Effects of microbial phytase on the apparent and standardized total tract digestibility of phosphorus in rice coproducts fed to growing pigs

G. A. Casas and H. H. Stein[1]

Department of Animal Sciences, University of Illinois, Urbana 61801

ABSTRACT: The objectives of this experiment were to determine the apparent total tract digestibility (ATTD) and the standardized total tract digestibility (STTD) of P and the effect of microbial phytase on ATTD and STTD of P in full-fat rice bran (FFRB), defatted rice bran (DFRB), brown rice, broken rice, and rice mill feed when fed to pigs. Ninety-six barrows (initial BW of 19.4 ± 1.4 kg) were allotted to 12 diets with 8 replicate pigs per diet in a randomized complete block design. A basal diet based on corn and soybean meal was formulated. Five additional diets containing corn, soybean meal, and each rice coproduct were also formulated, and the ratio between corn and soybean meal in these diets was similar to that in the basal diet. Six additional diets that were similar to the initial 6 diets with the exception that 1,000 units of microbial phytase were added to the diets were also formulated. The ATTD and STTD of P were calculated for each diet using the direct procedure, and the ATTD and STTD of P in each rice coproduct were calculated using the difference procedure. Results of the experiment indicated that the concentration of P in feces was reduced ($P < 0.05$) from pigs fed diets with microbial phytase compared with pigs fed diets without phytase. No differences were observed between the basal diet and the broken rice diet, but the ATTD and the STTD of P in those diets was greater ($P < 0.05$) than in all other diets both without and with phytase. Among the rice coproducts, the greatest ($P < 0.05$) ATTD and STTD of P were observed for broken rice regardless of inclusion of phytase. If no microbial phytase was used, the values for STTD of P in brown rice, FFRB, DFRB, and rice mill feed were not different, but if microbial phytase was included in the diet, ATTD and STTD of P in brown rice was greater ($P < 0.05$) than in FFRB, DFRB, and rice mill feed. The STTD of P in brown rice, FFRB, and rice mill feed was greater ($P < 0.05$) if microbial phytase was used than if no microbial phytase was used. Addition of microbial phytase to the diets also increased ($P < 0.05$) the ATTD of Ca regardless of the rice coproducts used. In conclusion, the STTD of P is greater in broken rice than in all other rice coproducts. The STTD of P in brown rice, FFRB, DFRB, and rice mill feed is relatively low due to the high concentration of phytate in these ingredients, but addition of microbial phytase will increase the STTD of P in most rice coproducts.

Key words: broken rice, brown rice, phosphorus digestibility, phytase, pig, rice bran

J. Anim. Sci. 2015.93:3441–3448
doi:10.2527/jas2015-8877

INTRODUCTION

Coproducts from the rice milling industry include rice hulls, rice bran, broken rice, and rice mill feed (Singh et al., 2013). Approximately 20% of the weight of paddy rice is rice hulls, which contain large quantities of lignin and silica and, therefore, are not used as a food or feed ingredient (Serna-Saldivar, 2010). Brown rice is the whole rice grain that is left after the hull has been removed, but when white polished rice is produced, the brown layer is removed and marketed as rice bran, which includes several sublayers within the pericarp and aleurone layers and makes up 8 to 10% of the weight of the paddy rice. Rice bran may be sold as full-fat rice bran (**FFRB**) with a concentration of ether extract of 14 to 24%, or it may be defatted and marketed as defatted rice bran

---

[1] Corresponding author: hstein@illinois.edu

Received January 4, 2015.
Accepted April 25, 2015.

Table 1. Analyzed nutrient composition of soybean meal, corn, brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed (as-fed basis)

	Ingredient						
Item	Corn	Soybean meal	Brown rice	Broken rice	FFRB	DFRB	Rice mill feed
GE, kcal/kg	3,848	4,071	3,841	4,399	5,044	4,348	4,251
DM, %	83.3	88.4	88.1	88.1	96.2	91.0	91.0
CP, %	6.64	50.30	9.51	7.67	15.3	17.1	7.09
AEE[1], %	2.02	1.09	3.15	1.42	19.28	1.11	5.01
Ash, %	0.83	5.56	1.22	1.25	8.04	11.97	14.19
ADF, %	3.11	4.99	1.37	0.46	9.09	11.98	43.39
NDF, %	8.56	6.80	2.66	0.61	14.13	19.27	45.66
Ca, %	0.01	0.30	0.01	0.01	0.04	0.11	0.11
P, %	0.20	0.57	0.27	0.11	1.79	2.58	0.63
Phytate, %	0.49	1.31	0.79	0.22	5.82	8.43	2.01
Phytate-bound P[2], %	0.13	0.37	0.22	0.06	1.62	2.36	0.56
Phytate-bound P, % of total P	65.0	64.9	81.5	54.5	90.5	91.5	88.9
Nonphytate P[3], %	0.07	0.20	0.05	0.05	0.2	0.2	0.07
Nonphytate-bound P, % of total P	35.0	35.1	18.5	45.4	9.5	8.5	11.1

[1] AEE = acid hydrolyzed ether extract.

