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Effects of Analyzed Calcium to Phosphorus Ratio on Growth Performance, Carcass Characteristics, Bone Mineralization, and Economics of 56- to 279-lb Pigs Fed Diets Containing Phytase

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Abstract

A total of 1,215 barrows and gilts (PIC; 359 × Camborough) with an initial pen average body weight (BW) of 55.7 ± 2.06 lb were used in a 114-d growth trial to determine the effects of different analyzed calcium to analyzed phosphorus ratios on performance of growing-finishing pigs from 57- to 279-lb fed diets containing 1,000 phytase units. Pens of pigs were randomly assigned to 1 of 5 dietary treatments in a randomized complete block design with BW as a blocking factor. There were 9 replicate pens per treatment and 27 pigs per pen. The experimental diets were corn-soybean meal-based and were fed in 4 phases. The 5 dietary treatments were formulated to contain 0.75:1, 1.00:1, 1.25:1, 1.50:1, and 2.00:1 analyzed Ca:P ratios. The diets contained 1,000 phytase units (FYT) of Ronozyme Hiphos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ) with assumed releasing values of 0.15% available *P* (aP) and 0.132% standardized total tract digestible *P* (STTD P). All the diets were formulated to contain adequate STTD P across the dietary treatments in all phases, which included the expected release of phytase. The treatments were achieved by increasing the amount of calcium carbonate at the expense of corn while maintaining monocalcium phosphate constant. Overall, increasing analyzed Ca:P ratio quadratically increased ($P < 0.05$) average daily gain (ADG), final BW, and average daily feed intake (ADFI) ($P < 0.10$). The greatest increase in these criteria was observed as the ratio increased from 0.75:1 to 1.50:1, with no improvement thereafter. Feed efficiency improved linearly ($P < 0.05$) with increasing analyzed Ca:P ratio up to 2.00:1. For carcass characteristics, hot carcass weight (HCW) increased quadratically ($P < 0.05$) as the analyzed Ca:P ratio increased from 0.75:1 to 1.50:1, and started to decrease thereafter. Percentage carcass yield decreased (quadratic, $P < 0.10$) from 0.75:1 analyzed Ca:P ratio to 1.25:1, slightly increasing at higher ratios. Bone mineralization increased quadratically ($P < 0.05$) with increasing analyzed Ca:P ratio. The greatest improvement in percentage bone ash was observed as analyzed Ca:P ratio increased from 0.75:1 to 1.25:1, with no further increase. Feed cost per pig increased linearly ($P < 0.05$) with increasing analyzed Ca:P ratio. No evidence of differences ($P > 0.10$) was observed for feed cost per pound of gain. Gain value per pig increased quadratically ($P < 0.05$), with the greatest revenue observed for pigs fed diets with 1.50:1 analyzed Ca:P ratio. There was a marginal quadratic improvement ($P < 0.10$) in income over feed cost (IOFC), with the highest income observed at 1.25:1 analyzed Ca:P ratio. The best fitting models for ADG, ADFI, feed efficiency, HCW, and bone ash were the quadratic polynomial (QP), linear, broken-line linear (BLL), QP, and BLL models, respectively. The maximum responses in ADG, feed efficiency, HCW, and bone ash were estimated at 1.63:1, 1.05:1, 1.11:1, and 1.25:1 analyzed Ca:P ratio, respectively. In conclusion, the estimated analyzed Ca:P ratio requirement for finishing pigs from 56- to 279-lb fed diets containing 1,000 phytase units and that were adequate in STTD P ranged from 1.05:1 to 1.63:1 to maximize growth rate, feed efficiency, HCW, and bone mineralization criteria.

