Energy value of rice, broken rice, and rice bran for broiler chickens by the regression method

Y. C. Zhang,* M. Luo,[†] X. Y. Fang,* F. Q. Zhang,* and M. H. Cao[*,1]

*College of Animal Science and Technology, Hunan Agriculture University, Changsha 410128, China; and
[†]International Department of Yali High School, Hunan Province, Changsha 410100, China

ABSTRACT The objective of this study was to determine the ileal digestible energy (**IDE**), ME, and ME_n of rice, broken rice, and rice bran. The birds were fed a standard starter diet from day 0 to 14 and experimental diets from day 15 to 21 after hatching. A total of 336 birds were grouped by BW and assigned to 7 diets, each diet comprised 8 replicates with 6 birds per replicate. The diets comprised a reference diet (**RD**) and 6 test diets (**TD**). The TD contained 2 levels of rice, broken rice or rice bran that partly replaced the energy sources in the RD at 120 or 240 g/kg (rice and broken rice) or 150 or 300 g/kg (rice bran). Addition of rice or broken rice to RD linearly increased ($P < 0.01$) ileal digestibility of DM, energy, as well as total tract metabolizability of DM, energy, and N-corrected energy in the TD. The inclusion of rice bran in the TD linearly decreased ($P < 0.01$) energy digestibility and utilization in the test diet. Regressions of rice-associated, broken rice–associated, or rice bran–associated IDE, ME, or ME_n intake in kcal against rice, broken rice, or rice bran intake were as follows: IDE = Y = 2 (6) + 3,185 (73) × Rice + 3,199 (72) × Broken Rice + 2,562 (61) × Rice Bran, r2 = 0.98; ME = Y = 8 (6) + 3,103 (72) × Rice + 3,190 (71) × Broken Rice + 2,709 (60) × Rice Bran, r2 = 0.98; ME_n = Y = 4 (5) + 3,014 (68) × Rice + 3,092 (101) × Broken Rice + 2,624 (57) × Rice Bran, r2 = 0.98; Based on the regression equations, the IDE, ME, ME_n values (kcal/kg of DM) of rice were 3,185, 3,103 and 3,014, respectively, while for broken rice, the values were 3,199, 3,190, and 3,092 and for rice bran, the values were 2,562, 2,709, and 2,624, respectively.

Key words: rice, broken rice, rice bran, ME, regression method

INTRODUCTION

The evaluation of novel feed ingredients is of great importance for the sustainable development of animal production. China is a major rice producer in the world, which accounts for 33% of the global rice production. The annual yield of rice in China is 180–200 million tonnes. Meanwhile, there are 18–27 million tonnes of broken rice and 10–15 million tonnes of rice bran production each year, as 2 byproducts of rice milling (China Statistical Yearbook, 2018). Rice contains high energy content, the byproducts of rice milling are mainly used in animal feed. Lyu et al. (2018) reported that the net energy of full-fat rice bran and defatted rice bran for growing barrows determined by indirect calorimetry method were 2,952 and 1,100 kcal/kg DM, respectively. Studies in broiler chickens using the regression method reported by Pereira and Adeola (2016) showed that the ileal digestible energy (**IDE**), ME, and ME_n of rice bran were 2,498, 2,683 and 2,476 kcal/kg DM, respectively. The energy content and digestibility of rice and its byproducts vary depending on season, rice variety, and processing procedure (Kong et al., 2016; Zhang et al., 2016);however, there are limited data reporting ME, ME_n, and IDE of rice and its by-products reported by the Chemical Composition of China Feedstuff (**CCCF**) (CCCF, 2016) and NRC (1994), and few reported the evaluation of their energy contents for animals. The ingredient evaluation is a type of research that needs continuous measurements of ingredients from different sources and origins to enable future database summary updates, such as the NRC and CCCF. Therefore, the objective of the present study was to determine ME, IDE, and ME_n contents of rice and its by-products from Hunan Province using the regression method, for broiler chickens.

MATERIALS AND METHODS

All protocols used in the study were approved by the Hunan Agriculture University Animal Care and Use Committee.

Test Ingredients and Experimental Diets

The test ingredients evaluated for their energy values were samples of rice, broken rice, and rice bran. Rice was obtained by polishing brown rice after germ layer and skin removal. Broken rice was the crushed rice, which was a by-product of rice processing and included the germ layer. Rice bran was not defatted. The analyzed gross energy (**GE**) and chemical composition of the rice, broken rice and rice bran used in the present study are presented in Table 1.

The 3 ingredients were incorporated into a practical corn–soybean meal diet. Experimental diets consisted of a reference corn–soybean meal diet and 3 test diets, the composition of which are shown in Table 2. In the reference diet (**RD**), corn, soybean meal, and soy oil were used as the sources of energy. The test diets (**TD**) contained rice or broken rice at 0, 120, or 240 g/kg, or rice bran at 0, 150 ,or 300 g/kg to partly replaced corn, soybean meal, and soy oil in such a way that the same ratio of corn, soybean meal, and soy oil was maintained across the experimental diets. These ratios were 1.56, 10.96 and 7.00 for corn: soybean meal, corn: soy oil and soybean meal: soy oil, respectively. The inclusion rate of test ingredients in TD was selected based on the approach reported by Bolarinwa and Adeola (2012) in which it was indicated ideal proportional contribution of the test ingredient 20 to 30% proportion of the energy of the reference diet in the application of reference method. Titanium dioxide was used at 5 g/kg as a digestibility index marker.

