Effect of high-phytase supplementation in lactation diets on sow and litter performance

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ABSTRACT: A total of 109 sows (Line 241; DNA, Columbus, NE) were used to evaluate the effect of increasing dietary phytase in lactation diets, already adequate in P, on sow and litter performance. On d 107 of gestation, sows were blocked by body weight and parity and allotted to 1 of 3 dietary treatments of increasing phytase concentration (0, 1,000, or 3,000 FYT/kg; Ronozyme HiPhos GT 2700, DSM Nutritional Products, Inc., Parsippany, NJ). The control diet contained no phytase and was formulated to contain 0.50% standardized total tract digestible phosphorus (STTD P; 0.45% available P) and 0.62% STTD calcium (0.90% total Ca). The phytase diets that contained 1,000 or 3,000 FYT/kg were also formulated to 0.50% STTD P and 0.62% STTD Ca including the release of 0.132% STTD P and 0.096% STTD Ca. Diets were balanced for net energy and fed from d 107 of gestation until weaning (d 18 ± 3). All farrowings were monitored, with farrowing duration starting at the time the first pig was born until the first dispersal of placental tissues with no subsequent pigs born. Litters were cross-fostered within treatment until 48 h postfarrowing to equalize litter size. There were no differences among treatments in sow body weight at d 107 of gestation, 24 h after farrowing, or at weaning. Sow average daily feed intake from farrowing to weaning tended to increase (linear, $P = 0.093$) as phytase increased. There was no evidence for difference in the number of total born pigs, as well as the percentage of stillborns, mummies, and born alive pigs at the completion of farrowing. Similarly, phytase supplementation did not influence ($P > 0.05$) wean-to-estrus interval or litter size after cross-fostering among dietary treatments. Although not significant (linear, $P = 0.226$), farrowing duration decreased as added phytase increased with a decrease of 47 min (12%) for 3,000 FYT compared with the control. There were no differences in pig weight at weaning, but as a result of increased survivability (linear, $P = 0.002$), litter weaning weight and overall litter weight gain increased (quadratic, $P < 0.05$) up to 1,000 FYT of added phytase with no further benefit observed in sows fed 3,000 FYT. In conclusion, sow feed intake tended to increase linearly with increasing added phytase. Feeding 1,000 FYT/kg maximized overall litter gain and weaning weight; however, a larger-scale study with more sows is needed to determine the addition of phytase in lactation diets to reduce farrowing duration.

Key words: farrowing duration, lactation, phosphorus, phytase, sow

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INTRODUCTION

Phosphorus (P) is an essential nutrient necessary for skeletal mineralization, growth, and many other physiological processes in pigs

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(Kebreab et al., 2012). Phytate (*myo*-inositol hexakisdihydrogen phosphate; IP_6), a structure with six phosphate molecules surrounding a *myo*-inositol ring, accounts for 60% to 80% of the total P storage in grains, legumes, and oilseeds (Selle and Ravindran, 2008). The requisite enzyme needed to degrade phytate-P is available through endogenous phytase produced by the mucosa of the small intestine, gut microflora phytase activity present in the large intestine, intrinsic plant phytase activity, and the inclusion of dietary exogenous phytase (Humer et al., 2015). Monogastrics are unable to completely utilize phytate-P due to poor substrate solubility in the small intestine rather than low endogenous phytase activity, leading to increased need for dietary P supplementation and excretion of phosphorus to the environment (Adeola and Cowieson, 2011).

The inclusion of high concentrations of microbial phytase in P adequate diets to improve nursery pig growth performance has been documented (Beers and Jongbloed, 1992; Gourley et al., 2018; Holloway et al., 2019). High levels of exogenous phytase are suggested to decrease antinutritional effects associated with IP_6 (phytate) through extraphosphoric pathways by increasing the digestibility of energy, amino acids, and minerals. The exact mechanisms for improvements in performance experienced from high levels of dietary phytase are unknown; however, lactating sows may benefit from feeding high concentrations of phytase such as found for nursery pigs. Parturition is a process that requires a high level of metabolic energy, as modern sow genotypes experience extended farrowing durations with increased litter size (Tokach et al., 2019). This combination can result in an increased stillborn rate (van Dijk et al., 2005). Sows are required to nurse large litters and commonly meet the demand for nutrients by mobilizing body reserves (Pedersen et al., 2019).