Keywords

calcium, phosphorus, finishing pigs, phytase, bone ash

Cover Page Footnote

Appreciation is expressed to Genus PIC and DSM Nutritional Products Inc. for partial funding, to New Horizon Farms for use of the feed mill and animal facilities, and to Marty Heintz, Whitney Adler, and Heath

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Effects of Analyzed Calcium to Phosphorus Ratio on Growth Performance, Carcass Characteristics, Bone Mineralization, and Economics of 56- to 279-lb Pigs Fed Diets Containing Phytase[1]

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Summary

A total of 1,215 barrows and gilts (PIC; 359 × Camborough) with an initial pen average body weight (BW) of 55.7 ± 2.06 lb were used in a 114-d growth trial to determine the effects of different analyzed calcium to analyzed phosphorus ratios on performance of growing-finishing pigs from 57- to 279-lb fed diets containing 1,000 phytase units. Pens of pigs were randomly assigned to 1 of 5 dietary treatments in a randomized complete block design with BW as a blocking factor. There were 9 replicate pens per treatment and 27 pigs per pen. The experimental diets were corn-soybean meal-based and were fed in 4 phases. The 5 dietary treatments were formulated to contain 0.75:1, 1.00:1, 1.25:1, 1.50:1, and 2.00:1 analyzed Ca:P ratios. The diets contained 1,000 phytase units (FYT) of Ronozyme Hiphos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ) with assumed releasing values of 0.15% available P (aP) and 0.132% standardized total tract digestible P (STTD P). All the diets were formulated to contain adequate STTD P across the dietary treatments in all phases, which included the expected release of phytase. The treatments were achieved by increasing the amount of calcium carbonate at the expense of corn while maintaining monocalcium phosphate constant. Overall, increasing analyzed Ca:P ratio quadratically increased ($P < 0.05$) average daily gain (ADG), final BW, and average daily feed intake (ADFI) ($P < 0.10$). The greatest increase in these criteria was observed as the ratio increased from 0.75:1 to 1.50:1, with no improvement thereafter. Feed efficiency improved linearly ($P < 0.05$) with increasing analyzed Ca:P ratio up to 2.00:1. For carcass characteristics, hot

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carcass weight (HCW) increased quadratically ($P < 0.05$) as the analyzed Ca:P ratio increased from 0.75:1 to 1.50:1, and started to decrease thereafter. Percentage carcass yield decreased (quadratic, $P < 0.10$) from 0.75:1 analyzed Ca:P ratio to 1.25:1, slightly increasing at higher ratios. Bone mineralization increased quadratically ($P < 0.05$) with increasing analyzed Ca:P ratio. The greatest improvement in percentage bone ash was observed as analyzed Ca:P ratio increased from 0.75:1 to 1.25:1, with no further increase. Feed cost per pig increased linearly ($P < 0.05$) with increasing analyzed Ca:P ratio. No evidence of differences ($P > 0.10$) was observed for feed cost per pound of gain. Gain value per pig increased quadratically ($P < 0.05$), with the greatest revenue observed for pigs fed diets with 1.50:1 analyzed Ca:P ratio. There was a marginal quadratic improvement ($P < 0.10$) in income over feed cost (IOFC), with the highest income observed at 1.25:1 analyzed Ca:P ratio. The best fitting models for ADG, ADFI, feed efficiency, HCW, and bone ash were the quadratic polynomial (QP), linear, broken-line linear (BLL), QP, and BLL models, respectively. The maximum responses in ADG, feed efficiency, HCW, and bone ash were estimated at 1.63:1, 1.05:1, 1.11:1, and 1.25:1 analyzed Ca:P ratio, respectively. In conclusion, the estimated analyzed Ca:P ratio requirement for finishing pigs from 56- to 279-lb fed diets containing 1,000 phytase units and that were adequate in STTD P ranged from 1.05:1 to 1.63:1 to maximize growth rate, feed efficiency, HCW, and bone mineralization criteria.

