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# Evaluating HiPhorius Phytase in Two Diet Formulation Strategies on Finishing Pig Growth Performance, Serum Chemistry, Bone Mineralization, and Carcass Characteristics

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# Evaluating HiPhorius Phytase in Two Diet Formulation Strategies on Finishing Pig Growth Performance, Serum Chemistry, Bone Mineralization, and Carcass Characteristics

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# Evaluating HiPhorius Phytase in Two Diet Formulation Strategies on Finishing Pig Growth Performance, Serum Chemistry, Bone Mineralization, and Carcass Characteristics[1]

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## Summary

Two experiments were conducted to determine the effects of HiPhorius (DSM Nutritional Products, Parsippany, NJ) phytase on finishing pig growth performance, serum chemistry, bone mineralization, and carcass characteristics. In Exp. 1, 1,161 pigs (PIC 337 × 1050; initially 80.9 ± 1.06 lb) were used in a 105-d trial. There were 27 pigs per pen and 10 or 11 replications per treatment. Treatments consisted of: 1) Control diet with no added phytase and formulated to NRC (2012)[4] requirement estimates for standard total tract digestible (STTD) P; 2) 600 FYT/kg added phytase formulated to the same STTD P as the control diet considering a release of 0.13% STTD P and 0.095% STTD Ca; 3) 1,000 FYT/kg added phytase formulated to the same STTD P as the control diet considering release of 0.16% STTD P and 0.107% STTD Ca; and 4) high STTD P (no phytase; approximately 22% above NRC requirement estimates). All diets were formulated to a 1.30:1 STTD Ca:STTD P ratio. Overall, pigs fed NRC (2012) or high STTD P had increased ADG ($P < 0.05$) compared to pigs fed the treatments with added phytase. Pigs fed diets with phytase tended to have decreased ($P = 0.056$) 25-hydroxyvitamin-$D_3$ compared to pigs fed NRC levels of STTD P without phytase. In Exp. 2, 1,160 pigs (PIC 337 × 1050; initially 167.4 ± 2.92 lb) were used in a 58-d trial. There were 27 pigs per pen and 11 replications per treatment. Treatments were the same as in Exp. 1, except diets were formulated to the same total Ca:P ratio (the phase 1 ratio was 1.15:1; the phase 2 ratio was 1.12:1) without an STTD Ca release consideration from phytase. Overall, there were no differences in ADG, ADFI, or F/G among treatments ($P > 0.10$). For pigs fed NRC or high STTD P, there was an increase ($P < 0.05$) in metacarpal bone density, and a tendency for increased bone ash weight (g) ($P < 0.10$) and percentage bone ash ($P < 0.10$) compared to pigs fed treatments

[1] The authors appreciate DSM Nutrition Products North America (Parsippany, NJ) for partial financial support.

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[3] DSM Nutritional Products North America, Parsippany, NJ.

[4] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298

containing phytase. In conclusion, regardless of diet formulation strategy, pigs fed diets with phytase had decreased growth performance (Exp. 1) and bone mineralization (Exp. 2). The unexpected result may be caused by several, or a combination of, factors, such as low or no monocalcium phosphate being included in the diets with phytase, lower analyzed than formulated P (based on sampled diets), not enough phytate-bound P in the diets for phytase to provide sufficient P, too wide of an analyzed Ca:P ratio that may have reduced phytase activity compared to the intended Ca:P ratio, or the expected P attributed to the phytase being overestimated.

## Introduction

Phytase is an enzyme commonly added to swine diets to improve the digestibility of phytate-bound-phosphorus. Exogenous phytase has also been proven to improve calcium (Ca) digestibility.[5] Phytate or phytic acid is a six-fold dihydrogen phosphate ester of inositol that is the major storage form of phosphorus (P) found in feedstuffs of plant origin. Pigs and other monogastric animals do not synthesize adequate levels of endogenous phytase to effectively cleave the P from the phytate. Consequently, adding phytase to a swine diet has been shown to improve the hydrolysis of phytic acid, making P more available. This decreases the added level of inorganic P, lowers diet cost, and reduces the amount of P excreted in swine waste.

Many commercial phytase sources are available for producers to use; however, when a new phytase enters the marketplace, feeding studies are required to determine its efficacy. A new source of phytase (HiPhorius) has been introduced to the US swine industry by DSM Nutritional Products (Parsippany, NJ) and little information is available to confirm its efficacy. Therefore, the objective of these experiments was to determine performance, serum chemistry, carcass characteristics, and bone mineralization of finishing pigs fed various levels of a newly introduced phytase (HiPhorius) when diets were formulated either to the same STTD Ca:STTD P or Ca:P ratio.

## Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments. The studies were conducted at a commercial research-finishing site in southwest Minnesota. Barns were mechanically ventilated and double-curtain-sided. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a bowl waterer for *ad libitum* access to feed and water. Pigs were provided 6.67 $ft^2$ of floor space per pig until 265 lb and then 7.86 $ft^2$ until the remaining pigs were marketed. Pigs were weighed approximately every 14 days to determine ADG, ADFI, and F/G.

### *Animals and diets*

HiPhorius phytase was provided by DSM Nutritional Products (Parsippany, NJ). The phytase was analyzed and the concentration of the product was found to be 2,402 FTU/g which was then used in diet formulation. All finishing diets were manufactured at the New Horizon Farms Feed Mill in Pipestone, MN.

[5] Selle, P. H.; Cowieson, A. J.; Ravindran, V., 2009: Consequences of calcium interactions with phytate and phytase for poultry and pigs. *Livestock Science* 124, 126-141.

All diets were formulated to meet or exceed NRC (2012) requirement estimates for all nutrients. Complete diet samples were collected in phases 1, 2, and 3 of Exp. 1 and phase 2 of Exp. 2. Diet samples in phase 4 of Exp. 1 and phase 1 of Exp. 2 were not collected at the farm. Samples were stored at -4°F until they were submitted for analysis of DM and CP (Midwest Laboratories, Omaha, NE), and Ca and P (K-State Research and Extension Soil Testing Laboratory, Manhattan, KS). In phases 1 and 3 of Exp. 1, diets were analyzed to verify phytase additions (DSM Laboratory, Belvidere, NJ).