The inclusion of microbial phytase has been shown to increase P digestibility in sow diets (Kemme et al., 1997; Baidoo et al., 2003), although P excretion was decreased in sows fed a corn–soybean meal diet supplemented with 500 FYT/kg (Torrallardona et al., 2012). Sows also fed a low-P diet supplemented with 500 FYT/kg of phytase experienced similar performance to that of sows fed a positive control diet (Nasir et al., 2014). Data regarding phytase dose-response effects on lactating sow performance is scarce (Jongbloed et al., 2004). Wealleans et al. (2015) observed decreased body weight (BW) loss for sows fed a low-P diet supplemented with 2,000 FTU/kg of phytase. Manu et al. (2018) observed that feeding 2,500 FTU/kg of phytase in lactation diets formulated to adequate P levels had no effect on sow performance; however, a reduction in farrowing duration and the number of stillborn pigs was observed. These results are interesting to consider for the modern, high-producing sow, but there is no data available to confirm this response. Therefore, the objective of this study was to determine the effect of increasing amounts of phytase in STTD P adequate diets on farrowing duration and sow and litter performance.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the protocol for this study. The study was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. A total of 109 sows initially 240.1 ± 29.3 kg (Line 241; DNA, Columbus, NE) were used across four consecutive batch farrowing groups from November 2018 to March 2019. The average parity was 2.1 ± 1.03. On approximately d 107 of gestation, sows were weighed and moved into the farrowing house. Females were blocked by initial body weight and parity, then allotted to 1 of 3 dietary treatments within those blocks. There were 36 to 37 sows per treatment.

Dietary treatments were corn–soybean meal based and consisted of increasing concentration of phytase (0, 1,000, or 3,000 FYT/kg). The control diet containing no phytase was formulated to 0.50% standardized total tract digestible phosphorus (STTD P; 0.45% available P) and 0.62% STTD calcium (0.90% total Ca; Table 1). Coefficients for STTD P were obtained from NRC (2012), and values for STTD Ca were obtained from Stein et al. (2016). Contributions of Ca from vitamin and trace mineral premixes were accounted for in diet formulation. Both phytase diets were also formulated to 0.50% STTD P and 0.62% STTD Ca including the release of 0.132% STTD P and 0.096% STTD Ca by phytase as recommended by the manufacturer (DSM Nutritional Products, Inc., Parsippany, NJ). The same release values were used for both phytase diets. The commercially available phytase used in this study is a coated fungal phytase from *Citrobacter braakii* expressed in *Aspergillus oryzae* (Ronozyme HiPhos GT 2700, DSM Nutritional Products, Inc., Parsippany, NJ). Diets were balanced for net energy by altering amounts of choice

Table 1. Diet composition (as-fed basis)[a]

	Added phytase, FYT/kg	
Item	0	1,000/3,000
Ingredient, %		
Corn	63.27	64.31
Soybean meal, 46.5% CP	30.00	30.00
Choice white grease	2.40	2.00
Limestone	0.95	0.88
Monocalcium phosphate, 21%	1.78	1.10
Salt	0.50	0.50
L-Lysine HCL	0.18	0.18
DL-Methionine	0.05	0.05
L-Threonine	0.10	0.10
L-Valine	0.12	0.12
Sow add pack[b]	0.25	0.25
Vitamin premix[c]	0.25	0.25
Trace mineral premix[d]	0.15	0.15
Phytase[e]	–	0.04/0.11
Total	100	100
Calculated analysis		
Standardized ileal digestible (SID) amino acids, %		
Lysine	1.05	1.05
Isoleucine:lysine	68	68
Leucine:lysine	141	142
Methionine:lysine	30	30
Methionine and cysteine:lysine	56	56
Threonine:lysine	67	67
Tryptophan:lysine	20.1	20.1
Valine:lysine	85	85
Total lysine, %	1.19	1.19
Net energy, kcal/kg	2,499	2,499
SID Lysine:NE, g/Mcal	4.19	4.19
Crude protein, %	19.9	20.0
STTD[f] Ca, %	0.62	0.62
Phytate P %	0.25	0.25
STTD[f] P, %	0.50	0.50