Introduction

Among other functions, calcium and phosphorus play an essential role in growth performance and bone mineralization. However, the amount of one mineral can affect the utilization of the other.[5] Moreover, recent studies have demonstrated that feeding excess Ca can result in reduced growth performance and bone mineralization,[6] particularly when pigs are fed diets with low or marginal P.[7,8] Thus, it is important to consider an optimum Ca:P ratio when formulating diets for pigs to ensure an appropriate absorption and utilization of both minerals. However, there is still a need for research to determine the optimum Ca:P ratio to maximize different response criteria.

A recent study[9] has shown that the total analyzed Ca:P ratio to maximize growth performance, HCW, and IOFC criteria for growing-finishing pigs from 53 to 287 lb ranged from 1.10:1 to 1.49:1. In addition, a higher analyzed Ca:P ratio, estimated at 1.93:1, was required to maximize bone mineralization. These ratios were achieved with

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[5]Crenshaw, T. D. 2001. Calcium, phosphorus, vitamin D, and vitamin K in swine nutrition. In: A. J. Lewis and L. L. Southern, editors, Swine nutrition. 2nd ed. CRC Press, Boca Raton, FL. p. 187–212.
[6]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. 94:33213334. doi:10.2527/jas.2016-0444.
[7]Wu, F., Tokach, M.D., Dritz, S. S., Woodworth, J. C., DeRouchey, J. M., Goodband, R. D., Gonçalves, M. A. D., and Bergstrom, J. R. 2018. Effects of dietary calcium to phosphorus ratio and addition of phytase on growth performance of nursery pigs. J. Anim. Sci. doi:10.1093/jas/sky101
[8]Merriman, L. A., Walk, C. L., Murphy, M. R., Parsons, C. M., and Stein, H. H. 2017. Inclusion of excess dietary calcium in diets for 100-to 130-kg growing pigs reduces feed intake and daily gain if dietary phosphorus is at or below the requirement. Journal of animal science, 95(12), 5439-5446.
[9]Vier C. M., Dritz S. S., Tokach M. D., Gonçalves M. A. D., Orlando U. A. D., Bergstron, J., Woodworth J. C., Goodband R. D., DeRouchey J. M. 2018. Effects of Dietary Total Calcium to Total Phosphorus Ratio on Growth Performance, Carcass Characteristics, Bone Mineralization and Economics in 58 to 281 lb pigs. Kansas Agricultural Experiment Station Research Reports: Vol. 4: Iss. 9.

the inclusion of monocalcium P, which is an expensive source of P. In addition, swine diets are formulated with cereal grains that contain a large amount of P in the form of phytic acid. However, this is an unavailable form of P to pigs as they lack endogenous phytase to cleave the phosphates from the phytic acid. Thus, to decrease the inclusion of inorganic sources of P and to increase the P availability to the pig, phytase is typically added to swine diets. However, there is little research that defines the optimum Ca:P ratio in diets that contain phytase.

Therefore, the objective of this study was to investigate the effects of different Ca:P ratios on growth performance, carcass characteristics, bone mineralization, and economics of growing-finishing pigs fed diets containing 1,000 phytase units that are adequate in STTD P when considering the P release from the phytase.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This experiment was conducted at a commercial research-finishing site in southwestern Minnesota. The barn was naturally ventilated and double-curtain-sided. Pens had completely slatted flooring and deep pits. Each pen was equipped with a 5-hole stainless steel feeder and cup waterer to allow *ad libitum* access to feed and water. The facility was equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of measuring and recording daily feed additions to individual pens.

A total of 1,215 barrows and gilts (PIC; 359 × Camborough, initial pen average BW of 55.7 ± 2.06 lb) were used in a 114-d growth trial. At placement (35 lb), pigs were fed a common diet containing 0.66% total Ca and 0.42% STTD P until the initiation of the trial. On d 0, pens of pigs were weighed and ranked by average BW. Pens were then randomly assigned to 1 of 5 dietary treatments in a randomized complete block design, with BW used as a blocking factor. There were 27 pigs per pen and 9 replicate pens per treatment. The 5 dietary treatments were formulated to contain 0.75:1, 1.00:1, 1.25:1, 1.50:1, and 2.00:1 analyzed Ca:analyzed P ratio. The analyzed Ca or P was defined as that calculated based on ingredient analysis.

