Effect of low-phytate barley or phytase supplementation to a barley-soybean meal diet on phosphorus retention and excretion by grower pigs[1,2]

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ABSTRACT: Two studies were conducted to determine the effect of diets containing low-phytate barley or supplemented with phytase on P balance and excretion in grower pigs. In Exp. 1, eight 32-kg barrows were assigned to a repeated, 4×4 Latin square design and fed 4 diets that contained 96% barley: normal-phytate hulled barley (HB), low-phytate hulled barley (LPHB), normal-phytate hull-less barley (HLB), and low-phytate hull-less barley (LPHLB). The barley cultivars contained 0.16, 0.05, 0.24, and 0.03% phytate, respectively. Inorganic P (iP) was added to the HB and HLB diets to meet the 1998 National Research Council recommendation of available P (aP, 0.23%), whereas LPHB and LPHLB contained sufficient aP. The diets were fed at 2.5 times the maintenance requirement for ME. The apparent total tract digestibilities (ATTD) of P did not differ between the hulled and hull-less barley diets, but P retention (%) and excretion were greater in pigs fed the hull-less barley diets ($P < 0.05$). The ATTD of P was greater and P excretion was 35% lower in pigs fed the low-phytate compared with the normal-phytate diets ($P < 0.001$). The amount of P retained (g/d) was greater ($P < 0.001$) in pigs fed low-phytate barley, reflecting an ATTD of P of 65 and 49% for low-phytate and normal-phytate barley, respectively ($P < 0.001$). In Exp. 2, eight 21-kg barrows were assigned to a repeated, 4×4 Latin square design and fed 4 diets based on barley and soybean meal (SBM): HB-SBM, HB-SBM + iP, HB-SBM + phytase, and LPHB-SBM. The HB-SBM and HB-SBM + phytase diets were deficient in aP, whereas the HB-SBM + iP and LPHB-SBM diets had adequate aP. The feeding regimen was similar to that of Exp. 1. Adding iP to the HB-SBM diet did not affect the ATTD but increased the amount of P retained (g/d) and excreted ($P < 0.001$). The ATTD and amount of P retained (g/d) did not differ among pigs fed the HB-SBM + iP, HB-SBM + phytase, and LPHB-SBM diets. However, pigs fed the HB-SBM + phytase and LPHB-SBM diets excreted 32 and 29% less P, respectively, than pigs fed the HB-SBM + iP diet ($P < 0.05$), confirming that low-phytate barley is as effective as supplemental phytase in improving P digestibility and utilization and decreasing P excretion in grower pigs.

Key words: barley, low phytate, nutrient excretion, phosphorus, phytase, pig

INTRODUCTION

Barley is a feedstuff for grower-finisher pigs in western Canada and across the globe. Barley ranks fourth after wheat, rice, and corn in world cereal production (FAO, 2002). In Canada, barley production ranks second after that of wheat in terms of cereal grains (FAO, 2002).

Approximately two-thirds of the P in feedstuffs of plant origin, including barley, is present in the form of phytate (Cromwell, 1992; Ravindran et al., 1995). Phytate P is poorly utilized by swine because of insufficient activity of endogenous phytases (Nelson, 1967). Inorganic P (**iP**) sources are therefore routinely added to swine diets to meet P requirements, and most of the phytate P is excreted. Phosphorus in swine manure is increasingly becoming an environmental concern (Jongbloed and Lenis, 1998; Kornegay, 2001), and strategies to reduce P excretion warrant investigation.

One method to reduce P excretion by pigs, besides the use of supplemental phytase (e.g., Mroz et al., 1994), is the use of low-phytate feedstuffs (Raboy, 2002). In recent years, several low-phytate crops have been developed, including low-phytate hulled barley (**LPHB**), which is phenotypically identical to normal-phytate hulled barley (**HB**), and low-phytate hull-less barley (**LPHLB**). Normal-phytate hull-less barley (**HLB**) has an 8 to 10% greater energy digestibility than HB (Huang et al., 2003), and thus provides further nutritional benefits. The effectiveness of low-phytate feedstuffs to improve P utilization should be determined and compared with phytase supplementation.

The objective of Exp. 1 was to determine and compare the digestibility, balance, and excretion of P in pigs fed diets that contained normal-phytate or low-phytate cultivars of either hulled or hull-less barley origin. The objective of Exp. 2 was to determine the effect of iP and phytase supplementation of an 18% CP barley-soybean meal (**SBM**) diet deficient in available P (**aP**) and the effect of replacing normal-phytate barley with low-phytate barley in the barley-SBM diet on the digestibility, balance, and excretion of P.

MATERIALS AND METHODS

Animals, Diets, and Experimental Design

The experimental proposals and procedures for the care and treatment of the pigs were approved by the Animal Care Committee of the University of Alberta in accordance with the guidelines of CCAC (1993). Two experiments were conducted at the Swine Research and Technology Center of the University of Alberta (Edmonton, Alberta, Canada).