### *Experiment 1*

A total of 1,161 pigs (PIC 337 × 1050; initially 80.9 ± 1.06 lb) were used in a 105-d study. Pens were randomly assigned to 1 of 4 dietary treatments in a completely randomized design. There were 27 pigs per pen and 10 or 11 replications per treatment. Treatments were corn-soybean meal-based and consisted of: 1) a control diet without phytase, formulated to NRC (2012) requirement estimates for STTD P; 2) 600 FYT/kg formulated to the same STTD Ca and P as the control diet considering a release of 0.13% STTD P and 0.095% STTD Ca; 3) 1,000 FYT/kg formulated to the same STTD Ca and P as the control diet considering a release of 0.16% STTD P and 0.107% STTD Ca; and 4) high STTD P (no phytase; approximately 22% above NRC 2012) based on the results of Vier et al. (2019)[6], which indicated improved growth performance when pigs were fed STTD P levels above the NRC (2012) requirement estimates. Based on the assumed release of STTD Ca and P for each inclusion level of phytase, the dietary limestone and monocalcium phosphate were reduced to maintain the same STTD Ca:STTD P ratio in each treatment. Dietary treatments were fed in 4 phases (Tables 1 to 4). Phase 1 was fed from 60 to 110 lb, phase 2 from 110 to 165 lb, phase 3 from 165 to 220 lb, and phase 4 from 220 to approximately 290 lb. In phases 3 and 4, monocalcium phosphate was completely removed from diets containing phytase and thus STTD P level could not be further reduced to match the STTD P level considering P release from phytase.

On d 88, the 3 heaviest pigs in each pen were selected and marketed. These pigs were included in growth performance data but not in the blood analysis or final pen carcass data. On the last day of the trial (d 105), final pen weights were obtained, and remaining pigs were tattooed with a pen identification number and transported to a U.S. Department of Agriculture-inspected packing plant (JBS Swift, Worthington, MN) for carcass data collection. Carcass measurements included hot carcass weight, loin depth, backfat depth, and percentage lean. Percentage lean was calculated from a plant proprietary equation. Carcass yield was calculated by dividing the pen average HCW by the pen average final live weight obtained at the farm.

Blood was collected into tubes that did not contain anticoagulant from one pig per pen approximately 12 h prior to harvest. Serum samples were immediately placed on dry ice and shipped to Iowa State University College of Veterinary Medicine Veterinary Diagnostic Laboratory (ISU-VDL) in Ames, IA. Analyses consisted of a full serum chemistry panel (including Ca and P levels), 25-hydroxyvitamin-$D_3$, and 1,25-Dihydroxyvitamin-$D_3$ at the ISU-VDL and Heartland assays, respectively, in Ames, IA.

[6] Vier, C. M., Dritz, S. S., Wu, F., Tokach, M. D., DeRouchey, J. M., Goodband, R. D., and Woodworth, J. C. 2019. Standardized total tract digestible phosphorus requirement of 24-to 130-kg pigs. J. Anim. Sci. 97(10):4023-4031. doi:10.1093/jas/skz256.

### *Experiment 2*

A total of 1,160 pigs (PIC 337 × 1050; initially 167.4 ± 2.92 lb) were used in a 58-d study. Pens were randomly assigned to 1 of 4 dietary treatments in a completely randomized design. There were approximately 27 pigs per pen and 11 replications per treatment. For this trial, treatments were formulated using a similar diet strategy to that of the first experiment, apart from slight differences in the monocalcium phosphate and limestone amounts so that the diets were formulated to the same total Ca:P ratio. Dietary treatments consisted of: 1) a control diet without added phytase formulated to NRC (2012) requirement for STTD P; 2) 600 FYT/kg phytase formulated to the same STTD P as the control diet considering a release of 0.13% STTD P; 3) 1,000 FYT/kg added phytase formulated to the same STTD P as the control diet considering a release of 0.16% STTD P; and 4) high levels for STTD P (no phytase; approximately 22% STTD P above NRC requirement estimates; Vier et al., 2019)[6]. Dietary treatments were fed in 2 phases (Tables 5 and 6). Phase 1 was fed from 165 to 220 lb, and phase 2 from 220 to approximately 290 lb. In phases 1 and 2, there was no monocalcium phosphate included in the experimental diets containing phytase and thus STTD P level could not be further reduced to match the STTD P level considering P release from phytase.

On d 45, the 3 heaviest pigs in each pen were selected and marketed. These pigs were included in growth performance data but not in the blood analysis or final pen carcass data. On the last day of the trial (d 58), final pen weights were obtained, and the remaining pigs were tattooed with a pen identification number and transported to a U.S. Department of Agriculture-inspected packing plant (JBS Swift, Worthington, MN) for carcass data collection using identical procedures to Exp. 1.

Blood was collected from one pig per pen approximately 12 h prior to harvest and analyzed as indicated in Exp. 1. Along with blood collection, one pig per pen (visually identified as having an average body weight of the pen, with barrows and gilts equally represented within treatment) was transported to a commercial abattoir (JBS Swift, Worthington, MN) for collection of the right front foot. The feet were then transported to Kansas State University and the third and fourth metacarpal bones were extracted. From each foot, the third metacarpal was utilized to determine bone density and the fourth metacarpal for de-fatted bone ash.[7] Calcium and P content within each bone was also determined (K-State Research and Extension Soil Testing Laboratory, Manhattan, KS).

