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F. Wu
Kansas State University, Manhattan, fangzhou@k-state.edu

M. D. Tokach
Department of Animal Science and Industry, Kansas State University, mtokach@ksu.edu

J. M. DeRouchey
Kansas State University, Manhattan, jderouch@k-state.edu

See next page for additional authors

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Effects of Dietary Calcium and Phosphorus Concentrations and Addition of Phytase on Growth Performance of Nursery Pigs[1]

F. Wu, M.D. Tokach, J.M. DeRouchey, S.S. Dritz,[2] J.C. Woodworth, and R.D. Goodband

Summary

A total of 720 nursery pigs (PIC 1050 × 280, initially 13.4 ± 0.47 lb) were used in a 42-d growth study to determine the effects of feeding 2 calcium (Ca) and 3 standardized total tract digestible (STTD) phosphorus (P) concentrations on growth performance and bone ash content. Pens of pigs (10 pigs/pen, 12 pens/treatment) were blocked by initial pen weight, and within blocks pens were allotted randomly to 1 of 6 dietary treatments. Dietary treatments were arranged in a 2 × 3 factorial, with 2 levels of Ca (0.58 vs. 1.03%) and 3 levels of STTD P (0.33 and 0.45% without phytase, and 0.45% with 0.12% of the P being released by phytase). Diets were provided in 3 phases, with pigs fed experimental diets during phase 1 (d 0 to 14) and phase 2 (d 14 to 28), followed by a common phase 3 diet from d 28 to 42. For the majority of the feeding periods, Ca × P interactions were observed for growth responses ($P < 0.05$). From d 0 to 28, when diets contained low Ca concentration, pigs fed 0.45% STTD P with phytase had greater ($P < 0.01$) ADG and ADFI compared with those fed 0.45% STTD P without phytase or 0.33% STTD P. When high Ca was fed, ADG and ADFI were similar among pigs fed 0.45% STTD P with or without phytase but were greater than those fed 0.33% STTD P. Feed efficiency was poorer ($P < 0.01$) when low STTD P and high Ca were added to diet compared with other dietary treatments. During phase 3, pigs previously fed 0.33% STTD P had similar ADG, but decreased ($P < 0.05$) ADFI and improved F/G compared with pigs previously fed 0.45% STTD P with or without phytase. However, pigs fed 0.33% STTD P, with high Ca were not able to fully compensate for the negative effects of P deficiency, resulting in decreased ($P < 0.05$) overall ADG and ADFI compared with pigs fed 0.45% STTD P diet with or without phytase. On d 21, 1 median-weight gilt from each pen was euthanized and fibulas were collected for analysis of bone ash content. Pigs fed 0.33% STTD P had decreased ($P < 0.05$) bone ash concentration compared with those fed 0.45% STTD P with or without phytase when high Ca was added to diets, but this P effect was not observed when diets

[1] Appreciation is expressed to DSM Nutritional Products, Inc. (Parsippany, NJ) and PIC North America (Hendersonville, TN) for their technical support and partial funding. Special appreciation is also expressed to Julie Salyer, Dr. Brad James, and Lorene Parkhurst from Kalmbach Feeds, Inc. (Sycamore, OH), for their technical support and expertise in conducting the experiment.

[2] Department of Diagnostic Medicine/Pathology, College of Veterinary Medicine, Kansas State University.

contained low Ca concentration (Ca × P interaction, $P = 0.007$). In conclusion, excess Ca in diets decreased growth performance and bone ash concentration of nursery pigs when diets were deficient in STTD P. Adding phytase to achieve 0.45% STTD P in diets improved ADG and ADFI of pigs compared with diets containing 0.45% STTD P without phytase, indicating a potential underestimation of the P release from phytase or an increased availability of other nutrients liberated by phytase.

Introduction

Appropriate dietary Ca and P concentrations are essential for nursery pig performance. Accurate formulation for Ca and P is even more important in recent years with the increased use of phytase and the desire to minimize P excretion. Research has demonstrated that feeding excess dietary Ca impairs P digestibility and, therefore, reduces growth performance and bone ash concentration in nursery[3] and growing-finishing[4,5] pigs.