Experimental Procedures

A total of 336 Arbor Acres broiler chickens were fed a nutritionally adequate common starter diet (Table 3) from day 0 to 14 after hatch. On day 14, the birds were weighed individually, sorted by BW, and randomly assigned to 7 diets, each diet comprised 8 replicates with 6 birds per replicate. The diets comprised a RD and 6 TD. The TD contained 2 levels of rice, broken rice, or rice bran that partly replaced the energy sources in the RD at 120 or 240 g/kg (rice and broken rice) or 150 or 300 g/kg (rice bran). The length, width, and height of the metabolic cage are 100 cm, 40 cm, and 50 cm, respectively, and 24-hour light was used. Birds were allowed free access to water and feed during the experiment. Experimental diets were fed from day 14 to 21 after hatching.

Excreta were collected twice daily on day 18, 19 and 20 after hatch. During collection, the waxed paper was placed in trays under the cages, and excreta on the waxed paper were collected. The collected excreta samples were pooled per cage over the 3 d, kept in the freezer at $-20°C$, and ground to pass through a 0.5-mm screen using a mill grinder (Herbal medicine disintegrator, FW135; Tianjin Taisite Instrument). At the end of the experiment, feeders and birds were weighed to determine weight gain and feed intake, which excluded the feed residues in the waxed paper. All birds were killed by asphyxiating using carbon dioxide, and ileal digesta were collected from the distal two-thirds of the ileum. The ileum was identified from Meckel's diverticulum to about 2 cm cranial to the ileocecal junction. Ileal contents from birds were flushed with distilled water into plastic containers, pooled by cage, and stored in a freezer $(-20°C)$, then dried at $65°C$ in a forced-air oven, and grounded.

Chemical Analyses

Ileal contents, excreta, and diet samples were analyzed in duplicates for GE to determine the IDE, ME, and ME_n. Gross energy of ileal contents, excreta, and diets were determined using an oxygen bomb calorimeter (Bomb calorimeter, HXR-6000; Huaxing Instruments). DM was determined by placing samples in air-flow oven (DHG-III, 225 L; Xinmiao Instruments) at $105 \pm 2°C$ for 24 h. Nitrogen (**N**) was determined by the Kjeldahl determination procedure (GB/T 6432-1994) using 0.1% hydrochloric acid as a calibration standard. Crude fiber (**CF**), neutral detergent fiber, and acid detergent fiber were analyzed using Association of Official Analytical Chemists (AOAC, 2006) methods 978.10 and 973.18 (A, B, C, D). Ash in samples was determined by burning in a muffle furnace at 600°C (method 942.05; AOAC, 2000). The titanium concentration was determined (GB/T 23499-2009) using

Table 1. Analyzed gross energy and chemical composition of the rice, broken rice, and rice bran on an as fed basis.

Item, %	Rice	Broken rice	Rice bran
DM	90.5	86.9	88.2
Gross energy, kcal/kg	3,660	3,720	4,500
Starch	46.78	51.22	20.98
CP (N × 6.25)	7.65	10.24	12.57
Crude fat	1.13	2.21	16.58
Neutral detergent fiber	0.52	0. 80	22.92
Acid detergent fiber	0.34	0.63	134.58
CF	0.58	1.10	7.57
Ca	0.08	0.06	0.07
Total P	0.36	0.35	1.43
Indispensable amino acids, g/kg			
Arg	6.0	7.8	10.6
His	2.7	2.7	3.9
Ile	2.9	3.9	6.3
Leu	5.9	7.4	10.0
Lys	2.8	4.2	7.4
Met	1.5	2.2	2.5
Cys	1.2	1.7	1.9
Phe	3.7	4.9	6.3
Tyr	3.2	3.9	5.0
Thr	2.4	3.8	4.8
Trp	-	1.2	1.4
Val	4.2	5.7	8.1

Abbreviation: CF, crude fiber.

Table 2. Ingredient and nutrient content of experimental diets (air-dry basis).

