Ileal Amino Acid Digestibility of Broken Rice Fed to Postweaned Piglets with or without Multicarbohydrase and Phytase Supplementation

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ABSTRACT:

Most of amino acid (AA) digestibility values for feed ingredients are obtained using pigs cannulated in the distal ileum. The ileal-cannulated pig model uses pigs older than six weeks due to difficulties related to implanting the T-cannula in distal ileum of younger pigs and complications during the post-surgical recovery. However, to properly formulate the diet of weaned pigs, the nutritive value of feed ingredients should be determined with younger pigs. Thus, 25 weaned pigs were used to determine the apparent total tract digestibility (ATTD) of nutrients, energy, and apparent ileal digestibility (AID) and standardized ileal digestibility (SID) ileal AA digestibility of broken rice (BR), with or without multicarbohydrase (MC) and phytase (Phy) supplementation. Piglets were weaned at 23 d of age and individually housed in digestibility cages until 45 d of age. The trial consisted of 7 d of adaptation to the experimental diets and 3 d of excreta (feces and urine) collection. Ileal digesta was collected at slaughter (about 6 weeks of age). A completely randomized experimental design was used to determine the effects of MC and Phy. Reference diets (RD, 5% casein) was replaced by 30% of BR with or without MC, Phy, or MC+Phy. The RD was used to quantify endogenous AA losses. BR with Phy supplied had increased the ATTD of dry matter (p<0.05) and SID of histidine (p = 0.05), arginine, leucine, lysine, valine, alanine, and proline (p<0.05). BR with MC had been increased digestible energy and protein and SID for histidine (p<0.05). There was no interaction between Phy and MC on the BR nutrient digestibilities. Standardized amino acid digestibilities of BR, without enzymes, were lower than those values reported in the literature. The MC and Phy improved the digestibility of some nutrients and energy of BR in post-weaned piglet diets. (Key Words: Amino Acids Digestibility, Broken Rice, Exogenous Enzymes, Metabolism, Nutrient Balance, Weaned Pigs)
the information about standardized ileal digestibility (SID) of AA of BR for weaned pigs remains limited (NRC, 2012).

The exogenous enzyme supplementation has become a common practice when feed ingredients containing high fiber and high phytate phosphorus are used. Phytase can alleviate the negative effects associated with phytic acid by release of P from phytate. Carbohydrases have potential to enhance the nutritive value of the diet eliminating the nutrient encapsulating effect of the cell walls and therefore improving energy and AAs availabilities. AAs availability can be improved by enzymes due to their ability to the hydrolysis of certain types of carbohydrate-protein linkages (Slominski, 2011). Dietary supplementation with enzymes degrading the non-starch polysaccharides can not only enhance the cell wall solubility but have the potential of improving phytase efficacy by elevating the release of P from phytate (Kim et al., 2005).

The experiments were conducted to determine the apparent total tract digestibility (ATTD) of nutrients and energy, and apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of AA of BR in piglet fed diets supplemented with multicarbohydrase (MC) or phytase (Phy), alone or in combination.

MATERIALS AND METHODS

All research methods and procedures were approved by the ethics and animal experimentation committee at the University of Sao Paulo (project 2843/2012), and followed all the requirements in relation to animal welfare.

Experimental design, diets and enzymes

The BR sample used for the current study was obtained from Hi-Tech Feeds; Pelotas, Rio Grande do Sul, Brazil. For the four experimental treatments, reference diet (RD, 5% casein) was replaced by 30% of test ingredient (BR) with or without the MC (BR+MC); phytase (BR+Phy) or combination of both enzymes (BR+MC+Phy), respectively. A RD was used in AID and SID calculations and a reference corn dry-whey milk-powder diet was used for ATTD determination. Twenty-five 23 d old weaned pigs with average body weight (BW) of 6 kg were housed individually in metabolism crates with transparent sides and woven flooring. Pigs were allotted to the four experimental and one reference dietary treatments (Table 1) for a total of five pigs per treatment. A completely randomized experimental design was used to determine the effects of enzymes on ATTD of nutrients and energy; and AID and SID of AA. The ferric oxide (Fe₂O₃) was added to experimental diets (ATTD of nutrients determination) at 0.25% to determine the collection time-frame by the appearance of marked feces. Chromium oxide (Cr₂O₃) was used as an indigestible marker (0.3% of the diet) for the calculation of AID and SID of AA. The MC and Phy used for the current study were obtained from Uniquimica, Sao Paulo, Brazil. The MC blend contained: galactomannanase, 10%; xylanase, 10%; β-glucanase, 10%; malted barley, 60%; α-galactosidase, 10% and was added at 200 g/ton in the diet. The phytase used was fermented from *Saccharomyces cerevisiae* (KCCM 80051). Phytase