[2] Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[3] Nonphytate P was calculated as the difference between total P and phytate-bound P.

(**DFRB**) with a concentration of ether extract of less than 5% (Sauvant et al., 2004).

Broken rice is made up of fragments and broken kernels of white rice grain that are generated during milling and is used for brewing, rice flour production, or for animal feeding (USA Rice Federation, 2011). Rice mill feed is a combination of rice hulls, rice bran, and rice polishings, but limited information is available about the nutritional value of rice mill feed (Stacey and Rankins, 2004).

Most P in rice coproducts is bound to phytate (Sauvant et al., 2004), which results in low digestibility of P by pigs, and the majority of the phytate is located in the bran layers. As a consequence, rice bran has a greater concentration of phytate than other ingredients commonly used in diets for pigs (NRC, 2012). It is, therefore, likely that the digestibility of P in rice coproducts may be improved if microbial phytase is included in the diets. Therefore, the objective of this experiment was to test the hypothesis that the apparent total tract digestibility (**ATTD**) and the standardized total tract digestibility (**STTD**) of P in rice coproducts fed to pigs is improved if microbial phytase is included in the diet.

MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Five rice coproducts were evaluated: broken rice, brown rice, FFRB, DFRB, and rice mill feed (Table 1). Brown rice was sourced from Augason Farms (Salt Lake City, UT), and broken rice was procured from Consumers Supply Distributing (North Sioux City, SD); DFRB and FFRB were purchased from NutraCea (Scotsdale, AR) and Triple Crown Nutrition, Inc. (Waynata, MN), respectively, and rice mill feed was obtained from Crescent Feed Co. (Springfield, MO).

Animals and Housing

Ninety-six barrows that were the offspring of F-25 females mated to G-Performer males (Genetiporc, Alexandria, MN) with an average initial BW of 19.4 ± 1.4 kg were randomly allotted to 12 diets in a randomized complete block design. The experiment was conducted in 3 blocks with 2 blocks each containing 36 pigs (3 replicates) and 1 block containing 24 pigs (2 replicates). Therefore, there were 8 replicate pigs per diet. Pigs were placed in metabolism crates that were equipped with a feeder and a nipple drinker, fully slatted floors, and a screen floor, which allowed for the total collection of feces.

Diets and Feeding

A basal diet based on corn and soybean meal was formulated (Table 2). Five additional diets were formulated by adding each of the 5 rice coproducts to the basal diet in such a way that the ratio between corn and soybean meal remained constant at 1.5:1. The rice coproducts and corn and soybean meal were the only sources of P in the diets. Six additional diets that were identical to the initial 6 diets with the exception that 1,000 units of microbial phytase (Optiphos; Huvepharma, Sofia, Bulgaria) were included in each diet were also formulated.

Table 2. Composition of basal diet and diets containing brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), or rice mill feed without or with microbial phytase (as-fed basis)

	Diet[1]					
Ingredient, %	Basal	Brown rice	Broken rice	FFRB	DFRB	Rice mill feed
Corn	52.25	25.50	25.50	28.50	37.50	26.90
Soybean meal	35.00	17.00	17.00	19.00	25.00	18.00
Rice coproducts		50.00	50.00	50.00	30.00	40.00
Sucrose	6.45	1.05	1.05	0.10	1.20	8.65
Soybean oil	4.00	4.00	4.00	4.00	4.00	4.00
Limestone	1.60	1.75	1.75	1.70	1.60	1.75
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.0	100.0	100.0	100.0	100.0	100.0
Analyzed composition						
Diets without microbial phytase						
DM, %	86.9	88.5	85.6	90.7	88.2	89.6
Ca, %	0.62	0.75	0.76	0.70	0.68	0.68
P, %	0.31	0.28	0.23	0.97	0.95	0.37
Ash, %	4.77	3.52	2.93	7.73	7.09	9.28
Phytase, phytase units/kg	<70	<70	<70	<70	<70	<70
Diets with microbial phytase						
DM, %	87.5	87.9	88.0	90.5	87.8	90.2
Ca, %	0.68	0.82	0.66	0.70	0.67	0.72
P, %	0.31	0.29	0.22	1.03	0.91	0.39
Ash, %	4.59	3.69	3.49	7.26	7.52	8.95
Phytase, phytase units/kg	840	1,500	1,300	1,700	1,000	1,400

[1] All diets were produced without microbial phytase and with inclusion of 1,000 units/kg complete feed of microbial phytase (Optiphos 2000; Huvepharma, Sofia, Bulgaria).

[2] The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylpyrimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu as copper sulfate and copper chloride, 20 mg; Fe as ferrous sulfate, 126 mg; I as ethylenediamine dihydriodide, 1.26 mg; Mn as manganese sulfate, 60.2 mg; Se as sodium selenite and selenium yeast, 0.3 mg; and Zn as zinc sulfate, 125.1 mg.