A total of 3 samples of all the ingredients used in the diets that contained Ca and P were analyzed for Ca and P in duplicate (Ward Laboratories, Inc., Kearney, NE; Table 1). The average of the six lab results for each ingredient was used for diet formulation. The experimental diets were corn-soybean meal-based, and fed in 4 different phases (Tables 2, 3, 4, and 5). Phase 1 diets were fed from d 0 to 25 (55.7 to 98.4 lb); phase 2 diets were fed from d 26 to 58 (98.5 to 164.0 lb); phase 3 diets were fed from d 59 to 87 (164.1 to 227.1 lb); and phase 4 diets were fed from d 88 to 114 (227.2 to 279 lb). The diets contained 1,000 phytase units (FYT) of Ronozyme Hiphos 2500 (DSM Nutritional Products, Inc., Parsippany, NJ) with assumed release values of 0.15% available P and 0.132% STTD P. The diets were formulated to contain adequate STTD P across the dietary treatments in all phases based on the estimated requirement previously determined in this facility.[9] Thus, formulated STTD P levels were 0.38, 0.33, 0.29, and 0.25% for phases 1, 2, 3, and 4, respectively. These STTD P concentrations included the expected phytase release of 0.132% STTD P. The analyzed total Ca:P ratios to form the dietary treatments were achieved by increasing the amount of calcium carbonate at the expense of corn while maintaining monocalcium phosphate constant.

Experimental diets were manufactured at the New Horizon Farms Feed Mill (Pipestone, MN) and fed in meal form. Representative samples of treatment diets were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of each phase and stored at -4°F. After blending, 6 subsamples were analyzed in duplicates for dry matter (DM), crude protein (CP), crude fiber, ash, ether extract, Ca, and P and average values were reported (Tables 6 and 7; Ward Laboratories, Inc., Kearney, NE, and Midwest Laboratories, Omaha, NE).

Pens of pigs were weighed, and feed disappearance was recorded approximately every 14 d to determine ADG, ADFI, and feed-to-gain ratio (F/G). On d 99, the 2 heaviest pigs in each pen were selected, weighed, and sold according to standard farm procedures. On d 114, final pen weights were taken and one barrow and one gilt with intermediate weights were selected, tattooed with a pen ID, and marketed for bone data collection. These pigs were transported to a commercial abattoir in northwest Iowa (Natural Foods, Sioux Center, IA) for processing and collection of metacarpal bone samples for analysis of their mineral content. The remaining pigs were individually tattooed with the specific pen identity on the shoulder to allow carcass measurements to be recorded on a pen basis. These pigs were transported to a commercial packing plant in southwestern Minnesota (JBS Swift and Company, Worthington, MN) for processing and carcass data collection. Carcass measurements included HCW, loin depth, backfat depth, and percentage lean. Percentage carcass yield was calculated by dividing the average pen HCW by the average final live weight at the farm.

Bones were collected following processing for mineralization analysis. The left front feet were separated at the junction of carpals and radius and ulna, and individually placed in a plastic bag with a permanent identification tag within the bag, then stored at -20°C. Feet were thawed overnight, and then were autoclaved for 1 h at 121°C. The third metacarcapal of each foot was removed. These bones were cleaned of extraneous soft tissue, and refrozen. The third metacarpal was dried at ambient temperature for 24 h, cut in half, and weighed. They were wrapped in cheesecloth to keep their tag ID, and defatted by petroleum ether using a Soxhlet apparatus for 7 d. Defatted metacarpals were placed in a 105°C drying oven for another 7 d to determine the dry fat-free weight. Bones were then ashed in a muffle furnace at 600°C for 24 h to determine percentage ash. Ash is expressed as a percentage of dried fat-free bone weight.

