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Amino acid digestibility in rice co-products fed to growing pigs

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ABSTRACT

The global production of paddy rice exceeds 700 million tons per year. The primary objective of rice production is to produce polished white rice for human consumption, but in this process, several co-products that may be fed to livestock are also generated. The objective of this experiment was to determine the coefficient of ileal apparent digestibility (CIAD) and the coefficient of ileal standardized digestibility (CISD) of crude protein (CP) and amino acids (AA) in 2 sources of full fat rice bran (FFRB), 1 source of defatted rice bran (DFRB), and in broken rice when fed to growing pigs. Seven finishing pigs with an average initial body weight of 70.1 ± 6.3 kg were used. Pigs were surgically fitted with a T-cannula in the distal ileum. Animals were allotted to a 7 × 7 Latin square design with 7 diets and 7 periods. Seven diets were prepared, but 1 diet was unrelated to this experiment; therefore only 6 diets were used in this experiment. One diet was based on bakery meal, and 1 diet was based on broken rice. Three additional diets were formulated by mixing bakery meal and each of the 2 sources of FFRB (FFRB-1 and FFRB-2) or DFRB. The last diet was an N-free that was used to estimate the basal ileal endogenous losses of CP and AA. The CIAD of CP and AA in bakery meal and broken rice was calculated using the direct procedure, but the CIAD of CP and AA in both sources of FFRB and in DFRB was calculated using the difference procedure. The CIAD and CISD of CP and AA in broken rice were greater ($P < 0.05$) than the CIAD and CISD of CP and AA in all other ingredients. The CIAD of the average of indispensable AA was greater ($P < 0.05$) for broken rice and less ($P < 0.05$) for DFRB, than for the 2 sources of FFRB. The CISD for the average of indispensable AA in broken rice (0.949) was greater than in FFRB-1 (0.862), FFRB-2 (0.850), and DFRB (0.817), but there were no differences between the 2 sources of FFRB, and the average CISD of indispensable AA in DFRB was less ($P < 0.05$) than in the other ingredients. The concentrations of CISD CP and indispensable AA in DFRB were greater ($P < 0.05$) than in all other ingredients. In conclusion, the CIAD and CISD of CP and AA in broken rice was greater than in FFRB and DFRB, but the greater concentration of CP and AA in FFRB and DFRB result in greater concentrations of CISD CP and AA in FFRB and DFRB than in broken rice.

Abbreviations: AA, amino acids; AEE, acid-hydrolyzed ether extract; CIAD, coefficient of ileal apparent digestibility; CISD, coefficient of ileal standardized digestibility; CP, crude protein; CTTAD, coefficient of total tract apparent digestibility; DFRB, defatted rice bran; DM, dry matter; FFRB, full fat rice bran; GE, gross energy; SEM, standard error of the mean.

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1. Introduction

Rice is the main source of carbohydrates for humans worldwide, but its use in pig feeding is limited because of relatively high price and limited availability (Vicente et al., 2009). The global production of rice is approximately 718 million tons per year (FAOSTATS, 2012), and the majority is used for production of white polished rice. When rice is milled, 60–72% of the grain is recovered as polished rice, which is used for human consumption, but the remaining 28–35% are co-products, which may be used in animal feeding. The co-products include rice hulls, rice bran, and broken rice (Singh et al., 2013). Rice hulls constitute about 20% of the weight of the rough rice, but contain large quantities of lignin and silica and have low nutritional value (Serna-Saldívar, 2010). Broken rice, also called brewers rice, are kernels of polished rice that are 25% or less of the original length of the grain and are used for production of rice meal, brewing or other fermented products, or for animal feeding (USA Rice and Federation, 2013). Broken rice is high in starch, low in fiber, fat, and CP, and has been used in diets for nursery pigs without detrimental effects on growth performance, but improved intestinal health has been reported (Vicente et al., 2009). Rice bran is the brown layer of dehulled rice and includes several sub layers within the pericarp and aleurone layers. Rice bran is categorized as full fat rice bran (**FFRB**) or defatted rice bran (**DFRB**) that contains approximately 140 g/kg and 35 g/kg ether extract, respectively (NRC, 2012). The concentration of crude protein (**CP**) ranges from 150 g/kg in FFRB to 173 g/kg in DFRB (NRC, 2012). Different procedures used in rice milling may negatively affect the digestibility and availability of amino acids (**AA**) and CP by growing pigs (Kaufmann et al., 2005), but there is limited information about the ileal digestibility of AA in rice co-products. Therefore, the objective of this research was to determine the coefficient of ileal apparent digestibility (**CIAD**) and the coefficient of ileal standardized digestibility (**CISD**) of CP and AA in 2 sources of FFRB (**FFRB-1 and FFRB-2**), 1 source of DFRB, and in broken rice when fed to growing pigs.

