Available energy and amino acid digestibility of defatted rice bran fed to growing pigs[1]

Bingbing Huang, Chengfei Huang, Zhiqian Lyu, Yifan Chen, Peili Li, Ling Liu, and Changhua Lai[2]

State Key Laboratory of Animal Nutrition, College of Animal Science and Technology, China Agricultural University, Beijing 100193, China

ABSTRACT: This study was conducted to determine and compare available energy and apparent ileal digestibility (**AID**) and standardized ileal digestibility (**SID**) of CP and AA in 9 samples of defatted rice bran (**DFRB**) fed to growing pigs and to generate prediction equations for DE and ME based on chemical analysis. In Exp. 1, 60 crossbred growing pigs (Duroc × Landrace × Yorkshire; 40.7 ± 3.5 kg BW) were fed 1 of 10 diets in a completely randomized design to determine the available energy of DFRB. The diets included a corn-soybean meal–basal diet and 9 experimental diets formulated by replacing the corn and soybean meal with 29.16% DFRB. In Exp. 2, 6 growing pigs (initial BW = 28.5 ± 2.8 kg) were surgically equipped with a T-cannula in the distal ileum and arranged in a 6 × 6 Latin square design with 6 diets and 6 periods. The diets included an N-free diet based on cornstarch and sucrose and 5 experimental diets containing 60% DFRB as the sole source of AA. Chromic oxide (0.3%) was used as an indigestible marker. Among the 9 samples, the concentrations of ether extract (**EE**), crude fiber (**CF**), NDF, ADF, starch, Ca, and P averaged 1.33 (0.50% to 4.14%), 14.54 (9.78% to 23.85%), 28.62 (20.19% to 38.85%), 14.22 (9.32% to 23.99%), 38.80% (30.62% to 47.55%), 0.16% (0.09% to 0.24%), and 1.96% (1.11% to 2.28%), respectively. The average DE and ME were 2,643 and 2,476 kcal/kg DM, respectively, and ranged from 2,039 to 3,157 kcal/kg DM and 1,931 to 2,978 kcal/kg DM, respectively. In Exp. 2, there were significant differences in the AID and SID of CP and most AA except for His, Tyr, and Met ($P < 0.05$). The AID and SID of CP averaged 67.75% and 76.37%, respectively. The digestibility of Met was the greatest, averaging 86.15% and 90.08% for AID and SID, respectively. The AID and SID of Lys ranged from 51.88% to 71.43% (mean = 63.27%) and from 61.93% to 79.98% (mean = 72.97%), respectively. These results indicated that there is significant variability in chemical composition, energy content, and the SID and AID of CP and most AA among the selected DFRB. The DE and ME of DFRB are primarily related to their NDF and starch concentrations.

Key words: amino acid digestibility, defatted rice bran, energy, equation, growing pigs

J. Anim. Sci. 2018.96:3138–3150
doi: 10.1093/jas/sky191

INTRODUCTION

Paddy rice is the third most commonly grown cereal grain produced worldwide after maize and wheat (FAO, 2015). Sixty million metric tons of rice bran, a coproduct from rice milling, is produced annually of which the majority is underutilized as

[1]This study was supported by the 111 Project (B16044), and the National Natural Science Foundation of China (31630074).

[2]Corresponding author: laichanghua999@163.com

Received November 13, 2017.
Accepted May 11, 2018.

animal feed or discarded directly (Orthoefer, 2005). Direct use of the whole rice bran is problematic because it is highly prone to lipid oxidation during storage and processing operations due to high oil content (Sibakov et al., 2013). Therefore, the rice bran needs to be either stabilized or further processed into different fractions for food application, such as defatting.

Numerous studies have been conducted using rice bran as an ingredient to evaluate the effects of rancid rice bran or full-fat rice bran on performance and metabolism of poultry (Hussein and Kratzer, 1982; Sayre et al., 1987; Warren and Farrell, 1990) and swine (Warren and Farrell, 1990; Shi et al., 2015), but few studies exist evaluating defatted rice bran (**DFRB**; Casas and Stein, 2016; Wang, 2016). In addition, there is little information about DFRB published in the NRC (2012) and CVB (2007), which not only reported calculated values for DFRB but also did not specify the processing technology used (i.e., pressing or solvent extraction). Furthermore, there is little information available on quantification energy content and digestibility of AA of DFRB fed to growing pigs.

Information on the nutritional value of DFRB is essential for the formulation of livestock rations. The development of prediction equations saves time and money and improves the accuracy of estimating energy values (Powles et al., 1995) and has been widely used to determine the DE and ME of feed ingredients. Therefore, the objectives of this study were to determine the energy content and digestibility of CP and AA in DFRB fed to growing pigs and to develop prediction equations for DE and ME based on its chemical composition.

MATERIALS AND METHODS

The China Agricultural University Laboratory Animal Welfare and Animal Experimental Ethical Inspection Committee (Beijing, China) reviewed and approved all protocols used in this experiment.

Exp. 1: Energy Measurements

Animals, diets, and experimental design. Sixty crossbred growing barrows (Duroc × Landrace × Yorkshire) with an initial BW of 40.7 ± 3.5 kg were assigned to 1 of 10 diets in a completely randomized design with 6 barrows per treatment. Pigs were weighed at the beginning and end of the experiment.

All pigs were individually housed in stainless-steel metabolism crates (1.4 × 0.7 × 0.6 m) equipped with a feeder and a nipple drinker located in an environmentally controlled room with the temperature maintained at 22 ± 2 °C. The daily feed allowance (4% of the individual pig BW) was provided in 2 equal-sized meals fed at 0830 and 1530 h. Water was provided ad libitum. The experiment was approved by the Swine Nutrition Research Center of the National Feed Engineering Technology Research Center (Chengde, China).

Nine DFRB samples (approximately 200 kg per sample) were collected from 9 provinces around China (Table 1). Before the start of the experiments, DFRB subsamples were collected and analyzed for chemical composition (Tables 2 and 3). Ten diets were prepared (Tables 4 and 5), including a corn-soybean meal–basal diet and 9 DFRB experimental diets. The DFRB experimental diets were formulated by replacing 30% of the energy supplying ingredients in the basal diet with 29.2% of DFRB. The basal diet met the nutrient requirements (NRC, 2012). The amount of vitamin and mineral premix was kept constant in all diets.

Sample collection. Samples of the diets and ingredients were collected and stored at −20 °C until needed for analysis.

The experiment lasted 12 d. The initial 7 d were considered an adaptation period to the diet and 5 d for the collection of feces and urine. During the collection period, feed refusals and spillage were collected twice daily and subsequently dried and weighed. All feces were quickly collected into plastic bags and stored at −20 °C. At the end of collection, the 5-d collection of feces from each pig was pooled and weighed, and a 350-g sample was taken and dried in a forced draft oven at 65 °C for 72 h (She et al., 2015). After drying and grinding through a 1-mm screen, subsamples were stored at −20 °C until used for further chemical analysis.

Total urine production was collected into plastic buckets attached to funnels located under

Table 1. Sources of defatted rice bran used in the 2 experiments

Number	Sources within China	Processing techniques	
1	Guangzhou	Pressed	Exp.2
2	Zhejiang	Pressed	
3	Hubei	Pressed	Exp.2
4	Jiangsu	Pressed	
5	Jilin	Pressed	Exp.2
6	Shenyang	Solvent extracted	
7	Beijing	Pressed	Exp.2
8	Anhui	Pressed	
9	Hunan	Pressed	Exp.2

Table 2. Analyzed chemical composition of defatted rice bran (% of DM)

Item	DM	NDF	ADF	CP	EE[1]	starch	CF[2]	Ash	IDF	SDF	TDF[3]	Ca	P	GE, kcal/kg
Defatted rice bran number[4]														
1	90.14	37.99	23.58	15.49	0.66	31.30	23.85	11.48	39.67	1.37	41.04	0.08	1.11	4,154
2	90.08	38.85	23.99	15.66	0.65	30.62	22.27	12.82	38.60	3.33	41.93	0.12	1.75	4,108
3	87.53	20.19	9.32	16.57	0.50	47.55	10.18	10.83	23.08	2.90	25.98	0.14	2.10	4,155
4	89.96	25.98	11.72	16.66	1.08	43.48	11.68	10.33	25.53	3.62	29.15	0.12	1.97	4,251
5	89.28	35.57	18.54	16.84	0.54	34.48	18.26	12.51	35.08	4.92	40.00	0.13	1.92	4,150
6	88.73	28.67	11.96	16.91	1.34	39.60	11.87	11.14	27.10	6.99	34.10	0.14	2.13	4,230
7	89.64	22.16	9.56	17.03	1.20	39.56	11.80	9.86	20.81	2.63	23.44	0.15	2.11	4,230
8	88.60	24.17	9.82	17.98	1.85	41.07	11.21	12.28	24.01	3.33	27.34	0.21	2.28	4,188
9	88.15	23.97	9.44	18.31	4.14	41.50	9.78	11.63	21.62	2.65	24.27	0.16	2.25	4,321
Mean	89.12	28.62	14.22	16.83	1.33	38.80	14.54	11.43	28.39	3.53	31.92	0.14	1.96	4,198
CV[5]	1.04	24.77	43.15	5.49	86.03	14.52	37.34	8.74	26.03	45.53	23.44	25.31	18.24	1.56

[1]EE = ether extract.