Diets containing FFRB and DFRB were formulated to contain approximately 0.33% STTD of P, but because of the low P concentration in the other coproducts, diets containing brown rice, broken rice, or rice mill feed contained less STTD P. Vitamins and all minerals except P were included in the diets according to requirements (NRC, 2012). Feed was provided daily in an amount of 3 times the maintenance energy requirement (i.e., 197 kcal ME per $kg^{0.60}$; NRC, 2012). Pigs were fed twice daily at 0800 and 1700 h, and water was provided on an ad libitum basis.

Sample Collection

Pigs were fed experimental diets for 12 d. The initial 5 d were considered an adaptation period to the diet. Fecal markers were fed in the morning meals on d 6 (carmine blue) and d 11 (ferric oxide), and fecal collections were initiated when carmine blue appeared in the feces and ceased when ferric oxide appeared (Kong and Adeola, 2014). Feces were collected twice daily and stored at −20°C as soon as collected.

Chemical Analyses

Samples of ingredients, diets, and feces were analyzed for DM (Method 930.15; AOAC, 2007) and Ca and P (Methods 985.01A, B and C; AOAC, 2007). Diets and ingredients were also analyzed for ash (Method 942.05; AOAC, 2007). All ingredients were analyzed for GE by isoperibolic bomb calorimetry, CP by combustion (Method 990.03; AOAC, 2007), acid hydrolyzed ether extract by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (Method 2003.06; AOAC, 2007), ADF (Method 973.18; AOAC, 2007), NDF (Holst, 1973), and phytate concentration (Ellis et al., 1977). Phytase (Method 200.12; AOAC, 2007) was also analyzed in all diets.

Calculation and Statistical Analysis

The concentrations of nonphytate-P and phytate-bound P in corn, soybean meal, and rice coproducts were calculated as previously described (Tran and Sauvant, 2004). The ATTD of P was calculated for each diet using the direct procedure and the following equation (Almeida and Stein, 2010):

$$\text{ATTD} (\%) = [(\text{Pi} - \text{Pf})/\text{Pi}] \times 100$$

where Pi is the total P intake (g) from d 6 to 11 and Pf is the total P output (g) in the same period. The STTD of P was calculated for each diet by correcting the ATTD of P for the basal endogenous P loss, which was assumed to be 200 mg/kg DMI (Stein, 2011). Data from the corn-soybean meal diet were used to calculate the contribution of P from corn and soybean meal to the diets that contained rice coproducts, and the ATTD and STTD of P in each rice coproduct were calculated using the difference procedure, which assumes that there are no interactions between the test ingredient and the ingredients in the basal diet (Kong and Adeola, 2014). The ATTD and STTD in rice coproducts were calculated using the following equation (Mosenthin et al., 2007):

$$D_A = (D_D - D_B \times S_B)/S_A$$

where D_A is the ATTD or STTD of P in the test ingredient (%), D_D is the ATTD or STTD of P in the diet containing the test ingredient (%), D_B is the ATTD or STTD of P in the basal diet (%), S_B is the contribution level of basal diet to the test diet (%), and S_A is the contribution level of P from the test feed ingredient to the assay diet (%). The ATTD and STTD of ingredients without phytase were calculated using data from the basal diet without phytase, and the ATTD and STTD of P in the ingredients with phytase were calculated using data from the basal diet with phytase.

Outliers and homogeneity of the variances among treatments were tested using the UNIVARIATE procedure. Data were analyzed using the Proc MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a 5 × 2 factorial. The fixed effects were the diet, phytase, and the interaction between diets and phytase. Block was considered a random effect. The LSMEANS statement was used to calculate treatment means, and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses and an α level of 0.05 was used to consider significance among dietary treatments.

RESULTS

The concentrations of P were 2.58% in DFRB, 1.79% in FFRB, 0.63% in rice mill feed, 0.27% in brown rice, and 0.11% in broken rice (Table 1). Corn and soybean meal contained 0.20 and 0.57% P, respectively. The concentration of phytate-bound P in rice coproducts was 2.36% in DFRB, 1.62% in FFRB, 0.56% in rice mill feed, 0.22% in brown rice, and 0.06% in broken rice. As a consequence, 91.5, 90.5, 88.9, 81.5, and 54.0% of total P in DFRB, FFRB, rice mill feed, brown rice, and broken rice, respectively, was bound to phytate. Corn and soybean meal contained 0.37 and 0.13% phytate-bound P, respectively, which amounted to approximately 65% of total P. Calcium concentration was 0.01% in broken rice and brown rice, 0.11% in DFRB and rice mill feed, and 0.04% in FFRB. Corn and soybean meal contained 0.01 and 0.30% Ca, respectively.

All diets had concentrations of P and Ca that were in good agreement with the formulated values (Table 2). All diets without microbial phytase did not contain detectable levels of phytase, whereas diets with phytase analyzed between 840 and 1,700 units of phytase.