[a]Lactation diets were fed from d 107 of gestation until d 18 of lactation. Diets were fed in meal form.

[b]Provided per kg of premix: 80 mg chromium; 1,653,467 IU vitamin A; 8,818 IU vitamin E; 88 mg biotin; 880 mg folic acid; 396 mg pyridoxine; 220,000 mg choline; 19,800 mg carnitine.

[c]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D; 22,455 IU vitamin E; 1,764 mg vitamin K; 15 mg B12; 19,841 mg niacin; 11,023 mg pantothenic acid; 3,307 mg riboflavin.

[d]Provided per kg of premix: 73 g from Zn sulfate; 73 g Fe from iron sulfate; 22 g Mn from manganese oxide; 11 g Cu from copper sulfate; 0.2 I from calcium iodate; 0.2 Se from sodium selenite.

[e]Ronozyme HiPhos 2700, DSM Nutritional Products Inc., Parsippany, NJ.

[f]STTD, standardized total tract digestible.

white grease. All other nutrients met or exceeded the NRC (2012) requirement estimates.

From d 107 of gestation until farrowing (approximately d 116), sows were offered up to 2.7 kg/d of their respective treatment diets. Postpartum, sows were allowed *ad libitum* access to feed distributed by an electronic feeding system (Gestal Solo Feeders Jyga Technologies, Quebec City, QC, Canada). Sow feed intake was recorded by weighing the amount of feed placed in a feed hopper and the amount remaining every 7 d until weaning (d 18 ± 3).

Farrowing duration was monitored by 24-h care where the initiation of farrowing was classified as the birth of the first piglet, and the completion of farrowing was determined by the first dispersal of placental tissues with no subsequent pigs born. From the onset of farrowing, sows were checked in 15-min intervals and were sleeved if the time between births reached 30 to 45 min. Oxytocin (Bimeda, Inc., Oakbrook Terrace, IL) was administered in 1 or 2 cc doses to gilts and sows, respectively, who produced no piglets when sleeved and the time in between births was greater than approximately 2 h. Sows were excluded from the study if retained fetuses were expelled 24 h after a sow's parturition time was recorded (6 sows) or if initial farrowing time could not be determined (2 sows). Farrowing duration data were collected on 101 of the 109 sows enrolled in the study. Sow body weight was measured 24 h after farrowing and at weaning. Cross fostering occurred within dietary treatment until 48-h postpartum in an attempt to equalize litter size (minimum of 10 pigs per litter). Litters were weighed on d 2, 7, and 14 postfarrowing and at weaning. Piglet survivability was calculated as the number of pigs weaned per sow divided by the number of pigs on d 2 after cross fostering was completed.

At weaning (average of 18.2 d post farrowing and range of 15 to 21 d), sows were moved to a breeding barn, individually housed, and checked daily for signs of estrus using a boar. The wean-to-estrus interval (WEI) was determined as the number of days between weaning and when sows were first observed to show a positive response to the back-pressure test.

Diets were manufactured at the Kansas State University O.H. Kruse Feed Technology Innovation Center in Manhattan, KS. A new batch of each treatment diet was manufactured for each farrowing group and packaged in 22-kg bags. During bagging, feed samples were collected from every fifth bag, pooled, and stored at –20°C and later homogenized for nutrient analysis.