For the economic analysis, total feed cost per pig, cost per lb of gain, gain value, and income over feed cost (IOFC) were calculated. The total feed cost per pig was calculated by multiplying ADFI by feed cost per pound and number of days the diet was fed in each respective period, then taking the sum of these values for each period. Cost per lb of gain was calculated by dividing total feed cost per pig by total gain per pig. Gain value per pig was calculated by multiplying carcass gain by an assumed carcass value of $58.35 per cwt. To calculate IOFC, total feed cost was subtracted from gain value. For all economic evaluations, prices of ingredients during spring of 2018 were used with corn valued at $3.55/bu ($127/ton), soybean meal at $373/ton, L-lysine HCL at $0.74/lb, DL-methionine at $1.40/lb, L-threonine at $1.05/lb, L-tryptophan at $9.00/lb, Ronozyme Hiphos 2500 at $0.77/lb, monocalcium phosphate at $0.29/lb, and calcium carbonate at $0.02/lb.

Growth performance data were analyzed as a randomized complete block design, with pen considered the experimental unit and BW the blocking factor. The study was structured as a split-plot design in a randomized complete block design for the bone data. The whole-plot treatments included the different total Ca:P ratios. Within each of the dietary treatments, there was a one-way treatment structure with gender as the factor level. A random effect of block by treatment was used to identify the pair of pigs (one barrow and one gilt) within each pen as the experimental unit for gender. The two-way interaction between dietary treatments and gender was tested, and no significant interactions were observed. Response variables were analyzed using generalized linear and non-linear mixed models. Polynomial contrasts were implemented to evaluate the functional form of the dose response to increasing analyzed Ca:P on growth performance, carcass characteristics, and economic response variables. Statistical models were fitted using GLIMMIX procedure of SAS (Version 9.3, SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 \leq P \leq 0.10$.

In addition, the effects of analyzed Ca:analyzed P dose response on ADG, ADFI, feed efficiency (modeled as gain to feed, G:F), HCW, and percentage bone ash were fit using GLIMMIX and NLMIXED procedure of SAS according to Gonçalves et al.[10] Models were expanded to account for heterogeneous residual variances when needed. Competing statistical models included a linear (LM), quadratic polynomial (QP), broken-line linear (BLL), and broken-line quadratic (BLQ). Dose response models were compared based on the Bayesian information criterion (BIC), where the smaller the value, the better.[11] A decrease in BIC greater than 2 was considered a significant improvement in fit. The 95% confidence interval of the estimated requirement to reach maximum performance or to reach plateau performance was computed. Results reported correspond to inferences yielded by the best fitting models.

Results and Discussion

Analysis of DM, CP, crude fiber, fat, and ash contents of experimental diets (Tables 6 and 7) showed that values were reasonably consistent with formulated estimates. Average values of analyzed Ca and P concentrations slightly differed from the formulated values; however, they followed similar patterns as the designed treatment structure. The average Ca:P ratio across the four phases were 0.78:1, 0.97:1, 1.32:1, 1.47:1, and 2.06:1 for the 0.75:1, 1.00:1, 1.25, 1.50, and 2.00:1 treatments, respectively.

During the grower period, which corresponds to phases 1 and 2 (d 0 to 58), there was a marginal quadratic increase ($P < 0.10$) in ADG, with the greatest gain observed at 1.50:1 analyzed Ca:P ratio and no improvements thereafter (Table 8). However,

[10]Gonçalves, M., N. Bello, S. Dritz, M. Tokach, J. DeRouchey, J. Woodworth, and R. Goodband. 2016. An update on modeling dose–response relationships: Accounting for correlated data structure and heterogeneous error variance in linear and nonlinear mixed models. Journal of Animal Science. 94(5): 1940-1950.