Daily intake of P was greater ($P < 0.05$) for pigs fed diets with FFRB or DFRB than for pigs fed diets containing broken rice, brown rice, rice mill feed, or the basal diet (Table 3). However, microbial phytase did not influence daily P intake. The concentration of P in feces was reduced ($P < 0.05$) from pigs fed diets with microbial phytase compared with pigs fed diets without phytase. The daily P output in feces from pigs fed diets with phytase was also less ($P < 0.05$) than in feces from pigs fed diets without microbial phytase, except for diets containing broken rice or rice mill feed (interaction $P < 0.05$).

The amount of P absorbed daily was greater ($P < 0.05$) for all diets with phytase than for diets without phytase. The greatest ($P < 0.05$) amount of P absorbed was from diets containing FFRB or DFRB. There were no differences in P absorbed between pigs fed diets containing broken rice and brown rice.

The ATTD of P was greater ($P < 0.05$) in diets with phytase than in diets without phytase. No differences were observed between the basal diet and the broken rice diet, but the ATTD of P in those diets was greater ($P < 0.05$) than in all other diets. The least ($P < 0.05$) ATTD of P was observed for diets containing FFRB, DFRB, or rice mill feed. Addition of microbial phytase to the diets did not influence the basal endogenous loss of P, but the STTD of P in diets with phytase was greater ($P < 0.05$) than in diets without phytase. If no phytase was used, pigs fed the basal diet or the diet containing broken rice had greater ($P < 0.05$) STTD of P than pigs fed all other diets, whereas pigs fed the FFRB diet had the least ($P < 0.05$) STTD of P. If microbial phytase was used, pigs fed the basal diet or the broken rice diet also had the greatest ($P < 0.05$) STTD of P, and pigs fed the FFRB or the DFRB diet had the least ($P < 0.05$) STTD of P. Values for the brown rice diet and the diet containing rice mill feed were intermediate between the broken rice diet and the FFRB and DFRB diets.

Table 3. Apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P (%) by pigs fed a basal corn-soybean meal based diet or diets containing brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), or rice mill feed without or with microbial phytase[1,2]

Item	Feed intake, g DM/d	P intake, g/d	P in feces, %	P output, g/d	P absorbed, g/d	ATTD of P, %	Basal EPL[3], mg/d	STTD of P[4], %
Without phytase								
Basal diet	837	3.09^{d}	1.83^{e}	1.70^{e}	1.36^{f}	44.4^{cde}	171.7	50.0^{c}
Brown rice	768	2.46^{e}	2.55^{c}	1.66^{e}	0.77^{h}	31.6^{fg}	153.9	38.0^{e}
Broken rice	733	2.05^{e}	2.03^{d}	1.10^{f}	0.93^{gh}	46.1^{cd}	147.3	53.5^{c}
FFRB	885	9.43^{a}	3.73^{a}	6.85^{a}	2.54^{d}	27.1^{g}	177.3	28.9^{f}
DFRB	890	9.55^{a}	3.81^{a}	6.47^{a}	3.04^{c}	32.0^{f}	178.3	35.4^{e}
Rice mill feed	843	3.6^{cd}	0.90^{g}	2.44^{d}	1.12^{fg}	31.7^{fg}	169.1	36.6^{e}
With phytase								
Basal diet	862	3.15^{d}	1.20^{f}	1.10^{f}	1.96^{e}	65.1^{a}	173.2	70.8^{a}
Brown rice	740	2.42^{e}	1.69^{e}	0.99^{f}	1.35^{f}	58.5^{b}	148.3	63.7^{b}
Broken rice	777	2.21^{e}	1.37^{f}	0.78^{f}	1.24^{f}	63.7^{a}	158.5	71.3^{a}
FFRB	860	9.75^{a}	3.18^{b}	5.72^{b}	3.99^{a}	42.9^{de}	172.4	44.6^{d}
DFRB	856	8.84^{b}	3.13^{b}	5.19^{c}	3.47^{b}	41.2^{e}	171.5	43.1^{d}
Rice mill feed	923	4.04^{c}	0.70^{h}	2.08^{de}	1.98^{e}	48.6^{c}	185.6	53.2^{c}
SEM	42.6	0.32	0.06	0.18	0.11	1.7	9.3	1.61
P-value								
Diet	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Phytase	0.41	0.68	<0.001	<0.001	<0.001	<0.001	0.48	<0.001
Diet × phytase	0.10	0.04	0.002	0.007	<0.001	<0.001	0.09	<0.001

[a–g] Within a column, means without a common superscript differ ($P < 0.05$).

[1] Microbial phytase (Optiphos 2000; Huvepharma, Sofia, Bulgaria) was included at 1,000 units/kg complete feed.

[2] Data are means of 8 observations per treatment.

[3] EPL = basal endogenous P loss. The daily basal EPL was calculated by multiplying DMI by 200 mg/kg DMI (Stein, 2011).

[4] Values for STTD were calculated by correcting values for ATTD for basal EPL.