2. Materials and methods

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Four rice co-products were evaluated: 2 sources of FFRB, 1 source of DFRB, and broken rice (Table 1). Broken rice was sourced from Consumers Supply Distributing, North Sioux City, SD; DFRB and FFRB-1 were donated by RiceBran Technologies, Scotsdale, AR; and FFRB-2 was sourced from Triple Crown Nutrition, Inc., Waynata, MN.

2.1. Animals and housing

Seven finishing pigs that were the offspring of F-25 females that were mated to G-Performer males (Genetiporc, Alexandria, MN) with an average initial body weight of 70.1 ± 6.3 kg were used. Pigs were surgically fitted with a T-cannula in the distal ileum (Stein et al., 1998) when they had a body weight of approximately 25 kg, and all pigs had been used in a previous experiment before being assigned to this experiment. Animals were allotted to a 7 × 7 Latin square design with 7 diets and 7 periods. Pigs were housed in individual pens (1.2 m × 1.5 m) in a temperature controlled room. Pens had smooth, plastic-coated sides, and a fully slatted tribar metal floor; a feeder and a nipple drinker were installed in each pen. Pig weights were recorded at the beginning of each period to calculate feed allowance during the following period.

2.2. Diets and feeding

Seven diets were prepared (Table 2), but 1 diet was unrelated to this experiment; therefore, only 6 diets were used in this experiment. One diet was based on bakery meal (17.6 MJ gross energy (**GE**) and 140.3 g/kg CP) and 1 diet was based on broken rice (17.5 MJ GE and 69.8 g/kg CP). Three additional diets were formulated by mixing bakery meal and each of the 2 sources of FFRB (FFRB-1 and FFRB-2) or DFRB. These diets contained 17.6, 17.7, and 17.4 MJ GE and 122.4, 130.8, and 130.4 g/kg CP, respectively). The last diet was an N-free diet (17.5 MJ GE and 2.6 g/kg CP) that was used to estimate the basal ileal endogenous losses of CP and AA. All diets contained vitamins and minerals in concentrations that exceeded the requirements for growing pigs (NRC, 2012). Chromic oxide (4.0 g/kg) was added to all diets as an indigestible marker.

Because all diets contained AA in quantities below the requirements for growing pigs (NRC, 2012), an AA mixture was prepared (Table 3). During the initial 5 days of each period, 150 g of this mixture was provided every day to each pig with 75 g provided at each feeding.

Pigs were fed twice daily at a level of 3 times the maintenance energy requirement (i.e., 0.82 MJ metabolizable energy per $kg^{0.60}$; NRC, 2012), and the average daily energy intake during the experiment was 25.5 MJ metabolizable energy. Water was available at all times throughout the experiment.

2.3. Sample collection

Each period consisted of 5 d of adaptation to the diets followed by 2 d of ileal digesta collection. Ileal digesta collection was initiated at 0800 and ceased at 1600 h each day. For collection of samples, a plastic bag of 232 ml was attached to the cannula barrel using a cable tie. Bags were removed when they were filled or every 30 min and stored at −20 °C to prevent bacterial degradation of AA.

Table 1
Analyzed nutrient composition (as-fed basis) of bakery meal, broken rice, full fat rice bran (FFRB-1 and FFRB-2), and defatted rice bran (DFRB), g/kg unless otherwise indicated, as-fed basis.

Item	Ingredient				
	Bakery meal	Broken rice	FFRB-1	FFRB-2	DFRB
Gross energy (MJ/kg)	17.7	18.4	19.0	21.1	19.2
Dry matter	893.9	881.3	951.1	962.0	909.6
Crude protein	140.3	76.7	143.0	153.1	170.8
AEE[a]	76.0	8.5	170.6	192.8	10.9
Ash	35.5	12.5	86.9	80.4	119.7
Starch	435.3	768.3	255.8	295.8	283.0
Neutral detergent fiber	107.2	6.1	147.6	141.3	192.7
Acid detergent fiber	44.0	4.6	94.2	90.9	119.8
Lignin	12.0	3.5	30.1	35.1	43.2
Calcium	1.4	0.1	0.4	0.4	1.1
Phosphorus	3.2	1.1	17.6	17.9	25.8
Indispensable amino acids					
Arginine	6.0	5.2	11.1	6.1	12.1
Histidine	3.1	1.6	3.8	7.6	4.2
Isoleucine	5.0	2.9	4.7	2.7	5.9
Leucine	10.5	5.9	9.4	32.2	11.8
Lysine	4.1	2.8	6.5	5.5	7.9
Methionine	2.0	2.0	2.7	11.8	3.3
Phenylalanine	6.1	3.6	5.7	5.6	7.1
Threonine	4.4	2.5	4.9	3.5	6.3
Tryptophan	1.6	0.7	1.6	1.5	1.8
Valine	6.2	4.0	7.2	7.9	9.1
Total	49.0	31.2	57.6	84.4	69.5
Dispensable amino acids					
Alanine	6.1	4.0	8.2	8.7	10.3
Aspartic acid	7.6	6.3	11.5	12.6	14.9
Cysteine	2.7	1.5	2.8	3.0	3.2
Glutamic acid	32.2	12.3	17.6	18.6	20.9
Glycine	5.5	3.2	7.3	7.08	8.9
Proline	11.8	3.5	5.8	6.2	7.8
Serine	5.6	3.5	5.3	5.7	6.3
Tyrosine	3.5	1.6	3.5	4.0	4.7
Total	75.0	35.9	62.0	66.6	77.0
Lys:CP ratio[b]	2.92	3.65	4.54	3.59	4.62