Four samples (one per batch) per dietary treatment from the pooled feed samples were sent to a commercial laboratory (Ward Laboratories, Kearney, NE) for CP (AOAC 2006), Ca (method

6.3; Kovar, 2003), and P analysis (method 6.3; Kovar, 2003). In addition, four samples (one per batch) per dietary treatment were sent to another laboratory (DSM Nutritional Products, Inc., Belvidere, NJ) for phytase analysis (Table 2).

Statistical analysis

Data were analyzed using the lmer function from the lme4 package in R (version 3.5.1 2018-07-12), where sow was the experimental unit, dietary treatment was a fixed effect, and sow group and block were random effects. Statistical models were fit using RStudio (Version 3.5.2, R Core Team, Vienna, Austria). Preplanned linear and quadratic contrast statements were used to evaluate increasing phytase concentration. Predetermined polynomial orthogonal contrasts were used to account for unequal spacing in phytase doses.

Sow ADFI, BW, litter weight, litter gain, piglet gain, and lactation length were analyzed, assuming a normal distribution of the response variable. Litter weight on d 2 was used as a covariate for d 7, 14, and weaning litter weights and litter weight gain to improve the fit of the model. Pig weight on d 2 was used as a covariate for d 7, 14, and weaning pig weights to improve the fit of the model. In these cases, residual assumptions were checked using standardized residuals and were found to be reasonably met.

Litter counts, wean-to-estrus interval, and the duration of farrowing were analyzed using a negative binomial distribution. Total born, born alive, stillborn, mummified fetuses, and piglet survivability were analyzed using a binomial distribution. All results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.10$.

Table 2. Chemical analysis of diets (as-fed basis)[a]

	Added phytase, FYT/kg		
Item, %	0	1,000	3,000
Dry matter	88.43	88.03	87.94
Crude protein	19.7	20.2	20.4
Ca	0.94	0.79	0.76
P	0.66	0.54	0.54
Phytase, FYT[b]	17	1,261	3,744

[a]Diet samples were collected from each batch of feed at manufacturing from every fifth bag. Nutrient analysis was conducted on composite samples (Ward Laboratories Inc., Kearney, NE).

[b]Phytase analyzed at DSM Nutritional Products Inc., Technical Marketing Analytical Services, Belvidere, NJ.

RESULTS AND DISCUSSION

Chemical Analysis

Chemical analysis of DM, CP, Ca, and P of the experimental diets were similar to the formulated values (Table 2). Analyzed phytase concentration increased as phytase addition increased as anticipated.

Sow Performance

Phytase is commonly added to swine diets at 500 to 1,000 FTU/kg to release 0.10 to 0.15% available P (Wilcock and Walk, 2016) and higher concentrations of 1,500 FTU/kg or above are considered "super-dosing" levels. The main objective of this study was to determine if the extraphosphoric effects of feeding "super-dose" levels of phytase to lactating sows with diets formulated to adequate P levels influences sow or litter performance.

The addition of microbial phytase to sow diets formulated to low levels of P has been well documented to improve P digestibility resulting in a reduction of fecal P excretion (Kemme et al., 1997; Nasir et al., 2014), while maintaining performance through lactation (Baidoo et al., 2003; Jongbloed et al., 2004). In our study, there were no differences observed among treatments in body weight at d 107 of gestation, 24 h after farrowing, or at weaning (Table 3). Regardless of dietary treatment, sows lost an average of 10.5 kg due to the inability of voluntary feed intake to completely support nutrient demands during lactation. A previous study observed a decrease in BW loss experienced by lactating sows when fed 2,000 FTU/kg of phytase in a diet with P levels below NRC (2012) requirement estimates (Wealleans et al., 2015). While no differences between treatments were observed in our study, this could be attributed to all treatment diets formulated to meet or exceed NRC (2012) requirement estimates.