The ATTD and STTD of P in the rice coproducts increased ($P < 0.05$) if microbial phytase was added to the diets (Table 4). Among the rice coproducts, the greatest ($P < 0.05$) ATTD and STTD of P were observed for broken rice, and if microbial phytase was used, FFRB, DFRB, and rice mill feed had less ($P < 0.05$) ATTD and STTD than brown rice.

Daily intake of Ca was greater ($P < 0.05$) for pigs fed the rice mill feed diet with microbial phytase than for pigs fed all other diets except the brown rice diet with phytase and the FFRB diet without phytase (Table 5). The concentration of Ca in feces and total daily Ca output from pigs fed diets with microbial phytase was less ($P < 0.05$) than from pigs fed diets without microbial phytase. Addition of microbial phytase increased ($P < 0.05$) the ATTD of Ca regardless of which diet was fed, and the ATTD of Ca was greater ($P < 0.05$) in diets with brown rice or broken rice than in all other diets whereas the diets with FFRB and DFRB had the least ($P < 0.05$) ATTD of Ca.

DISCUSSION

Production of Rice Coproducts in the United States

The total annual production of paddy rice in the United States is between 8 and 10 million metric tons (USDA-FAS, 2014). Thus, the production in the United States is less than 1.5% of the global production of paddy rice, which totaled 729 million metric tons in 2012. China, India, Indonesia, Vietnam, and Thailand are the countries with the greatest production of paddy rice (USDA-FAS, 2014), but the United States is the fifth largest exporter of rice after Thailand, India, Vietnam, and Pakistan (USDA-FAS, 2014). Within the United States, Arkansas is the largest producer of paddy rice with approximately 50% of the total production followed by California, Louisiana, Texas, Mississippi, and Missouri (USDA-NASS, 2014). Of the total production of paddy rice in the United States, an estimated 10 to 15% is marketed to the animal feed industry in the form of brown rice, broken rice, FFRB, DFRB, or rice mill feed. Thus, the annual availability of rice coproducts produced in the United States is likely between 1.0 and 1.8 million metric tons.

Table 4. Apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P (%) by pigs in brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), and rice mill feed without or with microbial phytase[1,2]

Item	ATTD	STTD
Without phytase		
Brown rice	19.2^{f}	31.7^{ef}
Broken rice	50.1^{b}	75.6^{a}
FFRB	24.3^{ef}	26.4^{f}
DFRB	30.8^{de}	33.1^{def}
Rice mill feed	24.4^{ef}	32.3^{def}
With phytase		
Brown rice	49.8^{b}	64.5^{b}
Broken rice	60.8^{a}	79.8^{a}
FFRB	39.2^{cd}	41.3^{cd}
DFRB	35.2^{cd}	37.6^{cde}
Rice mill feed	39.5^{c}	46.7^{c}
SEM	3.05	3.29
P-value		
Ingredient	<0.001	<0.001
Phytase	<0.001	<0.001
Ingredient × phytase	0.001	0.002

[a–g] Within a column, means without a common superscript differ ($P < 0.05$).

[1] Microbial phytase (Optiphos 2000; Huvepharma, Sofia, Bulgaria) was included at 1,000 units/kg of complete diet.

[2] Data are means of 8 observations per treatment.

Table 5. Apparent total tract digestibility (ATTD) of Ca (%) by pigs fed a basal corn-soybean meal based diet or diets containing brown rice, broken rice, full-fat rice bran (FFRB), defatted rice bran (DFRB), or rice mill feed without or with microbial phytase[1,2]

Item	Ca intake, g/d	Ca in feces, %	Ca output, g/d	Ca absorbed, g/d	ATTD of Ca, %
Without phytase					
Basal diet	6.13^{de}	3.59	3.28	2.95^{d}	46.8
Brown rice	6.42^{cde}	4.06	2.67	3.82^{bc}	59.2
Broken rice	6.51^{cd}	4.25	2.46	4.19^{b}	63.4
FFRB	6.83^{abc}	2.26	4.59	2.73^{d}	39.7
DFRB	6.7^{8bc}	2.47	3.95	2.87^{d}	38.3
Rice mill feed	6.56^{bcd}	1.45	3.68	2.66^{d}	41.0
With phytase					
Basal diet	6.72^{bc}	2.90	2.65	4.20^{b}	61.4
Brown rice	7.06^{ab}	3.44	2.04	5.02^{a}	71.0
Broken rice	5.85^{e}	3.83	2.12	3.81^{bc}	64.5
FFRB	6.66^{bcd}	2.05	3.56	3.08^{d}	46.1
DFRB	6.54^{bcd}	2.00	3.31	3.22^{cd}	49.2
Rice mill feed	7.37^{a}	1.24	3.41	3.77^{bc}	50.7
SEM	0.37	0.19	0.26	0.28	3.35
P-value					
Diet	0.005	<0.001	<0.001	<0.001	<0.001
Phytase	0.159	<0.001	<0.001	<0.001	<0.001
Diets× phytase	0.001	0.687	0.571	0.002	0.353

[a–e] Within a column, means without a common superscript differ ($P < 0.05$).