| Table 1. Feed composition and nutrient content of reference and experimental diets for piglets¹ |
|-----------------|-----------------|-----------------|-----------------|
| Ingredients (%) | ATTD            | SID             |
|                 | R    | BR    | R    | BR    |
| Corn            | 61.65| 43.14 | -    | -     |
| Corn starch     | 5.00 | 3.50  | 41.56| 29.09 |
| Broken rice     | -    | 30.00 | -    | 30.00 |
| Soybean oil     | 1.98 | 1.40  | 3.13 | 2.19  |
| Dry whey        | 15.00| 10.50 | -    | -     |
| Skim milk powder| 10.00| 7.00  | -    | -     |
| Dextrose        | -    | -     | 21.00| 14.70 |
| Lactose         | -    | -     | 20.00| 14.00 |
| Casein          | -    | 5.00  | -    | 3.50  |
| Choline, 96%    | 0.01 | 0.01  | 0.01 | 0.01  |
| Potassium chloride| -  | -     | 1.04 | 0.73  |
| Sodium bicarbonate| 0.43| 0.30  | 1.04 | 0.73  |
| Dicalcium phosphate| 1.71| 1.19  | 3.01 | 2.11  |
| Limestone       | 0.54 | 0.38  | 0.22 | 0.15  |
| Chromium oxide  | -    | -     | 0.30 | 0.21  |
| Zinc oxide      | 0.35 | 0.25  | 0.35 | 0.25  |
| Vitamin Premixa¹ | 0.10| 0.07  | 0.10 | 0.07  |
| Mineral premixa¹| 0.10 | 0.07  | 0.10 | 0.07  |
| Cellulose       | 3.00 | 2.10  | 3.00 | 2.10  |
| Antioxidant     | 0.01 | 0.01  | 0.12 | 0.08  |
| Flavores        | 0.12 | 0.08  | 0.02 | 0.01  |
| Total           | 100  | 100   | 100  | 100   |

¹ R, reference diet; BR, broken rice. BR replaced 30% of reference diet, with or without multicarbohydrase (200 g/ton); phytase (50 g/ton) and multicarbohydrase (200 g/ton)+phytase (50 g/ton), respectively.

² Providing the following quantities of minerals and vitamins per kg of complete diet: Mn (MnO), 40.2 mg; Fe (FeSO₄·H₂O), 90 mg; Zn (ZnO), 117.8 mg; Cu (CuSO₄·5H₂O), 105 mg; I (KI), 42 mg; Se (Na₂SeO₃), 36 mg; retinyl acetate, 10,500 IU; cholecalciferol, 1,650 IU; DL-alfa-tocopheryl acetate, 6 mg; menadione sodium bisulfite complex, 2 mg; niacin, 30 mg; vitamin B₆, 22 mg; thiamine, 1.2 mg; pyridoxine, 2.2 mg; riboflavin, 4 mg; pantothenic acid, 18 mg; choline chloride, 210 mg.
(activity of 10,000 FTU/g) was added at 50 g/ton in the diet. All diets were supplemented with minerals and vitamins to meet or exceed recommended nutrient specification for growing pigs (Rostagno et al., 2011).