Diets can have excessive Ca for multiple reasons, including variability in laboratory analysis of ingredients, neglecting the Ca content of carriers in premixes or other additives, and not accounting for Ca released by phytase. Meanwhile, diets can also be deficient in P due to formulation errors, by phytase being mistakenly not included at expected levels in the diet, or by overestimating the amount of P released for the given amount of phytase included in the diet. Therefore, the objective of this study was to evaluate the growth performance and bone ash concentration of nursery pigs in response to different combinations of dietary STTD P and Ca levels provided by monocalcium P or phytase.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in the experiment. The study was conducted at the Cooperative Research Farm's Swine Research Nursery (Kalmbach Feeds, Inc., Sycamore, OH). Each pen (5×6 ft^2) had completely slatted metal floors and was equipped with a 4-hole stainless-steel feeder and a nipple-cup waterer. Pigs were allowed ad libitum access to feed and water throughout the experiment.

A total of 720 weaned pigs (PIC 1050 × 280) were housed in 2 rooms with 36 pens per room. Upon arrival, pigs were individually weighed and assigned to pens (10 pigs/pen) in order to achieve balanced pen weights within room. After 4 d of adaptation, pens of pigs were blocked by BW (initial pig BW = 13.4 ± 0.47 lb) and allotted randomly to 1 of 6 dietary treatments (Tables 1 and 2). The dietary treatments were arranged in a 2 × 3 factorial, with 2 levels of Ca (0.58 and 1.03%) and 3 levels of STTD P (0.33% with no

[3] González-Vega, J. C., Y. Liu, J. C. McCann, C. L. Walk, J. J. Loor, and H. H. Stein. 2016. Requirement for digestible calcium by eleven- to twenty-five-kilogram pigs as determined by growth performance, bone ash concentration, calcium and phosphorus balances, and expression of genes involved in transport of calcium in intestinal and kidney cells. J. Anim. Sci. 94:3321-3334.

[4] Liu, J., D. W. Bollinger, D. R. Ledoux, and T. L. Veum. 1998. Lowering the dietary calcium to total phosphorus ratio increases phosphorus utilization in low-phosphorus corn-soybean meal diets supplemented with microbial phytase for growing-finishing pigs. J. Anim. Sci. 76:808–813.

[5] Stein, H. H., O. Adeola, G. L. Cromwell, S. W. Kim, D. C. Mahan, and P. S. Miller. 2011. Concentration of dietary calcium supplied by calcium carbonate does not affect the apparent total tract digestibility of calcium, but reduces digestibility of phosphorus by growing pigs. J. Anim. Sci. 89:2139–2144.

phytase, 0.45 with no phytase, and 0.45% with 0.12% of the P assumed to be released by phytase). All ingredients containing Ca and P were sampled and sent to Ward Laboratories, Inc. (Kearney, NE) and Cumberland Valley Analytical Services Inc. (Maugansville, MD) for analysis of Ca and P (Table 3). The average of these analyzed values were used in the diet formulation. Diets with phytase addition contained 1000 FTU of Ronozyme HiPhos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ) with an assumed releasing value of 0.12% for Ca and STTD P. Pigs were fed in 3 phases, with the experimental diets provided in phase 1 (d 0 to 14) and 2 (d 14 to 28). A common phase 3 diet was then fed to all pigs from d 28 to 42. All diets were provided in meal form. Pigs and feeders were weighed every 7 d to determine ADG, ADFI, and F/G.

Complete diet samples were obtained and delivered to the Kansas State University Swine Laboratory, Manhattan, KS, and stored at -4°F until analysis. Feed samples were analyzed for DM, CP, fat, Ca, and P at Ward Laboratories, Inc. (Kearney, NE). Concentrations of Ca and P were also analyzed at Cumberland Valley Analytical Services Inc. (Maugansville, MD) and Midwest Laboratories (Omaha, NE). The means of analyzed nutrient values are presented in Tables 1 and 2. On d 21 of the study, 1 median-weight gilt from each pen was euthanized and fibulas were collected. Bones were then transferred to the Kansas State University Swine Laboratory for analysis of bone ash. Bones were autoclaved for 60 min, adhering tissue and cartilage caps were removed, then dried at 221°F for 7 d. Dried fibulas were ashed in a muffle furnace at 1,112°F for 24 h to determine total ash weight and percentage bone ash.