[2]CF = crude fiber.

[3]TDF = total dietary fiber.

[4]Sources of defatted rice bran are described in Table 1.

[5]CV = coefficient of variation.

Table 3. Analyzed AA composition of defatted rice brans (% of DM)

	Defatted rice bran numbers[1]										
Item	1	2	3	4	5	6	7	8	9	Mean	CV[2]
Indispensable AA											
Arg	0.78	0.87	1.12	1.08	1.02	1.08	1.09	1.24	1.13	1.05	13.44
His	0.38	0.25	0.33	0.33	0.33	0.38	0.35	0.47	0.44	0.36	18.07
Ile	0.41	0.41	0.49	0.53	0.49	0.53	0.50	0.57	0.55	0.50	11.45
Leu	0.89	0.83	0.97	1.08	0.95	1.05	1.02	1.13	1.05	1.00	9.64
Lys	0.49	0.55	0.69	0.68	0.67	0.74	0.74	0.75	0.70	0.67	13.38
Met	0.69	0.28	0.22	0.37	0.29	0.15	0.37	0.26	0.25	0.32	48.39
Phe	0.43	0.39	0.46	0.53	0.44	0.51	0.51	0.58	0.52	0.49	12.23
Thr	0.46	0.48	0.57	0.63	0.59	0.65	0.61	0.68	0.64	0.59	12.75
Trp	0.14	0.13	0.20	0.19	0.18	0.20	0.20	0.21	0.20	0.18	15.59
Val	0.66	0.67	0.80	0.87	0.78	0.87	0.83	0.92	0.87	0.81	11.30
Dispensable AA											
Ala	0.79	0.75	0.87	0.93	0.89	0.98	0.92	1.03	0.98	0.90	10.11
Asp	0.99	1.11	1.37	1.42	1.31	1.51	1.47	1.57	1.45	1.36	14.09
Cys	0.65	0.29	0.21	0.38	0.43	0.13	0.36	0.25	0.25	0.33	46.28
Glu	1.70	1.62	2.08	2.06	1.76	2.04	1.99	2.28	2.15	1.97	11.31
Gly	0.61	0.64	0.78	0.80	0.76	0.85	0.80	0.91	0.86	0.78	12.59
Pro	0.65	0.57	0.59	0.86	0.71	0.74	0.78	0.87	0.73	0.72	14.67
Ser	0.52	0.53	0.65	0.70	0.63	0.71	0.67	0.75	0.71	0.65	12.39
Tyr	0.37	0.27	0.43	0.46	0.40	0.44	0.44	0.52	0.50	0.43	17.51

[1]Sources of defatted rice bran are described in Table 1.

[2]CV = coefficient of variation.

the metabolic crates at the same time as the fecal collection was conducted. Approximately 50 mL of 6*N* HCl was added to the buckets to limit microbial growth and to reduce the loss of ammonia (Li et al., 2015a). Urine volume was recorded daily and a subsample of 10% of the urine excreted from each pig was collected and stored at −20 °C. At the end of the collection, urine samples were pooled for each pig and a subsample (about 45 mL) was saved for further analysis. Urine samples (4 mL) were dried at 65 °C for 8 h with a quantitative filter paper in crucibles for energy determination (Li et al., 2015a). Two sheets of quantitative filter paper from each box were used to calibrate the energy content of the paper.

Chemical analysis. Samples of all experimental diets and dried feces were ground to pass through a 1-mm (40 mesh) screen. All samples were

Table 4. Composition of experimental diets in Exp. 1 and 2 (as-fed basis)

Item	Exp. 1		Exp. 2	
Ingredient, %	Basal diet	Defatted rice bran diets	Defatted rice bran diets	N-free diet
Corn	74.43	52.10	–	–
Soybean meal	22.91	16.04	–	–
Defatted rice bran	–	29.20	60.00	–
Cornstarch	–	–	23.95	73.35
Soybean oil	–	–	3.00	3.00
Sucrose	–	–	10.00	15.00
Cellulose acetate[1]	–	–	–	4.00
Dicalcium phosphate	0.90	0.90	1.50	3.00
Potassium carbonate	–	–	–	0.30
Magnesium oxide	–	–	–	0.10
Limestone	0.90	0.90	0.30	–
Choline chloride	0.06	0.06	–	–
Salt	0.30	0.30	0.45	0.45
Chromic oxide	–	–	0.30	0.30
Mineral and vitamin premix[2]	0.50	0.50	0.50	0.50

[1]Made by Chemical Reagents Company (Beijing, China).

[2]Premix provided the following per kg of complete diet: vitamin A as retinyl acetate, 5,512 IU; vitamin D_3 as cholecalciferol, 2,200 IU; vitamin E as DL-alpha-tocopheryl acetate, 30 IU; vitamin K_3 as menadione nicotinamide bisulfite, 2.2 mg; vitamin B_{12}, 27.6 µg; riboflavin, 4 mg; pantothenic acid as DL-calcium pantothenate, 14 mg; niacin, 30 mg; choline chloride, 400 mg; folacin, 0.7 mg; thiamin as thiamine mononitrate, 1.5 mg; pyridoxine as pyridoxine hydrochloride, 3 mg; biotin, 44 µg; Mn as MnO, 40 mg; Fe as $FeSO_4 \cdot H_2O$, 75 mg; Zn as ZnO, 75 mg; Cu as $CuSO_4 \cdot 5H_2O$, 100 mg; I as KI, 0.3 mg; Se as Na_2SeO_3, 0.3 mg.

Table 5. Analyzed composition of the experimental diets used in Exp. 1 (%, as-fed basis)

Diet	DM	NDF	ADF	CP	EE[1]	Starch	Ash	Ca	P	GE, kcal/kg
Basal diet	87.15	11.01	4.15	15.97	2.12	53.94	4.78	0.64	0.51	3,805
Defatted rice bran diets[2]										
1	88.18	18.29	9.78	14.52	1.82	48.75	4.60	0.64	0.70	3,782
2	87.81	17.67	8.81	15.11	2.15	44.39	7.83	0.65	0.87	3,792
3	87.22	13.71	4.67	14.48	2.33	49.00	7.08	0.65	0.94	3,756
4	88.12	14.20	6.30	16.57	2.09	47.81	7.02	0.65	0.92	3,768
5	87.81	16.76	6.50	14.86	1.91	48.24	7.26	0.65	0.91	3,799
6	87.68	14.52	4.56	13.80	2.04	49.35	6.95	0.65	0.96	3,806
7	87.79	13.09	5.24	17.90	2.10	47.04	7.02	0.66	0.96	3,774
8	87.36	13.45	4.69	15.76	2.29	49.72	7.63	0.67	1.00	3,729
9	87.33	12.57	5.22	16.42	2.55	52.76	7.19	0.66	0.99	3,768

[1]EE = ether extract.

[2]Sources of defatted rice bran are described in Table 1.

thoroughly mixed for each pig before analysis and duplicate proximate analyses were performed.