Item	Reference diet	Rice, g/kg 120	Rice, g/kg 240	Broken rice, g/kg 120	Broken rice, g/kg 240	Rice bran, g/kg 150	Rice bran, g/kg 300
Ingredients, g/kg							
Corn	548.0	478.6	409.3	478.6	409.3	461.3	374.6
Soybean meal (43% CP)	350.0	305.7	261.4	305.7	261.4	294.6	239.2
Soybean oil	50.0	43.7	37.3	43.7	37.3	42.1	34.2
Rice	0	120.0	240.0	0	0	0	0
Broken rice	0	0	0	120	240	0	0
Rice bran	0	0	0	0	0	150	300
Dicalcium phosphate	21.4	21.4	21.4	21.4	21.4	21.4	21.4
Limestone (34% Ca)	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Salt	3.0	3.0	3.0	3.0	3.0	3.0	3.0
DL-methionine (98.5% Met)	2.0	2.0	2.0	2.0	2.0	2.0	2.0
L-Lysine (98% Lys)	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Choline chloride	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Titanium dioxide[1]	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Mineral–vitamin premix[2]	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Nutrient content[3]							
GE, kcal/kg	3,465	3,465	3,468	3,473	3,480	3,591	3,718
ME, kcal/kg	3,029	3,048	3,070	3,053	3,079	2,953	2,874
CP, g/kg	214.2	197.7	181.1	199.6	185	199.5	184.8
CF, g/kg	29.5	27.1	24.7	26.6	23.7	36.2	42.9
Ca, g/kg	10.7	10.6	10.5	10.6	10.5	10.6	10.5
Total P, g/kg	7.5	7.5	7.4	7.5	7.4	9.1	10.6
Nonphytate P, g/kg	5.2	5.2	5.2	5.2	5.1	5.3	5.4
Digestible amino acids composition, g/kg							
Arg	13.4	12.4	11.4	12.5	11.6	12.6	11.9
His	4.9	4.5	4	4.5	4.2	4.6	4.4
Ile	7.8	7.1	6.4	7.2	6.6	7.3	6.8
Leu	16	14.5	13.1	14.7	13.4	14.6	13.2
Lys	10.7	9.7	8.7	9.8	8.9	9.9	9.1
Met	3.1	2.9	2.7	2.9	2.7	2.9	2.7
Met + Cys	6.3	5.8	5.3	5.9	5.4	5.8	5.3
Phe	9.7	8.8	7.9	8.9	8.1	8.8	8
Phe + Tyr	16.5	15.0	13.5	15.2	13.9	15.1	13.8
Thr	7.1	6.4	5.8	6.5	6.0	6.5	5.9
Try	2.4	2.2	2.0	2.2	2	2.2	2.0
Val	8.9	8.2	7.6	8.3	7.7	8.4	7.9

Abbreviations: CF, crude fiber; GE, gross energy.

[1]Titanium dioxide was used as a digestibility index marker.

[2]Supplied the following per kilogram of diet: vitamin A, 135,000 IU; vitamin D$_3$, 4,500 IU; vitamin E, 21.0 IU; menadione sodium bisulfite, 4.5 mg; riboflavin, 9.0 mg; d-pantothenic acid, 15.0 mg; niacin, 36.0 mg; choline chloride, 1,300.0 mg; vitamin B$_{12}$, 30.0 mg; biotin, 150.0 μg; thiamine mononitrate, 3.0 mg; folic acid, 1.2 mg; pyridoxine hydrochloride, 3.3 mg; I, 1.1 mg; Mn, 66.1 mg; Cu, 4.4 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 300.0 μg.

[3]ME is calculated value; GE, CP, CF, Ca, TP, and AA are analyzed values.

peroxide as colored indicator. Crude fat was determined using the Soxhlet extraction (GB/T 6433-2006). Amino acid was determined by ion exchange chromatography (GB/T 18246-2000).

Calculation and Analysis

The regression method was used to estimate the IDE, ME, and MEn of the test ingredient, by regressing the ingredient-associated energy value on the inclusion rate (Adeola et al., 2010). The detailed calculation steps are described as in the following.

The IDE, ME, and MEn in assay diets containing rice, broken rice, or rice bran were calculated as described previously (Adeola et al., 2010). Coefficients (C) of ME, MEn, or IDE were calculated as follows:

$$C = 1 - [(M_d / M_o) \times (E_o / E_d)],$$

where Md is the concentration of the marker Ti in the diet, Mo is the concentration of the marker Ti in the excreta or ileal digesta output, Eo is the concentration of energy in the excreta or ileal digesta output, and Ed is the concentration of energy in the diet. ME (kcal/kg) of the diet was calculated as the product of coefficient and the GE concentration (kcal/kg) of the diet. Because catabolic compounds in excreted N can contribute to energy loss, ME was corrected to 0 N retention using a factor of 8.22 kcal/g (Hill and Anderson, 1958) as follows:

$$ME_n = ME - (8.22 \times N_{ret}),$$

where Nret is N retention in g/kg DM intake. The Nret was calculated as:

$$N_{ret} = N_i - (N_o \times C_i / C_o),$$

where Ni and No are the N concentrations (g/kg) in the diet and excreta, respectively (Bolarinwa and O. Adeola, 2012).

Table 3. Ingredient composition and characteristics of starter diet fed from day 0 to 14.

Ingredients, g/kg	
Corn	553.0
Soybean meal (43% CP)	350.0
Soybean oil	50.0
Limestone (34% Ca)	14.0
Dicalcium phosphate	21.4
DL-methionine (98.5% Met)	2.0
L-Lysine (98% Lys)	2.0
Salt	3.0
Choline chloride	2.6
Premix[1]	2.0
Total	1,000
Nutrient content[2]	
ME kcal/kg	3,173
CP, g/kg	21.47
Ca, g/kg	11.5
TP, g/kg	7.5
Nonphytate P, g/kg	5.2
Digestible amino acids composition, g/kg	
Arg	13.9
His	5.3
Ile	7.9
Leu	15.1
lys	10.8
Met	12.7
Cys	3.1
Phe	9.5
Tyr	6.5
Thr	7.1
Trp	2.5
Val	9.3

[1]Supplied the following per kilogram of diet: vitamin A, 135,000 IU; vitamin D_3, 4,500 IU; vitamin E, 21.0 IU; menadione sodium bisulfite, 4.5 mg; riboflavin, 9.0 mg; d-pantothenic acid, 15.0 mg; niacin, 36.0 mg; choline chloride, 1,300.0 mg; vitamin B_{12}, 30.0 mg; biotin, 150.0 μg; thiamine mononitrate, 3.0 mg; folic acid, 1.2 mg; pyridoxine hydrochloride, 3.3 mg; I, 1.1 mg; Mn, 66.1 mg; Cu, 4.4 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 300.0 μg.