[a] Acid-hydrolyzed ether extract.
[b] Lysine:CP ratio: Calculated by expressing the concentration of Lysine in each ingredient as a percentage of the concentration of crude protein (Stein et al., 2009).

At the conclusion of each period, ileal samples were thawed at room temperature and mixed within animal and a subsample was collected. Digesta samples were lyophilized and finely ground through a 1 mm screen prior to chemical analysis.

2.4. Chemical analyses

Ingredients were analyzed in duplicate for dry matter (Method 930.05; AOAC International, 2007), ash (Method 942.05, AOAC International, 2007), CP (Method 990.03; AOAC International, 2007), acid hydrolyzed ether extract determined by acid hydrolysis using 3 N HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN; Table 1). Ingredients were also analyzed in duplicate for GE using an adiabatic bomb calorimeter (Model 6300; Parr Instruments, Moline, IL), acid detergent fiber (Method 973.18; AOAC International, 2007), neutral detergent fiber (Holst, 1973), acid detergent lignin [Method 973.18 (A-D); AOAC International, 2007], starch (method 979.10; AOAC International, 2007), calcium and phosphorus (Method 985.01; AOAC International, 2007)] and for AA [Method 982.30 E (a, b, c); AOAC International, 2007], respectively (Table 1). All diet and digesta samples were analyzed in duplicate for dry matter, CP, and AA as explained for the ingredients. All diet and digesta samples were also analyzed in duplicate for chromium (Method 990.08; AOAC International, 2007).

2.5. Calculations and statistical analysis

Values for CIAD, basal ileal endogenous losses, and CISD of CP and AA were calculated for all diets except the N-free diet (Stein et al., 2007). The CIAD of CP and AA in the diets containing bakery meal and broken rice also represented the CIAD of CP and AA in these ingredients. Data from the bakery meal diet were used to calculate the contribution of AA from bakery meal to the diets containing FFRB or DFRB and the CIAD of CP and AA in both sources of FFRB and in DFRB, were calculated using the difference procedure (Mosenthin et al., 2007).

Table 2
Ingredient composition of experimental diets (g/kg, as-fed basis).

Ingredient	Diet[a]					
	Bakery meal	Broken rice	FFRB-1	FFRB-2	DDRB	N- Free
Bakery meal	930.6	–	376.5	376.5	335.2	–
Rice co-products	–	929.8	500.0	500.0	500.0	–
Cornstarch	–	–	–	–	–	672.4
Sucrose	–	–	100.0	100.0	100.0	200.0
Soybean oil	40.0	40.0	–	–	40.0	40.0
Cellulose[b]	–	–	–	–	–	50.0
Dicalcium phosphate	17.5	12.5	1.5	1.5	0.6	17.2
Limestone	0.9	6.7	11.0	11.0	13.2	4.4
Chromic oxide	4.0	4.0	4.0	4.0	4.0	4.0
Magnesium oxide	–	–	–	–	–	1.0
Potassium carbonate	–	–	–	––	–	4.0
Sodium chloride	4.0	4.0	4.0	4.0	4.0	4.0
Vitamin mineral premix[c]	3.0	3.0	3.0	3.0	3.0	3.0
Analyzed composition						
Gross energy (MJ/kg)	17.6	17.5	17.6	17.7	17.4	17.5
Dry matter, g/kg	921.2	893.2	944.2	944.3	921.7	917.9
Crude protein, g/kg	140.3	69.8	122.4	130.8	130.4	2.6
Ash, g/kg	57.0	28.5	77.9	69.9	89.8	25.5
AEE[d], g/kg	115.3	52.9	121.4	120.0	62.6	46.2

[a] FFRB-1: source 1 of full fat rice bran; FFRB-2: source 2 of full fat rice bran; DFRB: defatted rice bran.
[b] Solka floc. Fiber Sales and Development Corp., Urbana, OH, USA.
[c] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrocloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and niacotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.
[d] Acid-hydrolyzed ether extract.