### *Statistical analysis*

Data were analyzed as a completely randomized design for one-way ANOVA using the lm function from the lme4 package in R (version 3.5.2 (2018-07-02)) with pen as the experimental unit, and treatment considered as the fixed effect for all performance, blood, and bone criteria. For analysis of carcass data, individual carcass served as the observational unit and pen was included within the model as a random intercept to account for subsampling, with multiple observations within each experimental unit. In the analysis for backfat depth, lean %, and loin depth, HCW was used as a covariate in the model. Means within a row with different superscripts differ (a, b, c, $P < 0.05$; x, y, z,

[7] Wensley, M. R., C. M. Vier, J. T. Gebhardt, M. D. Tokach, J. C. Woodworth, R. D. Goodband, and J. M. DeRouchey. 2020a. Technical Note: Assessment of two methods for estimating bone ash in pigs. J. Anim. Sci. 98:1-8. doi:10.1093/jas/skaa251.

$0.05 < P \leq 0.10$) using a Tukey multiple comparison adjustment. Results were considered significant with *P*-values ≤ 0.05 and were considered marginally significant with *P*-values > 0.05 and ≤ 0.10.

## Results and Discussion

### *Experiment 1*

For the grower phase (d 0 to 54), there was evidence of a treatment effect for ADG (F-test: $P = 0.030$; Table 7) with the pigs fed dietary treatments formulated with phytase having a tendency for decreased ADG compared to pigs fed high levels of STTD P (T-test: $P \leq 0.066$) with pigs fed NRC STTD P intermediate. There was a tendency for a treatment effect for F/G ($P = 0.071$) with pigs fed current NRC (2012) requirement estimates for STTD P having improved feed efficiency compared to pigs fed diets with 1000 FYT/kg phytase. For the finisher phase (d 54 to 105), no significant differences ($P > 0.10$) between treatments were observed for ADG, ADFI, or F/G.

Overall (d 0 to 105), pigs fed the NRC or high STTD P diet had increased ADG ($P < 0.05$) compared to those pigs fed diets with either 600 or 1,000 FYT/kg phytase. Pigs fed 1,000 FYT/kg phytase had poorer F/G ($P < 0.05$) compared to pigs fed the NRC (2012) control diet, with pigs fed the other two treatments intermediate.

There was evidence of a difference in hot carcass weight between treatments ($P = 0.047$), but no evidence of pairwise differences between treatments ($P > 0.10$). There was also a tendency ($P = 0.061$) for backfat difference, with pigs fed NRC levels of STTD P having less backfat compared to pigs fed diets including phytase. For lean percentage, there was a difference ($P = 0.021$) where pigs fed the NRC (2012) control treatment had a higher lean percentage than pigs fed either treatment with added phytase ($P < 0.05$), with pigs fed the high STTD P intermediate. No other carcass characteristics differed between dietary treatments ($P > 0.10$).

There was a treatment effect for the serum concentration of 25-hydroxyvitamin-$D_3$ ($P = 0.022$; Table 7). Pigs fed diets with HiPhorius phytase had lower 25-hydroxyvitamin-$D_3$ than pigs fed NRC levels of STTD P ($P = 0.056$). There was no evidence of any differences for all other blood criteria measured ($P > 0.10$), including minerals (data not shown) and 1,25-dihydroxyvitamin-$D_3$.

### *Experiment 2*

There were no statistical differences between dietary treatment for BW throughout the study ($P > 0.10$; Table 8). From d 0 to 17, pigs fed NRC levels of STTD P had increased ADG and ADFI ($P < 0.05$) compared to pigs fed to the same STTD P considering the release of 600 FYT HiPhorius phytase, with pigs fed either 1,000 FYT/kg HiPhorius or high STTD P intermediate. There were no statistical differences ($P > 0.10$) between dietary treatments on any performance criteria throughout the remaining finishing periods, overall, or for carcass characteristics.

Metacarpals were denser ($P < 0.05$) for pigs fed either NRC (2012) or high levels of STTD P compared to pigs fed 600 FYT/kg phytase, with pigs fed 1,000 FYT/kg phytase intermediate (Table 9). There was also a tendency for a treatment effect ($P < 0.10$) for bone ash weight and percentage bone ash, where pigs fed NRC levels or high STTD P levels tended to have greater ash weight and percentage bone ash compared to pigs fed treatments including phytase. No significant differences ($P > 0.10$) were observed for weight or concentration of Ca and P in metacarpal bone ash between treatments. Levels of 25-hydroxyvitamin-$D_3$ in serum were not statistically different between treatments ($P > 0.10$).

In conclusion, regardless of diet formulation strategy there was decreased performance or bone mineralization observed for pigs fed diets containing phytase relative to pigs fed diets with only an inorganic P source. In Exp. 1, there was a significant decrease in ADG, F/G, and 25(OH)$D_3$ in pigs fed phytase compared to pigs fed NRC STTD P. In Exp. 2, while no statistical differences were observed between treatments for overall growth performance, pigs fed diets with phytase had decreased metacarpal bone density and percentage bone ash relative to pigs fed diets with NRC or high STTD P. These findings were unexpected and different than results of previous research conducted with the same phytase source that demonstrated its efficacy. The reason for these differences in phytase response are unclear and could be explained by one or a combination of the following: low or no monocalcium phosphate being included in the diets with phytase, lower analyzed than formulated P (based on sampled diets), not enough phytate-bound P in the diets for phytase to provide sufficient P, a too-wide analyzed Ca:P ratio that may have reduced phytase activity compared to the intended Ca:P ratio, or the overestimation of expected P attributed to the phytase.

