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Fecal Phosphorus Excretion and Characterization from Swine Fed Diets Containing a Variety of Cereal Grains

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Abstract: Twenty crossbred barrows weighing 35.8±3.1 kg, were fed 1 of 5 diets (N = 4) to determine the effects of different cereal grains on fecal P excretion and composition. The diets contained 97.15% corn, wheat, high fat-low lignin oat, normal barley or low phytate barley with the cereal grain supplying the sole source of dietary phosphorus. The diets were fed for a 7 day acclimation period followed by a three-day fecal collection. Total tract digestibility coefficients were determined for dry matter, phosphorus and phytate using the indicator method. Fecal phosphorus was characterized using solution state Phosphorus Nuclear Magnetic Resonance spectroscopy (^{31}P-NMR). Water Soluble Phosphorus (WSP) and the ratio of WSP to total phosphorus (WSP:TP) were determined in the feces. Digestibility coefficients for phosphorus and phytate ranged from 0.11 (corn) to 0.46 (wheat) and 0.94 (oat) to 1.00 (corn and low-phytate barley), respectively. There was very little phytate phosphorus excreted in the feces regardless of the type of cereal grain fed (< 6% of total phosphorus) and phytate degradation was not related to the level of endogenous phytase in the diet. There was a negative relationship between the fecal WSP:TP ratio and the concentration of phosphate monoesters in the feces. In summary, our results indicate that the majority of the phosphorus in the feces of pigs fed cereal grains is present in the form of inorganic phosphate and only trace amounts of phytate are excreted intact. The amount of phytate in the excreta was not related to the amount of phytate or endogenous phytase in the grain. Further research should be conducted with diets more typical of those used in commercial swine production to confirm these findings, as the high inorganic phosphate content and WSP:TP ratio in manure from swine could increase the potential for off-site phosphorus losses when swine feces are applied on agricultural lands.

Key words: Endogenous phytase, phytate degradation, swine, phosphorus, NMR

INTRODUCTION

Phytate (salts of *myo*-inositol hexakisphosphate) is the primary storage form of phosphorus found in cereal grains and comprises a large portion of the total phosphorus contained in plant-based diets fed to swine (Ravindran *et al*., 1994). Pigs are inefficient in utilizing phytate phosphorus which has been ascribed to inadequate secretion of the enzyme phytase that is required to hydrolyze the phytate molecule (Pointillart, 1994; Jongbloed *et al*., 1992; Yi and Kornegay, 1996).

The bioavailability of phosphorus from cereal grains has been shown to be low and varies from 14% in corn to 49% in wheat (Cromwell, 1992). It is commonly believed that the low bioavailability of phytate phosphorus results in substantial excretion of phytate phosphorus in swine feces. However, Leytem *et al*. (2004) reported that pigs fed diets based on normal or low phytate barley excreted only trace amounts of phytate in their feces, even though the diets contained as much as 55% of their total phosphorus in the form of phytate. These results suggest that phytate was hydrolyzed by swine prior to excretion, possibly in the hind gut by intestinal microflora (Seynaeve *et al*., 2000).

The amount of phytate excreted can alter the solubility of the phosphorus in swine feces. Turner and Leytem (2004) reported that 96% of the phosphorus contained in water extracts of swine manure was present as inorganic phosphorus while organic phosphorus forms (such as phytate) were only extracted when strongly acidic or basic extracting solutions were used. Therefore, the amount of phytate excreted could alter the proportion of Water Soluble Phosphorus (WSP) in the feces and thereby affect phosphorus losses following land

application of swine manure and the potential for phosphorus losses to surface and ground waters (Kornegay and Harper, 1997).

There is very little published information on phosphorus speciation in the feces of swine fed grains other than barley. Information is needed on the phosphorus composition of feces obtained from pigs fed a wide range of diets in order to assess differences between cereal grains on the extent of phytate phosphorus hydrolysis in the gastro-intestinal tract of swine and its subsequent impact on the WSP content of manure.

Therefore, the objective of this experiment was to quantify changes in fecal mphosphorus composition from swine fed diets containing cereal grains which contained a wide range of phytate and endogenous phytase concentrations.