Dry matter analysis of samples was performed by drying the samples in a forced-air oven at 105 °C for 6 h (method 930.15; AOAC, 2006). Ether extract (**EE**) of DFRB was determined by extraction in ether (method 920.39; AOAC, 2006). DFRB was analyzed for Ca (atomic absorption spectrometry; method 968.08; AOAC, 2006) and P (spectrophotometry at 620 nm; method 946.06; AOAC, 2006). Ash (method 942.05) and CP (method 984.13) were analyzed using AOAC, (2006), and crude fiber (**CF**) using AOAC, 2006 method 978.10. The NDF and ADF contents were determined using fiber bags (model F57; Ankom Technology, Macedon, NY) and a fiber analyzer (ANKOM200 Fiber Analyzer; Ankom Technology) by the basic procedure of Van Soest et al. (1991) with heat-stable α-amylase and sodium sulfite and expressed inclusive of residual ash for DFRB. The insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**) contents were determined using IDF bags and SDF bags (Dietary Fiber Analysis-IDF/SDF; Ankom Technology; AOAC 991.43). The total dietary fiber (**TDF**) was calculated by adding the values of IDF and SDF. The GE of feces, urine, diets, and DFRB was measured using an Automatic Isoperibol Oxygen Bomb Calorimeter (Parr 1281

Calorimeter; Parr Instrument Company, Moline, IL). Total starch was measured according to method 76-13.01 of the American Association of Cereal Chemists (1976), conducted using a commercial Starch Assay Kit (STA20; Sigma-Aldrich Corporation, St. Louis, MO).

Exp. 2: Amino Acid Digestibility

Animals, diets, and experimental design. This experiment was conducted to evaluate the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of AA in DFRB. Six crossbred barrows (Duroc × Landrace × Yorkshire) were used in this experiment, which were weighed after the cannulation procedure (28.5 ± 2.8 kg BW) and at the end of the trial (41.7 ± 5 kg BW). Each pig was surgically equipped with a T-cannula in the distal ileum using procedures adapted from the work of Stein et al. (1998). The barrows were individually housed in stainless-steel metabolism crates (1.4 × 0.7 × 0.6 m) located in a temperature-controlled room (22 ± 2 °C) and were allotted to a 6 × 6 Latin square design with 6 periods and 6 diets. Each experimental period lasted 10 d. Pig BW was recorded at the beginning of each experimental period, and the quantity of feed supplied during the following period was calculated based on this weight. The daily feed allowance was divided into 2 equal meals that were fed at 0800 and 1700 h. Water was available from drinking nipples at all times. Six experimental diets were prepared (Tables 4 and 6). The initial 8 d of each period were considered an adaptation period to the diet. The 6 experimental diets included an N-free diet and 5 DFRB experimental diets (Table 4). The 5 DFRB samples were 2 low, 1 medium, and 2 high content of CP and were chosen from Exp. 1 based on the varied CP contents. The N-free diet was used to determine basal ileal endogenous N losses and contained 73.35% cornstarch and 15% sucrose. A pre-experiment was performed with different diet inclusion levels of DFRB (50%, 60%, and 70%) to confirm the maximal inclusion level tolerated by the pig based on the degree of feed refusal. The experimental diets contained 60% DFRB as the sole source of AA. All diets contained 0.3% chromic oxide as an indigestible marker and the chromic oxide was added when preparing diets. Vitamins and minerals were supplemented in all diets to meet or exceed the estimated nutrient requirements for growing pigs (NRC, 2012).

Sample collection. The 6 pigs were cannulated in a single day and the recovery period lasts for 20 d after a fixed duration from the last pig cannulated, then the barrows were fed 1 of 6 diets for each period consisting of an 8-d dietary acclimation period followed by a 2-d digesta collection, which lasted for 9 h daily, and ileal digesta samples were collected beginning at 0800 h using the procedures described by Stein et al. (1998). On days 9 and 10, a plastic bag was attached to the cannula barrel using a cable tie, and digesta flowing into the bag were collected. The bags were removed whenever they were filled with digesta or at least once every 30 min and immediately stored at −20 °C. Kim et al. (2016) indicated that the combination of using small collection bags, frequent change of bags, and immediate storage at −20 °C prevents bacterial degradation of AA.

Table 6. Analyzed composition of the experimental diets used in Exp. 2 (%, as-fed basis)

	Defatted rice bran test diets[1]					
Items	1	3	5	7	9	N-free diet
DM	91.97	91.34	91.65	91.76	91.83	91.44
CP	12.85	15.03	14.09	13.50	14.22	1.08
Indispensable AA						
Arg	0.60	0.68	0.62	0.74	0.86	0.01
His	0.22	0.26	0.24	0.28	0.31	0.01
Ile	0.30	0.33	0.31	0.36	0.41	0.01
Leu	0.71	0.73	0.71	0.79	0.89	0.05
Lys	0.38	0.47	0.46	0.57	0.53	0.01
Met	0.16	0.22	0.2	0.22	0.27	0.03
Phe	0.36	0.41	0.39	0.44	0.49	0.03
Thr	0.33	0.38	0.38	0.43	0.46	0.01
Trp	0.09	0.11	0.11	0.13	0.14	0.00
Val	0.48	0.52	0.52	0.59	0.65	0.01
Dispensable AA						
Ala	0.59	0.62	0.61	0.68	0.74	0.01
Asp	0.75	0.92	0.88	1.06	1.11	0.03
Cys	0.14	0.18	0.17	0.20	0.23	0.05
Glu	1.27	1.35	1.07	1.40	1.64	0.06
Gly	0.46	0.53	0.52	0.59	0.64	0.01
Ser	0.40	0.45	0.41	0.49	0.55	0.01
Tyr	0.24	0.27	0.25	0.28	0.32	0.09

[1]Sources of defatted rice bran are described in Table 1.

Chemical analyses. At the conclusion of the experiment, frozen ileal digesta samples were allowed to thaw at room temperature and then mixed and weighed. A subsample was collected, weighed, lyophilized, and weighed again. Lyophilized digesta samples were finely ground through a 1-mm screen and thoroughly mixed prior to chemical analysis. All diets and lyophilized digesta samples were conducted according to Li et al. (2015b). Except for Met, Cys, and Trp, samples were hydrolyzed with 6*N* HCl at 110 °C for 24 h and then quantified on an Amino Acid Analyzer (Hitachi L-8900; Hitachi Ltd., Tokyo,

Japan). The sulfur AA (Met and Cys) was determined as methionine sulfone and cysteic acid after cold performic acid oxidation overnight and hydrolyzed with 7.5*N* HCl at 110 °C for 24 h before measurement using an Amino Acid Analyzer (Hitachi L-8900). Tryptophan was determined after hydrolysis with LiOH for 22 h at a constant temperature of 110 °C and then analyzed using high-performance liquid chromatography (Agilent 1200 Series; Agilent Technologies Inc., Santa Clara, CA). Analysis of the Cr in all diets and digesta was conducted using a polarized Zeeman Atomic Absorption Spectrometer (Hitachi Z2000; Hitachi Ltd., Tokyo, Japan) after nitric acid–perchloric acid wet ash sample preparation. All analyses were conducted in duplicate.

Calculations. In Exp. 1, the apparent total tract digestibility (**ATTD**; %) of GE as well as the DE and ME of the diets was calculated using the methods of Adeola (2001) according to the following equations:

$$DE_d = (GE_i - GE_f) / F_i,$$

$$DE_{dc} = DE_d / 0.9734,$$

$$DE_r = [DE_d - (100\% - X\%) \times DE_{dc}] / X\%,$$

$$ME_d = (GE_i - GE_f - GE_u) / F_i,$$

$$ME_{dc} = ME_d / 0.9734,$$

$$ME_r = [ME_d - (100\% - X\%) \times ME_{dc}] / X\%,$$

$$\text{And } ATTD = (GE_i - GE_f) / GE_i,$$

where DE_d and ME_d are the DE and ME values in each diet (kcal/kg of DM); GE_i is the total GE intake of each pig (kcal of DM) calculated as the product of the GE content of the diet over F_i, which was the actual feed intake over the 5-d collection period; GE_f and GE_u are the GE content in feces and urine of each pig (kcal of DM) over the 5-d collection period; DE_{dc} and ME_{dc} are the adjusted DE and ME in the basal diet (kcal/kg of DM) and 0.9734 is the percentage of the ingredients that supplied energy in the diet; DE_r and ME_r are the DE and ME values in each DFRB sample (kcal/kg of DM); and X% is the percentage of energy supplied by DFRB in the basal diet.

In Exp. 2, AID and SID of AA and CP were calculated as described by Stein et al. (2007) using the following equation:

$$AID = [1 - (AA_d / AA_r) \times (M_r / M_d)] \times 100\%,$$

where AA_d and AA_r represent the AA concentrations (g/kg) in digesta and diet DM, respectively, and M_d and M_r represent the Cr concentrations (g/kg) in digesta and diet DM, respectively.