**Table 1. Diet composition (as-fed basis) phase 1, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Ingredient, % | | | | |
| Corn | 73.30 | 73.95 | 74.10 | 72.65 |
| Soybean meal | 23.35 | 23.31 | 23.30 | 23.40 |
| Calcium carbonate | 0.93 | 0.95 | 0.98 | 1.11 |
| Monocalcium phosphate | 0.85 | 0.20 | -- | 1.25 |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 |
| Liquid lysine, 55% | 0.63 | 0.63 | 0.63 | 0.63 |
| DL-Met | 0.13 | 0.12 | 0.12 | 0.13 |
| L-Trp | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Val | 0.09 | 0.09 | 0.09 | 0.09 |
| Thr[4] | 0.20 | 0.20 | 0.20 | 0.20 |
| Phytase[5] | -- | 0.03 | 0.04 | -- |
| Vitamin-trace mineral premix | 0.10 | 0.10 | 0.10 | 0.10 |
| Total | 100 | 100 | 100 | 100 |
| | | | | |
| Calculated analysis | | | | |
| Standard ileal digestible (SID) amino acids, % | | | | |
| Lys | 1.10 | 1.10 | 1.10 | 1.10 |
| Ile:Lys | 56 | 56 | 56 | 56 |
| Leu:Lys | 123 | 124 | 124 | 123 |
| Met:Lys | 34 | 34 | 34 | 34 |
| Met and Cys:Lys | 56 | 56 | 56 | 56 |
| Thr:Lys | 62 | 62 | 62 | 62 |
| Trp:Lys | 18.6 | 18.6 | 18.6 | 18.6 |
| Val:Lys | 70 | 70 | 70 | 70 |
| Total Lys, % | 1.22 | 1.22 | 1.22 | 1.22 |
| NE, kcal/lb | 1,126 | 1,133 | 1,135 | 1,118 |
| SID Lys:NE, g/Mcal | 4.44 | 4.41 | 4.40 | 4.47 |
| STTD Ca, % | 0.40 | 0.41 | 0.40 | 0.50 |
| STTD P, % | 0.31 | 0.31 | 0.31 | 0.38 |
| STTD Ca:STTD P | 1.30 | 1.30 | 1.30 | 1.30 |
| Ca, % | 0.58 | 0.47 | 0.45 | 0.72 |
| P, % | 0.54 | 0.40 | 0.36 | 0.63 |
| Ca:P | 1.07 | 1.17 | 1.24 | 1.15 |
| Phytate P, % | 0.25 | 0.25 | 0.25 | 0.25 |

*continued*

**Table 1. Diet composition (as-fed basis) phase 1, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Chemical analysis, % | | | | |
| DM | 85.18 | 84.78 | 85.06 | 85.17 |
| CP[6] | 17.10 | 16.10 | 15.70 | 14.70 |
| Ca | 0.89 | 0.64 | 0.67 | 0.69 |
| P | 0.47 | 0.35 | 0.26 | 0.64 |
| Ca:P | 1.92 | 1.86 | 2.54 | 1.08 |

[1]Phase 1 was fed from approximately 60 to 110 lb. Diets were analyzed for phytase concentrations (DSM Laboratory, Belvidere, NJ). The 600 and 1,000 FYT/kg actual phytase units were 895 and 1,183 FYT/kg, respectively.
[2]Considering release of 0.13% STTD P and 0.095% STTD Ca.
[3]Considering release of 0.16% STTD P and 0.107% STTD Ca.
[4]Thr Pro; CJ America-Bio, Downers Grove, IL.
[5]HiPhorius 2,400 (2,400 FYT/g; DSM, Parsippany, NJ).
[6]CP = crude protein.

**Table 2. Diet composition (as-fed basis) phase 2, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Ingredient, % | | | | |
| Corn | 79.71 | 80.44 | 80.37 | 79.23 |
| Soybean meal | 17.29 | 17.23 | 17.24 | 17.32 |
| Calcium carbonate | 0.86 | 0.85 | 0.95 | 1.00 |
| Monocalcium phosphate | 0.75 | 0.05 | -- | 1.05 |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 |
| Liquid lysine, 55% | 0.57 | 0.57 | 0.57 | 0.57 |
| DL-Met | 0.07 | 0.07 | 0.07 | 0.07 |
| L-Trp | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Val | 0.07 | 0.07 | 0.07 | 0.07 |
| Thr[4] | 0.16 | 0.16 | 0.16 | 0.16 |
| Phytase[5] | -- | 0.03 | 0.04 | -- |
| Vitamin-trace mineral premix | 0.10 | 0.10 | 0.10 | 0.10 |
| Total | 100 | 100 | 100 | 100 |

*continued*

**Table 2. Diet composition (as-fed basis) phase 2, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Calculated analysis | | | | |
| Standard ileal digestible (SID) amino acids, % | | | | |
| Lys | 0.92 | 0.92 | 0.92 | 0.92 |
| Ile:Lys | 56 | 56 | 56 | 56 |
| Leu:Lys | 132 | 133 | 133 | 132 |
| Met:Lys | 32 | 32 | 32 | 32 |
| Met and Cys:Lys | 56 | 56 | 56 | 56 |
| Thr:Lys | 62 | 62 | 62 | 62 |
| Trp:Lys | 18.6 | 18.6 | 18.6 | 18.6 |
| Val:Lys | 70 | 70 | 70 | 70 |
| Total Lys, % | 1.03 | 1.03 | 1.03 | 1.03 |
| NE, kcal/lb | 1,126 | 1,133 | 1,135 | 1,118 |
| SID Lys:NE, g/Mcal | 3.66 | 3.63 | 3.63 | 3.67 |
| STTD Ca, % | 0.35 | 0.35 | 0.38 | 0.43 |
| STTD P, % | 0.27 | 0.27 | 0.29 | 0.33 |
| STTD Ca:STTD P | 1.30 | 1.30 | 1.30 | 1.30 |
| Ca, % | 0.52 | 0.39 | 0.42 | 0.62 |
| P, % | 0.49 | 0.34 | 0.33 | 0.56 |
| Ca:P | 1.05 | 1.14 | 1.25 | 1.12 |
| Phytate P, % | 0.23 | 0.23 | 0.23 | 0.23 |
| Chemical analysis, % | | | | |
| DM | 85.60 | 85.51 | 85.58 | 85.67 |
| CP[6] | 12.10 | 14.70 | 14.0 | 13.6 |
| Ca | 0.57 | 0.50 | 0.53 | 0.56 |
| P | 0.41 | 0.31 | 0.27 | 0.51 |
| Ca:P | 1.40 | 1.61 | 2.06 | 1.09 |

[1]Phase 2 was fed from approximately 110 to 165 lb.
[2]Considering release of 0.13% STTD P and 0.095% STTD Ca.
[3]Considering release of 0.16% STTD P and 0.107% STTD Ca.
[4]Thr Pro; CJ America-Bio, Downers Grove, IL.
[5]HiPhorius 2,400 (2,400 FYT/g; DSM, Parsippany, NJ).
[6]CP = crude protein.