Outliers and homogeneity of the variances among treatments were tested using the UNIVARIATE procedure of SAS (Version 9.4: SAS Institute, Inc. Cary, NC). The Proc Mixed of SAS was used to analyze all data. Diet was included in the model as a fixed effect and pig and period were included as random effects. The LSMeans option was used to calculate mean values for each diet and the PDIFF option in SAS was used to separate means if they were different. The pig was the experimental unit for all analyses. An alpha level of 0.05 was used to consider significance among dietary treatments.

3. Results

3.1. CIAD and CISD of CP and AA in diets

The broken rice diet had greater ($P < 0.05$) CIAD and CISD of CP and AA than the other diets, with the exception of the CIAD of glutamic acid and proline (Tables 4 and 5). There were no differences in CISD of CP and AA between the 2 diets containing FFRB except for lysine, tryptophan, aspartic acid, and cysteine. Values for CIAD and CISD of CP and AA in the bakery meal diet were less ($P < 0.05$) than in the broken rice diet, but greater ($P < 0.05$) for most AA than for the diets containing FFRB or DFRB.

Table 3
Amino acid mixture[a] (as fed basis).

Amino acid	Inclusion (g/kg)
Glycine	580.0
L-Lysine HCl	1630
DL-Methionine	38.0
L-Threonine	62.0
L-Tryptophan	22.0
L-Isoleucine	47.0
L-Valine	48.0
L-Histidine	11.0
L-Phenylalanine	29.0
Total	100

[a]One hundred and fifty grams of this mixture was fed daily to each pig during the adaptation period.

Table 4
Coefficient of ileal apparent digestibility of CP and AA in experimental diets.[a]

Item	Diet[b]						
	Bakery meal	Broken rice	FFRB-1	FFRB-2	DFFB	SEM	*P*-value
Crude protein	0.782b	0.820a	0.757c	0.737cd	0.730d	90	<0.0001
Indispensable amino acids							
Arginine	0.831d	0.906a	0.875b	0.863bc	0.852c	0.0072	<0.0001
Histidine	0.825bc	0.878a	0.840b	0.823c	0.802d	0.0066	<0.0001
Isoleucine	0.832b	0.864a	0.804c	0.802c	0.773d	0.0068	<0.0001
Leucine	0.870b	0.886a	0.825c	0.824c	0.790d	0.0063	<0.0001
Lysine	0.677d	0.852a	0.790b	0.750c	0.755c	0.0091	<0.0001
Methionine	0.845b	0.897a	0.844b	0.831b	0.786c	0.0063	<0.0001
Phenylalanine	0.848a	0.854a	0.788b	0.775b	0.768b	0.0130	<0.0001
Threonine	0.722b	0.792a	0.711b	0.713b	0.701b	0.0100	<0.0001
Tryptophan	0.758bc	0.837a	0.771b	0.747c	0.743c	0.0095	<0.0001
Valine	0.808b	0.876a	0.800b	0.799b	0.769c	0.0075	<0.0001
Mean	0.814b	0.871a	0.812b	0.805b	0.781c	0.0069	<0.0001
Dispensable amino acids							
Alanine	0.771c	0.846a	0.789b	0.781bc	0.765c	0.0075	<0.0001
Aspartic acid	0.712d	0.861a	0.760b	0.737c	0.726cd	0.0079	<0.0001
Cysteine	0.794b	0.861a	0.773b	0.742c	0.732c	0.0100	<0.0001
Glutamic acid	0.911a	0.890b	0.879c	0.873c	0.841d	0.0050	<0.0001
Glycine	0.651ab	0.693a	0.637ab	0.599b	0.632b	0.0254	<0.0001
Proline	0.809a	0.54.8c	0.582bc	0.528bc	0.702ab	0.0784	<0.0001
Serine	0.796b	0.846a	0.769c	0.762c	0.742d	0.0072	<0.0001
Mean[c]	0.835b	0.852a	0.802c	0.792c	0.773d	0.0079	<0.0001
All amino acids	0.826b	0.861a	0.807c	0.799c	0.779d	0.0076	<0.0001

Means within a row lacking a common letter (a–d) are different ($P < 0.05$).
[a] Least square means; $n = 7$/treatment.
[b] FFRB-1: source 1 of full fat rice bran; FFRB-2: source 2 of full fat rice bran; DFRB: defatted rice bran.
[c] Values for Pro were not included in the calculated mean for dispensable AA.