Exp. 1. Nine crossbred barrows (Large White × Landrace), with an average initial BW of 25.0 ± 0.77 kg, were housed individually in stainless steel metabolic crates (height = 82 cm; length = 124 cm; width = 76 cm) in a temperature-controlled room (22 ± 1°C). During a 7-d adaptation to the crates, the barrows were fed an 18% CP grower diet ad libitum. Water was freely available from a low-pressure drinking nipple. Based on their feed intake pattern, 8 barrows were selected and fed 4 diets according to a repeated 4 × 4 Latin square design. Each of the 4 experimental periods lasted 13 d. The barrows were fed twice daily at 0800 and 1500, with equal amounts at each meal. The diets were fed at a rate of 2.5 times the maintenance requirement for ME (i.e., 106 kcal of ME/kg of $BW^{0.75}$; NRC, 1998) based on the average BW of the pigs, which was recorded at the beginning of each experimental period.

Four barley-based diets were formulated with 4 barley cultivars (Field Crop Development Center, Lacombe, Alberta, Canada): 95.6% HB (cultivar Metcalfe), 95.8% LPHB (mutant line 99043), 95.8% HLB (cultivar Falcon), and 95.8% LPHLB (mutant line 99054). The phytate P content was 69 and 88% lower in the low-phytate HB and HLB than in the normal-phytate HB

Table 1. Nutrient composition of the barley cultivars in Exp. 1, % as-fed

Item	Hulled barley		Hull-less barley	
	Normal phytate	Low phytate	Normal phytate	Low phytate
DM	92.00	92.80	91.80	92.60
CP	12.88	13.58	13.15	13.18
Total P	0.29	0.30	0.45	0.34
Phytate P	0.16	0.05	0.24	0.03
Available P[1]	0.13	0.25	0.21	0.31

[1]Calculated by subtracting phytate P from total P.

and HLB, respectively, and the normal-phytate barley cultivars were, thereby, limiting in calculated aP (Table 1). As such, the HB and HLB diets were supplemented with iP, so that the calculated aP content met or exceeded the NRC (1998) recommendation. The diets were supplemented with Lys, Met, Thr, and Trp (Table 2) to meet their apparent ileal digestible supplies (NRC, 1998). The HB and HLB diets were supplemented with monocalcium phosphate to meet the NRC (1998) recommendation for aP, which is 0.23% for grower pigs over the range from 20 to 50 kg of BW. The LPHB and LPHLB diets were not supplemented with monocalcium phosphate because these diets contained sufficient aP (0.26 and 0.33%, respectively). The diets were formulated to contain 0.60% Ca. Canola oil was included to meet the recommendation for ME, and vitamins and minerals were supplemented to meet or exceed the recommendations (NRC, 1998). Chromic oxide (0.3%) was included as an indigestible marker. The barley was ground through a 2-mm mesh screen before incorporation into the diets. The diets were fed in the form of mash. Water was mixed with the feed at a ratio of 2.5 to 1 (wt/wt) and was freely available between meals.

Exp. 2. Nine crossbred barrows of the same origin as in Exp. 1 were used, with an average initial BW of 19.9 ± 1.13 kg. With the exception of the formulation of the experimental diets, Exp. 2 had the same experimental design and conditions as those described for Exp. 1.

Four diets based on barley and SBM were formulated to contain 18% CP by using a HB or LPHB (same batches as Exp. 1): HB-SBM, HB-SBM + iP, HB-SBM + phytase supplemented at a rate of 500 phytase units/ kg of diet, and LPHB-SBM (Table 3). Monocalcium phosphate (17% Ca and 21.1% P) was used as the iP source, and *Aspergillus niger* phytase (Natuphos, DSM Food Specialties, Delft, the Netherlands) was used as microbial phytase. The HB-SBM and HB-SBM + phytase diets were formulated to contain less aP than the NRC (1998) recommendation. The HB-SBM + iP and LPHB-SBM diets were formulated to meet the NRC (1998) recommendation for aP, which is 0.23% for pigs from 20 to 50 kg of BW. One phytase unit is defined as the quantity of enzyme that liberates one micromole of orthophosphate per minute from 5.1 mM Na-phytate at pH 5.5 and 37°C (Engelen et al., 1994). The diets

Table 2. Ingredient and nutrient composition of the experimental diets in Exp. 1, as-fed basis