[11]G. A. Milliken, and D. E. Johnson. 2009. Analysis of messy data: designed experiments. Vol. 1, 2nd ed., CRC Press, Boca Raton, FL.

there was no evidence ($P > 0.10$) of differences in ADFI and F/G due to increasing the analyzed Ca:P ratio from 0.75:1 to 2.00:1. During the finisher period, which corresponds to phases 3 and 4 (d 59 to 114), increasing analyzed Ca:P ratio resulted in an increase (quadratic, $P < 0.05$) in ADG driven by a quadratic increase ($P < 0.05$) in ADFI. The greatest improvement in ADG occurred as the analyzed Ca:P ratio increased from 0.75:1 to 1.25:1, with little increase thereafter. The greatest improvement in ADFI was observed as the analyzed Ca:P ratio increased from 0.75:1 to 1.50:1, with no further improvement. Feed efficiency improved linearly ($P < 0.05$) as the analyzed Ca:P ratio increased up to the highest ratio of 2.00:1.

Overall, increasing analyzed Ca:P ratio quadratically increased ($P < 0.05$) ADG and final BW. The greatest increase in both criteria was observed as the ratio increased from 0.75:1 to 1.50:1, with no improvement thereafter. Similarly, there was a marginal quadratic increase ($P < 0.10$) in ADFI, with the greatest intake observed at an analyzed Ca:P ratio of 1.50:1. Feed efficiency improved linearly ($P < 0.05$) with increasing the analyzed Ca:P ratio from 0.75:1 to 2.00:1.

For carcass characteristics, HCW increased quadratically ($P < 0.05$) as the analyzed Ca:P ratio increased up to 1.50:1, and started to decrease thereafter. Percentage carcass yield decreased (quadratic, $P < 0.10$) from 0.75:1 analyzed Ca:P ratio to 1.25:1, slightly increasing at higher ratios. No evidence of differences ($P > 0.10$) was observed for backfat depth, fat-free lean, and loin depth measurements.

Feed cost per pig increased linearly ($P < 0.05$) with increasing analyzed Ca:P ratio up to the highest ratio at 2.00:1. No evidence of difference ($P > 0.10$) was observed for feed cost per pound of gain. Gain value per pig increased (quadratic, $P < 0.05$) with increasing analyzed Ca:P ratio. The greatest revenue was observed for pigs fed diets with 1.50:1 analyzed Ca:P ratio, which is a result of the quadratic improvement in ADG and final BW. The increased gain value was sufficient to overcome the increased feed cost, resulting in a marginal quadratic improvement ($P < 0.10$) in IOFC, with the greatest income observed at 1.25:1 analyzed Ca:P ratio.

For bone mineralization, the two-way interaction between dietary treatment and gender was tested and no evidence ($P > 0.10$) for significant interaction was observed. There was a marginal significant gender effect ($P < 0.10$) on percentage bone ash, with barrows having greater bone mineralization than gilts (61.55 and 61.30% for barrows and gilts, respectively). Bone mineralization increased quadratically ($P < 0.05$) with increasing analyzed Ca:P ratio (Table 8). The greatest improvement in percentage bone ash was observed as analyzed Ca:P ratio increased from 0.75:1 to 1.25:1, with no further increase.

Homogeneous variance was used for G:F models and heterogeneous variance was used for ADG, ADFI, HCW, and bone ash models. The best fitting model for ADG was the QP model (Figure 1). The analyzed Ca:P ratio with phytase for maximum ADG was estimated at 1.63:1 (95% CI: [1.25:1, >2.00:1]), with 99% of the maximum response being achieved at 1.28:1. Based on the best fitting model, the estimated regression equation was ADG, g = $729.12 + 233.25 \times (\text{Ca:P}) - 71.3315 \times (\text{Ca:P})^2$. The best fitting model for ADFI was the LM (Figure 2), which estimated the maximum mean