[2]ME is calculated value; CP, Ca, TP, nonphytate P, and AA are analyzed values.

Ci and Co stand for coefficients of feed intake and excreta output, respectively. The coefficients of ME, MEn, or IDE for assay diets, the basal diet, and the test ingredients are Cad, Cbd, and Cti, respectively.

The test ingredient-assosciated IDE, ME, and MEn in each assay diet as calculated using the difference approach. The proportional contribution of energy by the basal diet and test ingredients to the assay diet are Pbd and Pti, respectively; by definition:

$$P_{bd} + P_{ti} = 1$$

The assumption of additivity in diet formulation implies that

$$C_{ad} = (C_{bd} \times P_{bd}) + (C_{ti} \times P_{ti});$$

The product of Cti at each level of the test ingredient substitution rate (0, 120, or 240 g/kg for rice and broken rice, or 0, 150, or 300 g/kg for rice bran), kilograms of dry test ingredient intake, and the GE of the test ingredient is the test ingredient-associated intake of IDE, ME, or MEn.

Growth performance and digestibility data were analyzed using the GLM procedures of SAS Institute (2006) in a randomized complete block design. Pens were considered as experimental units. The initial BW was considered as block and included as random effect in the statistical model. The effects of increasing levels of rice, broken rice, or rice bran in the TD were compared using linear and quadratic contrasts. Regression of the test ingredient-associated IDE, ME, or MEn intake in kilocalories against kilograms of test ingredient DM intake for cage of birds was conducted using multiple linear regression using the following SAS statements as described by Bolarinwa and Adeola (2012). Procedure GLM was applied. The model was Y = TI*DM intake. The solution option was used to generate intercept and slopes. Y represents the test ingredient-associated IDE, ME, or MEn intake in kilocalories; TI represents the slope of the linear regression, which is the corresponding energy value of rice, broken rice, or rice bran. DM intake is test ingredient intake (as inclusion rate, g/kg) in kilograms of DM, which is used as a regressor. Statistical significance was set at an α level of 0.05.

RESULTS

The rice, broken rice, and rice bran used in this study contained 3,660, 3,720, and 4,500 kcal GE/kg, respectively (Table 1). The growth performance of birds is shown in Table 4. As per these results, partly replacing the energy source of RD with rice or broken rice did not affect the final BW and weight gain, whereas part replacement with rice bran linearly decreased ($P < 0.01$) final weight, weight gain, and gain-to-feed ratio.

The ileal digestibility and total tract utilization of DM, N, and energy of experimental diets are shown in Table 5. Energy source part replacement with rice in TD linearly increased ($P < 0.01$) the ileal digestibility coefficient of DM, energy, and IDE. Total tract metabolizability coefficient of DM, energy, and N-corrected energy also were linearly increased ($P < 0.05$) by part inclusion of rice in TD. There were significant differences in the ME ($P < 0.05$) and ME_n ($P < 0.01$) values with increasing levels of inclusion of rice compared to the RD. Inclusion of broken rice in the TD linearly increased ($P < 0.01$) the ileal digestibility of DM, energy, and IDE digestibility coefficient except for N. Total tract utilization of DM, energy, N-corrected energy, ME, and ME_n were linearly increased ($P < 0.01$) by broken rice inclusion in the TD. As per the obtained results, inclusion of rice bran in the TD resulted in a linearly decreased ($P < 0.01$) ileal digestibility and total tract utilization of DM, N, energy and N-corrected energy, IDE, ME, and ME_n. Regressions of rice-associated, broken rice–associated, or rice bran–associated IDE, ME, or ME_n intake in kcal against rice, broken rice, or rice bran intake were as follows: IDE = Y = 2 (6) + 3,185 (73) × Rice + 3,199 (72) × Broken Rice + 2,562 (61) × Rice Bran, $r^2 = 0.98$; ME = Y = 8 (6) + 3,103 (72) × Rice + 3,190 (71) × Broken Rice + 2,709 (60) × Rice Bran, $r^2 = 0.98$; ME_n = Y = 4 (5) + 3,014 (68) × Rice + 3,092 (101) × Broken Rice + 2,624 (57) × Rice Bran, $r^2 = 0.98$, the details

Table 4. Initial and final weights, weight gain, feed intake, and feed efficiency of birds offered experimental diets for 7 d.[1]

| | | Test diets | | | | | | | P-value | | | | | |
| | | Rice, g/kg | | Broken rice, g/kg | | Rice bran, g/kg | | | | | | | | |
Items	Reference diet	120	240	120	240	150	300	SEM	L[2]	Q[2]	L[3]	Q[3]	L[4]	Q[4]
Initial weight, g	407	408	407	408	408	407	407	0.338	0.452	0.167	0.060	0.964	0.500	0.741
Final weight, g	811	826	809	761	823	723	760	7.810	0.852	0.095	0.279	<0.001	<0.001	<0.001
Weight gain, g	404	410	393	344	406	306	343	6.914	0.244	0.182	0.810	<0.001	<0.001	<0.001
Daily weight gain, g	57.7	58.6	56.1	49.1	58.3	43.7	49.0	2.483	0.113	0.121	0.382	<0.001	<0.001	<0.001
Feed intake, g	618	625	623	557	636	572	615	8.289	0.678	0.715	0.131	<0.001	0.756	<0.001
G:F, g/kg	653	656	630	618	639	534	558	6.073	0.010	0.056	0.103	0.001	<0.001	<0.001

Abbreviation: G:F, gain-to-feed ratio.