[1] Microbial phytase (Optiphos 2000; Huvepharma, Sofia, Bulgaria) was included at 1,000 units/kg complete diet.

[2] Data are means of 8 observations per treatment.

Composition of Ingredients

The chemical composition of corn and soybean meal used in this experiment was in agreement with values reported by Almeida and Stein (2010), Rodríguez et al. (2013), and Rojas et al. (2013), but the concentration of phytate was greater in corn and less in soybean meal compared with data reported by NRC (2012). Most of the total P in cereals is bound to phytate, which results in low digestibility for pigs because they lack endogenous phytase to release the P from the phytate molecule. This results in a relatively large output of P in the manure and reduces the availability of other minerals such as Ca, Mn, Zn, and Fe (Steiner et al., 2007).

In rice, 84 to 88% of phytate is stored in the aleurone layer, which is included in the rice bran fraction after processing of the rice (Reddy et al., 1982). As a consequence, the concentration of phytate and P in rice bran is very high compared with other plant ingredients, whereas the concentrations of phytate and P in polished rice and broken rice is low. However, concentrations of P and phytate in all rice coproducts may vary depending on variety, climatic conditions, growing locations, soil type, and the quality of the milling process (Steiner et al., 2007).

The concentration of P, Ca, and phytate in brown rice used in this experiment concur with values reported by Reddy et al. (1982), Sauvant et al. (2004), and Li et al. (2006), although a greater concentration of P has also been reported (Yang et al., 2007). Broken rice in this experiment contained less P and Ca than reported previously, but the phytate-bound P was close to values in the literature (Sauvant et al., 2004; NRC, 2012).

The P concentration and phytate-bound P in FFRB were within the range reported previously, but the concentration of Ca was less than previously reported (Sauvant et al., 2004; NRC, 2012; Abelilla, 2014). The concentrations of P and phytate-bound P in DFRB were greater than reported by Sauvant et al. (2004) and NRC (2012), whereas the concentration of Ca was in agreement with previous values. The concentrations of P and Ca in rice mill feed were less compared with values reported by Ofongo et al. (2008), but these values were greater than those observed in brown rice and broken rice and less than in FFRB or DFRB. To our knowledge, no values for the concentration of phytate in rice mill feed have been previously reported.

Digestibility of Phosphorus and Calcium

The difference procedure was used to calculate the digestibility of P in the rice coproducts. This procedure has the advantage that diets that are palatable to the pigs can be formulated, which may not always be the case if the direct procedure is used. In addition, the digestibility of P in ingredients with low concentrations of P can be determined. However, accurate results for individual ingredients are obtained using the difference procedure only if the calculated digestibility of P in the basal diet is accurate and if there are no interactions between the basal diet and the ingredients used (Kong and Adeola, 2014). In the present experiment, the STTD of P in the basal diet without microbial phytase was slightly greater (50.0 vs. 43.4%) than the STTD of P that can be calculated for this diet from NRC (2012), but this is likely a result of the reduced concentration of phytate in the soybean meal used in this experiment compared with the soybean meal used by NRC (2012). This hypothesis is supported by the fact that the STTD of P for the basal diet with microbial phytase is in agreement with the STTD of P that can be calculated from Almeida and Stein (2010). It is, therefore, likely that the results obtained in this experiment for the basal diet are accurate, which indicates that results obtained for the rice coproducts are also accurate.

Values for the STTD of P were calculated by correcting values for the ATTD of P for the basal endogenous loss of P, which was assumed to be 200 mg/kg DMI (Stein, 2011). This value is in very good agreement with the basal endogenous loss of P (199 mg/kg DMI) that can be calculated from a recently published equation (basal endogenous loss [g/kg DMI] = 2.23 × initial BW + 156.4; Son et al., 2013).

The ATTD of P in brown rice obtained in this experiment concurs with the value reported by Yang et al. (2007), whereas the values for ATTD and STTD of P in broken rice were greater than reported by Wu et al. (2008). The ATTD of P in diets containing FFRB without phytase is in agreement with the value reported by Agudelo et al. (2010), when 7.5% FFRB was added to the basal diet; however, when the inclusion of FFRB was increased to 30%, the ATTD was less than observed in this experiment in which the inclusion of FFRB was 50%. The ATTD of P in diets containing FFRB with phytase was also greater in this experiment than reported by Agudelo et al. (2010). In contrast, the ATTD and STTD of P for FFRB in this experiment were less than those reported by Abelilla (2014). These differences may be a result of variation in the concentration of phytate in FFRB used in each experiment, but the concentrations of phytate in the diets used by Agudelo et al. (2010) and Abelilla (2014) were not reported. It is also possible that the coproducts designated as FFRB may sometimes include other fractions of rice than only the bran depending on the quality of the milling process, and because of the large variation in the phytate concentration among different fractions of rice, this may influence the ATTD and STTD of P in the rice bran. The ATTD and STTD of P in the DFRB obtained in this experiment are in agreement with the values reported by NRC (2012) but are greater than those reported by Wu et al. (2008). To our knowledge, no values for ATTD and STTD of P in rice mill feed have been reported before.