Data were analyzed using the GLIMMIX procedure of SAS version 9.4 (SAS Institute, Inc., Cary, NC) in a randomized completely block design with pen as the experimental unit. The treatment effects were analyzed as in a 2 × 3 factorial, with main effects of Ca (0.58% or 1.03%) and P (0.45 with no phytase, 0.33% with no phytase, and 0.45% with 0.12% of the P assumed to be released by phytase) and their interactions as well as random effects of room and weight block within room. The initial statistical model included treatment and the effect of treatment within room as fixed effects. Because there was no evidence that the treatment effect was different across rooms, the treatment within room term was removed from the model and data from the 2 rooms were pooled in the analyses of growth performance and bone ash concentration. Means were reported as least-squares means and were separated by the PDIFF option with a Tukey–Kramer adjustment. Results were considered significant at $P < 0.05$ and marginally significant at $0.05 < P < 0.10$.

Results and Discussion

Analyzed Ca and P concentrations of dietary treatments were similar to calculated values (Table 3). The average values were slightly greater than the formulated levels but followed similar patterns as the designed treatment structure.

During phase 1 (d 0 to 14), Ca × P interactions were observed for ADG and F/G ($P < 0.05$) but not for ADFI ($P = 0.241$). Pigs fed diets containing 0.45% STTD P with phytase had greater ($P < 0.01$) ADG than pigs fed 0.45% STTD P without phytase or pigs fed 0.33% STTD P regardless of dietary Ca concentration. The ADG of pigs fed diets containing 0.45% STTD P without phytase was greater ($P < 0.001$) than that of pigs fed 0.33% STTD P when diet contained high (1.03%) Ca concentration but not for diets with low (0.58%) Ca concentration. Regardless of Ca level, feeding 0.45% STTD P with phytase improved ($P < 0.05$) ADFI compared with diets with 0.33 or 0.45% STTD P with no phytase. Pigs fed 0.45% STTD P with or without phytase exhibited better ($P < 0.10$) F/G than pigs fed 0.33% STTD P, and the magnitude of these differences was more prominent when diets contained high Ca concentrations.

During phase 2 (d 14 to 28), Ca × P interactions were observed for all growth responses ($P < 0.05$). Pigs fed diets containing 0.45% STTD P with or without phytase had greater ($P < 0.05$) ADG than those fed 0.33% STTD P when high Ca was added to diets but not for diets containing low Ca concentrations. When diets contained low Ca, feeding 0.45% STTD P with phytase resulted in greater ($P < 0.001$) ADFI than feeding the 0.33% STTD P diet, with ADFI of pigs fed 0.45% STTD P without phytase intermediate. When fed high Ca, ADFI of pigs fed 0.45% STTD P with or without phytase was greater ($P < 0.01$) than those fed 0.33% STTD P. Pigs fed 0.33% STTD P had poorer ($P < 0.10$) F/G than those fed 0.45% STTD P with or without phytase when diets contained high Ca concentration; however, no differences were observed among low Ca diets.

When combining the treatment periods (d 0 to 28), Ca × P interactions were observed for all growth responses ($P < 0.05$). When low Ca was added to diets, feeding 0.45% STTD P with phytase increased ($P < 0.01$) ADG and ADFI compared with pigs fed 0.45% STTD P without phytase and pigs fed 0.33% STTD P. However, with high Ca, ADG and ADFI were similar among pigs fed 0.45% STTD P with or without phytase but were greater than those fed 0.33% STTD P diet. Feed efficiency was worsened ($P < 0.01$) when low STTD P and high Ca were added to the diet compared with other dietary treatments. On d 28, when diets contained low Ca concentrations, pigs fed 0.45% STTD P with phytase had greater ($P < 0.01$) BW than pigs fed 0.45% STTD P without phytase and those fed 0.33% STTD P. When diets contained high Ca, BW was similar among pigs fed 0.45% STTD P with or without phytase, but was greater ($P < 0.01$) than those fed 0.33% STTD P diet.