MATERIALS AND METHODS

Acquisition of cereal grains: The cereal grains used as the principle ingredient in the 5 diets fed in this experiment were commercial grade corn and wheat which were obtained from a local feed mill, a newly developed high fat-low lignin oat (Thacker and Rossnagel, 2005), Harrington barley (Harvey and Rossnagel, 1984) and a low phytate mutant barley (LP635) with approximately 50% less phytate phosphorus compared with commercial barley cultivars (Dorsch *et al*., 2003).

Digestibility trial: The pigs used in this experiment were cared for following the guidelines of the Canadian Council on Animal Care (1993). Twenty crossbred barrows (Camborough 15 Line female × Canabred sire, Pig Improvement Canada Ltd., Acme Alberta) weighing an average of 35.8±3.1 kg were housed in groups of 4 in 2.7 × 3.6 m concrete floored pens and were provided with water *Ad libitum* (the water contained 0.00014% phosphorus). The pens were equipped with 4 individual feeders. Each animal was allowed access to its own individual feeder for 30 min twice daily (07:00 and 15:00 h).

The barrows were assigned to one of five (N = 4) dietary treatments (Table 1). The experimental diets were formulated to contain 97.15% grain, 1.0% vitamin-mineral premix, 1.0% limestone, 0.5% salt and 0.35% chromic oxide. The diets were fed for a seven-day acclimatization period, followed by a three-day fecal collection. Feces were obtained by bringing the barrows into a clean room immediately after feeding and recovering freshly voided feces. The fecal samples from the three-day collection were pooled by animal and then immediately frozen for storage. Prior to analysis, the samples were dried in a forced air oven dryer at 66°C for 60 h, followed by fine grinding (0.5 mm screen). Total tract digestibility coefficients for dry matter, phosphorus and phytate were calculated using the equations for the indicator method described by Schneider and Flatt (1975).

Chemical analysis of feeds and feces: Samples of the diets were chemically analyzed according to the methods of the Association of Official Analytical Chemists (1990). Analyses were conducted for moisture (AOAC method

Table 1: Ingredient composition and chemical analysis of diets used to determine fecal phosphorus excretion and fecal phosphorus characterization of growing pigs fed various cereal grains

	Corn	Wheat	High fat-low lignin oat	Normal barley	Low phytate barley
Ingredients (g kgG[1] as fed)					
Cereal grain	97.15	97.15	97.15	97.15	97.15
Limestone	1.00	1.00	1.00	1.00	1.00
Vitamin-mineral premix[1]	1.00	1.00	1.00	1.00	1.00
Salt	0.50	0.50	0.50	0.50	0.50
Chromic oxide	0.35	0.35	0.35	0.35	0.35
Chemical analysis[2] (g kgG[1] as fed)					
Moisture	12.00	11.84	8.93	10.81	11.55
Crude protein	8.16	13.71	10.49	12.49	10.95
Ether extract	2.77	3.84	6.70	1.79	1.46
Neutral detergent fibre	11.37	11.17	25.29	19.43	15.33
Ash	2.94	3.10	5.13	4.22	3.62
Calcium	0 .48	0.56	0.57	0.66	0.59
Total phosphorus[3]	0.31	0.41	0.33	0.35	0.35
Non phytate phosphorus[4]	0.06	0.18	0.09	0.11	0.25
Phytate phosphorus	0.25	0.23	0.24	0.24	0.10
Endogenous phytase activity FTU kgG[1]	16.00	172.00	29.00	153.00	73.00

[1]Supplied per kilogram of diet: 8250 IU vitamin A; 825 IU vitamin D_3; 40 IU vitamin E; 4 mg vitamin K; 1 mg thiamine; 5 mg riboflavin; 35 mg niacin; 15 mg pantothenic acid; 2 mg folic acid; 12.5 µg vitamin B_{12}; 0.2 mg biotin; 80 mg iron: 25 mg manganese; 100 mg zinc; 50 mg Cu; 0.5 mg I; 0.1 mg selenium.[2]All chemical composition data are the results of a chemical analysis conducted in duplicate, [3]No supplemental P (dicalcium phosphate) were used in formulating the diets, [4]Non-phytate P calculated as the difference between total P and phytate P

930.15), crude protein (AOAC method 984.13), ash (AOAC method 942.05) and ether extract (AOAC method 920.39). Neutral detergent fibre was analyzed using the method of Van Soest *et al*. (1991). Diets were analyzed for calcium using atomic absorption spectroscopy (AOAC method 968.08).