Table 5
Coefficient of ileal standardized digestibility of CP and AA in experimental diets.[a,b]

Item	Diet[c]						
	Bakery meal	Broken rice	FFRB-1	FFRB-2	DFRB	SEM	*P*-value
Crude protein	0.866b	0.973a	0.851bc	0.841c	0.815d	0.0088	<0.0001
Indispensable amino acids							
Arginine	0.911c	0.989a	0.931b	0.919bc	0.907c	0.0072	<0.0001
Histidine	0.865bc	0.951a	0.878b	0.868bc	0.837d	0.0057	<0.0001
Isoleucine	0.874b	0.934a	0.852c	0.848c	0.816d	0.0068	<0.0001
Leucine	0.902b	0.942a	0.863c	0.860c	0.825d	0.0068	<0.0001
Lysine	0.741d	0.947a	0.839b	0.802c	0.800c	0.0091	<0.0001
Methionine	0.877b	0.930a	0.875bc	0.861c	0.81.8d	0.0058	<0.0001
Phenylalanine	0.904b	0.945a	0.852c	0.836cd	0.817d	0.0138	<0.0001
Threonine	0.815b	0.952a	0.815b	0.805bc	0.785c	0.0099	<0.0001
Tryptophan	0.830bc	0.945a	0.839b	0.815c	0.809c	0.0095	<0.0001
Valine	0.856b	0.943a	0.847b	0.844b	0.810c	0.0071	<0.0001
Mean	0.868b	0.951a	0.864b	0.856b	0.829c	0.0070	<0.0001
Dispensable amino acids							
Alanine	0.842bc	0.949a	0.852b	0.842b	0.820c	0.0075	<0.0001
Aspartic acid	0.786c	0.945a	0.819b	0.794c	0.777c	0.0079	<0.0001
Cysteine	0.844b	0.942a	0.826b	0.794c	0.781c	0.0100	<0.0001
Glutamic acid	0.931a	0.942a	0.908b	0.901b	0.870c	0.55	<0.0001
Glycine	0.870b	1.039a	0.832bc	0.78.4c	0.80.7c	2.54	<0.0001
Proline	1.185b	1.844a	1.226b	1.149b	1.267b	0.109	<0.0001
Serine	0.864b	0.965a	0.845c	0.835c	0.811d	0.72	<0.0001
Mean[d]	0.889b	0.956a	0.865c	0.853c	0.831d	0.797	<0.0001
All amino acids	0.880b	0.953a	0.865bc	0.855c	0.832d	0.768	<0.0001

Means within a row lacking a common letter (a–d) are different ($P < 0.05$).
[a] Least square means; $n = 7$/treatment.
[b] Values for standardized ileal digestibility were calculated by correcting apparent ileal digestibility values for basal endogenous losses. Basal endogenous losses were determine, using pigs fed the N-free diets as (g/kg dry matter intake) CP, 12.26; Arg, 0.51; His, 0.13; Ile, 0.22; Leu, 0.35; Lys, 0.26; Met, 0.12; Phe, 0.36; Thr, 0.43; Trp, 0.11; Val 0.30; Ala, 0.43; Asp, 0.58; Cys, 0.14; Glu, 1.27; Gly, 1.19; Pro, 4.99; Ser, 0.43.
[c] FFRB-1: source 1 of full fat rice bran; FFRB-2: source 2 of full fat rice bran; DFRB: defatted rice bran.
[d] Values for Pro were not included in the calculated mean for dispensable AA.

Table 6
Coefficient of ileal apparent digestibility of crude protein and amino acids in broken rice, 2 sources of full fat rice bran (FFRB-1 and FFRB-2) and in defatted rice bran (DFRB).[a]

Item	Ingredient					
	Broken rice	FFRB-1	FFRB-2	DFRB	SEM	*P*-value
Crude protein	0.820a	0.738b	0.706b	0.700b	0.011	<0.0001
Indispensable amino acids						
Arginine	0.906a	0.883b	0.875bc	0.859c	0.0080	<0.0001
Histidine	0.878a	0.845b	0.833b	0.792c	0.0062	<0.0001
Isoleucine	0.864a	0.793b	0.780b	0.740c	0.0091	<0.0001
Leucine	0.886a	0.807b	0.787c	0.742d	0.0082	<0.0001
Lysine	0.852a	0.815b	0.786c	0.783c	0.0097	<0.0001
Methionine	0.897a	0.846b	0.824c	0.761d	0.0065	<0.0001
Phenylalanine	0.854a	0.765b	0.745bc	0.723c	0.0196	<0.0001
Threonine	0.792a	0.721b	0.707bc	0.690c	0.0122	<0.0001
Tryptophan	0.837a	0.776b	0.749bc	0.735c	0.0119	<0.0001
Valine	0.876a	0.798b	0.793b	0.751c	0.0084	<0.0001
Mean	0.871a	0.811b	0.798b	0.765c	0.0077	<0.0001
Dispensable amino acids						
Alanine	0.846a	0.794b	0.788b	0.763c	0.0087	<0.0001
Aspartic acid	0.861a	0.771b	0.747c	0.731c	0.0082	<0.0001
Cysteine	0.861a	0.766b	0.728c	0.696d	0.126	<0.0001
Glutamic acid	0.890a	0.857b	0.821c	0.767c	0.0072	<0.0001
Glycine	0.693a	0.633ab	0.612b	0.623a	0.0324	<0.0001
Proline	0.548a	0.516a	0.463a	0.647a	0.1102	0.3047
Serine	0.846a	0.759b	0.736c	0.710d	0.0092	<0.0001
Mean[b]	0.852a	0.781b	0.759c	0.734d	0.0118	<0.0001
All amino acids	0.861a	0.800b	0.783b	0.753c	0.0104	<0.0001