**Table 3. Diet composition (as-fed basis) phase 3, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Ingredient, % | | | | |
| Corn | 83.76 | 84.41 | 84.28 | 83.37 |
| Soybean meal | 13.58 | 13.53 | 13.54 | 13.60 |
| Calcium carbonate | 0.80 | 0.82 | 0.93 | 0.91 |
| Monocalcium phosphate | 0.65 | -- | -- | 0.90 |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 |
| Liquid lysine, 55% | 0.50 | 0.50 | 0.50 | 0.50 |
| DL-Met | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Trp | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Val | 0.03 | 0.03 | 0.03 | 0.03 |
| Thr[4] | 0.13 | 0.13 | 0.13 | 0.13 |
| Phytase[5] | -- | 0.03 | 0.04 | -- |
| Vitamin-trace mineral premix | 0.10 | 0.10 | 0.10 | 0.10 |
| Total | 100 | 100 | 100 | 100 |
| | | | | |
| Calculated analysis | | | | |
| Standard ileal digestible (SID) amino acids, % | | | | |
| Lys | 0.79 | 0.79 | 0.79 | 0.79 |
| Ile:Lys | 57 | 57 | 57 | 57 |
| Leu:Lys | 143 | 144 | 144 | 143 |
| Met:Lys | 30 | 30 | 30 | 30 |
| Met and Cys:Lys | 56 | 56 | 56 | 56 |
| Thr:Lys | 63 | 63 | 63 | 63 |
| Trp:Lys | 18.5 | 18.5 | 18.5 | 18.5 |
| Val:Lys | 70 | 70 | 70 | 70 |
| Total Lys, % | 0.89 | 0.89 | 0.89 | 0.89 |
| NE, kcal/lb | 1,154 | 1,162 | 1,160 | 1,150 |
| SID Lys:NE, g/Mcal | 3.11 | 3.09 | 3.09 | 3.12 |
| STTD Ca, % | 0.32 | 0.33 | 0.37 | 0.38 |
| STTD P, % | 0.24 | 0.25 | 0.28 | 0.29 |
| STTD Ca:STTD P | 1.30 | 1.30 | 1.30 | 1.30 |
| Ca, % | 0.47 | 0.36 | 0.40 | 0.55 |
| P, % | 0.46 | 0.32 | 0.32 | 0.51 |
| Ca:P | 1.03 | 1.13 | 1.26 | 1.09 |
| Phytate P, % | 0.22 | 0.22 | 0.22 | 0.22 |

*continued*

**Table 3. Diet composition (as-fed basis) phase 3, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Chemical analysis, % | | | | |
| DM | 84.93 | 84.74 | 85.92 | 84.89 |
| CP[6] | 11.10 | 12.40 | 12.90 | 11.20 |
| Ca | 0.55 | 0.33 | 0.34 | 0.56 |
| P | 0.42 | 0.25 | 0.27 | 0.49 |
| Ca:P | 1.33 | 1.33 | 1.25 | 1.15 |

[1]Phase 3 was fed from approximately 165 to 220 lb. Diets were analyzed for phytase concentrations (DSM Laboratory, Belvidere, NJ). The 600 and 1000 FYT/kg actual phytase units were 845 and 1,286 FYT/kg, respectively.
[2]Considering release of 0.13% STTD P and 0.095% STTD Ca.
[3]Considering release of 0.16% STTD P and 0.107% STTD Ca.
[4]Thr Pro; CJ America-Bio, Downers Grove, IL.
[5]HiPhorius 2,400 (2,400 FYT/g; DSM, Parsippany, NJ).
[6]CP = crude protein.

**Table 4. Diet composition (as-fed basis) phase 4, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Ingredient, % | | | | |
| Corn | 86.86 | 87.27 | 87.13 | 86.46 |
| Soybean meal | 10.70 | 10.67 | 10.68 | 10.72 |
| Calcium carbonate | 0.72 | 0.81 | 0.93 | 0.84 |
| Monocalcium phosphate | 0.59 | -- | -- | 0.75 |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 |
| Liquid lysine, 55% | 0.50 | 0.50 | 0.50 | 0.50 |
| DL-Met | 0.04 | 0.04 | 0.04 | 0.04 |
| L-Trp | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Val | 0.03 | 0.03 | 0.03 | 0.03 |
| Thr[4] | 0.14 | 0.14 | 0.14 | 0.14 |
| Phytase[5] | -- | 0.03 | 0.04 | -- |
| Vitamin-trace mineral premix[6] | 0.10 | 0.10 | 0.10 | 0.10 |
| Total, % | 100 | 100 | 100 | 100 |

*continued*

**Table 4. Diet composition (as-fed basis) phase 4, Exp. 1[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Calculated analysis | | | | |
| Standard ileal digestible (SID) amino acids, % | | | | |
| Lys | 0.72 | 0.72 | 0.72 | 0.72 |
| Ile:Lys | 56 | 56 | 56 | 56 |
| Leu:Lys | 148 | 148 | 148 | 148 |
| Met:Lys | 32 | 32 | 32 | 32 |
| Met and Cys:Lys | 59 | 59 | 59 | 59 |
| Thr:Lys | 65 | 65 | 65 | 65 |
| Trp:Lys | 18.8 | 18.8 | 18.8 | 18.8 |
| Val:Lys | 70 | 70 | 70 | 70 |
| Total Lys, % | 0.81 | 0.81 | 0.81 | 0.81 |
| NE, kcal/lb | 1,165 | 1,169 | 1,168 | 1,160 |
| SID Lys:NE, g/Mcal | 2.81 | 2.80 | 2.80 | 2.82 |
| CP[6] | 12.80 | 12.80 | 12.80 | 12.70 |
| STTD Ca, %[7] | 0.27 | 0.32 | 0.36 | 0.33 |
| STTD P, % | 0.21 | 0.24 | 0.27 | 0.26 |
| STTD Ca:STTD P | 1.30 | 1.30 | 1.30 | 1.30 |
| Ca, % | 0.40 | 0.35 | 0.39 | 0.49 |
| P, % | 0.41 | 0.30 | 0.30 | 0.46 |
| Ca:P | 0.98 | 1.14 | 1.28 | 1.06 |
| Phytate P, % | 0.22 | 0.22 | 0.22 | 0.22 |