	Hulled barley		Hull-less barley	
Item	Normal phytate	Low phytate	Normal phytate	Low phytate
Ingredients, %				
Hulled barley				
Normal phytate[1]	95.56	—	—	—
Low phytate[2]	—	95.84	—	—
Hull-less barley				
Normal phytate[3]	—	—	95.76	—
Low phytate[4]	—	—	—	95.81
L-Lysine·HCl	0.45	0.45	0.45	0.45
DL-Methionine	0.05	0.05	0.05	0.05
L-Threonine	0.19	0.19	0.19	0.19
L-Tryptophan	0.05	0.05	0.05	0.05
Canola oil	1.00	1.00	1.00	1.00
Limestone	1.31	1.52	1.39	1.55
Monocalcium phosphate[5]	0.49	—	0.21	—
Iodized salt	0.35	0.35	0.35	0.35
Mineral premix[6]	0.10	0.10	0.10	0.10
Vitamin premix[7]	0.10	0.10	0.10	0.10
Choline chloride[8]	0.05	0.05	0.05	0.05
Chromic oxide	0.30	0.30	0.30	0.30
Nutrient composition, %				
DM	88.10	87.35	87.17	88.03
OM	84.28	83.74	83.63	84.68
CP	12.28	13.02	12.55	12.58
Total P	0.41	0.31	0.46	0.36
Phytate P	0.15	0.05	0.23	0.03
Available P[9]	0.26	0.26	0.23	0.33
Ca[10]	0.60	0.61	0.59	0.61
Ca:available P ratio	2.31	2.35	2.57	1.85

[1]Cultivar Metcalfe.
[2]Mutant line 99043.
[3]Cultivar Falcon.
[4]Mutant line 99054.
[5]Monocalcium phosphate contained 17% Ca and 21.1% P.
[6]Provided per kilogram of diet: Fe, 150 mg as ferrous sulfate; Zn, 150 mg as zinc carbonate; Mn, 40 mg as manganese sulfate; Cu, 25 mg as copper sulfate; I, 0.21 mg as potassium iodate; Co, 0.5 mg as cobalt sulfate; Se, 0.3 mg as sodium selenite; and Ethoxyquin, 5.0 mg.
[7]Provided per kilogram of diet: vitamin A, 10,000 IU; vitamin D_3, 1,000 IU; vitamin E, 80 IU; vitamin K_3, 2.0 mg; vitamin B_{12}, 0.03 mg; riboflavin, 12 mg; niacin, 40 mg; D-pantothenic acid, 25 mg; biotin, 0.25 mg; folic acid, 1.6 mg; thiamine, 3.0 mg; and pyridoxine, 2.25 mg.
[8]Provided 0.3 g choline chloride per kilogram of diet.
[9]Calculated by subtracting phytate P from total P.
[10]Calculated (NRC, 1998).

were formulated to contain 0.6% Ca. Chromic oxide (0.3%) was included in the diets.

Sample Collection and Chemical Analysis

Samples of the major feed ingredients were taken before diet formulation. Samples of the diets were taken during the time in which the meal allowances were prepared. The collection of feces was initiated at 0800 on d 8 of each experimental period and continued for 120 h. Feces were collected at 0800 and 1600 and immediately frozen at −28°C. Trampled feces or feces contaminated with feed or urine were discarded. A total collec-

tion of urine was carried out during the same time feces were collected. Urine samples were collected into a container through glass wool and measured volumetrically; a subsample (20% of total volume) was stored at −4°C. Before collection, 5 mL of 10% (vol/vol) formic acid solution was placed into each container.

Prior to chemical analyses, feces and urine were pooled for each pig in each experimental period. Feces were dried to constant weight in a forced-air oven at 55°C. The dried samples of feces and samples of ingredients and diets were ground through a 0.5-mm mesh screen (Thomas-Wiley Laboratory Mill, Arthur H. Thomas Co., Philadelphia, PA). Urine samples were filtered through Whatman No. 2 filter paper and dried in a forced-air oven at 55°C to constant weight.

Analyses for DM and OM were carried out according to the AOAC (2000). Crude protein (N × 6.25) was determined by combustion (FP-428 N Determinator, Leco Corporation, St. Joseph, MI). The P contents were determined spectrophotometrically by the molybdovanadate procedure (AOAC, 2000). Barley phytate P content was analyzed according to the procedures described by Haug and Lantzsch (1983). Chromic oxide was determined with a spectrophotometric procedure according to the methods of Fenton and Fenton (1979). Diet and barley samples were analyzed in triplicate; feces and urine were analyzed in duplicate.

Calculations and Statistical Analyses

The apparent total tract digestibilities (**ATTD**) of DM, OM, and P were calculated by using the following equation:

$$ATTD, \% = 100\% - \{[(A_F \times I_D)/(A_D \times I_F)] \times 100\%\},$$

where A_F is the concentration of a component in feces (%), I_D is the chromic oxide concentration in the assay diet (%), A_D is the concentration of a component in the assay diet (%), and I_F is the chromic oxide concentration in feces (%). The total P excretion in feces was determined by taking into account the intake and ATTD of P (determined via chromic oxide). For normal-phytate barley, digestibility and retention of P and retained P (g/d) contributed solely by the barley samples were calculated by assuming that the bioavailability of monocalcium phosphate is 100% (NRC, 1998).