Means within a row lacking a common letter (a–d) are different ($P < 0.05$).
[a] Least square means; $n = 7$/treatment.
[b] Values for Pro were not included in the calculated mean for dispensable AA.

3.2. CIAD and CISD of CP and AA in ingredients

The CIAD and CISD of CP and AA in broken rice were greater ($P < 0.05$) than the CIAD and CISD of CP and AA in all other ingredients with the exception of the CIAD of glycine and proline (Tables 6 and 7). The CIAD of leucine, lysine, methionine, aspartic acid, cysteine, glutamic acid, and serine in FFRB-1was greater ($P < 0.05$) than in FFRB-2, but no differences were observed for CP or other AA between these 2 ingredients. The CIAD of AA was greater ($P < 0.05$) in both sources of FFRB than in DFRB except for arginine, lysine, phenylalanine, threonine, tryptophan, aspartic acid, glutamic acid, glycine, and proline. The CIAD of the average of indispensable AA was greater ($P < 0.05$) for broken rice and less ($P < 0.05$) for DFRB, than for FFRB.

The CISD of CP, histidine, lysine, methionine, aspartic acid, and glycine was greater ($P < 0.05$) in FFRB-1 than in FFRB-2, but the CISD of all other AA was not different between the 2 sources of FFRB. The CISD of all AA except arginine, lysine, phenylalanine, threonine, tryptophan, and glycine was greater ($P < 0.05$) in both sources of FFRB than in DFRB. The CISD for the average of indispensable, dispensable, and total AA in broken rice was greater ($P < 0.05$) than in the other ingredients, but there were no differences between the 2 sources of FFRB. The average CISD of AA in DFRB was less ($P < 0.05$) than in all other ingredients.

The concentrations of standardized ileal digestible CP and AA in DFRB were greater ($P < 0.05$) than in all other ingredients and less ($P < 0.05$) in broken rice than in the other ingredients (Table 8). The concentrations of standardized ileal digestible CP and AA in the 2 sources of FFRB were not different except for histidine, lysine, tryptophan, and alanine, for which the concentration was greater ($P < 0.05$) in FFRB-1, and isoleucine, leucine and valine, for which values were greater ($P < 0.05$) in FFRB-2.

4. Discussion

Bakery meal is a feed ingredient that stimulates feed intake and in this experiment, bakery meal was used in diets containing FFRB and DFRB to improve palatability of the diets. The concentrations of GE, acid hydrolyzed ether extract, acid detergent fiber, starch, CP, calcium and phosphorus in bakery meal were within the range of values previously reported (Slominski et al., 2004; Almeida et al., 2011; NRC, 2012; Rojas et al., 2013). In contrast, the concentration of AA in bakery meal was greater and the concentration of neutral detergent fiber was less than reported by Almeida et al. (2011), which may be the reason the CIAD and CISD values for AA observed for bakery meal in this experiment were greater than reported by Almeida et al., 2011). Bakery meal is a mixture of inedible products from the bakery and confectionary industries, and is known for its good palatability in pig diets (Slominski et al., 2004), which is the reason this ingredient was used in this experiment.