The AID of CP was calculated using the equation shown above. The following equation was used for the endogenous loss of N for which each AA was measured from pigs fed the N-free diet:

$$IAA_{end} = [AA_d \times (M_r / M_d)],$$

where IAA_{end} is the basal ileal endogenous AA losses (g/kg of DM intake; DMI) and AA_d and M_d represent the AA and Cr concentrations in the ileal digesta from the pigs fed the N-free diet. The Cr concentration in the N-free diet is represented by M_r. The endogenous loss of CP was determined using the same equation. The average IAA_{end} for the 6 pigs fed the N-free diet was used to calculate the SID of AA in all diets. SID was calculated using the following equation:

$$SID = [AID + (IAA_{end} / AA_r) \times 100\%].$$

Statistical analyses. Data in Exp. 1 were analyzed using the MIXED procedure of SAS 9.2 with an individual pig as the experimental unit. Normal distribution and equal variances of the data were determined using the UNIVARIATE procedure of SAS 9.2 (SAS Inst. Inc., Cary, NC) but no outliers were found. The statistical model had treatment as a fixed effect. Statistical differences among the treatments were separated by Tukey's multiple range test. Treatment means were calculated using the LSMEANS statement and statistical significance was declared at $P < 0.05$.

The relationship between energy content and chemical composition in the DFRB was correlated using PROC CORR of SAS 9.2. Prediction equations for DE, ME, and the ATTD of GE in the DFRB were developed using PROC REG of SAS 9.2. Stepwise regression was used to determine the effect of different chemical constituents on energy values. Variables with *P*-values ≤ 0.15 were retained in the model. The R^2, the Mallows statistic [**C(p)**], Bayesian information criterion (**BIC**), root-mean-square error (**RMSE**), and Akaike information criterion (**AIC**) were used to define the best-fit equations. The equations with the greatest R^2 and the smallest RMSE and AIC were chosen as the best-fit models (Dong et al., 2014).

Data in Exp. 2 were analyzed by ANOVA using the MIXED procedure of SAS 9.2. The normality of the data was verified according to the method of Exp. 1. No outliers were identified. The individual pig was the experiment unit for all analyses. The model included the fixed effect of DFRB and the random effects of pig and period. The REPEATED statement was used to model the effect of the period using the individual pig as the subject from which repeated observations were recorded (Littell et al., 1998). The LSMEANS statement in SAS 9.2 was used to calculate means. The significance of differences between treatments was tested using Tukey's multiple range test, and an α level of $P < 0.05$ was set as the criterion for statistical significance.

RESULTS AND DISCUSSION

Chemical Composition of DFRB

As expected, the proximate (Table 2) and the AA composition (Table 3) of the DFRB were quite variable. On a DM basis, the concentrations of EE, starch, CF, NDF, ADF, IDF, SDF, TDF, Ca, and P averaged 1.33 (0.50% to 4.14%), 38.80 (30.62% to 47.55%), 14.54 (9.78% to 23.85%), 28.62 (20.19% to 38.85%), 14.22 (9.32% to 23.99%), 28.39 (20.81%to39.67%),3.53(1.37%to6.99%),31.92(23.44% to 41.93%), 0.14 (0.08% to 0.21%), and 1.96 (1.11% to 2.28%), respectively.

The variation in the EE content (ranging from 0.50% to 4.14%) may be due to the variation in processing conditions. The oil content in rice bran varies from 12 to 25 wt% and approximately 95% to 98% of the oil is extractable (Pillaiyar, 1980); thus, the oil content in the DFRB is 2% to 5%. The average EE content (1.33%) in the DFRB observed in the current study was less than the average (3.52% and 2%) reported by the NRC (2012) and Chinese Feed Database (2013), but NRC did not distinguish among processing technologies used (i.e., pressed or solvent extracted). Accordingly, different processing technologies may be a reason for the discrepancies observed between different reports. The other reasons are that the values reported by the above-listed databases are based only on a few samples and different rice ecotypes.

Rice bran contains a large quantity of dietary fiber (24% to 34% of total bran solids), which corresponds to changes in content and composition of dietary fiber during germination (Kim, et al.,2001; Ohtsubo et al., 2005; Mohan, et al., 2010). Abdul-Hamid and Luan (2000) reported that the content of TDF, CP, and ash was 65% (9% soluble dietary fiber), 17%, and 18%, respectively. The content of CP in the current study is similar to above data, but TDF, SDF, and ash were all lower. Wang et al. (2016) reported that the values of TDF, CP, ash, and starch were 31.7%, 16.2%, 8.9%, and 36.7%, respectively. With the exception of ash, the TDF, CP, and starch contents in the current study are all greater than the values reported by Wang et al. (2016). The NDF, ADF, and starch determined in the current study are greater than those values (18.1%, 9.17%, and 18.58%, respectively) reported by Casas and Stein (2016). The contents of fiber compounds all significantly varied among the different DFRB tested in the current study. It is possible that the result of the variation is due to varied processing temperatures at the different plants, which can result in Maillard reactions of different magnitudes (Woyengo et al., 2010).

The content of NDF was 23.56% from the NRC (2012) and 23.3% from the Chinese Feed Database (2013) on a DM basis, respectively. These mean values were within the range obtained in the present study. The value of starch was 26.25% from the NRC (2012), which was below the range reported in the present study.

Starch is the main component of rice, which determines the quality and use of rice. The content of starch in DFRB mainly was affected by the rice cultivar and processing conditions. Shi et al. (2015) collected and analyzed 19 rice bran samples from 11 provinces around China: rice bran from Indica rice had higher starch than that from Japonica rice. The variation in the composition of DFRB may also be a result of differences among rice mills in the milling process in which some fraction of the hulls and varying proportions of starch may be included in the rice bran (Casas et al., 2016). DFRB contains important nutrients including high-quality proteins with unique nutritional value and nutraceutical properties (Saunders, 1990). The proteins in bran have been shown to have a nutritionally balanced amino acid composition (Di Lena et al., 1997). The analyzed concentration of CP and AA in DFRB agrees with previous reports (Sauvant et al., 2004; NRC, 2012; Casas and Stein, 2016).

Energy Content and Energy Digestibility of DFRB

The substantial variation in nutrient composition of DFRB sources led to variation in the DE and ME content as shown in Table 7. DFRB numbers and sources are shown in Table 1. The average DE and ME were 2,643 and 2,476 kcal/kg DM,

Table 7. Energy content and apparent total tract digestibility (ATTD) of GE of defatted rice meal fed to growing pigs (Exp. 1, DM basis)

Items	DE, kcal/kg	ME, kcal/kg	ATTD of GE, %
Defatted rice bran number[1]			
1	2,039[c]	1,931[d]	75.63[d]
2	2,244[c]	2,087[cd]	76.84[d]
3	3,107[a]	2,978[a]	82.99[a]
4	2,664[b]	2,517[abc]	80.23[bc]
5	2,317[c]	2,237[bcd]	77.05[d]
6	2,723[b]	2,409[bc]	79.59[c]
7	2,721[b]	2,541[abc]	80.43[bc]
8	2,816[b]	2,640[ab]	81.84[ab]
9	3,157[a]	2,943[a]	83.23[a]
Mean	2,643	2,476	79.76
SEM	84.00	113.77	0.58
P-value	<0.01	<0.01	<0.01

Data are means of 6 observations per treatment.

[a–d]Within a column, means followed by the same letter are not different ($P > 0.05$); multiple comparison correction is used by Tukey.

[1]Sources of defatted rice bran are described in Table 1.

respectively, and ranged from 2,039 to 3,157 kcal/kg DM and 1,931 to 2,978 kcal/kg DM, respectively. The ATTD of GE averaged 77.86% (66.97% to 82.70%).

The average value for the 9 samples (2,643 kcal of DE per kg of DM) is greater than the value of 2,199 kcal of DE per kg of DM that has been published in NRC (2012). The second highest value for DE and the highest value for ME were obtained for the DFRB from source 3 (DFRB from Hubei in Tables 1 and 2). This sample also had the lowest concentration of NDF, ADF, and EE and the highest concentration of starch. The highest concentrations of NDF and ADF were found in source 2 (DFRB sample from Zhejiang in Tables 1 and 2), which had concentrations of starch and GE that were among the lowest of all samples, and DE and ME were the second lowest values. Thus, it seems that the DE in DFRB is, in part, related to the concentration of starch and NDF in the sample, but not all differences in DE concentrations can be explained by the concentration of these 2 nutrients.