[1]Data are least squares means of 8 replicate cages with 6 birds per cage. There were 6 replicate cages for 150 g/kg rice bran groups because data from 2 replicate cages were outliers.

[2]Linear (L) and quadratic (Q) contrasts for rice.

[3]Linear (L) and quadratic (Q) contrasts for broken rice.

[4]Linear (L) and quadratic (Q) contrasts for rice bran.

are shown in Table 6. Based on the regression equations, the IDE, ME, and ME_n values (kcal/kg of DM) of rice were 3,185, 3,103, and 3,014, respectively. The IDE, ME, and ME_n for broken rice were 3,199, 3,190, and 3,092, and the IDE, ME, ME_n for rice bran were 2,562, 2,709, and 2,624, respectively.

DISCUSSION

The main objective of the study was to determine the IDE, ME, and ME_n of rice, broken rice and rice bran for broiler chickens using the regression method. The determined chemical composition of rice and broken rice in present study were all lower than the values reported by the NRC (1994), but similar to the values reported by the CCCF (2016). The DM and protein values were greater than values reported by Ebling et al. (2015). The analyzed composition of rice and broken rice used in the study were slightly different, the energy, CP, and fat concentrations contained in broken rice was slightly greater than those contained in rice.

Increasing substitution of the ingredients supplying energy in the RD with rice or broken rice from 0 and 120 to 240 g/kg of diets increased the ileal digestibility coefficient of DM, energy and IDE, total tract metabolizability coefficient of DM, energy, and N-corrected energy were linearly increased. This result suggested that rice and broken rice had greater digestibility of DM and energy than RD because rice and broken rice were replacing the RD to formulate the TD. The result of the present study indicated that the IDE, ME, and ME_n of rice which were determined by the regression method were 3,185, 3,103, and 3,014 kcal/kg, respectively. This is lower than the value (3,360 kcal/kg) reported by the CCCF (2016) but similar to the value (3,090 kcal/kg) reported by the NRC (1994). The IDE, ME, and ME_n of broken rice were 3,199, 3,190, and 3,092 kcal/kg, respectively, by the regression method, this is slightly lower than the value (3,400 kcal/kg) reported by the CCCF (2016) and similar to the value reported by Ebling et al., 2015 and greater than the value (2,900 kcal/kg) reported by the NRC (1994). The reasons could be

attributed to variability in nutrient composition, variety, planting area, and processing of the rice (Srikanta et al., 2012; Jung et al., 2014). The protein content and CF of rice used in the present study was lower (7.6 and 0.58% vs. 8.8 and 0.70%) than those reported by the CCCF (2016) value and also lower than the value (12.2 and 4.1%) reported by the NRC (1994). It was reported that adding 2.5 to 5% of the fiber in broiler chicken diets could improve the growth (Jiménezmoreno et al., 2010; Incharoen, 2013). The CF content of experimental treatments with the 2 inclusion levels of rice were 2.66 and 2.37%, respectively. A thing to be noted is the ADFI was decreased in the diets contained 120 g/kg broken rice and rice bran. By definition, the basal endogenous loss depends on DM intake. The regression method estimates the energy value by the proportional contribution of ME or digestible energy intake from the test ingredient, which is correcting the feed intake during the calculation. Therefore, theoretically, the feed intake should not impact the determination.

The 2 main varieties of rice in the southern part of China are classified by the planting season, early-season indica rice (spring rice) and late-season indica rice (autumn rice) varieties (Hizukuri et al., 1989; Morrison, 1995). Usually, the former contains more starch and protein than rice planted in autumn (Zobel, 1988; Zhong, 2004). The rice used in the study was late-season indica rice planted in autumn. This can partly explain the lower energy value observed in present study when compared with that reported by the CCCF (2016).