Table 7
Coefficient of ileal standardized digestibility of crude protein and amino acids in broken rice, 2 sources of full fat rice bran (FFRB-1 and FFRB-2) and in defatted rice bran (DFRB).[a,b]

Item	Ingredient					
	Broken rice	FFRB-1	FFRB-2	DFRB	SEM	*P*-value
Crude protein	0.972a	0.839b	0.798c	0.787c	0.0125	<0.0001
Indispensable amino acids						
Arginine	0.987a	0.938b	0.922bc	0.905c	0.0081	<0.0001
Histidine	0.951a	0.886b	0.870c	0.827d	0.0067	<0.0001
Isoleucine	0.932a	0.835b	0.829b	0.784c	0.0101	<0.0001
Leucine	0.941a	0.830b	0.828b	0.777c	0.0095	<0.0001
Lysine	0.945a	0.885b	0.831c	0.823c	0.0102	<0.0001
Methionine	0.929a	0.874b	0.872c	0.787d	0.0060	<0.0001
Phenyalanine	0.940a	0.810b	0.811b	0.780b	0.0222	<0.0001
Threonine	0.950a	0.814b	0.798bc	0.770c	0.0141	<0.0001
Tryptophan	0.943a	0.846b	0.814bc	0.797c	0.0135	<0.0001
Valine	0.942a	0.842b	0.836b	0.790c	0.0097	<0.0001
Mean	0.949a	0.862b	0.850b	0.817c	0.101	<0.0001
Dispensable amino acids						
Alanine	0.947a	0.858b	0.844b	0.823c	0.0109	<0.0001
Aspartic acid	0.94.4a	0.83.6b	0.798c	0.774d	0.0090	<0.0001
Cysteine	0.942a	0.812b	0.783b	0.745c	0.0133	<0.0001
Glutamic acid	0.941a	0.875b	0.864b	0.818c	0.0103	<0.0001
Glycine	1.036a	0.810b	0.781bc	0.780b	0.0340	<0.0001
Proline	1.855a	1.270b	1.261b	1.347b	0.1901	<0.0001
Serine	0.963a	0.830b	0.813b	0.779c	0.0106	<0.0001
Mean[c]	0.950a	0.862b	0.851b	0.817c	0.0130	<0.0001
All amino acids	0.952a	0.853b	0.842b	0.805c	0.0114	<0.0001

Means within a row lacking a common letter (a–d) are different ($P < 0.05$).

[a] Least square means; $n = 7$/treatment.

[b] Values for standardized ileal digestibility were calculated by correcting apparent ileal digestibility values for basal endogenous losses. Basal endogenous losses were determine using pigs fed the N-free diets as (g/kg dry matter intake) CP, 12.26; arginine, 0.51; histidine, 0.13; isoleucine, 0.22; leucine, 0.35; lysine, 0.26; methionine, 0.12; phenylalanine, 0.36; threonine, 0.43; tryptophan, 0.11; valine 0.30; alanine, 0.43; aspartic acid, 0.58; cysteine, 0.14; glutamic acid, 1.27; glycine, 1.19; proline, 4.99; serine, 0.43.

[c] Values for Pro were not included in the calculated mean for dispensable AA.

Table 8
Concentrations (g/kg dry matter) of standardized ileal digestible CP and AA in broken rice, 2 sources of full fat rice bran (FFRB-1 and FFRB-2) and in defatted rice bran (DFRB).[a,b]

Item (g/kg dry matter)	Ingredient					
	Broken rice	FFRB-1	FFRB-2	DFRB	SEM	*P*-value
Crude protein	84.6a	126.1b	127.16b	148.3c	2.22	<0.001
Indispensable amino acids						
Arginine	5.8c	10.0b	11.3b	12.1a	0.97	<0.001
Histidine	1.7d	3.5c	3.6b	3.9a	0.04	<0.001
Isoleucine	3.1d	4.1c	4.4b	5.2a	0.64	<0.001
Leucine	6.3d	8.2c	8.7b	10.1a	0.11	<0.001
Lysine	3.0d	6.1b	5.5c	7.2a	0.83	<0.001
Methionine	2.1c	2.5b	2.5b	2.9a	0.04	<0.001
Phenyalanine	3.9c	4.9b	5.0b	6.1a	0.13	<0.001
Threonine	2.7c	4.2b	4.4b	5.4a	0.09	<0.001
Tryptophan	0.7d	1.4b	1.2c	1.6a	0.21	<0.001
Valine	4.3d	6.4c	6.8b	8.0a	0.95	<0.001
Mean	33.6c	52.2b	53.3b	62.7a	0.70	<0.002
Dispensable amino acids						
Alanine	4.3d	7.4b	5.2c	9.3a	0.11	<0.001
Aspartic acid	6.7c	10.1b	10.3b	12.8a	0.14	<0.001
Cysteine	1.6c	2.4b	2.4b	2.6a	0.05	<0.001
Glutamic acid	13.1c	16.2b	16.3b	13.1a	0.25	<0.001
Glycine	3.8c	6.2b	6.0b	7.7a	0.28	<0.001
Proline	7.4b	7.7b	7.6b	12.1a	1.07	<0.001
Serine	3.8c	4.6b	4.7b	5.5a	0.07	<0.001
Mean	37.2c	51.9b	49.7b	51.9b	0.97	<0.001
All amino acids	70.8c	104.2b	103.2b	126.1a	1.65	<0.001

Means within a row lacking a common letter (a–d) are different ($P < 0.05$).