Researchers[6,7] have suggested that high concentrations of Ca reduces P digestion and absorption by forming a Ca-P complex. Gonzalez-Vega et al.[3] reported that decreased growth performance was observed for pigs from 24 to 55 lb BW when more than 0.50% STTD Ca (approximately 0.74% analyzed Ca) was added to diets containing adequate STTD P. Observations from this study indicated that the detrimental effects of excess Ca were only observed when diets also contained deficient P concentration. Supplementing phytase to low P diets improved growth performance of pigs over those fed sufficient STTD P without phytase. It is possible that the 0.12% P and Ca release value for 1,000 FTU of phytase underestimated the true digestible P and Ca release, resulting in more Ca, P, or possibly other nutrients becoming available to the pig. In addition, this phytase response was more evident during phase 1 of the experiment, when dietary P would have been more limiting than during phase 2.

[6] Liu, J., D. W. Bollinger, D. R. Ledoux, and T. L. Veum. 1998. Lowering the dietary calcium to total phosphorus ratio increases phosphorus utilization in low-phosphorus corn-soybean meal diets supplemented with microbial phytase for growing-finishing pigs. J. Anim. Sci. 76:808–813.

[7] Stein, H. H., O. Adeola, G. L. Cromwell, S. W. Kim, D. C. Mahan, and P. S. Miller. 2011. Concentration of dietary calcium supplied by calcium carbonate does not affect the apparent total tract digestibility of calcium, but reduces digestibility of phosphorus by growing pigs. J. Anim. Sci. 89:2139–2144.

From d 28 to 42, all pigs received a common phase 3 diet. No significant Ca × P interaction was observed for ADG. Pigs previously fed 1.03% Ca had greater ($P < 0.001$) ADG than those previously fed 0.58% Ca. Pigs previously fed 0.33% STTD P tended to have greater ($P = 0.054$) ADG than those previously fed 0.45% STTD P with phytase, but similar ADG to pigs previously fed 0.45% STTD P without phytase. Pigs previously fed 0.45% STTD P with or without phytase had greater ($P < 0.05$) ADFI than those previously fed 0.33% STTD P, but the magnitude of these differences was greater in high Ca than in low Ca diets (Ca × P interaction, $P = 0.063$). For F/G, a Ca × P interaction ($P < 0.001$) was observed. When diets contained low Ca concentration, feeding 0.45% STTD P with phytase worsened ($P = 0.027$) F/G compared with pigs previously fed 0.33% STTD P, with F/G of pigs previously fed 0.45% STTD P without phytase intermediate. When high Ca was added to diets, F/G was similar among pigs previously fed 0.45% STTD P with or without phytase, but was poorer ($P < 0.01$) than those previously fed 0.33% STTD P.

Overall (d 0 to 42), Ca × P interaction was observed for all growth responses ($P < 0.10$). Feeding 0.33% STTD P decreased ($P < 0.01$) ADG compared with feeding 0.45% STTD P with or without phytase, but this effect was only observed when high Ca was added to diets. For ADFI, when diets contained low Ca concentration, feeding 0.45% STTD P with phytase resulted in greater ($P = 0.018$) ADFI than feeding 0.33% STTD P diet, with that of pigs fed 0.45% STTD P without phytase being intermediate. When high Ca was added to diets, ADFI of pigs fed 0.45% STTD P with or without phytase was greater ($P < 0.01$) than those fed 0.33% STTD P. Standardized total tract digestible P did not affect overall F/G regardless of Ca concentration; however, F/G was worsened ($P = 0.005$) by feeding 1.03% Ca compared with feeding 0.58% Ca when diets contained 0.33% STTD P. This Ca effect was not observed when diets contained 0.45% STTD P with or without phytase. Similarly, final BW of pigs fed 0.33% STTD P was decreased ($P < 0.01$) relative to pigs fed 0.45% STTD P with or without phytase when high Ca was fed with no P response with low dietary Ca concentration. During the common period of the experiment, pigs previously fed low STTD P grew faster and were more feed efficient than pigs from other treatments; however, these pigs were not able to fully compensate for the negative effects of P deficiency when diets contained excess Ca concentration.