The energy values of ingredients depend on chemical characteristics, technological treatments, animal factors, and interactions between these factors (Noblet and van Milgen, 2004). In terms of chemical characteristics, the concentrations of EE (Seneviratne et al., 2010; Woyengo et al., 2010) and NDF (Bell, 1993; Noblet and Perez, 1993) are major factors resulting in variation in the energy utilization of some ingredients. Full-fat rice bran contains a high oil content; after oil extraction, the content of residual oil is variable in DFRB. What is more, the digestibility of the nutrient decreases with increasing fiber level (JøRgensen et al., 1996). Starch digestion may affect the utilization of other nutrients such as protein (Langworthy and Deuel, 1920, 1922; Womack and Marshall, 1955), fat (MacDonald, 1962, 1964; MacDonald and Braithwaite, 1964), vitamins (Harper and Elvehjem, 1957), and minerals (Suzuki et al., 1981). Processing treatments, storage conditions, chemical modification, and genetics influence the digestibility of starch (Mark et al., 1984).

Correlation Analysis and DE and ME Prediction Equations

Correlation coefficients (r) between chemical characteristics and the GE, DE, and ME content of the 9 DFRB samples are shown in Table 8. In the 9 DFRB samples, CF had a high negative correlation with DE ($r = -0.94$; $P < 0.01$) and ME content ($r = -0.91$; $P < 0.01$). Although the correlation coefficients were less than those for CF, the other fibrous compounds (NDF, ADF, IDF, and TDF) also had significant negative correlations with DE and ME. Starch showed a high positive correlation with DE ($r = 0.89$; $P < 0.01$) and ME content ($r = 0.91$; $P < 0.01$). The samples of CP had a positive correlation with DE ($r = 0.76$; $P < 0.05$) and ME ($r = 0.74$; $P < 0.05$).The stepwise regression equations and best prediction equations for DE and ME in the DFRB samples are presented in Table 9. Starch or NDF was the first predictor and EE or ash was the second predictor. Considering the accuracy and efficiency of estimating the DE and ME, equations that included starch, NDF, EE, GE, and ash were more practical with greatest R^2 and least RMSE, BIC, and AIC. The second regression model for DE is the best fit (lowest AIC of 88.17). It is almost 40 times better than equation 1 [1/exp ((88.17 − 95.53)/2) = 39.6], despite the relatively small difference in R^2 (80 vs. 93). It is about 16 times better than model 3, almost 5 times better than model 4, and only 20% better than model 5. The seventh regression model for ME is the best fit (lowest AIC of 88.55) and is similar to equation 9. It is about 7.5 and 10.6 times better than equation 8 and 6, repectively. The R^2 alone is an insufficient means for comparing various statistical models, as it will generally prefer the more complicated model, and is thus prone to over-fitting. The R^2 was used to test how well the model fits the data and the AIC method was used to determine the goodness-of-fit models. The optimal models predicting DE and ME are as follows:

Table 8. Correlation coefficients between chemical compositions and energy values of the 9 defatted rice bran samples (Exp. 1)

Item[1]	DE	ME	GE	CP	EE	NDF	ADF	CF	Ash	IDF	SDF	TDF	starch	NDF-ADF	ATTD
DE	1.00														
ME	0.98**	1.00													
GE	0.57	0.52	**1.00**												
CP	0.76*	0.74*	0.64	1.00											
EE	0.60	0.55	0.68**	0.79*	1.00										
NDF	–0.91**	–0.91**	–0.63	–0.67*	–0.39	1.00									
ADF	–0.92**	–0.89**	–0.69*	–0.78*	–0.48	0.97**	1.00								
CF	–0.94**	–0.91**	–0.67	–0.78*	–0.50	0.95**	0.99**	1.00							
Ash	–0.38	–0.36	–0.65	–0.06	0.02	0.63	0.57	0.52	1.00						
IDF	–0.92**	–0.89**	–0.75*	–0.77*	–0.52	0.98**	0.99**	0.97**	0.60	1.00					
SDF	0.07	–0.03	–0.03	0.15	–0.10	0.04	–0.15	–0.23	0.11	–0.05	1.00				
TDF	–0.89**	–0.89**	–0.75*	–0.72*	–0.53	0.97**	0.94**	0.91**	0.62	0.98**	0.17	1.00			
Starch	0.89**	0.91**	0.46	0.56	0.28	–0.93**	–0.91**	–0.92**	–0.57	–0.88**	0.08	–0.85**	1.00		
NDF-ADF	–0.45	–0.53	–0.13	0.03	0.07	0.61	0.40	0.34	0.53	0.47	0.63	0.60	–0.55	1.00	
ATTD	0.99**	0.98**	0.54	0.73*	0.58	–0.92**	–0.91**	–0.92**	–0.39	–0.91**	0.01	–0.89**	0.91**	–0.51	1.00

[1]CP = crude protein; EE = ether extract; CF = crude fiber; IDF = insoluble dietary fiber; SDF= soluble dietary fiber; TDF = total dietary fiber; ATTD = apparent total tract digestibility of gross energy.

*The 2 criteria are significantly correlated ($P < 0.05$).

**The 2 criteria are significantly correlated ($P < 0.01$).

Table 9. Regression equations to estimate DE and ME in defatted rice brans (Exp. 1)

		Statistics[1]				
Number	Regression equation	R^2	C(p)	RMSE	AIC	BIC
1	DE = 311.10 + (60.11 × % starch)	0.80	5.61	183.24	95.53	96.88
2	DE = 416.57 + (53.10 × % starch) + (125.18 × % EE)	0.93	0.75	117.68	88.17	94.65
3	DE = 4,041 – (48.85 × % NDF)	0.83	6.12	166.23	93.78	94.94
4	DE = 3,750 – (42.96 × % NDF) + (92.32 × % EE)	0.90	3.78	140.18	91.32	95.08
5	DE = 10,811 – (50.69 × % NDF) + (148.04 × % EE) – (1.64 × GE)	0.94	2.98	117.7	88.54	97.44
6	ME = 258.27 + (57.16 × % starch)	0.82	15.53	161.71	93.28	92.41
7	ME = 342.31 + (51.57 × % starch) + (99.75× % EE)	0.92	6.71	120.13	88.55	90.10
8	ME = 3,787 – (45.80 × % NDF)	0.83	6.22	155.54	92.58	93.71
9	ME = 2,669 – (56.95 × % NDF) + (125.73× % ash)	0.91	3.17	124.56	89.20	93.53
10	ATTD of GE = 0.89 – (0.0033 × % NDF)	0.84	17.84	0.011	–79.76	–80.92
11	ATTD of GE = 0.87 – (0.0029 × % NDF) + (0.0057 × % EE)	0.90	11.65	0.0094	–80.76	–82.37
12	ATTD of GE = 1.43 – (0.0035 × % NDF) + (0.010 × % EE) – (0.00013 × GE)	0.96	5.32	0.0067	–87.33	–82.30
13	ATTD of GE = 0.64 + (0. 0041 × % starch)	0.82	10.16	0.012	–78.58	–79.47
14	ATTD of GE = 0.64 + (0. 0037 × % starch) + (0. 0080 × % EE)	0.94	2.16	0.0073	–86.28	–82.74
15	ATTD of GE = 1.18 + (0. 0041 × % starch)+ (0. 014 × % EE) – (0. 032 × GE)	0.97	2.56	0.0057	–90.40	–80.84

Regression equations are developed by stepwise regression analyses, $P < 0.01$ of all equations.

[1]RMSE = root-mean-square error; AIC = Akaike information criterion; BIC = Bayesian information criterion; C(p) = the Mallows statistic.

$$\mathrm{DE} = 416.57 + (53.10 \times \%\ \mathrm{starch}) + (125.18 \times \%\ \mathrm{EE})\ (\mathrm{R}^2 = 0.93), \text{or}$$

$$\mathrm{DE} = 10{,}811 - (50.69 \times \%\ \mathrm{NDF}) + (148.04 \times \%\ \mathrm{EE}) - (1.64 \times \mathrm{GE})\ (\mathrm{R}^2 = 0.94),$$

$$\mathrm{ME} = 342.31 + (51.57 \times \%\ \mathrm{starch}) + (99.75 \times \%\ \mathrm{EE})\ (\mathrm{R}^2 = 0.92), \text{or}$$

$$\mathrm{ME} = 2{,}669 - (56.95 \times \%\ \mathrm{NDF}) + (125.73 \times \%\ \mathrm{ash})\ (\mathrm{R}^2 = 0.91)$$

Lysine Prediction Equations

Lysine is the first limiting amino acid, and it is worth applying predictive regression to Lysine. Crude protein was the predictor. The best quadratic regression equation for Lysine is as follows:

$$\text{Lys} = -(0.055 \times \%\ \text{CP}^2) + (1.95 \times \%\ \text{CP}) - 16.40\ (\text{R}^2 = 0.95).$$

Digestibility of CP and AA

The AID and SID for CP and AA in the DFRB are presented in Tables 10 and11, respectively. The AID and SID of CP averaged 67.75% and 76.37%, respectively, and varied from 62.10% to 70.41% and from 70.60% to 78.38%, respectively. With the exception of His, Tyr, and Met, the AID and SID of AA significantly varied ($P < 0.05$). For the AID and SID of the dispensable AA, the digestibility of Gly was the least and averaged 40.08% and 61.33%, respectively. Conversely, the greatest value for AID and SID was obtained for Met, averaging 86.15% and 90.08%, respectively. Overall, the digestibility of AA for samples 1 and 9 (the DFRB samples from Guangzhou and Hunan in Tables 1 and 2) was the greatest, whereas the AA digestibility of sample 5 (the DFRB sample from Jilin in Tables 1 and 2) was the least.