[a] Least square means; $n = 7$/treatment.

[b] The concentration of CISD AA for each ingredient was calculated by multiplying the CISD of each AA by the concentration of AA (dry matter basis) in each rice co-product.

The composition of broken rice is in agreement with previous values for polished white rice and broken rice (NRC, 2012; Brestensky et al., 2013; Cervantes-Pahm et al., 2014). The CIAD and CISD of CP and AA in the broken rice used in this experiment are greater than values reported by Yin et al. (2008) and Cervantes-Pahm et al. (2014), but less than values reported by Brestensky et al. (2013). Compared with other cereals grains commonly used in pig diets, such as yellow dent maize, sorghum and wheat, polished rice has the greatest CIAD and CISD of AA and CP (Cervantes-Pahm et al., 2014), which is likely due to the low concentration of fiber and anti-nutritional factors in rice (Brestensky et al., 2013). The reduced concentration of fiber in broken rice compared with FFRB and DFRB, likely reduces the specific endogenous losses of CP and AA (Souffrant, 2001). Likewise, the nutritional quality of rice protein is positively influenced by the high concentration of glutein, which has a greater biological value than that of the prolamin fraction, which is present in other cereal grains (Shewry, 2007).

The nutrient composition of the 2 sources of FFRB used in this experiment was similar, except for the concentration of acid hydrolyzed ether extract and starch, which were greater in FFRB-2 than in FFRB-1. This is likely the reason for the increased GE in FFRB-2 compared with FFRB-1. The concentrations of acid hydrolyzed ether extract, CP, and AA in the FFRB used in this experiment were in agreement with values reported by NRC (2012), but less than observed by Kaufmann et al. (2005). However, concentrations of neutral detergent fiber and acid detergent fiber in both sources of FFRB were less than reported in the literature (Sauvant et al., 2004; NRC, 2012), which indicates that less of the pericarp or more of the endosperm may have been included in the 2 sources of FFRB used in this experiment compared with sources used previously. The reduced concentration of fiber is likely the reason for the greater values for CIAD of CP and AA for both sources of FFRB observed in this experiment compared with values reported by Sauvant et al. (2004) and NRC (2012). The concentration of acid hydrolyzed ether extract and neutral detergent fiber in the DFRB used in this experiment were also less than previous values whereas the concentration of CP and AA were within the range of reported values (Sauvant et al., 2004; NRC, 2012). However, the values for CIAD of CP and AA in DFRB were greater than previously reported (Kaufmann et al., 2005; NRC, 2012), which likely is a consequence of the reduced concentration of detergent fiber in the source of DFRB used in this experiment because increased concentration of neutral detergent fiber reduces the digestibility of AA (Mosenthin et al., 1994).

The observation that values for the CIAD and CISD of most AA in both sources of FFRB were greater than in DFRB is in agreement with Kaufmann et al. (2005), and may be a result of the greater concentration of fat in FFRB compared with DFRB, because there is a positive relationship between the concentration of fat in rice bran and the CIAD of AA (Kaufmann et al., 2005). Addition of oil to diets fed to pigs also increases the digestibility of AA in other sources of protein (Cervantes-Pahm and Stein, 2008). In addition, the increased concentration of neutral detergent fiber in the DFRB used in this experiment likely also contributed to a reduced CIAD and CISD of AA.

The concentration of standardized ileal digestible CP and most AA in the broken rice evaluated in this experiment were less than reported for polished white rice (Cervantes-Pahm and Stein, 2014). However, the concentration of standardized ileal digestible CP and AA calculated for the 2 sources of FFRB and DFRB were greater than the values reported for dehulled barley and similar to values reported for dehulled oats (Cervantes-Pahm and Stein, 2014). As a consequence, FFRB and DFRB will provide more CP and AA for protein synthesis, compared with other cereal grains commonly fed to pigs.

5. Conclusion

The CIAD and CISD of CP and AA in FFRB and DFRB were less than in broken rice, but because of the lower concentration of CP and AA, the concentration of standardized ileal digestible CP and AA is less in broken rice than in the other ingredients evaluated in this experiment. The greater concentration of acid hydrolyzed ether extract in FFRB and the reduced concentration of neutral detergent fiber are likely the reason for the improved CIAD and CISD of CP and AA in FFRB compared with DFRB. The reduced concentration of neutral detergent fiber in FFRB and DFRB used in this experiment compared with qualities used in previous experiments likely contributed to greater CIAD and CISD of CP and AA. However, experiments to determine the quality and type of fiber in FFRB and DFRB need to be conducted to confirm the effects of fiber on CIAD and CISD of CP and AA in growing pigs.

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