**Samples collection and chemical analyses**

Weaned piglets were fed reference corn dry-whey milk-powder diet for 10 days and subsequently were introduced to experimental diets. Following the 7-d adaptation period, feces and urine were quantitatively collected for 3 days for the determination of ATTD of nutrients. Pigs were weighted at the initial collection period of feces and urine (8.8±1.1 kg) and at slaughter on ileal content collection (9.9±1.3 kg). The daily amount of feed provided to the pigs was calculated as 3 times the estimated requirement for maintenance energy (i.e., 197 kcal of ME/kg of BW0.60; NRC, 2012) and provided in 2 equal meals at 0700 and 1700 h. Pigs were allowed ad libitum access to water throughout the experiment. Fecal samples were collected twice a day (0800 and 1800 h), weighed and stored in a freezer at –10°C. Urine was collected in plastic containers with 5 mL of 10% H2SO4 to minimize the NH3 volatilization. The volume was weighed daily, and a 10% aliquot was removed and refrigerated at –10°C. At the end of the collection, the feces were homogenized, sub sampled (about 300 g) and dried in a forced air oven at 60°C for 72 h. Diet, BR, and feces sample were ground to pass a 1 mm sieve, and subjected to crude protein (CP) analysis (N×6.25) using Kjeldahl procedures (analyzer model Tecnal TE/036/1). Standard AOAC (2005) procedures were used for dry matter (DM) (930.15), fat (2003.06), ash (942.05) and AAs (994.12 alternative 1 and 3) determination. The acid detergent fiber (ADF) and neutral detergent fiber (NDF) contents in diets were determined according to the method of Goering and Van Soest (1970). The AA content was determined using an analyzer 1260 Infinity LCs (Agilent Technologies, Santa Clara, CA, USA). Tryptophan was not determined. Cysteine and glycine were not detected. All analyses were done in duplicate. Gross energy (GE) of BR, diets, feces and freeze-dried urine samples was determined using adiabatic oxygen bomb calorimeter (IKA C5000, Staufen, Germany) with benzoic acid used as the calibration standard. Two days prior to slaughter animals were fed low protein reference diet containing 5% casein as a sole source of protein to determine the endogenous AA losses, and experimental diets where 30% of the reference diet was replaced by test ingredient with or without enzymes. At the end of the trial, animals were slaughtered and digesta samples were collected from the terminal ileum (about 30 cm segment). Before slaughter, pigs were weighed and then given an intramuscular injection of acepromazine maleate (0.3 mg/kg of BW) mixed in a single syringe with 15 mg of ketamine hydrochloride/kg of BW as a preanesthetic tranquilizer. Once tranquilized sufficiently, approximately 20 mg of thiopental/kg of BW was administered by intracardiac injection. Ileal content samples were freeze-dried, ground and analyzed for DM, AA, and Cr2O3. Chromium was analyzed using atomic absorption spectrophotometry (UV-1201, Shimadzu, Kyoto, Japan), according to Williams et al. (1962).

**Calculation and statistical analyses**

ATTD of nutrients was determined by the total collection method as described by Woyengo et al. (2010) using the following equations:

\[
\text{ATTD} \% = 100 \times \left( \frac{\text{NI} - \text{NO}_{\text{f}}}{\text{NI}} \right),
\]

where: NI is the nutrient or energy intake (MJ) and NO_{f} is the nutrient or energy output in feces (MJ).

The digestible energy (DE) and ME values of the BR were determined using the following equations:

\[
\text{DE (MJ/kg)} = \left[ \left( \text{total tract GE digestibility for BR, }% \right) \times \left( \text{GE value of BR, MJ/kg} \right) \right] / 100
\]

and

\[
\text{ME (MJ/kg)} = \left[ \left( \text{GE retention for the ingredient, }% \right) \times \left( \text{GE values in ingredient, MJ/kg} \right) \right] / 100
\]

The GE retention was calculated using the following equation:

\[
\text{GE retention }% = 100 \times \left[ \left( \text{GE of BR, MJ} - \text{GE of feces, MJ} - \text{GE of urine, MJ} \right) / \text{GE of BR, MJ} \right],
\]

where: GE of BR is the GE intake (MJ/kg) and GE of feces is the energy output in feces (MJ/kg), and GE of urine is the energy output in urine (MJ/kg).

Apparent ileal AA digestibility were calculated using formula (Nyachoti et al., 1997):

\[
\text{AID }% = 100 - \left[ 100 \times \left( \frac{\text{AA}_{\text{d}} \times \text{Cr}_{2\text{O}_{3}}}{\text{AA}_{\text{d}} \times \text{Cr}_{2\text{O}_{3}}} \right) \right]
\]

where AA_{d} and AA_{d} are the concentrations (mg/kg DM) of AA in the diet and digesta, respectively, and CrO2_{d} and CrO2_{d} are the concentrations (mg/kg DM) of the indigestible marker in the diet and digesta, respectively. Apparent ileal AA digestibility were standardized using average values for basal endogenous AA losses calculated using formula (Nyachoti et al., 1997):