Feed samples were wet-ashed using the nitric-perchloric acid method of Zasoski and Burau (1977) and total phosphorus was determined colorimetrically (Pharmacia Ultraspec III, LKB Biochrome, St Albans, England) using a molybdovanadate reagent (AOAC method 965.17). The ferric precipitation method (Raboy *et al*., 1990) was used to extract and precipitate the phytate phosphorus in the feeds and the resulting extracts were analyzed for phytate by the colorimetric assay of Chen *et al*. (1956). Chromic oxide was determined in feed and feces by the method of Fenton and Fenton (1979). Phytase activity in feed was determined via an assay for complete feed samples (phytase activity is expressed as phytase units or FTU per unit of feed; one phytase unit is the amount of phytase that liberates 1 micromole of inorganic phosphorus per minute from an excess of sodium phytate at pH 5.5 and 37°C (Engelen *et al*., 2001).

Fecal samples were analyzed for WSP by shaking 1g dry feces with 100 mL deionized water for 1 h, filtering through a 0.45 µm membrane and analyzing total WSP by inductively-coupled plasma optical-emission spectrometry (ICP-OES; Perkin Elmer Optima 4300 DV, Wellesley, MA, USA). Total fecal phosphorus was determined by microwave-assisted digestion of a 0.5 g dried sample with 8 mL of concentrated HNO_3 and 2 mL of 30% H_2O_2 (v/v) with phosphorus quantified using ICP-OES detection.

Phosphorus speciation of feces: The phosphorus composition of feces was determined by solution ^{31}P NMR spectroscopy as described by Turner (2004). Briefly, phosphorus was extracted in triplicate by shaking 2.00±0.01 g of dried feces with 40 mL of a solution containing 0.5 M NaOH and 0.05 M EDTA for 4 h at 20°C. Extracts were centrifuged at 10,000 x g for 30 min and aliquots were analyzed for total phosphorus by ICP-OES. The remaining solutions from the triplicate extracts were combined, frozen rapidly at -80°C, lyophilized and ground to a fine powder.

Freeze-dried extracts were re-dissolved in 0.1 mL of D_2O (for signal lock) and 0.9 mL of a solution containing 1 M NaOH and 0.1 M EDTA and then transferred to a 5 mm NMR tube. Solution ^{31}P NMR spectra were obtained using a Bruker Avance DRX 500 MHz spectrometer (Rhinestetten, Germany) operating at 202.456 MHz for ^{31}P. A 5 µs pulse (45°), a delay time of 5.0 s, an acquisition time of 0.8 s and broadband proton decoupling were used for all samples. The number of scans varied between 3.331 and 10.580 and spectra were plotted with a line broadening of 1 Hz. Chemical shifts of signals were determined in parts per million (ppm) relative to 85% H_3PO_4 and assigned to individual phosphorus compounds or functional groups based on literature values (Turner *et al*., 2003). Signal areas were calculated by integration and phosphorus concentrations were calculated by multiplying the proportion of the total spectral area assigned to a specific signal by the total phosphorus concentration (g phosphorus kg^{-1} dry feces) in the original extract. This NMR procedure detects phosphorus compounds at concentrations of approximately 0.1 mg phosphorus kg^{-1} of dried feces (Turner, 2004).

Statistical analysis: All variables were tested for normality using the Shapiro-Wilk test with the PROC UNIVARIATE procedure of SAS (SAS, 2004). To evaluate treatment effects of complete diets, data were analyzed with Proc Mixed (SAS, 2004) using a randomized complete block design with diet as a fixed effect and block as a random effect. Where appropriate, means separation was done using Tukey's HSD with alpha levels of 0.05.