The reason broken rice had the greatest ATTD and STTD of P is that the concentration of phytate in broken rice is less than in the other coproducts because of the removal of the aleurone layers during the milling process. In contrast, brown rice, FFRB, DFRB, and rice mill feed contain different proportions of the aleurone layer where phytate is stored, which is the reason the ATTD and STTD of P in these coproducts are less than those in broken rice.

Positive effects of addition of microbial phytase to pig diets and ingredients to improve P digestibility and reduce P output have been reported (Selle and Ravindran, 2008; Goebel and Stein, 2011; Rojas and Stein, 2012). However, there are limited data on effects of phytase on ATTD or STTD of P in rice coproducts. In this experiment, the addition of microbial phytase increased the ATTD and STTD of P in all rice coproducts, but the effect was relatively less in FFRB, DFRB, and rice mill feed than in broken rice and brown rice. This may be a result of differences in the chemical composition as a result of the milling process or interactions between intrinsic phytase in these rice coproducts and exogenous phytase (Selle and Ravindran, 2008). In previous experiments with FFRB, addition of phytase also increased the digestibility of P (Agudelo et al., 2010; Abelilla, 2014), which is most likely due to the release of some of the phytate-bound P (Selle and Ravindran, 2008).

The reduced daily output of Ca and increased ATTD of Ca that was observed as phytase was added to the diets agree with previous reports (Goebel and Stein, 2011; Gonzalez-Vega et al., 2013; Rodríguez et al., 2013); however, the effect was less in diets with broken rice that had lower concentrations of phytate compared with diets containing brown rice, DFRB, or FFRB. This observation is most likely due to the greater availability of Ca in broken rice as a result of the reduced concentration of phytate and thus reduced formation of insoluble Ca-phytate complexes (Selle et al., 2009).

Conclusions

The ATTD and STTD of P in broken rice were greater than those in brown rice, FFRB, DFRB, and rice mill feed. The addition of microbial phytase to rice coproducts increased the ATTD and STTD of P and decreased the excretion of P from pigs fed diets containing all rice coproducts. Thus, the relatively low digestibility of P in rice coproducts can be increased by use of microbial phytase. The high concentration of P in several of the rice coproducts makes these ingredients valuable sources of digestible P in diets for growing pigs if used in combination with microbial phytase. Addition of microbial phytase to rice coproducts also reduces the excretion of Ca and increases the ATTD of Ca in diets containing rice coproducts.

LITERATURE CITED

Abelilla, J. J. 2014. Standardized total tract digestibility of phosphorus in rice bran with and without phytase supplementation in swine diets. MS Thesis. Univ. of the Philippines, Los Baños, the Philippines.

Agudelo, J. H., M. D. Lindemann, and G. L. Cromwell. 2010. Phosphorus utilization in growing pigs fed a phosphorus deficient diet supplemented with a rice bran product and amended with phytase. Rev. Colomb. Cienc. Pecuarias 23:429–443.

Almeida, F. N., and H. H. Stein. 2010. Performance and phosphorus balance of pigs fed diets formulated on the basis of values for standardized total tract digestibility of phosphorus. J. Anim. Sci. 88:2968–2977.

AOAC. 2007 Officials methods of analysis. 18th ed. Rev. 2. Assoc. Off. Anal. Chem., Gaithersburg, MD.

Ellis, R., E. R. Morris, and C. Philpot. 1977. Quantitative determination of phytate in the presence of high inorganic phosphate. Anal. Biochem. 77:536–539.

Goebel, K. P., and H. H. Stein. 2011. Phosphorus digestibility and energy concentration of enzyme-treated and conventional soybean meal fed to weanling pigs. J. Anim. Sci. 89:764–772.

Gonzalez-Vega, J. C., C. L. Walk, Y. Liu, and H. H. Stein. 2013. Endogenous losses of calcium and true total tract digestibility of calcium in canola meal fed to growing pigs. J. Anim. Sci. 91:4807–4816.

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. Assoc. Off. Anal. Chem. 56:1352–1356.

Kong, C., and O. Adeola. 2014. Evaluation of amino acid and energy utilization in feedstuffs for swine and poultry diets. Asian-Australas. J. Anim. Sci. 27:917–925.

Li, X. L., S. L. Yuan, X. S. Piao, C. H. Lai, J. J. Zang, Y. H. Ding, L. J. Han, and I. K. Han. 2006. The nutritional value of brown rice and maize for growing pigs. Asian-Australas. J. Anim. Sci. 19:882–897.

Mosenthin, R., A. J. M. Jansman, and M. Eklund. 2007. Standardization of methods for the determination of ileal amino acid digestibilities in growing pigs. Livest. Sci. 109:276–281.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl Acad. Press, Washington, DC.