[1]Phase 4 was fed from approximately 220 to 300 lb.
[2]Considering release of 0.13% STTD P and 0.095% STTD Ca.
[3]Considering release of 0.16% STTD P and 0.107% STTD Ca.
[4]Thr Pro; CJ America-Bio, Downers Grove, IL.
[5]HiPhorius 2400 (2,400 FYT/g; DSM, Parsippany, NJ).
[6]CP = crude protein.
[7]Standardized total tract digestible.

**Table 5. Diet composition (as-fed basis) phase 1, Exp. 2[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Ingredient, % | | | | |
| Corn | 83.60 | 84.40 | 84.38 | 83.28 |
| Soybean meal | 13.59 | 13.53 | 13.53 | 13.61 |
| Calcium carbonate | 0.95 | 0.83 | 0.83 | 1.00 |
| Monocalcium phosphate | 0.65 | -- | -- | 0.90 |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 |
| Liquid lysine, 55% | 0.50 | 0.50 | 0.50 | 0.50 |
| DL-Met | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Trp | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Val | 0.03 | 0.03 | 0.03 | 0.03 |
| Thr[4] | 0.13 | 0.13 | 0.13 | 0.13 |
| Phytase[5] | -- | 0.03 | 0.04 | -- |
| Vitamin-trace mineral premix[6] | 0.10 | 0.10 | 0.10 | 0.10 |
| Total, % | 100 | 100 | 100 | 100 |
| | | | | |
| Calculated analysis | | | | |
| Standard ileal digestible (SID) amino acids, % | | | | |
| Lys | 0.79 | 0.79 | 0.79 | 0.79 |
| Ile:Lys | 57 | 57 | 57 | 57 |
| Leu:Lys | 143 | 144 | 144 | 143 |
| Met:Lys | 30 | 30 | 30 | 30 |
| Met and Cys:Lys | 56 | 56 | 56 | 56 |
| Thr:Lys | 63 | 63 | 63 | 63 |
| Trp:Lys | 18.5 | 18.5 | 18.5 | 18.5 |
| Val:Lys | 70 | 70 | 70 | 70 |
| Total Lys, % | 0.89 | 0.89 | 0.89 | 0.89 |
| NE, kcal/lb | 1,151 | 1,160 | 1,160 | 1,147 |
| SID Lys:NE, g/Mcal | 3.11 | 3.09 | 3.09 | 3.12 |
| CP[6] | 13.90 | 13.90 | 13.90 | 13.80 |
| STTD P,[7] % | 0.24 | 0.25 | 0.28 | 0.29 |
| STTD Ca:STTD P | 1.44 | 1.31 | 1.22 | 1.37 |
| Ca, % | 0.52 | 0.36 | 0.36 | 0.59 |
| P, % | 0.45 | 0.32 | 0.32 | 0.51 |
| Ca:P | 1.15 | 1.15 | 1.15 | 1.15 |
| Phytate P, % | 0.22 | 0.22 | 0.22 | 0.22 |

[1]Phase 1 was fed from approximately 165 to 220 lb.
[2]Considering release of 0.13% STTD P.
[3]Considering release of 0.16% STTD P.
[4]Thr Pro; CJ America-Bio, Downers Grove, IL.
[5]HiPhorius 2400 (2,400 FYT/g; DSM, Parsippany, NJ).
[6]CP = crude protein.
[7]Standardized total tract digestible.

**Table 6. Diet composition (as-fed basis) phase 2, Exp. 2[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Ingredient, % | | | | |
| Corn | 86.69 | 87.29 | 87.27 | 86.37 |
| Soybean meal | 10.71 | 10.67 | 10.67 | 10.73 |
| Calcium carbonate | 0.88 | 0.79 | 0.79 | 0.92 |
| Monocalcium phosphate | 0.50 | -- | -- | 0.75 |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 |
| Liquid lysine, 55% | 0.50 | 0.50 | 0.50 | 0.50 |
| DL-Met | 0.04 | 0.04 | 0.04 | 0.04 |
| L-Trp | 0.03 | 0.03 | 0.03 | 0.03 |
| L-Val | 0.03 | 0.03 | 0.03 | 0.03 |
| Thr[4] | 0.14 | 0.14 | 0.14 | 0.14 |
| Phytase[5] | -- | 0.03 | 0.04 | -- |
| Vitamin-trace mineral premix | 0.10 | 0.10 | 0.10 | 0.10 |
| Total, % | 100 | 100 | 100 | 100 |
| | | | | |
| Calculated analysis | | | | |
| Standard ileal digestible (SID) amino acids, % | | | | |
| Lys | 0.72 | 0.72 | 0.72 | 0.72 |
| Ile:Lys | 56 | 56 | 56 | 56 |
| Leu:Lys | 148 | 148 | 148 | 148 |
| Met:Lys | 32 | 32 | 32 | 32 |
| Met and Cys:Lys | 59 | 59 | 59 | 59 |
| Thr:Lys | 65 | 65 | 65 | 65 |
| Trp:Lys | 18.8 | 18.8 | 18.8 | 18.8 |
| Val:Lys | 70 | 70 | 70 | 70 |
| Total Lys, % | 0.81 | 0.81 | 0.81 | 0.81 |
| NE, kcal/lb | 1,161 | 1,168 | 1,168 | 1,157 |
| SID Lys:NE, g/Mcal | 2.81 | 2.80 | 2.80 | 2.82 |
| STTD P, % | 0.21 | 0.24 | 0.27 | 0.26 |
| STTD Ca:STTD P | 1.47 | 1.28 | 1.19 | 1.37 |
| Ca, % | 0.46 | 0.34 | 0.34 | 0.52 |
| P, % | 0.41 | 0.30 | 0.30 | 0.46 |
| Ca:P | 1.12 | 1.12 | 1.12 | 1.12 |
| Phytate P, % | 0.22 | 0.22 | 0.22 | 0.22 |