Pigs fed 0.33% STTD P had decreased ($P < 0.05$) bone ash concentration compared with those fed 0.45% STTD P with or without phytase when high Ca was added to diets, but this P effect was not observed among treatments with low Ca concentration (Ca × P interaction, $P = 0.007$). Response of bone ash to Ca and STTD P concentrations generally followed a similar pattern as ADG; however, the growth promoting effects of phytase was not observed for bone ash content. This observation is in contrast with the growth performance data, where it appeared that the P release by adding phytase was underestimated because bone ash concentration is a sensitive indicator of available P. Therefore, it is possible that the beneficial effect of phytase on growth performance was a result of other nutritional compounds liberated by phytase.

In summary, these results suggest that feeding excess dietary Ca negatively affects growth performance and bone ash deposition of nursery pigs when diets are deficient in STTD P. Moreover, the diet including phytase to achieve 0.45% STTD P slightly improved ADG and ADFI of pigs compared with diets containing 0.45% STTD P without phytase, and this effect was especially evident during the early nursery phase. Future research is need to determine if this promoting effect of phytase is due to an underestimation of releasing ability for 1,000 FTU of Ronozyme HiPhos 2500 or increased availability of other nutrients.

Table 1. Diet formulation, phase 1 (as-fed basis)

	Phase 1 (d 0 to 14)					
Calcium, %:	0.58	1.03	0.58	1.03	0.58[1]	1.03[1]
STTD P, no phytase, %:	0.45	0.45	0.33	0.33	0.33	0.33
STTD P, with phytase, %:	-	-	-	-	0.45	0.45
Ingredients, %						
Corn	43.32	41.16	44.02	41.86	44.49	42.40
Soybean meal	25.23	25.38	25.18	25.33	25.15	25.29
HP 300[2]	6.00	6.00	6.00	6.00	6.00	6.00
Dried whey	20.00	20.00	20.00	20.00	20.00	20.00
Beef tallow	2.45	3.25	2.20	3.00	2.05	2.80
Monocalcium P (21% P)	0.87	0.88	0.19	0.20	0.19	0.20
Limestone	0.34	1.52	0.62	1.80	0.29	1.47
Salt	0.45	0.45	0.45	0.45	0.45	0.45
L-Lys HCl	0.38	0.38	0.38	0.38	0.38	0.38
DL-Met	0.23	0.23	0.23	0.23	0.23	0.23
L-Thr	0.18	0.18	0.18	0.18	0.18	0.18
L-Trp	0.03	0.03	0.03	0.03	0.03	0.03
L-Val	0.08	0.09	0.08	0.09	0.08	0.09
Trace mineral premix	0.09	0.09	0.09	0.09	0.09	0.09
Vitamin premix	0.05	0.05	0.05	0.05	0.05	0.05
Choline chloride	0.04	0.04	0.04	0.04	0.04	0.04
Phytase[3]	-	-	-	-	0.04	0.04
Zinc oxide	0.27	0.27	0.27	0.27	0.27	0.27
Selenium	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00

continued

Table 1, *continued*. Diet formulation, phase 1 (as-fed basis)