Phytate has been suggested to be an appetite suppressant, thus feed intake may be increased by improving digestible nutrient intake with phytate degradation (Cowieson et al., 2011; Morales et al., 2016). From d 0 to 7 and 7 to 14 of lactation, ADFI was similar across treatments; however, from d 14 to weaning ADFI increased (linear, $P = 0.020$) with increasing dietary phytase and overall ADFI tended to increase (linear, $P = 0.093$) as phytase dosage increased. Average daily feed intake in the current study was 5.8 kg, similar to intake levels observed by Wealleans et al. (2015); however, in

Table 3. Effect of high phytase supplementation in lactation diets on sow performance[a]

	Added phytase, FYT/kg[b]			Probability, P =		
	0	1,000	3,000	SEM	Linear	Quadratic
Number of sows, n	36	36	37	–	–	–
Parity	2.1	2.1	2.1	1.13	0.990	0.924
Sow body weight, kg						
d 107[c]	240.2	243.9	236.2	4.89	0.452	0.418
Postfarrow	230.1	232.7	232.6	4.59	0.424	0.475
Wean	219.5	221.9	221.9	4.30	0.507	0.551
Change (farrow to wean)	-10.5	-10.6	-10.6	1.64	0.943	0.943
Sow ADFI, kg						
d 0 to 7	4.3	4.7	4.6	0.13	0.140	0.144
d 7 to 14	6.2	6.4	6.5	0.18	0.367	0.793
d 14 to wean	6.8	7.2	7.4	0.20	0.020	0.264
Farrow to wean	5.6	5.9	6.0	0.13	0.093	0.285
Farrowing duration, min[d]	398	376	351	30.0	0.226	0.873
Lactation length, d	18.1	18.3	18.1	0.18	0.586	0.366
Wean to estrus, d	4.8	4.6	4.6	1.08	0.707	0.710

[a]A total of 109 sows (DNA Genetics, Columbus, NE) and their litters were used.

[b]Ronozyme HiPhos 2700, DSM Nutritional Products Inc., Parsippany, NJ.

[c]Dietary treatments were fed from the time when sows were loaded into the farrowing room at d 107 of gestation until weaning (d 18 of lactation).

[d]Farrowing duration was determined for a total of 101 sows and excludes any sow that expelled a retained fetus 24 h past the parturition of the initial piglet or initial time of farrowing could not be confirmed. The initiation of farrowing was classified as the birth of the first piglet, and the completion of farrowing was determined by the first dispersal of placental tissues with no subsequent pigs born.

contrast, those authors observed no differences in sow feed intake regardless of phytase level. In addition, Manu et al. (2018) observed no influence of up to 2,500 FTU/kg added phytase on sow ADFI from d 109 of gestation to weaning. In some studies, "super-dose" levels of phytase fed to weanling pigs resulted in increased ADFI (Beers and Jongbloed, 1992; Kies et al., 2006), but in others, no differences were found (Gourley et al., 2018; Holloway et al., 2019), as these responses could be attributed to basal diets formulated at or below the P requirement. The mechanisms of "super dosing" phytase are still unknown, although the available literature is not clear on the effect of high levels of phytase on feed intake (Adeola and Cowieson, 2011). The efficacy of phytase is dependent on numerous factors including dietary Ca:P ratios, solubility of phytate in the gut, amount of added phytase, phytase source, and especially phytate substrate levels (Selle and Ravindran, 2008).

To evaluate increasing phytase level on farrowing duration, treatment diets were fed approximately 1 wk before farrowing. There was no statistical difference (linear, $P = 0.226$) in farrowing duration; however, farrowing duration numerically decreased with increasing phytase dose. They observed a significant reduction in farrowing duration from 710.4 ± 83.63 to 521.5 ± 45.24 min monitoring 25 sows using infrared video cameras. In the present study, farrowing duration was generally much shorter averaging from 398 to 351 min, which could be attributed to differences in farrowing assistance protocols or litter size between studies. However, we still observed on average a 22- and 47-min reduction in farrowing duration when 1,000 or 3,000 FYT/kg of phytase, respectively, was fed.