\[
\text{AA}_{\text{EL}} = \frac{\alpha \times \left( \text{CrO}_{2} \text{digesta} \right)}{\text{AA}_{\text{d}}} - \text{AA}_{\text{d}}
\]

where AA_{EL} = average endogenous AA loss in (g/kg of
Determined endogenous ileal AA losses (g/kg of dry matter intake) were as follow: arginine, 0.50; histidine, 0.31; isoleucine, 0.50; leucine, 0.80; lysine, 0.41; methionine, 0.21; phenylalanine, 0.52; threonine, 0.93; valine, 0.67; alanine, 0.76; asparagine, 0.60; glutamine, 1.13; proline, 0.95; serine, 0.99, and tyrosine, 0.35 g/kg.

SID was calculated according to equation below as described by Opapeju (2006):

\[
\text{SID} (%) = \left[ \frac{\text{AID} + (\text{AAEL}/\text{AA_diet})}{\text{AA_diet}} \right] \times 100
\]

Data was subjected to Analysis of Variance using the Mixed Procedure of SAS (2002) (SAS Software Release 9.2, SAS Institute, Inc., Cary, NC, USA). The homogeneity of variances was evaluated by Hartley test and the normality of residuals by the Shapiro-Wilk test (UNIVARIATE procedure). The statistical model used was:

\[
Y_{ij} = \mu + a_i + b_j + (a_i \times b_j) + e_{ij}
\]

where \(Y_{ij}\) = variable response of piglets fed MC (i) and phytase (j); \(\mu\) = overall effect of average; \(a_i\) = fixed effect of MC; \(b_j\) = fixed effect of phytase; \((a_i \times b_j)\) = interaction of MC and phytase; \(e_{ij}\) = error term (residue).

### RESULTS AND DISCUSSION

The chemical composition of BR and experimental diets are presented in Table 2 and 3. CP content (7.75%) and AA variances was evaluated by Hartley test and the normality of residuals by the Shapiro-Wilk test (UNIVARIATE procedure). The statistical model used was:

\[
Y_{ij} = \mu + a_i + b_j + (a_i \times b_j) + e_{ij}
\]

where \(Y_{ij}\) = variable response of piglets fed MC (i) and phytase (j); \(\mu\) = overall effect of average; \(a_i\) = fixed effect of MC; \(b_j\) = fixed effect of phytase; \((a_i \times b_j)\) = interaction of MC and phytase; \(e_{ij}\) = error term (residue).

### Table 2. Analyzed composition of broken rice and experimental diets used for the apparent total tract digestibility (ATTD) determination

| Item (%)               | BR     | R      | BR     | BR+MC  | BR+Phy | BR+MC+Phy |
|------------------------|--------|--------|--------|--------|--------|------------|
| Dry matter             | 86.97  | 90.25  | 89.27  | 89.44  | 89.39  | 89.31      |
| GE (MJ/kg)             | 13.08  | 14.46  | 14.33  | 14.40  | 13.91  | 14.08      |
| Crude protein          | 7.75   | 10.78  | 9.75   | 9.69   | 9.61   | 9.59       |
| Ash                    | 1.18   | 5.88   | 4.24   | 4.64   | 4.47   | 4.78       |
| Crude fiber            | 0.72   | -      | -      | -      | -      | -          |
| NDF                    | 4.81   | -      | -      | -      | -      | -          |
| ADF                    | 3.22   | -      | -      | -      | -      | -          |
| Fat                    | 0.78   | -      | -      | -      | -      | -          |

NDF, neutral detergent fiber; ADF, acid detergent fiber.

1 R, reference diet; BR, broken rice; MC, multicrohohydase; Phy, phytase.

### Table 3. Analyzed amino acids content of broken rice and experimental diets used for the apparent (AID) and standardized (SID) ileal digestibility determination