*continued*

**Table 6. Diet composition (as-fed basis) phase 2, Exp. 2[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase[2] | 1,000 FYT/kg Phytase[3] | High STTD P |
|---|---|---|---|---|
| Chemical analysis, % | | | | |
| DM | 84.90 | 84.64 | 84.88 | 84.90 |
| CP | 12.30 | 11.50 | 10.80 | 11.00 |
| Ca | 0.57 | 0.37 | 0.36 | 0.74 |
| P | 0.45 | 0.26 | 0.26 | 0.52 |
| Ca:P | 1.27 | 1.45 | 1.36 | 1.42 |

[1]Phase 2 was fed from approximately 220 to 290 lb.
[2]Considering release of 0.13% STTD P.
[3]Considering release of 0.16% STTD P.
[4]Thr Pro; CJ America-Bio, Downers Grove, IL.
[5]HiPhorius 2400 (2,400 FYT/g; DSM, Parsippany, NJ).

**Table 7. Effects of feeding to the same STTD Ca:STTD P with the inclusion of HiPhorius phytase on finishing pig growth performance, carcass characteristics, and serum chemistry, Exp. 1[1,2]**

| | NRC STTD P | 600 FYT/kg Phytase | 1,000 FYT/kg Phytase | High STTD P | SEM | *P* = |
|---|---|---|---|---|---|---|
| BW, lb | | | | | | |
| d 0 | 80.8 | 80.9 | 81.0 | 81.0 | 1.06 | 0.999 |
| d 54 | 186.9 | 184.0 | 183.5 | 189.5 | 2.17 | 0.174 |
| d 105 | 300.5[a] | 291.6[b] | 292.2[b] | 299.2[ab] | 2.13 | 0.005 |
| Grower phase, d 0 to 54 | | | | | | |
| ADG, lb | 1.96[xy] | 1.89[y] | 1.90[y] | 2.01[xy] | 0.031 | 0.030 |
| ADFI, lb | 5.10 | 5.05 | 5.15 | 5.26 | 0.071 | 0.184 |
| F/G | 2.60[x] | 2.67[xy] | 2.72[y] | 2.63[xy] | 0.034 | 0.071 |
| Finisher phase, d 54 to 105 | | | | | | |
| ADG, lb | 2.29 | 2.17 | 2.21 | 2.23 | 0.043 | 0.250 |
| ADFI, lb | 7.31 | 7.20 | 7.29 | 7.35 | 0.089 | 0.658 |
| F/G | 3.20 | 3.32 | 3.31 | 3.30 | 0.051 | 0.301 |
| Overall (d 0 to 105) | | | | | | |
| ADG, lb | 2.12[a] | 2.02[b] | 2.04[b] | 2.11[a] | 0.012 | < 0.001 |
| ADFI, lb | 6.15 | 6.06 | 6.16 | 6.25 | 0.058 | 0.159 |
| F/G | 2.90[b] | 3.00[ab] | 3.01[a] | 2.96[ab] | 0.027 | 0.027 |
| Carcass characteristics[3] | | | | | | |
| HCW, lb[4] | 221.2 | 216.3 | 216.5 | 220.8 | 1.60 | 0.047 |
| Carcass yield, % | 74.0 | 74.0 | 73.7 | 73.8 | 0.003 | 0.775 |
| Loin depth, in. | 2.56 | 2.51 | 2.50 | 2.53 | 0.018 | 0.177 |
| Back fat depth, in. | 0.65[x] | 0.68[y] | 0.68[y] | 0.68[xy] | 0.009 | 0.061 |
| Lean, % | 56.62[a] | 55.98[b] | 55.96[b] | 56.14[ab] | 0.162 | 0.021 |
| Serum chemistry | | | | | | |
| 25-Hydroxyvitamin-$D_3$, ng/mL | 34.7[x] | 28.2[y] | 28.2[y] | 32.9[xy] | 1.82 | 0.022 |
| 1,25-Dihydroxyvitamin-$D_3$, pg/mL | 203.8 | 188.4 | 198.2 | 153.0 | 20.65 | 0.303 |

[abc]Means within row with different superscripts differ ($P < 0.05$).
[xyz]Means within row with different superscripts differ ($P < 0.10$).
[1] A total of 1,161 pigs (initially 80.8 ± 3.22 lb) were used in a 105-d finisher trial with 27 pigs per pen and 10 or 11 pens per treatment.
[2] Treatments consisted of: 1) No phytase and formulated to NRC requirement estimates for STTD P; 2) 600 FTU/kg added HiPhorius phytase formulated to the same STTD Ca and STTD P as treatment 1 considering a release of 0.13% STTD P and 0.095% STTD Ca; 3) 1,000 FTU/kg HiPhorius phytase formulated to the same STTD Ca and STTD P as treatment 1 considering release of 0.16% STTD P and 0.107% STTD Ca; and 4) industry levels for STTD P (no phytase; approximately 22% above NRC). All diets were formulated to the same STTD Ca: STTD P ratio.
[3]In the analysis for backfat depth, lean %, and loin depth, HCW was used as a covariate in the model.
[4]When performing pairwise comparisons using a Tukey multiple comparison adjustment, no comparisons were $P < 0.05$. However, the greatest difference between dietary treatments was between pigs fed diets formulated with 600 FYT/kg of phytase compared to pigs fed NRC levels of STTD P, which did not significantly differ ($P = 0.131$).