RESULTS

Chemical analysis of diets: The chemical analyses of the experimental diets are presented in Table 1. The total phosphorus concentration of the diets ranged from 0.31% for the corn diet to 0.41% for the wheat diet. Phytate phosphorus ranged from 0.10% for the low phytate barley to 0.25% for corn while endogenous phytase activity ranged from 16 FTU per kg^{-1} for corn to 172 FTU per kg^{-1} for wheat.

Table 2: Coefficients for apparent digestibility for dry matter, crude protein, phosphorus and phytate from diets comprised of corn, barley, low-phytate barley, oat and wheat fed to swine

	Apparent digestibility		
Diet	Dry matter	Phosphorus	Phytate
Corn	0.81^{a}	0.11^{c}	1.00^{a}
Normal barley	0.71^{bc}	0.26^{b}	0.97^{ab}
Low-phytate barley	0.76^{b}	0.35^{b}	1.00^{a}
High fat-low lignin oat	0.67^{c}	0.26^{b}	0.94^{b}
Wheat	0.83^{a}	0.46^{a}	0.98^{ab}
SEM	0.017	0.034	0.014
p>F	<0.0001	<0.0001	0.021

a-b Means in the same column followed by the same letter do not differ (p>0.05)

Table 3: Phosphorus characterization of swine faeces determined by NaOH-EDTA extraction and solution ^{31}P NMR spectroscopy

	NaOH–EDTA extractable P				
	Total NaOH-EDTA P[1]	Phosphate[2]	Phosphate monoesters[2,3]	Phytate[2]	Pyrophosphate[2]g P kg dry wt.G[1]
	g P kg dry wt.G[1]				
Normal barley	8.80±0.94	7.57 (86)^{abc}	0.88 (10)^{b}	0.26 (3)	0.09 (1)^{ab}
LP barley	8.19±1.42	6.80 (83)^{bc}	1.31 (16)^{ab}	ND	0.08 (1)^{ab}
Corn	11.39±1.83	9.68 (85)^{a}	1.59 (14)^{ab}	ND	0.11 (1)^{ab}
Oat	7.19±1.67	5.68 (79)^{c}	1.01 (14)^{b}	0.43 (6)	0.07 (1)^{b}
Wheat	11.17±0.90	8.82 (79)^{ab}	1.90 (17)^{a}	0.22 (2)	0.22 (2)^{a}
SEM	0.702	0.665	0.180	0.120	0.029
p>F	0.003	0.006	0.010	0.047	0.025

[1]Values are means±the standard deviation of four pens per feeding treatment, [2]Values in parenthesis are the proportion (%) of the NaOH–EDTA extracted P. [3]Values for phosphate monoesters include all monoesters other than phytate. 4ND, not detected. $^{a-c}$Means in the same column followed by the same letter do not differ (p>0.05)

Apparent digestibility coefficients: The coefficients for the apparent digestibility of dry matter, phosphorus and phytate are shown in Table 2. Total tract dry matter digestibility ranged from 0.67-0.83. Corn and wheat had the highest dry matter digestibility coefficients while oat and normal barley had the lowest. Apparent phosphorus digestibility ranged from 0.11-0.46 and was highest for the wheat diet and lowest for the corn diet (p<0.05) with no significant differences between the other treatments. Phytate digestibility ranged from 0.94-1.00 with the only significant difference occurring between the corn and oat treatments.

Fecal phosphorus characterization: The fecal phosphorus composition of the diets was determined with solution state ^{31}P NMR spectroscopy and is shown in Table 3. Total fecal phosphorus ranged from 6.94 for the oat diet to 11.86 g phosphorus kgG^{1} for the corn diet and the recovery of phosphorus in the NaOH-EDTA extracts ranged from 96-100% of total P. The phosphorus in the feces was primarily in the form of phosphate which ranged from 5.68-9.68 g phosphorus kgG^{1} and comprised between 79% (oats and wheat) and 86% (normal barley) of the total phosphorus in the feces. Phytate was detected only in the feces from swine fed the Harrington barley, oat and wheat diets and ranged from 0.22-0.43 g phosphorus kgG^{1} comprising only 2- 6% of the total fecal phosphorus. No phytate was detected in the feces of swine fed corn or the low-phytate barley. The phosphate monoester phosphorus concentrations (which contain lower esters of inositol phosphates) ranged from 0.88-1.90 g phosphorus kgG^{1} and comprised between 10-17% of the total fecal phosphorus. There were also small amounts of pyrophosphate in the feces but these comprised 2% or less of the total fecal phosphorus.