	Phase 1 (d 0 to 14)					
Calcium, %	0.58	1.03	0.58	1.03	0.58[1]	1.03[1]
STTD P, no phytase, %:	0.45	0.45	0.33	0.33	0.33	0.33
STTD P, with phytase, %	-	-	-	-	0.45	0.45
Calculated composition						
Standardized ileal digestible (SID) AA,[4] %						
Lys	1.40	1.40	1.40	1.40	1.40	1.40
Ile:Lys	61	61	61	61	61	61
Leu:Lys	116	115	116	115	116	115
Met:Lys	37	37	37	37	37	37
Met and Cys:Lys	58	58	58	58	58	58
Thr:Lys	65	65	65	65	65	65
Trp:Lys	20	20	20	20	20	20
Val:Lys	70	70	70	70	70	70
Total Lys, %	1.53	1.53	1.53	1.53	1.53	1.53
CP, %	20.98	20.92	21.01	20.95	21.02	20.96
NE, kcal/lb	1,165	1,165	1,165	1,166	1,166	1,165
Ca, no phytase, %	0.58	1.03	0.58	1.03	0.46	0.91
Ca, with phytase, %	0.58	1.03	0.58	1.03	0.58	1.03
STTD P, no phytase, %	0.45	0.45	0.33	0.33	0.33	0.33
STTD P, with phytase, %	0.45	0.45	0.33	0.33	0.45	0.45
Total P, %	0.66	0.66	0.52	0.52	0.52	0.52
Analyzed composition, %						
DM	92.17	91.61	91.31	91.52	91.76	91.22
CP	20.45	21.55	21.90	21.10	22.15	21.40
Fat	4.40	5.05	4.35	4.95	3.75	4.65
Ca[5]	0.65	1.00	0.56	0.93	0.60	0.87
P[5]	0.74	0.81	0.61	0.62	0.62	0.61

[1] Phytase (Ronozyme HiPhos 2500) was added to diets at the level of 1,000 FTU with assumed release value of 0.12% for calcium (Ca) and standardized total tract digestible (STTD) phosphorus (P).

[2] Hamlet Protein, Inc., Findlay, OH.

[3] Ronozyme HiPhos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ).

[4] AA = amino acids.

[5] Averaged across analyzed values from Ward Laboratories, Inc. (Kearney, NE), Cumberland Valley Analytical Services Inc. (Maugansville, MD), and Midwest Laboratories (Omaha, NE).

Table 2. Diet formulation, phase 2 and 3 (as-fed basis)[1]

	Phase 2						Phase 3
Ca, %:	0.58	1.03	0.58	1.03	0.58[2]	1.03[2]	0.86
STTD P, no phytase, %:	0.45	0.45	0.33	0.33	0.33	0.33	0.37
STTD P, with phytase, %:	-	-	-	-	0.45	0.45	0.47
Ingredients, %							
Corn	51.48	49.34	52.18	50.04	52.70	50.56	59.47
Soybean meal	29.59	29.74	29.54	29.69	29.50	29.65	35.15
HP 300[3]	3.00	3.00	3.00	3.00	3.00	3.00	-
Dried whey	10.00	10.00	10.00	10.00	10.00	10.00	-
Beef tallow	2.45	3.25	2.20	3.00	2.00	2.80	2.00
Monocalcium P (21% P)	1.27	1.28	0.59	0.60	0.59	0.60	1.22
Limestone	0.38	1.56	0.66	1.84	0.33	1.51	1.06
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.35
L-Lys HCl	0.38	0.38	0.38	0.38	0.38	0.38	0.29
DL-Met	0.20	0.20	0.20	0.20	0.20	0.20	0.15
L-Thr	0.18	0.18	0.18	0.18	0.18	0.18	0.13
L-Trp	0.03	0.03	0.03	0.03	0.03	0.03	0.01
L-Val	0.09	0.09	0.09	0.09	0.09	0.09	-
Trace mineral premix	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Vitamin premix	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Choline chloride	0.04	0.04	0.04	0.04	0.04	0.04	-
Phytase[4]	-	-	-	-	0.04	0.04	0.02
Zinc oxide	0.27	0.27	0.27	0.27	0.27	0.27	-
Selenium	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

continued

Table 2, *continued*. Diet formulation, phase 2 and 3 (as-fed basis)[1]