| Item (%)                | BR     | R      | BR     | BR+MC  | BR+Phy | BR+MC+Phy |
|-------------------------|--------|--------|--------|--------|--------|------------|
| Indispensable amino acid|        |        |        |        |        |            |
| Arginine                | 0.64   | 0.15   | 0.28   | 0.29   | 0.27   | 0.29       |
| Histidine               | 0.20   | 0.13   | 0.15   | 0.15   | 0.14   | 0.15       |
| Isoleucine              | 0.33   | 0.24   | 0.25   | 0.26   | 0.26   | 0.25       |
| Leucine                 | 0.63   | 0.46   | 0.51   | 0.50   | 0.49   | 0.49       |
| Lysine                  | 0.30   | 0.38   | 0.36   | 0.35   | 0.35   | 0.34       |
| Methionine              | 0.18   | 0.12   | 0.13   | 0.13   | 0.13   | 0.14       |
| Phenylalanine           | 0.37   | 0.36   | 0.42   | 0.41   | 0.40   | 0.41       |
| Threonine               | 0.33   | 0.23   | 0.25   | 0.25   | 0.24   | 0.23       |
| Valine                  | 0.54   | 0.33   | 0.37   | 0.37   | 0.37   | 0.36       |
| Dispensable amino acid  |        |        |        |        |        |            |
| Alanine                 | 0.45   | 0.16   | 0.24   | 0.25   | 0.23   | 0.24       |
| Aspartic acid           | 0.81   | 0.39   | 0.51   | 0.52   | 0.49   | 0.50       |
| Cystine                 | 0.07   | 0.02   | 0.03   | 0.03   | 0.03   | 0.03       |
| Glutamic acid           | 1.25   | 0.94   | 1.02   | 1.01   | 0.98   | 0.98       |
| Glycine                 | 0.35   | 0.09   | 0.16   | 0.17   | 0.16   | 0.16       |
| Proline                 | 0.40   | 0.45   | 0.41   | 0.40   | 0.40   | 0.39       |
| Serine                  | 0.41   | 0.28   | 0.32   | 0.32   | 0.30   | 0.31       |
| Tyrosine                | 0.36   | 0.25   | 0.29   | 0.29   | 0.27   | 0.27       |
| Total AA                | 7.64   | 4.98   | 5.71   | 5.70   | 5.53   | 5.54       |

1 R, reference diet; BR, broken rice; MC, multicrohohydase; Phy, phytase.
profile of BR are similar to the values proposed by Rostagno et al. (2011) and NRC (2012). The contents of NDF; ADF, and crude fiber of the BR are lower than previously reported in the literature. The compositional variability of BR used in the present experiment, and BR reported in literature, reflects the differences which depend of the manufacturing processes. There was no (p>0.05) interaction between enzymes on nutrient and energy digestibility of BR (Table 4). In comparison to treatment without enzymes, Phy supplementation improved digestibility of DM, while MC improved digestibility of CP (p<0.01), digestible (p<0.01) and ME (p = 0.02). The results of apparent digestibility of CP in BR without enzyme supplementation were 5.7% and 14.5% lower than those described by Apolônio et al. (2003) and Rostagno et al. (2011), respectively. It demonstrates that the utilization of BR protein by young pigs (9 kg average BW) is limited due to underdeveloped gastrointestinal tract when compared to the older and heavier pigs (20 kg and more) commonly used in an animal model to determine nutrients digestibility and widely presented in the literature. Results showed that the BR can be alternative energy source for pigs. Positive results on the GE digestibility with MC supplementation were demonstrated in this experiment, indicating that the enzyme could be a viable additive to BR-based diets for postweaned piglets. Some studies demonstrated benefits of BR showing that weaned pigs fed with rice-based diets had greater AID of GE, organic matter, fat, and ADFI compared with corn-based diets (Hongtrakul et al., 1998; Li et al., 2002; Mateos et al., 2006; Menoyo et al., 2011). According to Hongtrakul et al. (1998) in the United States, corn is the predominant energy source used in swine diets. However, in Asia and other parts of the world, many other carbohydrate sources are more available and less expensive.

BR, in comparison to the other cereals, contains more starch and less fiber which is favorable for diets for young piglets (Kim et al., 2007; Vicente et al., 2008) but its use in pig diets is limited due to unforeseen, small and seasonal supply on the market, and inconsistent nutritional profile compared to conventional ingredients, like soybean and corn. The lack of product on the market might also contribute to the limited research on BR for animal nutrition. According to Teixeira (1997) there are some controversy related to dietary inclusion of BR for pigs and might be associated with different degree of the product cleanliness. The same author reported that BR is considered a by-product, thus its batch to batch quality might not be uniform and some contaminants as rice hulls, barnyard grass seeds (Equinocloa spp.) and some Aeschynomene spp. contributes to elevated level of ash and fiber fraction.