The WSP content of the feces ranged from 4.26-6.45 g phosphorus kgG^{1} (Fig. 1a). The only significant differences in fecal WSP concentrations were between feces from pigs fed the oat diet which had the lowest WSP and feces from the corn and wheat diets that had the highest WSP concentrations. The ratio of fecal WSP to total phosphorus (WSP:TP) ranged from 0.53-0.68 with the only significant differences being between the corn diet which had the lowest ratio and the barley and oat diets which had the highest (Fig. 1). The fecal WSP: TP ratio was highly correlated with the concentration of monoester phosphorus in the feces (r = -0.71; p<0.0005). The regression of fecal monoester P vs. WSP:TP ratio was: WSP: TP = 0.76-0.0001 monoester phosphorus (r^2 = 0.50, p<0.0005, Fig. 2).

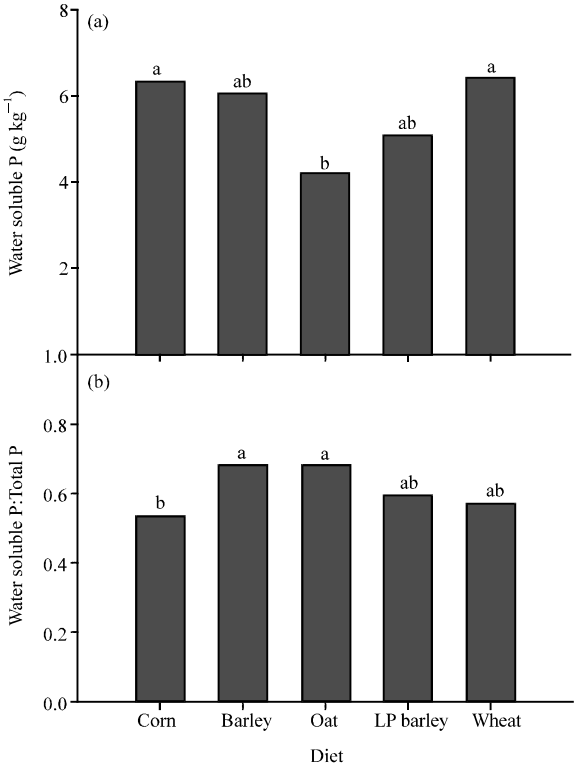

Fig. 1: Fecal water soluble P, a) and the ratio of fecal water soluble P to total P, b) from swine fed a variety of cereal based diets

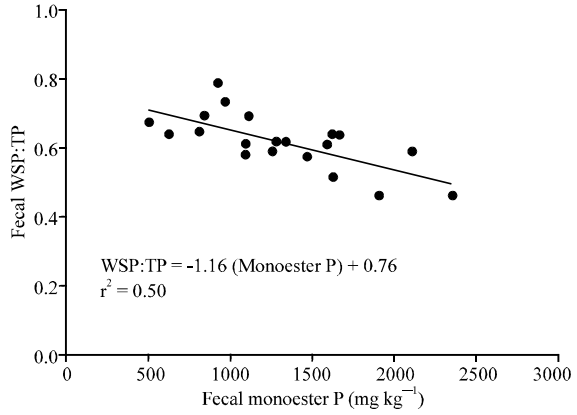

Fig. 2: The relationship between fecal water soluble phosphorus to total phosphorus ratio and the fecal monoester phosphorus concentration