With the exception of Trp and Tyr, SID of AA for DFRB was similar to or greater than values in NRC (2012). In the present experiment, digestibilities of amino acids were different for samples. The improved digestibility observed may have resulted from the higher fat contents of sample 9 compared with sample 5. Mateos et al. (1982) observed that increasing the fat content of a diet fed to chicks decreased the rate of passage and thus may have improved the digestibility of the dietary components. The AID of AA in the nursery and growing pigs was increased by the inclusion of additional fat to the diet (Imbeah and Sauer, 1991; Li, 1994). The increase in dietary fat delayed gastric emptying (Hunt and Knox, 1968), and the slower gastric emptying may result in slower rate of passage of the diet, causing an increase in the time of exposure of feed to proteolytic enzymes, thus providing longer time for peptides and AA to be digested and absorbed, and increase in AID of AA (Li, 1994). The addition of oil to diets fed to growing pigs increased not only the AID but also the SID of AA (Cervantes-Pahm and Stein, 2008; Kil and Stein, 2011). Kass et al. (1980) also showed that the rate of passage was correlated to the total-tract digestibility of dietary components in swine. Imbeah and Sauer (1991) concluded that the level of fat may affect ileal AA digestibility. A number of factors influence AA digestibility. The difference in digestibility could also be explained by differences in chemical composition (Hughes and Choct, 1999), antinutritive

Table 10. Apparent ileal digestibility (%) of AA in defatted rice brans fed to growing pigs (Exp. 2)

	Defatted rice brans number[1]							
Item	1	3	5	7	9	Mean	SEM	*P*-value
CP	67.31[a]	70.41[a]	62.10[b]	69.36[a]	69.55[a]	67.75	1.10	<0.01
Indispensable AA								
Arg	81.64[a]	81.10[a]	71.98[b]	82.69[a]	86.15[a]	80.71	2.39	<0.05
His	63.55	62.70	56.12	65.39	68.32	63.21	3.58	0.23
Ile	70.44[a]	65.67[ab]	55.45[c]	63.37[b]	70.69[a]	65.12	1.59	<0.01
Leu	72.80[a]	69.89[a]	60.32[c]	66.25[b]	72.81[a]	68.41	0.97	<0.01
Lys	61.74[a]	64.74[a]	51.88[b]	66.54[a]	71.43[a]	63.27	2.57	<0.01
Met	83.24	84.34	81.96	88.42	92.78	86.15	3.49	0.22
Phe	87.35[a]	79.30[b]	73.39[b]	71.92[b]	79.28[b]	78.25	2.00	<0.01
Thr	66.82[ab]	67.02[ab]	61.97[b]	68.92[a]	68.37[a]	66.62	1.42	<0.05
Trp	46.71[c]	66.73[ab]	62.15[b]	72.03[a]	74.88[a]	64.50	2.32	<0.01
Val	71.19[a]	69.19[a]	61.45[b]	67.05[a]	72.07[a]	68.19	1.38	<0.01
Dispensable AA								
Ala	69.67[ab]	68.39[ab]	60.89[c]	67.06[b]	72.55[a]	67.71	1.28	<0.01
Asp	72.60[a]	73.35[a]	64.84[b]	71.46[a]	74.99[a]	71.45	1.12	<0.01
Cys	51.06[b]	62.60[ab]	65.63[ab]	72.96[a]	76.84[a]	65.82	5.26	<0.05
Glu	76.26[a]	72.39[a]	67.77[b]	74.49[a]	76.45[a]	73.47	1.53	<0.01
Gly	33.33[b]	38.61[b]	20.72[c]	53.24[a]	54.50[a]	40.08	2.61	<0.01
Ser	73.90[a]	73.28[a]	66.24[b]	72.90[a]	74.49[a]	72.16	1.39	<0.01
Tyr	73.95	74.11	69.21	73.74	72.82	72.77	1.83	0.33

Data are means of 6 observations per treatment.

[a–c]Within a row, means followed by the same or no superscript letter are not different ($P > 0.05$); multiple comparison correction is used by Tukey.

[1]Sources of defatted rice bran are described in Table 1.

Table 11. Standardized ileal digestibility (SID) (%) of AA in defatted rice brans fed to growing pigs (Exp. 2)

	Defatted rice brans number[1]							
Item	1	3	5	7	9	Mean	SEM	*P*-value
CP	76.64[a]	78.38[a]	70.60[b]	78.23[a]	77.98[a]	76.37	1.10	<0.01
Indispensable AA								
Arg	86.82[a]	85.67[a]	77.05[b]	86.94[a]	89.79[a]	85.25	2.39	<0.05
His	72.55	70.23	64.39	72.40	74.76	70.87	3.58	0.34
Ile	81.64[a]	75.86[ab]	66.10[c]	72.62[b]	78.86[a]	75.02	1.59	<0.01
Leu	81.12[a]	77.93[a]	68.57[c]	73.70[b]	79.42[a]	76.15	0.97	<0.01
Lys	73.82[a]	74.54[a]	61.93[b]	74.59[a]	79.98[a]	72.97	2.58	<0.01
Met	88.25	88.07	86.13	92.18	95.78	90.08	3.48	0.34
Phe	93.01[a]	84.33[b]	78.67[b]	76.52[b]	83.46[b]	83.20	2.00	<0.01
Thr	79.69[a]	78.12[ab]	73.30[b]	78.73[ab]	77.65[ab]	77.50	1.42	0.05
Trp	56.33[c]	74.60[ab]	70.02[b]	78.69[a]	81.06[a]	72.14	2.32	<0.01
Val	82.40[a]	79.37[ab]	71.73[c]	76.05[b]	80.25[ab]	77.96	1.38	<0.01
Dispensable AA								
Ala	80.54[a]	78.63[a]	71.32[b]	76.47[a]	81.20[a]	77.63	1.28	<0.01
Asp	82.63[a]	81.44[a]	73.30[b]	78.50[a]	81.75[a]	79.53	1.12	<0.01
Cys	65.53	74.27	77.34	83.38	85.78	77.26	5.26	0.10
Glu	84.22[a]	79.85[ab]	77.18[b]	81.70[ab]	82.60[ab]	81.11	1.53	<0.05
Gly	58.40[b]	60.18[b]	42.91[c]	72.75[a]	72.40[a]	61.33	2.61	<0.01
Ser	83.79[a]	81.99[a]	75.89[b]	80.95[a]	81.72[a]	80.87	1.39	<0.05
Tyr	83.11	82.49	78.17	81.60	79.83	81.04	1.83	0.34

Data are means of 6 observations per treatment.

Values for SID are calculated by correcting the apparent ileal digestibility (AID) values with the basal endogenous losses. Basal endogenous losses (g/kg DM intake) averaged as CP, 11.98; Trp, 0.09; Cys, 0.20; Asp, 0.75; Arg, 0.31; His, 0.20; Gly, 1.20; Ile, 0.33; Leu, 0.59; Lys, 0.46; Met, 0.10; Phe, 0.20; Thr, 0.43; Ser, 0.40; Glu, 1.01; Trp, 0.08; Val, 0.53; Ala, 0.64; Tyr, 0.22.

[a–c]Within a row, means followed by the same or no superscript letter are not different ($P > 0.05$); multiple comparison correction is used by Tukey.

[1]Sources of defatted rice bran are described in Table 1.

factors (Bryden, 1996; Hughes and Choct, 1999), and processing (Marty and Chavez, 1993).