ADFI at greater than 2.00:1 analyzed Ca:P ratio. The estimated regression equation was ADFI, g = 2109.55 + 98.8323 × (Ca:P). The broken-line linear model provided the best fit for G:F (Figure 3), with the breakpoint observed at 1.05:1 analyzed Ca:P ratio (95% CI: [0.81:1, 1.30:1]). The estimated regression equation was G:F, g/kg = 406.43 - 31.4661 × (1.0543 - Ca:P) if analyzed Ca:P ratio < 1.05:1, and G:F, g/kg = 406.43 if analyzed Ca:P ratio ≥ 1.05:1. The QP and BLL models had similar fit to the HCW data (Figure 4). The QP model estimated the maximum mean HCW at 1.60:1 analyzed Ca:P ratio (95% CI: [1.14:1, >2.00:1]). The estimated regression equation was HCW, lb = 178.27 + 37.7255 × (Ca:P) – 11.7964 × $(Ca:P)^2$. The BLL plateau was estimated at 1.11:1 analyzed Ca:P ratio (95% CI: [0.87:1, 1.36:1]). The estimated regression equation was HCW, lb = 207.30 – 21.2124 × (1.11 – Ca:P) if analyzed Ca:P < 1.11:1, and HCW, lb = 207.30 if analyzed Ca:P ≥ 1.11:1. The best fitting model for percentage bone ash was the BLL model (Figure 5), which estimated the maximum mean percentage bone ash at 1.25:1 analyzed Ca:P ratio (95% CI: [1.10:1, 1.40:1]). The estimated regression equation was bone ash, % = 61.83 – 2.65158 × (Ca:P) if analyzed Ca:P ratio < 1.25:1. If analyzed Ca:P ≥1.25:1, then bone ash, % = 61.83.

Increasing analyzed Ca:P ratio in the diets quadratically improved ADG, ADFI, final BW, HCW, carcass yield, and bone ash. Although feed cost increased with increasing analyzed Ca:P ratios, the improved value in gain was sufficient to overcome the increase in feed cost. Thus, the return over the feed cost increased quadratically with increasing analyzed Ca:P ratio. In conclusion, the estimated analyzed Ca:P ratio requirement for finishing pigs from 56- to 279-lb fed diets containing 1,000 FYT of phytase and that were adequate in STTD P ranged from 1.05:1 to 1.63:1 to maximize growth rate, feed efficiency, HCW, and bone mineralization criteria.

Table 1. Analyzed Ca and P concentrations in feed ingredients (as-fed basis)[1]

Item	Ca, %	P, %
Corn	0.03	0.22
Soybean meal, 46.5% crude protein	0.51	0.65
Monocalcium P (21% P)	15.23	18.78
Limestone	34.64	0.07
Vitamin and trace mineral premix	6.21	0.02

[1]A total of six samples of each ingredient were submitted to Ward Laboratories, Inc. (Kearney, NE) and were analyzed in duplicate for Ca and P concentration. Average values were reported and used in diet formulation.

Table 2. Diet formulation, Phase 1 (as-fed basis)[1]

	Phase 1				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Ingredient, %					
Corn	67.85	67.21	66.63	66.05	64.83
Soybean meal, 46.5% crude protein	29.91	29.96	30.00	30.04	30.13
Beef tallow	0.50	0.75	0.95	1.15	1.60
Monocalcium phosphate, 21% P	0.48	0.48	0.48	0.48	0.48
Limestone	0.23	0.58	0.92	1.25	1.94
Sodium chloride	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.09	0.09	0.09	0.09	0.10
L-threonine	0.10	0.10	0.10	0.10	0.10
L-tryptophan	0.01	0.01	0.01	0.01	0.01
Phytase[2]	0.04	0.04	0.04	0.04	0.04
Vitamin and trace mineral premix	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00

continued

Table 2. Diet formulation, Phase 1 (as-fed basis)[1]