	Phase 2						Phase 3
Ca, %:	0.58	1.03	0.58	1.03	0.58[2]	1.03[2]	0.86
STTD P, no phytase, %:	0.45	0.45	0.33	0.33	0.33	0.33	0.37
STTD P, with phytase, %:	-	-	-	-	0.45	0.45	0.47
Calculated composition							
Standardized ileal digestible (SID) AA[5], %							
Lys	1.35	1.35	1.35	1.35	1.35	1.35	1.27
Ile:Lys	61	60	61	61	61	61	64
Leu:Lys	118	117	119	118	119	118	127
Met:Lys	36	36	36	36	36	36	35
Met and Cys:Lys	58	58	58	58	58	58	59
Thr:Lys	65	65	65	65	65	65	64
Trp:Lys	20	20	20	20	20	20	20
Val:Lys	71	71	71	71	71	71	68
Total Lys, %	1.49	1.49	1.49	1.49	1.49	1.49	1.42
CP, %	20.66	20.59	20.68	20.61	20.70	20.63	20.65
NE, kcal/lb	1,150	1,150	1,150	1,151	1,150	1,150	1,125
Ca, no phytase, %	0.58	1.03	0.58	1.03	0.46	0.91	0.76
Ca, with phytase, %	0.58	1.03	0.58	1.03	0.58	1.03	0.86
STTD P, no phytase, %	0.45	0.45	0.33	0.33	0.33	0.33	0.37
STTD P, with phytase, %	0.45	0.45	0.33	0.33	0.45	0.45	0.47
Total P, %	0.68	0.68	0.54	0.54	0.55	0.54	0.62
Analyzed composition, %							
DM	90.30	90.60	89.94	90.92	90.73	90.33	88.76
CP	21.35	21.45	23.05	22.10	22.35	21.10	21.80
Fat	4.50	4.95	4.75	4.80	4.25	4.45	4.45
Ca[6]	0.65	1.37	0.63	1.32	0.54	1.13	0.75
P[6]	0.78	0.76	0.69	0.65	0.64	0.62	0.69

[1] Phase 2 diets were fed from d 14 to 28 and phase 3 diet were fed from d 28 to 42.

[2] Phytase (Ronozyme HiPhos 2500) was added to diets at the level of 1000 FTU with assumed release value of 0.12% for calcium (Ca) and standardized total tract digestible (STTD) phosphorus (P).

[3] Hamlet Protein, Inc., Findlay, OH.

[4] Ronozyme HiPhos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ).

[5] AA = amino acids.

[6] Averaged across analyzed values from Ward Laboratories, Inc. (Kearney, NE), Cumberland Valley Analytical Services Inc. (Maugansville, MD), and Midwest Laboratories (Omaha, NE).

Table 3. Analyzed calcium (Ca) and phosphorus (P) concentrations in feed ingredients (as-fed basis)

	Ca, %			P, %		
	Ward[1]	CVAS[2]	Average	Ward[1]	CVAS[2]	Average
Corn	0.06	0.02	0.04	0.28	0.23	0.26
Soybean meal	0.35	0.31	0.33	0.63	0.62	0.62
HP 300[3]	0.39	0.37	0.38	0.72	0.72	0.72
Dried whey	0.84	0.86	0.85	0.86	0.87	0.86
Monocalcium P (21% P)	15.80	15.85	15.83	22.00	19.01	20.50
Limestone	36.48	39.55	38.02	0.01	0.01	0.01
Trace mineral premix	7.44	8.03	7.74	0.01	0.00	0.01
Vitamin premix	12.58	13.69	13.13	0.07	0.04	0.05
Phytase[4]	11.77	12.87	12.32	0.11	0.05	0.08
Selenium	35.66	40.41	38.04	0.02	0.02	0.02

[1] Ward Laboratories, Inc. (Kearney, NE); samples were analyzed in duplicates and average values were used in diet formulation.

[2] Cumberland Valley Analytical Services (CVAS) Inc. (Maugansville, MD); samples were analyzed in duplicate and average values were reported.

[3] Hamlet Protein, Inc., Findlay, OH.

[4] Ronozyme HiPhos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ).

Table 4. Effects of calcium (Ca) and phosphorus (P) concentrations on growth performance of nursery pigs[1]

