furthermore, many of the native feedstuffs that are potential candidates for inclusion in diets for Characid species are rich in carbohydrate (Araujo-Lima and Goulding 1997). Therefore, comparative information on digestibility of raw and cooked high-carbohydrate feedstuffs for *P. brachypomus* would be useful to facilitate diet development in different regions.

Another source of potential variability in the estimation of digestibility coefficients between studies is the use of semipurified versus practical-ingredient diets. It is possible that interactions between diet ingredients are different in semipurified and practical diets, and that the availability of energy and individual nutrients vary accordingly (De Silva and Anderson 1995). We assumed that there was no interaction between the test ingredients and the reference diet, but this assumption should be verified in future digestibility studies with pacu using practical-ingredient reference diets.

In summary, most of the digestibility data generated for pacu for fish meal, corn and wheat bran was similar to that generated for other warmwater omnivorous species. The values for protein, lipid, and energy digestibility of soybean meal in *P. brachypomus* were lower than those of other warmwater omnivorous species, except for the closely related *P. mesopotamicus*. Further studies are needed to determine the reasons, as soybean meal is an extremely important crop in Brazil and is also widely used in other areas where pacus are cultured for food. Additional work is also needed to determine the effect of variables such as heat processing on the availability of nutrients from feedstuffs for pacus.

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