To compare differences in the variables among main effects or diets, data were analyzed by ANOVA for a repeated, 4 × 4 Latin square design using PROC GLM (SAS Institute Inc., Cary, NC). In Exp. 1 and 2, the effects of diet (n = 4) and experimental period (n = 4) were included in the model. The diet effects were described and considered significant at $P < 0.05$. Means were reported as least squares means.

In Exp. 1, 3 orthogonal contrasts were constructed to test the main effects and interaction: 1) the effect of hulled vs. hull-less barley, 2) the effect of normal- vs. low-phytate, and 3) the interaction barley × phytate.

Table 3. Composition of the experimental diets in Exp. 2, %, as-fed basis

	Hulled barley			
	Normal phytate			Low phytate
Item	SBM[1]	SBM + inorganic P	SBM + phytase[2]	SBM
Ingredient, %				
Hulled barley				
Normal phytate[3]	78.80	78.46	78.80	—
Low phytate[4]	—	—	—	80.62
Soybean meal	17.92	18.03	17.92	16.10
Canola oil	1.00	1.00	1.00	1.00
Limestone	1.38	1.16	1.38	1.38
Monocalcium phosphate[5]	—	0.45	—	—
Iodized salt	0.35	0.35	0.35	0.35
Mineral premix[6]	0.10	0.10	0.10	0.10
Vitamin premix[7]	0.10	0.10	0.10	0.10
Choline chloride[8]	0.05	0.05	0.05	0.05
Chromic oxide	0.30	0.30	0.30	0.30
Nutrient composition, %				
DM	88.08	88.81	89.85	89.58
OM	83.85	84.38	85.54	85.33
CP	17.64	17.48	17.78	17.41
Total P	0.38	0.47	0.39	0.37
Phytate P[9]	0.22	0.22	0.22	0.13
Available P[10]	0.16	0.25	0.17	0.24
Ca[11]	0.60	0.60	0.60	0.59
Ca:available P ratio	3.75	2.40	3.53	2.46

[1]SBM = soybean meal.
[2]Supplemented with 500 phytase unit/kg of diet (Natuphos, DSM Food Specialties, Delft, the Netherlands).
[3]Cultivar Metcalfe.
[4]Mutant line 99043.
[5]Monocalcium phosphate contained 17% Ca and 21.1% P.
[6]Provided per kilogram of diet: Fe, 150 mg as ferrous sulfate; Zn, 150 mg as zinc carbonate; Mn, 40 mg as manganese sulfate; Cu, 25 mg as copper sulfate; I, 0.21 mg as potassium iodate; Co, 0.5 mg as cobalt sulfate; Se, 0.3 mg as sodium selenite; and ethoxyquin, 5.0 mg.
[7]Provided per kilogram of diet: vitamin A, 10,000 IU; vitamin D_3, 1,000 IU; vitamin E, 80 IU; vitamin K_3, 2.0 mg; vitamin B_{12}, 0.03 mg; riboflavin, 12 mg; niacin, 40 mg; D-pantothenic acid, 25 mg; biotin, 0.25 mg; folic acid, 1.6 mg; thiamine, 3.0 mg; and pyridoxine, 2.25 mg.
[8]Provided 0.3 g of choline chloride per kilogram of diet.
[9]Calculated by using the analyzed phytate P content of the barley cultivars and soybean meal (47.5% CP; NRC, 1998).
[10]Total P minus phytate P.
[11]Calculated (NRC, 1998).

In Exp. 2, when a significant F-value ($P < 0.05$) was indicated for diet by ANOVA, means were separated using the Student-Newman-Keuls' multiple range test.

RESULTS AND DISCUSSION

The balance and excretion of P in pigs fed diets with either normal-phytate or low-phytate hulled or hull-less barley were compared in Exp. 1. The average BW of the pigs was 32.3, 39.0, 46.2, and 53.7 kg at the beginning of experimental periods 1, 2, 3, and 4, respectively, and was 64.3 kg at the conclusion of the experiment, indicating that dietary aP allowed pigs to gain BW throughout the study.

Because of the lower phytate P intake, the ATTD and retention of P were greater ($P = 0.004$) in pigs fed the low-phytate barley diets compared with pigs fed the normal-phytate barley diets (Table 4). Similarly, the low-phytate barley had greater ATTD ($P < 0.001$) and

retention of P ($P < 0.001$) than the normal-phytate barley. The ATTD of P averaged 65% for low-phytate barley and 49% for normal-phytate barley. Thacker et al. (2003, 2004) also reported a greater ATTD of P in finishing pigs fed low-phytate hulled and hull-less barley diets compared with normal-phytate hulled and hull-less barley diets. The normal-phytate barley diets used by Thacker et al. (2004) were deficient in aP for finishing pigs, and the measured ATTD of P was 11% for normal-phytate barley and 37% for low-phytate barley. The greater ATTD coefficients in the current study may reflect true P digestibility in normal-phytate barley because endogenous P output will drastically reduce measured ATTD of P in diets that are limiting in aP (Ajakaiye et al., 2003). Differences in P digestibility may also reflect differences in endogenous phytase activity between hulled and hull-less barley or among the samples of hulled or hull-less barley (Tran and Skiba, 2005). In barley, effects of phytase supplementation and low-