DISCUSSION

The diets fed in the present experiment contained 97.15% grain and therefore the chemical analysis of the diets should reflect that of the test grain used as the principle ingredient in the diet. The results of the chemical analyses conducted on the diets (Table 1) were within the range of those previously reported for corn, wheat, oat and barley in standard industry publications, such as the United States-Canadian Tables of Feed Composition (National Research Council, 1982), Feedstuff's Ingredient Analysis Table (Dale, 1995), as well as the Nutrient Requirements of Swine (National Research Council, 1998). Notable exceptions would be the higher ether extract and lower neutral detergent fibre content of the high fat-low lignin oat cultivar and the lower phytate content of the low phytate barley compared with literature values for Harrington barley. The aforementioned differences can be attributed to selection for these specific traits by plant breeders who developed these varieties of oat and barley. The calcium content of all diets was also higher than that of the grain alone, as 1% limestone was added to all diets and the vitamin-mineral premix contained limestone as a carrier.

The digestibility coefficients for dry matter were similar to other data reported in the literature. Powers *et al*. (2006) reported that the dry matter digestibility of corn and soy based diets ranged from 0.78-0.85, whereas the dry matter digestibility coefficient for corn was 0.81 in the present study. Thacker *et al*. (2003) reported dry matter digestibility coefficients of 0.77 and 0.74 when swine were fed normal and low phytate barley diets, respectively and were similar to the values obtained for these treatments in the present study. Bruce and Sundstol (1995) reported a dry matter digestibility of oat based diets of 0.76 which was slightly higher than the value of 0.67 obtained in the present study. However, diets in the study by Bruce and Sundstol (1995) contained only 80% oat whereas 97% oat was included in diets in the present study and could be expected to decrease overall dry matter digestibility.

The apparent digestibility coefficients for phosphorus obtained in the present study were comparable to published data that have reported digestibility coefficients of phosphorus in feedstuffs. The apparent digestibility coefficients were 0.26, 0.11, 0.26 and 0.46 for the phosphorus in normal barley, corn, oat and wheat diets, respectively. Previously published values for bioavailability of phosphorus in these grains are 0.30, 0.14, 0.22 and 0.46 for barley, corn, oat and wheat, respectively (NRC, 1998). Thacker *et al*. (2003) reported a phosphorus digestibility coefficient of 0.39 when swine were fed a low phytate barley diet which was similar to the value of 0.35 obtained in the present study.

Since the diets in the present study contained different amounts of non-phytate phosphorus and phytase it was not possible to separate the effects of non-phytate phosphorus level and endogenous phytase in grains on the resultant phosphorus digestibility coefficients obtained. However, an interesting comparison can be made between the diets containing either oat or Harrington barley that contained only small differences in non-phytate phosphorus (0.90 vs. 1.10 g kg^{-1}), but had a five-fold difference in analyzed activity of endogenous phytase enzyme. In spite of the substantially higher amount of phytase in the barley diet, there was no improvement in the apparent digestibility of phosphorus, which suggests that there is very little contribution to phosphorus digestibility from the phytase enzymes naturally associated with the grains.

There is very little published data on the phosphorus composition of feces obtained from swine fed different cereal grains. Furthermore, little evidence exists of endogenous phytase secretion in the small intestine of swine (Jongbloed *et al*., 1992; Pointillart, 1994; Yi and Kornegay, 1996), which resulted in only small quantities of phytate hydrolyzed in the small intestine and poor availability of phytate bound phosphorus. Therefore, it could be expected that as the utilization of phytate phosphorus by swine was poor, there should be significant excretion of intact dietary phytate in the feces. However, our data clearly showed that very little phytate was excreted in the feces from pigs regardless of the type of cereal grain fed. This finding supported previous work in which Leytem *et al*. (2004) reported that only trace

amounts of phytate were found in the feces from swine fed diets containing either low-or high-phytate barley. Similarly, Seynaeve *et al*. (2000) reported that phytate degradation in the digestive tract of swine fed corn-soybean based diets was approximately 98% and that significant amounts of phytate could only be detected in the feces when diets had a high ratio of Ca: P.