	Treatment							Probability, P <		
Ca, %:	0.58	0.58	0.58[2]	1.03	1.03	1.03[2]				
STTD P, no phytase, %:	0.33	0.45	0.33	0.33	0.45	0.33				
STTD P, with phytase, %:	-	-	0.45	-	-	0.45	SEM[3]	Ca × P	Ca	P
BW, lb										
d 0	13.4	13.4	13.4	13.4	13.4	13.4	0.40	0.693	0.266	0.191
d 14	19.7[bc]	20.1[b]	22.1[a]	19.0[c]	20.5[b]	22.0[a]	0.61	0.016	0.413	0.001
d 28	36.2[c]	36.2[c]	39.2[a]	32.9[d]	37.1[bc]	38.2[ab]	0.49	0.001	0.002	0.001
d 42	60.9[ab]	60.8[ab]	63.1[a]	58.9[b]	62.2[a]	63.3[a]	0.87	0.014	0.837	0.001
d 0 to 14 (phase 1)										
ADG, lb	0.45[bc]	0.48[b]	0.62[a]	0.39[c]	0.51[b]	0.62[a]	0.019	0.019	0.393	0.001
ADFI, lb	0.60[b]	0.60[b]	0.75[a]	0.59[b]	0.64[b]	0.74[a]	0.019	0.241	0.594	0.001
F/G	1.34[b]	1.26[bc]	1.20[c]	1.51[a]	1.25[c]	1.20[c]	0.021	0.001	0.003	0.001
d 14 to 28 (phase 2)										
ADG, lb	1.18[a]	1.15[a]	1.20[a]	0.99[b]	1.18[a]	1.15[a]	0.030	0.001	0.002	0.001
ADFI, lb	1.60[c]	1.63[bc]	1.72[ab]	1.57[c]	1.72[ab]	1.74[a]	0.034	0.050	0.173	0.001
F/G	1.36[d]	1.42[cd]	1.43[cd]	1.58[a]	1.46[bc]	1.51[ab]	0.018	0.001	0.001	0.123
d 0 to 28										
ADG, lb	0.81[c]	0.81[c]	0.91[a]	0.69[d]	0.84[bc]	0.88[ab]	0.015	0.001	0.002	0.001
ADFI, lb	1.09[c]	1.10[bc]	1.22[a]	1.07[c]	1.16[ab]	1.23[a]	0.016	0.042	0.217	0.001
F/G	1.35[b]	1.37[b]	1.35[b]	1.56[a]	1.39[b]	1.40[b]	0.013	0.001	0.001	0.001
d 28 to 42 (phase 3)										
ADG, lb	1.76[ab]	1.76[ab]	1.71[b]	1.86[a]	1.80[ab]	1.80[ab]	0.033	0.428	0.001	0.068
ADFI, lb	2.33[c]	2.35[ab]	2.37[ab]	2.30[c]	2.47[a]	2.41[ab]	0.032	0.063	0.093	0.007
F/G	1.32[b]	1.34[ab]	1.39[a]	1.24[c]	1.38[ab]	1.34[ab]	0.026	0.001	0.013	0.001
d 0 to 42										
ADG, lb	1.11[ab]	1.11[ab]	1.16[a]	1.06[b]	1.14[a]	1.17[a]	0.015	0.020	0.806	0.001
ADFI, lb	1.55[c]	1.56[bc]	1.64[ab]	1.53[c]	1.64[ab]	1.65[a]	0.020	0.044	0.130	0.001
F/G	1.40[b]	1.41[ab]	1.41[ab]	1.45[a]	1.44[a]	1.42[ab]	0.010	0.052	0.001	0.588
Bone ash,[4] %	44.11[bc]	45.62[ab]	45.75[ab]	42.63[c]	47.95[a]	45.50[ab]	0.611	0.007	0.692	0.001

[1] A total of 720 mixed gender pigs (PIC 1050 × 280) with initial BW of 13.4 ± 0.49 lb were used in a 42-d growth trial with 10 pigs per pen and 12 replications (pen) per treatment. One pen from 0.58% calcium (Ca) + 0.45% standardized total tract digestible (STTD) phosphorus (P) treatment encountered issues with feeder allowance and had restricted feed intake; therefore, data from this pen were excluded from all the analyses.

[2] Phytase (Ronozyme HiPhos 2500) was added to diets at the level of 1,000 FTU with assumed release value of 0.12% for Ca and STTD P.

[3] SEM = standard error of the mean.

[4] Fibula samples collected from 1 median-weight gilt from each pen on d 21.

[abcd] Means with different superscripts within a row differ ($P < 0.05$).