Table 4. Phosphorus balance in growing pigs fed the experimental diets in Exp. 1[1]

Item	Hulled barley Normal phytate	Hulled barley Low phytate	Hull-less barley Normal phytate	Hull-less barley Low phytate	SEM	P-value Hulled vs. hull-less barley	P-value Normal vs. low phytate	P-value Barley × phytate
Measured for the diet								
ADFI, d 8 to 59, kg	1.30	1.30	1.30	1.30	—	—	—	—
ADG, d 8 to 59, g	631	596	633	605	—	—	—	—
Intake P, g/d	4.72	3.56	5.23	4.17	—	—	—	—
Phytate P intake, g/d	1.74	0.61	2.62	0.39	—	—	—	—
Digestibility of DM	86.1	85.0	90.2	89.8	0.6	<0.001	0.185	0.546
Digestibility of OM	88.7	87.8	92.7	91.8	0.5	<0.001	0.052	0.935
Fecal P, g/d	1.93	1.26	2.29	1.49	0.10	0.009	0.001	0.532
Urinary P, mg/d	9.9	9.0	10.6	9.6	1.0	0.616	0.487	0.979
Absorbed P, g/d	2.79	2.29	2.94	2.68	0.10	0.018	0.002	0.270
Total excreted P, g/d	1.94	1.27	2.30	1.50	0.10	0.009	0.001	0.532
Digestibility of P, %	58.6	64.9	56.2	64.5	2.3	0.550	0.004	0.671
Retention of P, %	58.4	64.6	56.0	64.3	2.3	0.555	0.004	0.667
Retained P, g/d	2.78	2.28	2.93	2.67	0.10	0.018	0.002	0.271
Calculated for barley[2]								
Digestibility of P, %	45.9	64.9	53.1	64.5	2.7	0.216	<0.001	0.168
Retention of P, %	42.5	64.6	50.6	64.3	2.6	0.155	<0.001	0.121
Retained P, g/d	1.44	2.28	2.35	2.67	0.13	<0.001	<0.001	0.052

[1]Based on 2 pigs/treatment for each of 4 successive 13-d feeding periods in a 4 × 4 Latin square design, resulting in 8 observations per treatment.
[2]Calculated by excluding P provided by monocalcium phosphate.

phytate cultivars on P digestibility were not additive (Thacker et al., 2004), indicating that combining both treatments does not result in a cumulative increase in P digestibility. The ATTD of DM did not differ between pigs fed the normal- and low-phytate diets in the current study. The digestibility of OM tended to be 1% greater ($P = 0.052$) in normal-phytate barley, indicating that the phytate content of barley might play a minor role in determining energy digestibility.

In the current study, the urinary excretion of P was of a very small magnitude as reported in several studies (e.g., Veum et al., 2002; Liao et al., 2006), indicating that pigs did not meet their P requirement (Ekpe et al., 2002). For this reason, the values for ATTD and retention of P for each dietary treatment are nearly identical numerically. Although the retention of P (%) was greater, the amount of P retained (g/d) was decreased ($P = 0.002$) in pigs fed the low-phytate compared with the normal-phytate barley diets (Table 4), indicating that the low-phytate barley diets might not have been nutritionally complete to stimulate further reductions in P excretion in feces. The reduced amount of P retained was also reported by Veum et al. (2002) in a study with growing pigs fed a diet in which normal-phytate hulled barley was replaced by low-phytate hulled barley in a barley-SBM diet. This observation requires further study because the objective of nutrient management is to reduce P excretion while maintaining the amount of P retained. When considering the barley only following correction for the P contributed by monocalcium phosphate, the amount of P retained (g/d) was greater ($P < 0.001$) for low-phytate than for normal-phytate barley. The total excretion of P was reduced

by 35% ($P < 0.001$) when normal-phytate barley was replaced by the low-phytate barley in the diets. These reductions are in agreement with previous studies with low-phytate barley (Li et al., 2001a,b; Veum et al., 2002), corn (Veum et al., 2001; Bohlke et al., 2005), and SBM (Sands et al., 2003) in swine and poultry diets. Thus, the current study provides further evidence that the low-phytate genotype in barley is just as important as in other feedstuffs to improve P utilization in pigs.