The lowest digestibility of CP and AA we observed may have resulted from the high NDF content of sample 1. Sauer et al. (1981) and Fernandez et al. (1986) assumed that fiber can reduce the digestibility of amino acid. Sources and levels of fiber can influence the amount of endogenous amino acids recovered at the distal ileum (Sauer et al., 1977; Taverner et al., 1981). This effect is thought to occur from increased endogenous losses of amino acids, adsorption of amino acids and peptides by fiber, and obstruction of digestive enzymes by the components of fiber (Sauer and Ozimek, 1986). Sample 9 had a greater apparent digestibility of CP and AA than sample 1, which may result from the higher CP content of sample 9 (Fan et al., 1994). Processing method also appears to affect digestibility. The bigger decrease in apparent digestibility of cystine, alanine, and glycine compared with the other amino acids may be partly due to a relatively high level of these amino acids in endogenous gut protein (Lenis, 1980; Sauer and Ozimek, 1986). The AID and SID of Met in pigs fed DFRB averaged 86.15% and 90.08%, respectively, which were greater than the AID and SID of Met in pigs fed rice bran 76.57% and 79.52%, respectively; the average Met of DFRB and rice bran were 0.32% and 0.27%, respectively (Shi et al., 2015). It seems that DFRB provides more available Met than rice bran. As a consequence, the DFRB is a better feedstuff which provides Met than rice bran.

CONCLUSIONS

The chemical composition and the DE and ME as well as the AID and SID of most AAs varied among the 9 DFRB samples. However, it is apparent that the nutritional values of DFRB are affected by their chemical composition, especially their NDF and starch content. Therefore, the chemical composition should be considered when using DFRB in feeds formulated for swine. In addition, the prediction equations derived from our data can be used to determine the DE and ME of DFRB fed to growing pigs.

LITERATURE CITED

Abdul-Hamid, A., and Y. S. Luan. 2000. Functional properties of dietary fibre prepared from defatted rice bran. Food. Chem. 68:15–19. doi:10.1016/S0308-8146(99)00145-4

Adeola, O. 2001. Digestion and balance techniques in pigs. In: J. Lewis and L. L. Southern, editors. Swine nutrition. CRC Press, Washington, DC. p. 903–916.

American Association of Cereal Chemists. 1976. Approved methods of analysis. Am. Assoc. Cereal Chem., St. Paul, MN.

AOAC. 2006. Official methods of analysis. 18th ed. AOAC Int., Arlington, VA.

Bell, J. M. 1993. Factors affecting the nutritional-value of canolameal: a review. Can. J. Anim. Sci. 73:689–697. doi:10.4141/cjas93-075

Bryden, W. L. 1996. Antinutritive factors in protein metabolism. In: A. F. Nunes, A. V. Portugal, J. P. Costa, and J. R. Ribeiro, editors. Protein metabolism and nutrition. Estacao Zootecnica Nacional, Vale de Santarem, Portugal. p. 517–518.

Carpenter, K. J. 1960. The estimation of the available lysine in animal-protein foods. Biochem. J. 77:604–612. doi:10.1042/bj0770604

Casas, G. A., and H. H. Stein. 2016. Effects of full fat or defatted rice bran on growth performance and blood characteristics of weanling pigs. J. Anim. Sci. 94:4179–4187. doi:10.2527/jas.2016-0565

Cervantes-Pahm, S. K., and H. H. Stein. 2008. Effect of dietary soybean oil and soybean protein concentration on the concentration of digestible amino acids in soybean products fed to growing pigs. J. Anim. Sci. 86:1841–1849. doi:10.2527/jas.2007-0721

Chinese Feed Database. 2013. Table of feed composition and nutritive value in China, 24th ed. China Feed, Beijing.

CVB. 2007. Veevoedertabel (Table of nutritional value of feed ingredients). Centraal Veevoederbureau, AD Lelystad, The Netherlands.

Di Lena, G., V. Vivanti, and G. B. Quaglia. 1997. Amino acid composition of wheat milling by-products after bioconversion by edible fungi mycelia. Food/Nahr. 41:285–288. doi:10.1002/food.19970410507

Dong, R. L., G. Y. Zhao, L. L. Chai, and K. A. Beauchemin. 2014. Prediction of urinary and fecal nitrogen excretion by beef cattle. J. Anim. Sci. 92:4669–4681. doi:10.2527/jas.2014-8000

Dreher, M. L., J. C. Dreher, J. W. Berry, and E. S. Fleming. 1984. Starch digestibility of foods: a nutritional perspective. Food. Sc. Nutr. 20:47–71. doi:10.1080/10408398409527383

Fan, M. Z., W. C. Sauer, R. T. Hardin, and K. A. Lien. 1994. Determination of apparent ileal amino acid digestibility in pigs: effect of dietary amino acid level. J. Anim. Sci. 72:2851–2859. http://jas.fass.org/content/72/11/2851

Fernandez, J. A. and J. N. Jorgensen. 1986. Digestibility and absorption of nutrients as affected by fibre content in the diet of the pig. Quantitative aspects. Livest. Prod. Sci. 15:53–64. doi:10.1016/0301-6226(86)90054-0

Food and Agriculture Organization of the United Nations (FAO). 2015. FAOSTAT. http://faostat.fao.org/ home/E. (Accessed 1 October 2015.)

Harper, A. E., and C. A. Elvehjem. 1957. A review of the effects of different carbohydrates on vitamin and amino acid requirements. J. Agric. Food. Chem. 5:754–758. doi:10.1021/jf60080a006

Hughes, R. J., and M. Choct. 1999. Chemical and physical characteristics of grains related to variability in energy and amino acid availability in poultry. Austral. J. Agri. R. 50:689–702. doi:10.1071/AR98161

Hunt, J. N., and M. T. Knox. 1968. A relation between the chain length of fatty acids and the slowing of gastric emptying. J. Physiol. 194:327–336. doi:10.1113/jphysiol.1968.sp008411

Hussein, A. S. and F. H. Kratzer. 1982. Effect of rancidity on the feeding value of rice bran for chickens. Poult. Sci. 61:2450–2455. doi:10.3382/ps.0612450

Imbeah, M., and W. C. Sauer. 1991. The effect of dietary level of fat on amino acid digestibilities in soybean meal and canola meal and on rate of passage in growing pigs. Livest. Prod. Sci. 29:227–239. doi:10.1016/0301-6226(91)90068-2

Jørgensen, H., X. Q. Zhao, K. E. Knudsen, and B. O. Eggum. 1996. The influence of dietary fibre source and level on the development of the gastrointestinal tract, digestibility and energy metabolism in broiler chickens. Br. J. Nutr. 75:379–395. doi:10.1079/BJN19960141

Kass, M. L., P. J. Van Soest, W. G. Pond, B. Lewis, and R. E. McDowell. 1980. Utilization of dietary fiber from alfalfa by growing swine. I. Apparent digestibility of the diet components in specific segments of the gastrointestinal tract. J. Anim. Sci. 50:175–191. doi:10.2527/jas1980.501175x

Kil, D. Y., and H. H. Stein. 2011. Dietary soybean oil and choice white grease improve apparent ileal digestibility of amino acids in swine diets containing corn, soybean meal, and distillers dried grains with solubles. Rev. Colomb. Cienc. Pecu. 24:248–253. http://www.scielo.org.co/scielo.php?pid=S0120-06902011000300003&script=sci_arttext&tlng=en

Kim, B. G., Y. Liu, and H. H. Stein. 2016. Effects of collection time on flow of chromium and dry matter and on basal ileal endogenous losses of amino acids in growing pigs. J. Anim. Sci. 94:4196–4204. doi:10.2527/jas.2015-0248

Kim, S. L., Y. K. Son, J. L. Son, and H. S. Hur. 2001. Effect of germination condition and drying methods on physicochemical properties of sprouted brown rice. Korean. J. Crop. Sci. 46:221–228 (in Korean).

Langworthy, C. F. and H. J. Deuel. 1920. Digestibility of raw corn, potato, and wheat starches. J. Biol. Chem. 42:27–40. http://www.jbc.org/

Langworthy, C. F. and H. J. Deuel. 1922. Digestibility of raw rice, arrowroot, canna, cassava, taro, tree-fern and potato starches. J. Biol. Chem. 52:251–261. http://www.jbc.org/

Lenis, N. P. 1980. De aminozuurverteerbaarheid bij het varken en de rol van de bacterieflora in de dikke darm en de bijdrage van het endogene eiwit (Hoorn Rapport No. 133). IVVO.