Despite the BR has a good nutritional composition and potential to be an alternative to corn in diets for growing and finishing pigs, few studies analyzing AA digestibility in BR with piglets have been reported in the literature. The results of current study revealed overall good AA digestibility of BR for young piglets (Tables 5 and 6). Most of the SID of AA of BR values presented in Nutrient Requirements of Swine (NRC, 2012) is higher than those determined in the current study: arginine, 89% vs 84%; histidine, 84% vs 77%; isoleucine, 81% vs 79%; leucine, 83% vs 79%; lysine, 77% vs 78%; methionine, 85% vs 81%; threonine, 76% vs 65%; valine, 78% vs 81%, respectively. It is suggested that postweaned piglets are less able to harness the AA in BR, compared with the growing-finishing phases.

The results of the study showed that Phy supplementation improved the SID of histidine (p = 0.05), arginine, leucine, lysine, valine, alanine, and proline (p<0.05) of BR, however the difference were not observed when diets were supplemented with MC. There was not interaction between Phy and MC on the BR nutrient digestibilities (p>0.05). Similarly, the positive effect of dietary inclusion of Phy on AA digestibility and energy utilization, in addition to improved P utilization, was demonstrated in broiler study by Ravindran et al. (2000). The enzymes can be more efficient on rice due to the morphology of the grain which has smaller size of the starch granules, and contains less amylase and less lipid/amylose complex in comparison to corn (Tester et al., 2004). According to Fireman and Fireman (1998), positive or negative results from the exogenous enzymes use, appeared to stem from of the substrate concentration in the

Table 4. Apparent total tract digestibility (ATTD) of nutrients and energy for broken rice, without or with enzymes for postweaned piglets

| Item (%) | Treatment1 | SEM | p-values |
|----------|------------|-----|----------|
|          | BR         | BR+MC | BR+Phy | BR+MC+Phy | MC | Phy | MC+Phy |
| Dry matter | 93.72     | 93.55 | 95.90   | 96.88     | 0.664 | 0.752 | 0.044 | 0.653 |
| Crude protein | 77.89     | 81.83 | 77.81   | 84.82     | 1.069 | 0.008 | 0.433 | 0.008 |
| Digestible energy (MJ/kg)* | 15.67 | 16.11 | 15.70 | 16.37 | 25.411 | 0.007 | 0.441 | 0.531 |
| Metabolizable energy (MJ/kg)* | 15.57 | 15.94 | 15.59 | 16.15 | 24.455 | 0.024 | 0.562 | 0.604 |
| ME/GE | 90.04 | 92.17 | 90.11 | 93.37 | 0.592 | 0.023 | 0.562 | 0.605 |

SEM, standard error of mean.
1 BR, broken rice; MC, multicarbohydrase; Phy, phytase.
* Calculate in, % DM; ME/GE, metabolizable: gross energy.
diet, the antagonism between enzymes, the enzyme concentration or by animal category tested. Since the supplemental enzyme has affinity by the substrate, increases on digestibility could be observed (Zijlstra et al., 2004).

In conclusion, the energy and nutrients digestibility of BR, without enzymes, indicates lower values than those reported in the literature are acquired from pigs in the later stages of growth. The MC enzyme effectively increase the energy and protein digestibility of BR, while phytase improved apparent digestibility of dry matter and the SID of arginine, histidine, leucine, lysine, alanine, and proline.

### Table 5. Apparent ileal digestibility (AID) of amino acids for broken rice, without or with enzymes, for postweaned piglets