In the current study, the diets were formulated to meet the recommendation of aP for grower pigs with a BW from 20 to 50 kg (0.23%; NRC, 1998). However, because of the restricted access to feed (2.5 times maintenance requirement for ME), the daily intakes of P and aP ranged from 43 to 64% and from 70 to 100% of the NRC (1998) recommended intake, respectively. In other P digestibility and balance studies, similar approaches have been used to study low-phytate feedstuffs. For example, Bohlke et al. (2005) restricted the feed allowance to 3 times the maintenance requirement for ME to study P digestibility of low-phytate corn. Veum et al. (2002) gave free access to feed, but restricted the aP content of the diet to study low-phytate barley. Therefore, both studies limited P supply using 2 different approaches, but were able to study effects of low-phytate feedstuffs on P digestibility and retention. Assuming that P and aP intake does not affect P retention from the amount fed in this study up to the daily recommended intake by NRC (1998), the relative reduction in P excretion will be constant when normal-phytate barley is replaced with low-phytate barley in feed formulation.

Table 5. Phosphorus balance in growing pigs fed the experimental diets in Exp. 2[1]

| | Hulled barley | | | | | |
| | Normal phytate | | | Low phytate | | |
Item	SBM[2]	SBM + inorganic P	SBM + phytase	SBM	SEM	P-value
ADFI, d 8 to 63, g	950	950	950	950	—	—
ADG, d 8 to 63, g	449	551	488	480	—	—
Intake P, g/d	3.16	4.00	3.31	3.19	—	—
Phytate P intake g/d	1.82	1.89	1.86	1.15	—	—
Digestibility of DM	87.1	88.5	88.3	87.9	1.1	0.803
Digestibility of OM	89.8	90.9	90.4	90.1	0.8	0.777
Fecal P, g/d	1.68[b]	1.97[a]	1.33[c]	1.39[c]	0.06	0.001
Urinary P, mg/d	4.9	5.8	4.8	5.0	1.0	0.762
Absorbed P, g/d	1.49[c]	2.03[a]	1.97[ab]	1.80[b]	0.07	0.001
Total excreted P, g/d	1.68[b]	1.98[a]	1.34[c]	1.40[c]	0.06	0.001
Digestibility of P, %	47.12[c]	50.70[bc]	59.89[a]	56.05[ab]	1.89	0.001
Retention of P, %	47.0[c]	50.5[bc]	59.8[a]	55.9[ab]	1.9	0.001
Retained P, g/d	1.48[c]	2.02[a]	1.97[ab]	1.79[b]	0.07	0.001

[a–c]Means within a row without a common superscript letter differ ($P < 0.05$).
[1]Based on 2 pigs/treatment for each of 4 successive 13-d feeding periods in a 4×4 Latin square design, resulting in 8 observations per treatment.
[2]SBM = soybean meal.

The ATTD of DM and OM were greater ($P < 0.001$) in pigs fed hull-less than hulled barley diets (Table 4), similar to other studies (Huang et al., 2003). Although the ATTD and retention of P did not differ, the amount of retained P was greater ($P = 0.018$) in pigs fed the hull-less compared with the hulled barley diets because intake of aP was greater for the hull-less barley diets (3.20 vs. 2.97 g/d); indicating that hull-less barley contained more total P and aP than hulled barley. The excretion of P in pigs fed the hull-less barley diets was greater than in pigs fed the hulled barley diets because the intake of phytate P was greater in hull-less barley (1.51 vs. 1.18 g/d).

The effects of iP and phytase supplementation of the HB-SBM diet and replacing HB with LPHB were investigated in Exp. 2. Because of the use of the same batches of HB and LPHB in both Exp. 1 and 2, the content of phytate P was considerably lower in the LPHB diet than in the HB diet and was reflected in a reduced phytate P in the LPHB-SBM diet. The average BW of the pigs was 20.7, 24.1, 32.4, and 38.9 kg at the beginning of experimental periods 1, 2, 3, and 4, respectively, and was 46.3 kg at the conclusion of the experiment. The daily intakes of P and aP ranged from 34 to 43% and from 31 to 49% of the NRC (1998) recommended intake, respectively.

As expected, the supplementation of iP to the HB-SBM diet, which was deficient in aP, increased the amount of P retained ($P < 0.05$; Table 5). However, the excretion of total P was also increased ($P < 0.05$). Similarly, phytase supplementation to the HB-SBM diet increased the ATTD, retention (%), and the amount of P retained, and simultaneously decreased the excretion of total P ($P < 0.05$). Similar results were previously reported in many studies with growing pigs when phy-

tase was supplemented to diets deficient in aP (e.g., Lei et al., 1993; Mroz et al., 1994; Kemme et al., 1999).

The amount of P retained did not differ between the HB-SBM + iP and the HB-SBM + phytase diets, but the excretion of total P was decreased in pigs fed the HB-SBM + phytase diet compared with pigs fed the HB-SBM + iP diet ($P < 0.005$; Table 5). Similarly, Harper et al. (1997) reported that growing-finishing pigs excreted 22% less P when phytase was supplemented to a diet deficient in P compared with a diet adequate in P. The supplementation of iP and phytase to the HB-SBM diets increased the daily amount of P retained to approximately the same extent (i.e., from 1.49 to 2.03 and from 1.49 to 1.97 g, respectively). These results are in agreement with Parr (1996) and Sauer et al. (2003) who reported that the supplementation of 500 phytase unit/kg of diet (as in this study) is equivalent to the supplementation of 1.0 g of P from monocalcium phosphate. Supplementation of the HB-SBM diet with 0.45% monocalcium phosphate supplied approximately 1.0 g of P.