It is important to note that the experimental diets used in the present study were formulated to quantify changes in fecal phosphorus composition in diets containing different varieties of cereal grains, free from the influence of other confounding phosphorus sources. Therefore, diets in the present study were deliberately formulated without including additional phosphorus sources such as soybean meal or dicalcium phosphate, as inclusion of these additional phosphorus sources would have hindered our ability to detect differences in phosphorus excretion between the different grain sources. However, future research should be conducted to determine the speciation of phosphorus in the manure of pigs fed diets more typical of those used in commercial practice to confirm whether or not the findings of the present experiment are reproduced when diets contain higher levels of Ca and phosphorus as well as having different ratios of Ca:P.

Since, swine do not produce appreciable amounts of the enzyme phytase (Jongbloed *et al*., 1992; Pointillart, 1994; Yi and Kornegay, 1996), it would appear that other sources of phytase are functioning within the gastrointestinal tract of the pig to breakdown phytate. The negligible effect of endogenous cereal phytase on apparent phosphorus digestibility, combined with the fact that phytate hydrolysis exceeded 94% for all the cereal grains, regardless of their phytase content, suggests that microbial activity in the hind gut was the most likely mechanism responsible for the high degree of phytate degradation in the present study. This is supported by previous observations that bacteria in the hind gut hydrolyzed large amounts of the phytate contained in the digesta (Seynaeve *et al*., 2000).

It is further important to note that the finding that there was little phytate present in swine feces does not necessarily mean that the phosphorus liberated from phytate is available to the pig. In monogastric animals, there is little evidence of phosphorus absorption occurring past the distal ileum (Crenshaw, 2001). Therefore, any phosphorus liberated as a result of phytate hydrolysis in the hindgut will most likely not be absorbed and will be voided in the feces. This is supported by the results of the present study which showed that in spite of high levels of total tract phytate hydrolysis, phosphorus digestibility coefficients were low. Therefore, the majority of phytate phosphorus hydrolysis occurred in the lower digestive tract (colon and rectum) and the phosphorus made available from phytate was not absorbed by the animals and was simply excreted in the feces.

Sharpley and Moyer (2000) found a correlation of 98% between Water Soluble Phosphorus (WSP) in manure and the amount of phosphorus leached from a soil following five simulated rainfall events, which suggested that WSP would be a good indicator to estimate the potential of manure to contribute to phosphorus runoff after surface application. In the present study, the only significant differences in fecal WSP concentrations were between the oat diet which had a WSP concentration 34% lower than that of feces from swine fed corn and wheat diets. As fecal WSP concentrations have been shown to be highly correlated with phosphorus losses from soil, the lower WSP concentration in feces from swine fed the oat diet would pose a lower risk for off-site phosphorus losses when applied at the same application rate as feces from the wheat, corn, or barley treatments.

Both the fecal WSP and WSP: TP in the present study were comparable with values obtained in other studies (Leytem *et al*., 2004; Leytem and Westermann, 2005; Powers *et al*., 2006). Since, the majority of the phytate in the feed had been degraded, there was no relationship between fecal phytate phosphorus and the proportion of total phosphorus that was water soluble. However, the monoester phosphorus fraction was greater than 10% in the feces from pigs fed any of the five diets and significantly influenced the proportion of WSP in the feces.

The finding that the majority of the phosphorus contained in the feces of pigs fed cereal grains was present in the form of inorganic phosphate may have important implications for the fate of the phosphorus in swine feces when this is applied to land as fertilizer. Inorganic phosphate is relatively soluble in soils whereas phytate is retained and is less likely to be lost in runoff (Anderson *et al*., 1974; Leytem *et al*., 2002). As our findings indicated that regardless of the type of cereal grain fed, the phosphorus in swine feces was present as the more soluble phosphate form rather than as phytate, care should be taken when applying swine manure to land to ensure that surface and groundwater resources are not contaminated.

CONCLUSION

In summary, our results indicate that the majority of the phosphorus in the feces of pigs fed cereal grains was present in the form of inorganic phosphate and only trace amounts of phytate are contained in the excreta. This

phenomenon did not appear to be related to the content of either phytate or phytase in the grain. Further research should be conducted with diets more typical of those used in commercial swine production to confirm these findings, as there could be greater potential than previously thought for off-site phosphorus losses when swine feces are applied on agricultural lands.

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