Ofongo, S. T., S. Kehraus, E. A. Iyayi, and K. H. Sudekum. 2008. Rice mill feed: An agro-industrial by-product with potential for rural development. In: Tropentag 2008. Conference on International Research on Food Security, Natural Resource Management and Rural Development, Stuttgart, Germany.

Reddy, N. R., S. K. Sathe, and D. K. Salunkhe. 1982. Phytate in legumes and cereals. Adv. Food Res. 28:1–92.

Rodríguez, D. A., R. C. Sulabo, J. C. González-Vega, and H. H. Stein. 2013. Energy concentration and phosphorus digestibility in canola, cottonseed, and sunflower products fed to growing pigs. Can. J. Anim. Sci. 93:493–503.

Rojas, O. J., Y. Liu, and H. H. Stein. 2013. Phosphorus digestibility and concentration of digestible and metabolizable energy in corn, corn co-products, and bakery meal fed to growing pigs. J. Anim. Sci. 91.:5326-5335.

Rojas, O. J., and H. H. Stein. 2012. Digestibility of phosphorus by growing pigs of fermented and conventional soybean meal without and with microbial phytase. J. Anim. Sci. 90:1506–1512.

Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats. In: W. Haresign and D. J. A. Cole, editors, Recent advances in animal nutrition. Butterworths, London, UK. p. 77–81.

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.

Selle, P. H., A. J. Cowieson, and V. Ravindran. 2009. Consequences of calcium interactions with phytate and phytase for poultry and pigs. Livest. Sci. 124:126–141.

Selle, P. H., and V. Ravindran. 2008. Phytate degrading enzymes in pig nutrition. Livest. Sci. 113:99–122.

Serna-Saldivar, S. R. 2010. Dry-milling operations. In: G. V. Barbosa Canovas, editor, Cereal grains: Properties, processing and nutritional attributes. CRC Press, Boca Raton, FL. p. 193–200.

Singh, A., M. Das, S. Bal, and R. Banerjee. 2013. Rice processing. In: R. P. Ferreira-Guine and P. M. Reis-Correa, editors, Engineering aspects of cereals and cereal based products. CRC Press, Boca Raton, FL. p. 71–97.

Son, A. R., S. Y. Shin, and B. G. Kim. 2013. Standardized total tract digestibility of phosphorus in copra expellers, palm kernel expellers, and cassava root fed to growing pigs. Asian-Australas. J. Anim. Sci. 26:1609–1613.

Stacey, W. N., and D. L. Rankins. 2004. Rice mill feed as a replacement for broiler litter in diets for growing beef cattle. J. Anim. Sci. 82:2193–2199.

Stein, H. H. 2011. Standardized total tract digestibility (STTD) of phosphorus. In: Proc. Midwest Swine Nutr. Conf., Indianapolis, IN. p. 47–52.

Steiner, T., R. Mosenthin, B. Zimmermann, R. Greiner, and S. Roth. 2007. Distribution of phytase activity, total phosphorus and phytate phosphorus in legume seeds, cereals and cereal by-products as influenced by harvest year and cultivar. Anim. Feed Sci. Technol. 133:320–334.

Tran, G., and D. Sauvant. 2004. Chemical data and nutritional value In: D. Sauvant , J.-M. Perez, and G. Tran, editors, Tables of composition and nutritional value of feed materials. 2nd ed. Wageningen Acad. Publ., Wageningen, The Netherlands. p. 17–24.

USA Rice Federation. 2011. Rice technical information kit. The complete guide for using U.S. rice as an ingredient. https://www.usarice.com/doclib/124/5572.pdf. (Accessed 14 August 2014.)

USDA-FAS. 2014. Grain: World markets and trade. http://apps.fas.usda.gov/psdonline/circulars/grain.pdf. (Accessed 29 Sep.tember 29, 2014.).

USDA-NASS. 2014. Quick stats tools. http://www.nass.usda.gov/Quick_Stats. (Accessed 29 September 2014.)

Wu, X., Z. Ruan, Y. G. Zhang, Y. Q. Hou, Y. L. Yin, T. J. Li, R. L. Huang, W. Y. Chu, X. F. Kong, B. Gao, and L. X. Chen. 2008. True digestibility of phosphorus in different resources of feed ingredients in growing pigs. Asian-Australas. J. Anim. Sci. 21:107–119.

Yang, H., A. D. Li, Y. L. Yin, T. J. Li, Z. R. Wang, G. Wu, R. L. Huang, X. F. Kong, C. B. Yang, P. Kang, J. Deng, S. X. Wang, B. E. Tan, Q. Hu, F. F. Xing, X. Wu, Q. H. He, K. Yao, Z. J. Liu, Z. R. Tang, F. G. Yin, Z. Y. Deng, M. Y. Xie, and M. Z. Fan. 2007. True phosphorus digestibility and endogenous phosphorus outputs associated with brown rice for weanling pigs measured by simple regression analysis technique. Animal 1:213–220.