The processing procedures and its effects, such as milling/breaking, polishing among others, are considered to affect the starch or protein content of rice and its by-products. This study showed the energy content of broken rice was slightly greater than that of rice. A possible explanation for that could be the processing of rice and broken rice. Rice is processed by removing the rice hull and rice pericarp, while broken rice is just dehulled and rice pericarp is kept. It could lead to differences in amino acid profile, starch, vitamins, and minerals content in rice and broken rice because rice

Table 5. Ileal digestibility and total tract utilization coefficients of DM, nitrogen, and energy by birds offered experimental diets.[1]

		Rice, g/kg		Broken rice, g/kg		Rice bran, g/kg			*P*-value					
Items	Reference diet	120	240	120	240	150	300	SEM	L[2]	Q[2]	L[3]	Q[3]	L[4]	Q[4]
Ileal digestibility coefficient														
DM	0.673	0.702	0.720	0.703	0.725	0.656	0.636	0.004	<0.001	0.155	<0.001	0.156	<0.001	0.722
Nitrogen	0.848	0.853	0.846	0.846	0.843	0.830	0.820	0.003	0.771	0.136	0.248	0.737	<0.001	0.335
Energy	0.676	0.698	0.721	0.700	0.719	0.657	0.644	0.004	<0.001	0.776	<0.001	0.569	<0.001	0.476
IDE, kcal/kg DM	3,130	3,241	3,319	3,273	3,333	3,232	3,181	17.976	<0.001	0.412	<0.001	0.049	0.044	0.001
Total tract metabolizability coefficient														
DM	0.721	0.744	0.755	0.744	0.743	0.696	0.675	0.004	<0.001	0.313	0.002	0.037	<0.001	0.752
Nitrogen	0.763	0.773	0.758	0.775	0.744	0.745	0.729	0.006	0.525	0.072	0.021	0.002	0.002	0.892
Energy	0.741	0.759	0.769	0.766	0.771	0.722	0.702	0.004	<0.001	0.445	<0.001	0.046	<0.001	0.978
N-corrected energy	0.696	0.713	0.728	0.719	0.726	0.677	0.663	0.004	<0.001	0.896	<0.001	0.121	<0.001	0.611
ME, kcal/kg DM	3,459	3,524	3,530	3,581	3,573	3,514	3,472	19.352	0.013	0.222	<0.001	0.009	0.656	0.057
MEn, kcal/kg DM	3,224	3,306	3,335	3,359	3,375	3,302	3,281	18.096	<0.001	0.232	<0.001	0.011	0.038	0.040
Test ingredient-associated energy value on reference diet inclusion rate, kcal/kg														
DM														
IDE	0	401	770	403	772	382	776	7.32	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ME	0	395	756	431	772	416	833	4.30	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
MEn	0	372	731	405	744	394	801	12.10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Abbreviation: IDE, Ileal digestible energy

[1]Data are least squares means of 8 replicate cages with 6 birds per cage. There were 6 replicate cages for 150 g/kg rice bran groups because data from 2 replicate cages were outliers.

[2]Linear (L) and quadratic (Q) contrasts for rice.

[3]Linear (L) and quadratic (Q) contrasts for broken rice.

[4]Linear (L) and quadratic (Q) contrasts for rice bran.

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Table 6. Regression equations for intakes of ME, MEn and ileal digestible energy in experimental diets.[1]

Item	Regression equation	R^2	SD
ME	Y = 8 (6) + 3,103 (72) × Rice + 3,190 (71) × Broken Rice + 2,709 (60) × Rice Bran	0.983	21
ME_n	Y = 4 (5) + 3,014 (68) × Rice + 3,092 (101) × Broken Rice + 2,624 (57) × Rice Bran	0.984	20
IDE	Y = 2 (6) + 3,185 (73) × Rice + 3,199 (72) × Broken Rice + 2,562 (61) × Rice Bran	0.983	21

[1]Values in parentheses are SE; Y is in kilocalories, intercept is in kilocalories, and the slopes are in kilocalories/kg of DM.

pericarp contains high level of amino acids, vitamins, and minerals (Zhu et al., 2014). In the CCCF (2016), the amino acids, vitamins, and minerals of broken rice are slightly higher in rice, which is also consistent with the studies of Reddy and Mittra (1985), Zhang et al. (2014), and Zhu et al. (2014).

The ether extract and CP of rice bran used in this study are similar to the values reported by the NRC (1994) (16.5 and 12.5% vs. 13.0 and 12.9%), while DM and CF are lower (88.2 and 7.5% vs. 91.0 and 11.4%). The DM, GE, CP, and CF are all lower than the values reported by Pereira and Adeola (2016). Rice bran is a by-product of rice processing and is mainly made up of the germ layer between white rice and hull (Campabadal et al., 1976; Zhang et al., 2012; Esa et al., 2013). Rice bran contains higher fat content than rice itself. In the present study, the fat content of rice bran was 16.5%, which was greater than that of rice and broken rice (1.1 and 2.2%, respectively). As a result, the GE level in rice bran is greater than that of rice and broken rice. The CP content of rice bran was 12.5% in the present study, which is comparable with the value of 12.9% reported in the NRC (1994). However, rice bran contains greater fiber content than rice. The fiber content of rice bran used in this study was up to 7.5%. The high phytate content in rice bran may negatively impact the digestibility of P and even Ca, therefore leading to an imbalanced Ca-to-P ratio in broilers (He et al., 2004; Jiménezmoreno et al., 2013). This may further decrease energy utilization and performance of animal. For this reason, although there is a considerable level of nutrient and energy content, the application of rice bran in feed is limited.