Li, P., D. F. Li, H. Y. Zhang, Z. C. Li, P. F. Zhao, Z. K. Zeng, X. Xu, and X. S. Piao. 2015. Determination and prediction of energy values in corn distillers dried grains with solubles sources with varying oil content for growing pigs. J. Anim. Sci. 93:3458–3470. doi:10.2527/jas.2014-8782

Li, S., and W. C. Sauer. 1994. The effect of dietary fat content on amino acid digestibility in young pigs. J. Anim. Sci. 72:1737–1780. doi:10.2527/1994.7271737x

Li, P., F. Wang, F. Wu, J. Wang, L. Liu, and C. Lai. 2015. Chemical composition, energy and amino acid digestibility in double-low rapeseed meal fed to growing pigs. J. Anim. Sci. Biotechnol. 6:37. doi:10.1186/s40104-015-0033-0

Littell, R. C., P. R. Henry, and C. B. Ammerman. 1998. Statistical analysis of repeated measures data using SAS procedures. J. Anim. Sci. 76:1216–1231. doi:10.2527/1998.7641216x

Macdonald, I. 1962. Some influences of dietary carbohydrate on liver and depot lipids. J. Physiol. 162:334–344. doi:10.1113/jphysiol.1962.sp006936

Macdonald, I. 1964. Dietary carbohydrates and lipid metabolism. Proc. Nutr. Soc. 23:119–123. doi:10.1079/PNS19640023

MacDonald, I., and D. M. Braithwaite. 1964. The different lipid response in adult males to dietary starch and sucrose. Clin. Sci. 27:23.

Mark, L. D., J. D. Claudia, W. B. James, and E. F. Sharon. 1984. Starch digestibility of foods: a nutritional perspective, C R C Crit. Rev. Food Sci. Nutr. 20:47–71. doi:10.1080/10408398409527383

Marty, B. J., and E. R. Chavez. 1993. Effects of heat processing on digestible energy and other nutrient digestibilities of full-fat soybeans fed to weaner, grower, and finisher pigs. Can. J. Anim. Sci. 73:411–419. doi:10.4141/cjas93-043

Mateos, G. G., J. L. Sell, and J. A. Eastwood. 1982. Rate of food passage (transit time) as influenced by level of supplemental fat. Poult. Sci. 61:94–100. doi:10.3382/ps.0610094

Mohan, B. H., N. G. Malleshi, and T. Koseki. 2010. Physicochemical characteristics and non-starch polysaccharide contents of indica and japonica brown rice and their malts. LWT – Food. Sci. Technol. 43:784–791. doi:10.1016/j.lwt.2010.01.002

Moughan, P. J., and S. M. Rutherfurd. 1996. A new method for determining digestible reactive lysine in foods. J. Agri. Food. Chem. 44:2202–2209. doi:10.1021/jf950032j

Noblet, J., and J. van Milgen. 2004. Energy value of pig feeds: effect of pig body weight and energy evaluation system. J. Anim. Sci. 82 E-Suppl:E229–E238. doi:10.2527/2004.8213_supplE229x

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389–3398. http://jas.fass.org/content/71/12/3389

NRC. 2012. Nutrient requirements of swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Ohtsubo, K., K. Suzuki, Y. Yasui, and K. Kasumi. 2005. Bio-functional components in the processed pre-germinated brown rice by a twin-screw extruder. J. Food. Compos. Anal. 18:303–316. doi:10.1016/j.jfca.2004.10.003

Orthoefer, F. T. 2005. Rice bran oil. Bailey's industrial oil and fat products. John Wiley & Sons, Inc, Hoboken. doi:10.1002/047167849X

Pillaiyar, P. 1980. Deoiled bran paste for rice bran pelletization. J. Oil. Technol. Association of India XII:42–44.

Powles, J., J. Wiseman, D. J. A. Cole, and S. Jagger. 1995. Prediction of the apparent digestible energy value of fats given to pigs. Anim. Sci. 61:149–154. doi:10.1017/S1357729800013631

Sauer, W. C., J. J. Kennely, F. X. Aherne and R. M. Cichon. 1981. Availabilities of amino acids in barley and wheat for growing pigs. Can. Vet. J. 61:793–802. doi:10.4141/cjas81-096

Sauer, W.C., and L. Ozimek. 1986. Digestibility of amino acids in swine: results and their applications. Livest. Prod. Sci. 15:367–388. doi:10.1016/0301-6226(86)90076-X

Sauer, W. C., S. C. Stothers, and R. J. Parker. 1977. Apparent and true availabilities of amino acids in wheat and milling by-products for growing pigs. Can. J. Anim. Sci. 57:775–784. doi:10.4141/cjas77-099

Saunders, R. M. 1990. The properties of rice bran as a food stuff. Cereal Foods World. 35:632–662.

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pig, poultry, sheep, goats, rabbits, horses, and fish. 2nd ed. Wageningen Acad. Publ., Wageningen, the Netherlands.

Sayre, R. N., L. Earl, F. H. Kratzer, and R. M. Saunders. 1987. Nutritional qualities of stabilized and raw rice bran for chicks. Poult. Sci. 66:493–499. doi:10.3382/ps.0660493

Seneviratne, R. W., M. G. Young, E. Beltranena, L. A. Goonewardene, R. W. Newkirk, and R. T. Zijlstra. 2010. The nutritional value of expeller-pressed canola meal for grower-finisher pigs. J. Anim. Sci. 88:2073–2083. doi:10.2527/jas.2009-2437

She, Y., Y. B. Su, L. Liu, C. F. Huang, J. T. Li, P. Li, D. F. Li, and X. S. Piao. 2015. Effects of microbial phytase on coefficient of standardized total tract digestibility of phosphorus in growing pigs fed corn and corn coproducts, wheat and wheat coproducts and oilseed meals. Anim. Feed Sci. Technol. 208:132–144. doi:10.1016/j.anifeedsci.2015.07.011

Shi, C. X., Z. Y. Liu, M. Shi, P. Li, Z. K. Zeng, L. Liu, C. F. Huang, Z. P. Zhu, and D. F. Li. 2015. Prediction of digestible and metabolizable energy content of rice bran fed to growing pigs. Asian-Australas. J. Anim. Sci. 28:654–661. doi:10.5713/ajas.14.0507

Sibakov, J., P. Lehtinen, and K. Poutanen. 2013. Cereal brans as dietary fibre ingredients, fibre-rich and wholegrain foods. Woodhead Publishing, Cambridge. p. 170–192. doi:10.1533/9780857095787.2.170

Stein, H. H., B. Sève, M. F. Fuller, P. J. Moughan, and C. F. de Lange; Committee on Terminology to Report AA Bioavailability and Digestibility. 2007. Invited review: amino acid bioavailability and digestibility in pig feed ingredients: terminology and application. J. Anim. Sci. 85:172–180. doi:10.2527/jas.2005-742

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: a technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436. http://jas.fass.org

Suzuki, K., Y. Kante, and S. Goto. 1981. Effect of starches on protein and mineral utilization. Nutr. Rep. Int. 23:645–652.

Taverner, M. R., I. D. Hume, and D. J. Farrell. 1981. Availability to pigs of amino acids in cereal grains. 1. Endogenous levels of amino acids in ileal digesta and faeces of pigs given cereal diets. Br. J. Nutr. 46:149–158. doi:10.1079/BJN19810017

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2

Wang, J., G. Suo, M. de Wit, R. M. Boom, and M. A. Schutyser. 2016. Dietary fibre enrichment from defatted rice bran by dry fractionation. J. Food. Eng. 186:50–57. doi:10.1016/j.jfoodeng.2016.04.012

Warren, B. E. and D. J. Farrell. 1990. The nutritive value of full-fat and defatted Australian rice bran. II. Growth studies with chickens, rats and pigs. Anim. Feed Sci. Technol. 27:229–246. doi:10.1016/0377-8401(90)90085-M

Womack, M., and M. W. Marshall. 1955. Starches sugars and related factors affecting liver fat and nitrogen balances in adult rats fed low levels of amino acids. J. Nutr. 57:193–202. doi:10.1093/jn/57.2.193

Woyengo, T. A., E. Kiarie, and C. M. Nyachoti. 2010. Energy and amino acid utilization in expeller-extracted canola meal fed to growing pigs. J. Anim. Sci. 88:1433–1441. doi:10.2527/jas.2009-2223