Litter Performance

There was no evidence for difference in total born, percentage born alive, stillborn, or mummified pigs among dietary treatments (Table 4). Furthermore, the number of pigs at weaning and individual pig weight and weight gain were not affected by increasing added phytase. Interestingly, pig survivability increased (linear, $P = 0.002$) as added phytase increased. No evidence for differences was found for litter weight at d 2 or 7; however, litter weaning weight increased (quadratic, $P = 0.039$) and overall litter gain increased (quadratic, $P = 0.047$) with sows fed 1,000 FYT/kg having the heaviest litters. The NRC (2012) model for lactating sows was used to predict the cause of increased litter weaning weight, overall litter gain, and pig survivability for pigs born to sows fed diets supplemented with phytase. Sows fed high phytase levels had increased feed intake, as the NRC model estimated milk production increased from 9.3 to 9.8 and 9.9 kg/d with increasing concentration of phytase. Sow body weight loss projected whole-body

Table 4. Effect of high phytase supplementation in lactation diets on litter performance[a]

	Added phytase, FYT/kg[b]			Probability, P =		
	0	1,000	3,000	SEM	Linear	Quadratic
No. of sows	36	36	37	–	–	–
Farrowing performance						
Total born	17.4	17.8	16.2	0.68	0.135	0.316
Born alive, %[c]	91.8	90.7	91.3	1.18	0.839	0.478
Stillborn, %[c]	5.8	6.6	6.0	1.20	0.995	0.541
Mummified, %[c]	2.0	2.4	2.4	1.35	0.710	0.729
Litter count, n						
d 2[d]	14.7	15.0	13.9	1.04	0.252	0.428
Wean	12.9	13.7	13.1	1.05	0.961	0.337
Piglet survivability, %[e]	88.3	91.3	94.2	1.20	0.002	0.676
Litter weight, kg						
d 2[f]	21.0	20.9	21.2	0.60	0.760	0.816
d 7[g]	32.9	34.1	33.7	0.46	0.278	0.108
d 14[g]	55.4	58.0	56.6	1.00	0.551	0.053
Wean[g]	67.5	71.5	69.2	1.41	0.613	0.039
Litter average daily gain, g[g]	2,866	3,092	2,989	79.4	0.427	0.053
Overall litter gain, kg	46.3	50.3	48.2	1.55	0.543	0.047
Pig weight, kg						
d 2	1.4	1.5	1.4	0.04	0.794	0.346
d 7[h]	2.5	2.4	2.5	0.03	0.210	0.119
d 14[h]	4.2	4.2	4.4	0.08	0.154	0.302
Wean[h]	5.2	5.2	5.4	0.12	0.281	0.457
Pig weight gain, g[i]	3,753	3,758	3,906	124.9	0.351	0.771

[a]A total of 109 sows (DNA Genetics, Columbus, NE) and their litters were used. Treatment diets were fed starting on d 107 of gestation until weaning (d 18 of lactation).

[b]Ronozyme HiPhos 2700, DSM Nutritional Products Inc., Parsippany, NJ.

[c]Percent of total born.

[d]Cross-fostering occurred within treatment in an attempt to equalize litter size.

[e]Piglet survivability = litter count at weaning/litter count on d 2.

[f]Litters were weighed at 48 h after cross-fostering.

[g]Litter weight on d 2 was used as a covariate.

[h]Pig weight on d 2 was used as a covariate.

[i]Pig weight gain = pig weight at weaning minus pig weight at d 2.

protein and lipid deposition across treatments were similar; therefore, we concluded that sows fed high levels of phytase were able to produce more milk per day, which increased piglet survivability.

In conclusion, our results demonstrate that supplementing high levels of phytase in lactation diets linearly increased feed intake in lactating sows. Sows fed diets with 1,000 FYT/kg phytase had increased overall litter gain and weaning weight. The number of pigs surviving to weaning increased with increasing phytase up to 3,000 FYT/kg. Although not significant, farrowing duration numerically decreased for sows fed up to 3,000 FYT/kg, which supports the need for additional research with more sows to determine the phytase impact on farrowing duration. This study presents interesting impacts on sow and litter performance due to high inclusions of dietary phytase; however, a commercial trial with more sows is warranted to determine the effects on farrowing duration.

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