Another approach to improve P utilization and simultaneously reduce excretion, besides phytase supplementation, is the use of low-phytate feedstuffs. Replacing HB with LPHB in the HB-SBM diet increased ($P < 0.05$) the ATTD and retention (%) of P and amount of P retained, and decreased ($P < 0.05$) the excretion of total P (Table 5). The amount of P retained for pigs fed the LPHB-SBM and the HB-SBM diets supplemented with iP or phytase did not differ, although the amount of P retained by pigs fed the LPHB-SBM diet was 0.20 to 0.25 g/d lower than in pigs fed the other 2 diets.

Pigs fed the HB-SBM + phytase and the LPHB-SBM diet excreted 20.2 and 16.7% less total P, respectively ($P < 0.05$; Table 5), compared with pigs fed the HB-SBM diet. These results, in which normal-phytate barley was

replaced with low-phytate barley, are in agreement with previous studies (Li et al., 2001a,b; Veum et al., 2002). Pigs fed the HB-SBM + phytase and LPHB-SBM diets excreted 32.4 and 29.3% less total P, respectively, compared with the HB-SBM + iP diet.

In the 2 experiments, the Ca:aP ratios in the diets ranged from 1.85:1 to 2.57:1 in Exp. 1 and 2.40:1 to 3.75:1 in Exp. 2, and the ratios remained below the recommended upper limit of 3:1 (NRC, 1998). In Exp. 1, an increased Ca:aP ratio was inversely related to P digestibility ($R^2 = 0.47$), and in Exp. 2, this relationship also existed ($R^2 = 0.61$) for the 3 diets that were not supplemented with phytase. A greater Ca:aP decreased P absorption, especially in diets that are marginal in P (NRC, 1998). Nonetheless, in Exp. 1, the Ca:aP ratio did not differ between the HB and LPHB diets, whereas P digestibility was 6% greater in the LPHB diet. The Ca:aP ratio was lower in the LPHLB than the HLB diet, but P digestibility was 8% greater for the LPHLB diet. These results indicate that although the dietary Ca:aP ratio might be important, P digestibility is changed more drastically by low-phytate cultivars of barley.

In conclusion, the results of Exp. 1 showed that the ATTD and retention of P were greater in pigs fed the low-phytate diets compared with the normal-phytate barley diets and less total P was excreted. However, the amount of P retained was decreased in pigs fed the low-phytate barley cultivars. The results of Exp. 2 showed that the replacement of HB with LPHB in the HB-SBM diet was as effective as phytase supplementation of the HB-SBM diet in increasing the amount of P retained and decreasing the excretion of total P. Low-phytate barley is as effective as supplemental phytase in improving P digestibility and utilization and decreasing P excretion in grower pigs.

LITERATURE CITED

Ajakaiye, A., M. Z. Fan, T. Archbold, R. R. Hacker, C. W. Forsberg, and J. P. Phillips. 2003. Determination of true digestive utilization of phosphorus and the endogenous phosphorous outputs associated with soybean meal for growing pigs. J. Anim. Sci. 81:2766–2775.

AOAC. 2000. Official Methods of Analysis. 17th ed. Assoc. Off. Anal. Chem., Gaithersburg, MD.

Bohlke, R. A., R. C. Thaler, and H. H. Stein. 2005. Calcium, phosphorus, and amino acid digestibility in low-phytate corn, normal corn, and soybean meal by growing pigs. J. Anim. Sci. 83:2396–2403.

CCAC. 1993. Guide to the Care and Use of Experimental Animals. Vol. 1. Canadian Council on Animal Care, Ottawa, ON, Canada.

Cromwell, G. L. 1992. The biological availability of phosphorus in feedstuffs for pigs. Pigs News Inf. 13:75N–79N.

Ekpe, E. D., R. T. Zijlstra, and J. F. Patience. 2002. Digestible phosphorus requirement of grower pigs. Can. J. Anim. Sci. 82:541–549.

Engelen, A. J., F. C. van der Heeft, P. H. G. Randsdorp, and E. L. C. Smit. 1994. Simple and rapid determination of phytase activity. J. AOAC Int. 77:760–764.

FAO. 2002. Food outlook. Global information and early warning system on food and agriculture. No. 1. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fenton, T. W., and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and feces. Can. J. Anim. Sci. 59:631–634.

Harper, A. F., E. T. Kornegay, and T. C. Schell. 1997. Phytase supplementation of low-phosphorus growing-finishing pig diets improves performance, phosphorus digestibility, and bone mineralization and reduces phosphorus excretion. J. Anim. Sci. 75:3174–3186.