| Item (%) | Treatments 1 | SEM | p-values |
|----------|--------------|-----|----------|
|          | BR | BR+MC | BR+Phy | BR+MC+Phy |       |       |       |
| Indispensable AA | | | | | | | |
| Arginine | 66.27 | 66.38 | 76.55 | 75.39 | 1.846 | 0.873 | 0.009 | 0.847 |
| Histidine | 62.62 | 73.92 | 73.21 | 74.10 | 1.671 | 0.040 | 0.066 | 0.074 |
| Isoleucine | 59.63 | 60.64 | 61.68 | 60.01 | 1.471 | 0.919 | 0.827 | 0.679 |
| Leucine | 70.02 | 70.14 | 78.89 | 78.60 | 1.517 | 0.973 | 0.003 | 0.936 |
| Lysine | 66.26 | 66.45 | 74.62 | 75.63 | 1.545 | 0.816 | 0.003 | 0.874 |
| Methionine | 70.99 | 71.27 | 74.91 | 74.48 | 1.401 | 0.980 | 0.240 | 0.905 |
| Phenylalanine | 72.14 | 76.50 | 76.16 | 73.84 | 1.266 | 0.701 | 0.798 | 0.220 |
| Threonine | 49.24 | 49.72 | 50.90 | 49.61 | 1.340 | 0.891 | 0.793 | 0.764 |
| Valine | 63.01 | 65.19 | 72.29 | 70.42 | 1.586 | 0.957 | 0.024 | 0.495 |
| Dispensable AA | | | | | | | |
| Alanine | 68.79 | 70.36 | 71.79 | 71.32 | 1.340 | 0.901 | 0.317 | 0.730 |
| Aspartic acid | 61.77 | 63.76 | 64.60 | 65.24 | 1.413 | 0.668 | 0.484 | 0.825 |
| Glutamine | 66.71 | 74.79 | 73.10 | 73.02 | 1.456 | 0.169 | 0.417 | 0.160 |
| Proline | 62.34 | 62.23 | 68.55 | 68.84 | 1.387 | 0.973 | 0.024 | 0.940 |
| Serine | 40.44 | 40.33 | 43.34 | 43.28 | 1.563 | 0.980 | 0.391 | 0.994 |
| Tyrosine | 74.39 | 76.22 | 76.31 | 75.46 | 1.050 | 0.829 | 0.800 | 0.561 |

SEM, standard error of mean; AA, amino acid.  
1 BR, broken rice; MC, multicarbohydrase; Phy, Phytase.

### Table 6. Standardized ileal digestibility (SID) of amino acids for broken rice, without or with enzymes, for postweaned piglets

| Item (%) | Treatments 1 | SEM | p-values |
|----------|--------------|-----|----------|
|          | BR | BR+MC | BR+Phy | BR+MC+Phy |       |       |       |
| Indispensable AA | | | | | | | |
| Arginine | 84.14 | 83.62 | 94.96 | 92.77 | 1.846 | 0.680 | 0.007 | 0.799 |
| Histidine | 76.94 | 88.17 | 87.90 | 88.54 | 1.671 | 0.045 | 0.054 | 0.070 |
| Isoleucine | 79.16 | 80.01 | 80.80 | 80.05 | 1.471 | 0.986 | 0.796 | 0.806 |
| Leucine | 78.95 | 79.10 | 88.08 | 87.83 | 1.517 | 0.984 | 0.003 | 0.938 |
| Lysine | 77.54 | 78.17 | 86.13 | 87.54 | 1.545 | 0.693 | 0.003 | 0.879 |
| Methionine | 80.76 | 80.78 | 87.65 | 83.88 | 1.401 | 0.530 | 0.107 | 0.526 |
| Phenylalanine | 84.33 | 88.97 | 90.66 | 86.33 | 1.266 | 0.955 | 0.490 | 0.106 |
| Threonine | 64.97 | 65.74 | 67.91 | 66.74 | 1.340 | 0.947 | 0.506 | 0.742 |
| Valine | 81.05 | 83.06 | 90.24 | 88.85 | 1.586 | 0.915 | 0.020 | 0.567 |
| Dispensable AA | | | | | | | |
| Alanine | 61.29 | 65.88 | 74.48 | 72.66 | 2.107 | 0.721 | 0.018 | 0.411 |
| Aspartic acid | 73.47 | 75.29 | 76.73 | 77.24 | 1.413 | 0.704 | 0.400 | 0.831 |
| Glutamine | 77.83 | 85.96 | 84.68 | 84.55 | 1.456 | 0.169 | 0.341 | 0.156 |
| Proline | 85.32 | 85.62 | 92.03 | 92.95 | 1.387 | 0.814 | 0.015 | 0.906 |
| Serine | 71.59 | 71.79 | 77.18 | 75.81 | 1.563 | 0.863 | 0.168 | 0.817 |
| Tyrosine | 86.50 | 88.22 | 89.13 | 88.37 | 1.050 | 0.833 | 0.545 | 0.590 |

SEM, standard error of mean; AA, amino acid.  
1 BR, broken rice; MC, multicarbohydrase; Phy, Phytase.

**CONFLICT OF INTEREST**

We certify that there is no conflict of interest with any financial organization regarding the material discussed in

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the manuscript.

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