The IDE, ME, and ME_n of rice bran were determined to be 2,562, 2,709, and 2,624 kcal/kg, respectively, by the regression method. This is slightly higher than the value (2,680 kcal/kg) reported by the CCCF (2016) and the values reported by Pereira and Adeola (2016) and lower than the value (2,980 kcal/kg) reported by the NRC (1994). The GE of rice bran in the present study was 4,500 kcal/kg, which was greater than the GE of rice and broken rice, but its coefficient of ME was lower than rice and broken rice. The higher GE contents in rice bran can be associated with the higher fat content. However, the digestibility and metabolizability coefficients were lower in rice bran, which was an indication of lower utilization of energy. The reason for that effect probably is the high CF content of rice bran. In the present study, the CF content of rice bran was 7.5% and was higher than what was found in rice (1.1%) and broken rice (2.2%). Because of the limited digestion of fiber in broiler chickens (He et al., 2004; Jiménezmoreno et al., 2009, 2010, 2013), the optimal CF content of broiler diet is about 2.5% (NRC, 1994). The CF contents in the 2 levels of inclusion of rice bran were 3.62 and 4.29%, which may be a reason of the low digestibility or metabolizability coefficient of DM, N, and energy.

The differences in ME, MEn, and IDE of rice, broken rice, and rice bran can be attributed to the differences in the chemical compositions of the 3 products, especially the difference of fiber and nonstarch polysaccharide (**NSP**) content (Pirgozliev et al., 2010). The neutral detergent fiber and acid detergent fiber contained in rice, broken rice, and rice bran in the present study were 0.52 and 0.34, 0.80 and 0.63, and 22.9 and 13.4%, respectively. Moreover, the presence of NSP in the gastrointestinal tract may form a gel viscous material (Nunes and Malmlöf, 1992; Choct et al., 2010) that decreases feed digestibility and nutrients utilization in birds (Franke et al., 1999; Kiarie et al., 2014). This may explain the reason IDE value of rice bran was lower than the value of ME. In addition, NSP may inhibit lipase activity in the pancreas and finally reduce energy utilization (Choct, 2006; Chandra Shekhar et al., 2014). The feed intake in experimental diets containing rice bran was lower than that of the experimental diet with added rice or broken rice. This effect may indicate the negative impact of dietary NSP on feed intake.

In conclusion, the present study showed that rice, broken rice, and rice bran are potential energy source in corn–soybean meal diets for broiler chickens. The IDE, ME, MEn values (kcal/kg of DM) of rice were 3,185, 3,103, and 3,014, respectively, while for broken rice, the values were 3,199, 3,190, and 3,092, respectively, and for rice bran, the values were were 2,562, 2,709, and 2,624, respectively.

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DISCLOSURES

The authors declare no conflicts of interest.

REFERENCES

Adeola, O., J. A. Jendza, L. L. Southern, S. Powell, and A. Owusuasiedu. 2010. Contribution of exogenous dietary

carbohydrases to the metabolizable energy value of corn distillers grains for broiler chickens. Poult. Sci. 89:1947–1954.

AOAC. Int. 2000. Official Methods of Analysis. 17th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

AOAC. Int. 2006. Official Methods of Analysis. 18th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Bolarinwa, O. A., and O. Adeola. 2012. Energy value of wheat, barley and wheat dried distillers' grains with solubles for broiler chickens determined using the regression method. Poult. Sci. 91:1928–1935.

Campabadal, C., D. Creswell, H. D. Wallace, and G. E. Combs. 1976. Nutritional value of rice bran for pigs. Trop. Agri. 53:141–149.

CCCF. 2016. Chemical Composition of China Feedstuff. China Feed. 2016 rev. ed. China Agricul. Academ. Press, Beijing, China.

Chandra Shekhar, K., S. Satyam, and P. V. Varsha. 2014. NSP enzymes and their uses. Poult. Fish Wildl. Sci. J. 2:R1001.

China Statistical Yearbook. 2018. Market Development Scale and Investment Prospect Trend Report of China Rice Industry. China Agricul. Academ. Press, Beijing, China.

Choct, M. 2006. Enzymes for the feed industry: past, present and future. World Poult. Sci 62:5–16.

Choct, M., Y. Dersjantli, J. Mcleish, and M. Peisker. 2010. Soy oligosaccharides and soluble non-starch polysaccharides: a review of digestion, nutritive and anti-nutritive effects in pigs and poultry. Asian Austral. J. Anim. 23:1386–1398.

Esa, N. M., B. L. Tan, and S. P. Loh. 2013. By-products of rice processing: an overview of health benefits and applications. J. Rice. Res. 1:1–11.

Franke, Kluge Danicke, and Jeroch. 1999. Inhaltsstoffe und futterwert von hafer aus dem mittel-deutschen anbaugebiet Fur broiler. Archiv. Für. Geflügelkunde. 63:204–207.

Ebling, P. D., A. M. Kessler, A. P. Villanueva, G. C. Pontalti, G. Farina, and A. M. Ribeiro. 2015. Rice and soy protein isolate in pre-starter diets for broilers. Poult. Sci. 94:2744–2752.

GB/T 6432-1994. 1994. Determination of Crude Protein in Feed, 1994 ed. China National Standards Commission, Beijing, China.

GB/T 18246-2000. 2000. Determination of Amino Acids in Feed. 2000 ed. China National Standards Commission, Beijing, China.

GB/T 6433-2006. 2006. Determination of Crude Fat in Feed. 2006 ed,. China National Standards Commission, Beijing, China.

GB/T 23499-2009. 2009. Determination of Residual Hydrogen Peroxide in Food. 2009 ed. China National Standards Commission, Beijing, China.