Haug, W., and H.-J. Lantzsch. 1983. Sensitive method for the rapid determination of phytate in cereals and cereal products. J. Sci. Food Agric. 34:1423–1426.

Huang, G. S., W. C. Sauer, J. M. He, J. Hwangbo, and X. Wang. 2003. The nutritive value of hulled and hullless barley for growing pigs. 1. Determination of energy and protein digestibility with the in vivo and in vitro method. J. Anim. Feed Sci. 12:759–769.

Jongbloed, A. W., and N. P. Lenis. 1998. Environmental concerns of animal agriculture. J. Anim. Sci. 76:2641–2648.

Kemme, P. A., A. W. Jongbloed, Z. Mroz, J. Kogut, and A. C. Beynen. 1999. Digestibility of nutrients in growing-finishing pigs is affected by *Aspergillus niger* phytase, phytate and lactic acid levels. II. Apparent total tract digestibility of phosphorus, calcium, and magnesium and ileal degradation of phytic acid. Livest. Prod. Sci. 58:119–127.

Kornegay, E. T. 2001. Digestion of phosphorus and other nutrients: the role of phytases and factors influencing their activity. Pages 237–259 in Enzymes in Farm Animal Nutrition. M. R. Bedford and G. G. Partridge, ed. CABI publishing, Marlborough, United Kingdom.

Lei, X. G., P. K. Ku, E. R. Miller, and M. T. Yokoyama. 1993. Supplementing corn-soybean meal diets with microbial phytase linearly improved phytate phosphorus utilization by weaning pigs. J. Anim. Sci. 71:3359–3367.

Li, Y. C., D. R. LeDoux, T. L. Veum, V. Raboy, K. Zyla, and A. Wikiera. 2001a. Bioavailability of phosphorus in low phytic acid barley. J. Appl. Poult. Res. 10:86–91.

Li, Y. C., D. R. LeDoux, T. L. Veum, V. Raboy, and K. Zyla. 2001b. Low phytic acid barley improves performance, bone mineralization, and phosphorus retention in turkey poults. J. Appl. Poult. Res. 10:178–185.

Liao, S. F., W. C. Sauer, A. K. Kies, M. Cervantes, J. K. Htoo, and J. M. He. 2006. Effect of phytase supplementation to diets for weanling pigs on the utilization of phosphorus and calcium. Interciencia 31:262–267.

Mroz, Z., A. W. Jongbloed, and P. A. Kemme. 1994. Apparent digestibility and retention of nutrients bound to phytate complex as influenced by microbial phytase and feeding regimen in pigs. J. Anim. Sci. 72:126–132.

Nelson, T. S. 1967. The utilization of phytate phosphorus by poultry. A review. Poult. Sci. 46:862–869.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Parr, J. 1996. Formulating Swine Diets with Natuphos Phytase. Pages 94–121 in Proc. BASF Technical Symp., Des Moines, IA.

Raboy, V. 2002. Progress in breeding low phytate crops. J. Nutr. 132:503S–505S.

Ravindran, V., W. L. Bryden, and E. T. Kornegay. 1995. Phytates: Occurrence, bioavailability and implications in poultry nutrition. Poult. Avian Biol. Rev. 6:125–143.

Sands, J. S., D. Ragland, J. R. Wilcox, and O. Adeola. 2003. Relative bioavailability of phosphorus in low-phytate soybean meal for broiler chicks. Can. J. Anim. Sci. 83:95–100.

Sauer, W. C., M. Cervantes, J. M. He, and H. Schulze. 2003. Effect of phytase supplementation to barley-canola meal and barley-soybean meal diets on phosphorus and calcium balance in growing pigs. Interciencia 28:476–481.

Thacker, P. A., B. G. Rossnagel, and V. Raboy. 2003. Phosphorus digestibility in low phytate barley fed to finishing pigs. Can. J. Anim. Sci. 83:101–104.

Thacker, P. A., B. G. Rossnagel, and V. Raboy. 2004. Effect of phytase supplementation on phosphorus digestibility in low-phytate barley fed to finishing pigs. Arch. Anim. Nutr. 58:61–68.

Tran, G., and F. Skiba. 2005. Inter and intra feed material variability of the contents in total and phytic phosphorus and of phytase activity. INRA Prod. Anim. 18:159–168.

Veum, T. L., D. R. Ledoux, D. W. Bollinger, V. Raboy, and A. Cook. 2002. Low-phytic acid barley improves calcium and phosphorus utilization and growth performance in growing pigs. J. Anim. Sci. 80:2663–2670.

Veum, T. L., D. R. Ledoux, V. Raboy, and D. S. Ertl. 2001. Low-phytic acid corn improves nutrient utilization for growing pigs. J. Anim. Sci. 79:2873–2880.