**Table 8. Effects of feeding to the same analyzed Ca:P with the inclusion of HiPhorius phytase on finisher growth performance and carcass characteristics[1]**

| | NRC STTD P | 600 FYT/kg Phytase | 1,000 FYT/kg Phytase | High STTD P | SEM | *P* = |
|---|---|---|---|---|---|---|
| BW, lb | | | | | | |
| d 0 | 167.6 | 167.5 | 167.4 | 167.3 | 2.92 | 0.999 |
| d 17 | 206.6 | 202.9 | 206.6 | 205.9 | 2.96 | 0.788 |
| d 45 | 268.4 | 264.2 | 269.7 | 268.5 | 2.55 | 0.453 |
| d 55 | 291.7 | 286.7 | 293.9 | 292.3 | 2.64 | 0.255 |
| Period 1, d 0 to 17 | | | | | | |
| ADG, lb | 2.33[a] | 2.09[b] | 2.29[ab] | 2.27[ab] | 0.052 | 0.015 |
| ADFI, lb | 6.17[a] | 5.72[b] | 6.05[ab] | 6.07[ab] | 0.094 | 0.009 |
| F/G | 2.66 | 2.75 | 2.66 | 2.68 | 0.053 | 0.615 |
| Period 2, d 17 to 45 | | | | | | |
| ADG, lb | 2.20 | 2.18 | 2.24 | 2.23 | 0.046 | 0.853 |
| ADFI, lb | 7.13 | 7.06 | 7.24 | 7.06 | 0.099 | 0.535 |
| F/G | 3.25 | 3.24 | 3.24 | 3.18 | 0.043 | 0.626 |
| Period 3, d 45 to 55 | | | | | | |
| ADG, lb | 2.18 | 2.12 | 2.25 | 2.21 | 0.054 | 0.420 |
| ADFI, lb | 7.76 | 7.61 | 7.67 | 8.02 | 0.134 | 0.163 |
| F/G | 3.57 | 3.63 | 3.43 | 3.64 | 0.093 | 0.369 |
| Overall, d 0 to 55 | | | | | | |
| ADG, lb | 2.24 | 2.14 | 2.25 | 2.24 | 0.038 | 0.175 |
| ADFI, lb | 6.96 | 6.76 | 6.97 | 6.95 | 0.080 | 0.216 |
| F/G | 3.12 | 3.16 | 3.10 | 3.11 | 0.038 | 0.673 |
| Carcass characteristics[2] | | | | | | |
| HCW, lb | 217.5 | 216.0 | 218.8 | 218.6 | 1.86 | 0.701 |
| Carcass yield, % | 74.0 | 74.6 | 74.0 | 74.3 | 0.004 | 0.684 |
| Loin depth, in. | 2.53 | 2.54 | 2.56 | 2.54 | 0.021 | 0.807 |
| Back fat depth, in. | 0.72 | 0.71 | 0.71 | 0.72 | 0.013 | 0.705 |
| Lean, % | 55.47 | 55.70 | 55.77 | 55.41 | 0.225 | 0.622 |

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

[1] A total of 1,160 pigs (initially 167.4 ± 2.92 lb) were used in a 55-d finisher trial with 27 pigs per pen and 11 pens per treatment. Pigs were allotted to treatment in a completely randomized design. Treatments consisted of: 1) No phytase, formulated to NRC requirement for Ca and STTD P; 2) Diet + 600 FYT/kg formulated to the same Ca and STTD P as treatment 1 considering release of 0.13% STTD P; 3) Diet + 1,000 FYT/kg formulated to the same Ca and STTD P as treatment 1 considering release of 0.16% STTD P; and 4) industry levels for STTD P (no phytase; approximately 22% above NRC). All diets were formulated to the same analyzed Ca:P ratio.

[2] In the analysis for backfat depth, lean, and loin depth, HCW was used as a covariate in the model.

**Table 9. Effects of feeding to the same analyzed Ca:P with the inclusion of HiPhorius phytase on finishing pig metacarpal bone mineralization and serum chemistry, Exp. 2[1]**

| Item | NRC STTD P | 600 FYT/kg Phytase | 1,000 FYT/kg Phytase | High STTD P | SEM | *P* = |
|---|---|---|---|---|---|---|
| Bone density, g/mL | 1.35[a] | 1.31[b] | 1.33[ab] | 1.36[a] | 0.008 | 0.001 |
| Bone ash weight, g | 9.27 | 8.23 | 8.98 | 9.73 | 0.394 | 0.057 |
| Bone ash, % | 58.5 | 54.4 | 56.7 | 59.0 | 0.013 | 0.060 |
| Ca, g | 3.91 | 3.82 | 4.08 | 4.29 | 0.276 | 0.587 |
| Ca, % | 42.1 | 46.0 | 45.4 | 43.9 | 1.810 | 0.447 |
| P, g | 1.61 | 1.56 | 1.67 | 1.74 | 0.115 | 0.715 |
| P, % | 17.3 | 18.8 | 18.6 | 17.8 | 0.900 | 0.572 |
| 25-Hydroxyvitamin-$D_3$, ng/mL | 28.73 | 29.00 | 27.29 | 30.45 | 2.014 | 0.745 |

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

[1]A total of 1,160 pigs (initially 167.4 ± 2.92 lb) were used in a 55-d finisher trial with 27 pigs per pen and 11 pens per treatment. Pigs were allotted to treatment in a completely randomized design. Treatments consisted of: 1) No phytase, formulated to NRC requirement for Ca and STTD P; 2) Diet + 600 FYT/kg formulated to the same Ca and STTD P as the PC considering release of 0.13% STTD P; 3) Diet + 1,000 FYT/kg formulated to the same Ca and STTD P as the PC considering release of 0.16% STTD P; and 4) high levels for STTD P (no phytase; approximately 22% above NRC) by using added monocalcium P and limestone to provide 14% Ca and 21% STTD P above NRC (2012) requirements. All diets were formulated to the same analyzed Ca:P ratio. Serum samples were collected from one pig per pen approximately 12 h prior to harvest and analyzed at the Iowa State University College of Veterinary Medicine Veterinary Diagnostic Laboratory (Ames, IA). On one pig per pen the right foot was collected, and third metacarpals were used to determine bone density, and fourth metacarpals were used for bone ash and bone Ca and P.