He, F., N. He, X. Pan, X. Fang, Y. Guo, and B. Cao. 2004. Effects of dietary fiber levels on dietary fibers and protein digestibility of emus. J. China Agricul.Univer. 9:44–47.

Hill, F. W., and D. L. Anderson. 1958. Comparison of metabolizable energy and productive determinations with growing chicks. J. Nutr. 64:587–603.

Hizukuri, S., Y. Takeda, N. Maruta, and B. O. Juliano. 1989. Molecular structures of rice starch. Carbohyd. Res. 189:227–235.

Incharoen, T. 2013. Histological adaptations of the gastrointestinal tract of broilers fed diets containing insoluble fiber from rice hull meal. Am. J. Vet. Anim. Sci. 8:79–88.

Jiménez-Moreno, E., M. Frikha, A. D. Coca-Sinova, J. García, and G. G. Mateos. 2013. Oat hulls and sugar beet pulp in diets for broilers 1. effects on growth performance and nutrient digestibility. Anim. Feed Sci. Tech. 182:33–43.

Jiménez-Moreno, E., J. M. Gonzálezalvarado, C. A. De, R. Lázaro, and G. G. Mateos. 2009. Effects of source of fibre on the development and ph of the gastrointestinal tract of broilers. Anim. Feed Sci. Tech. 154:93–101.

Jiménez-Moreno, E., J. M. Gonzálezalvarado, D. Gonzálezsánchez, R. Lázaro, and G. G. Mateos. 2010. Effects of type and particle size of dietary fiber on growth performance and digestive traits of broilers from 1 to 21 days of age. Poult. Sci. 89:2197–2212.

Jung, H. N., and O. J. Choi. 2014. The physicochemical characteristics of rice flour with different milling degree of rice cultivar. Korean J. Food Cookery Sci. 30:139–145.

Kiarie, E., L. F. Romero, and V. Ravindran. 2014. Growth performance, nutrient utilization, and digesta characteristics in broiler chickens fed corn or wheat diets without or with supplemental xylanase. Poult. Sci. 93:1186–1196.

Kong, H., F. R. Gao, and D. U. Zhong-Min. 2016. Factors influencing of rice quality and safety and the suggestions. Mod. Agricul. Sci. Technol. 7:478–489.

Lyu, Z., Y. Li, H. Liu, E. Li, P. Li, S. Zhang, F. Wang, and C. Lai. 2018. Net energy content of rice bran, defatted rice bran, corn gluten feed, and corn germ meal fed to growing pigs using indirect calorimetry. J. Anim. Sci. 96:1877–1888.

Morrison, W. R. 1995. Starch lipids and how they relate to starch granule structure and functionality. Cereal Food World 40:437–446.

NRC. 1994. Nutrient Requirements of Poultry. 9th rev. ed. Natl. Acad. Press, Washington, DC.

Nunes, C. S., and K. Malmlöf. 1992. Effects of guar gum and cellulose on glucose absorption, hormonal release and hepatic metabolism in the pig. Br. J. Nutr. 68:693–700.

Pereira, L. F., and O. Adeola. 2016. Energy and phosphorus values of sunflower meal and rice bran for broiler chickens using the regression method. Poult. Sci. 95:2081–2089.

Pirgozliev, V. R., S. P. Rose, and M. R. Bedford. 2010. The effect of amylose: amylopectin ratio in dietary starch on growth performance and gut morphology in broiler chickens. Arch. Geflugelkd. 74:21–29.

Reddy, M. D., and B. N. Mittra. 1985. Effect of complete plant submergence at different growth stages on grain yield, yield components and nutrient content of rice. Plant Soil 86:379–386.

SAS Institute. 2006. SAS/STAT User's Guide. Release 9.1. SAS Inst. Inc., Cary, N. C.

Srikanta, C, Md., T. A. Md. Chowdhury, and K. Golam. 2012. Comparative analysis on the major nutrient composition of locally available four different varieties of rice (Oryza sativa) in Bangladesh. Res. J. Sci. Tech. 4:13–17.

Zhang, M., D. X. Yang, C. L. Zhang, and F. Yang. 2014. Determination of nutrient components and principal component analysis of different varieties of rice. Food Sci. Tech-brazil 39:147–152.

Zhang, M., D. X. Yang, C. l. Zhang, and F. Yang. 2016. Determination of nutrient components and principal component of different varieties of rice. Food SCI. Technol. 39:149–152.

Zhang, H. J., H. Zhang, L. Wang, and X. N. Guo. 2012. Preparation and functional properties of rice bran proteins from heat-stabilized defatted rice bran. Food Res. Int. 47:359–363.

Zhong, L.-J. 2004. Pages 38–47 in Effects of Temperature on Physicochemical Characteristics and Biosynthesis Metabolism of Early Indica Rice Starch [D]. Zhejiang University, Hangzhou, Zhejiang, China.

Zhu, J. Y., L. Chen, Y. A. Yin, L. I. Li, S. L. Zhao, and X. W. Liu. 2014. Effect of the different harvest time and method on processing quality and appearance quality of agronomic traits of rice. North Rice 44:35–38.

Zobel, H. F. 1988. Molecules to granules: a comprehensive starch review. Starch – Stärke. 40:44–50.