	Phase 1				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	1.15	1.15	1.15	1.15	1.15
Isoleucine:lysine	63	63	63	63	63
Leucine:lysine	132	132	131	131	131
Methionine:lysine	32	32	32	32	32
Methionine and cysteine:lysine	56	56	56	56	56
Threonine:lysine	62	62	62	62	62
Tryptophan:lysine	18.9	18.9	18.9	18.9	18.9
Valine:lysine	69	69	69	69	68
Total lysine, %	1.29	1.29	1.29	1.29	1.29
Net energy, kcal/lb	1,129	1,129	1,129	1,129	1,129
SID lysine:ME,[3] g/Mcal	3.43	3.43	3.43	3.43	3.44
Crude protein, %	19.4	19.4	19.4	19.4	19.3
Calcium,[4] %	0.37	0.49	0.61	0.73	0.97
STTD Ca,[5] %	0.36	0.45	0.55	0.64	0.83
Phosphorus,[4] %	0.49	0.49	0.49	0.48	0.48
STTD P,[6] %	0.38	0.38	0.38	0.38	0.38
Available phosphorus, %	0.32	0.32	0.32	0.32	0.32
Calcium:phosphorus[4]	0.75	1.00	1.25	1.50	2.00
STTD Ca:STTD P	0.94	1.20	1.44	1.69	2.19

[1]Phase 1 diets were fed from d 0 to 25 (55.7 to 98.4 lb).
[2]Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) was included at 1,000 FYT/kg releasing an assumed 0.15% aP and 0.132% STTD P.
[3]ME = metabolizable energy.
[4]These values represent analyzed Ca and analyzed P.
[5]Standardized total tract digestible calcium.
[6]Standardized total tract digestible phosphorus.

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

	Phase 2				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Ingredient, %					
Corn	76.19	75.66	75.13	74.65	73.60
Soybean meal, 46.5% crude protein	21.74	21.77	21.81	21.85	21.92
Beef tallow	0.50	0.70	0.90	1.05	1.45
Monocalcium phosphate, 21% P	0.30	0.30	0.30	0.30	0.30
Limestone	0.28	0.57	0.86	1.15	1.73
Sodium chloride	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.06	0.06	0.06	0.06	0.07
L-threonine	0.09	0.09	0.09	0.10	0.10
L-tryptophan	0.01	0.01	0.01	0.01	0.01
Phytase[2]	0.04	0.04	0.04	0.04	0.04
Vitamin and trace mineral premix					
Total	100.00	100.00	100.00	100.00	100.00

continued

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

	Phase 2				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.95	0.95	0.95	0.95	0.95
Isoleucine:lysine	62	62	62	62	62
Leucine:lysine	140	140	139	139	138
Methionine:lysine	32	32	32	32	32
Methionine and cysteine:lysine	57	57	57	57	57
Threonine:lysine	63	63	63	63	63
Tryptophan:lysine	18.6	18.6	18.6	18.6	18.6
Valine:lysine	69	69	69	69	69
Total lysine, %	1.07	1.07	1.07	1.07	1.07
Net energy, kcal/lb	1,152	1,152	1,152	1,152	1,152
SID lysine:ME,[3] g/Mcal	2.82	2.82	2.82	2.83	2.83
Crude protein, %	16.1	16.1	16.0	16.0	16.0
Calcium,[4] %	0.31	0.41	0.52	0.62	0.82
STTD Ca,[5] %	0.31	0.39	0.47	0.55	0.71
Phosphorus,[4] %	0.41	0.41	0.41	0.41	0.41
STTD P,[6] %	0.33	0.33	0.33	0.33	0.33
Available phosphorus, %	0.27	0.27	0.27	0.27	0.27
Calcium:phosphorus[4]	0.75	1.00	1.25	1.50	2.00
STTD Ca:STTD P	0.95	1.19	1.44	1.68	2.17

[1]Phase 2 diets were fed from d 26 to 58 (98.5 to 164.0 lb).
[2]Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) was included at 1,000 FYT/kg releasing an assumed 0.15% aP and 0.132% STTD P.
[3]ME = metabolizable energy.
[4]These values represent analyzed Ca and analyzed P.
[5]Standardized total tract digestible calcium.
[6]Standardized total tract digestible phosphorus.

Table 4. Diet formulation, Phase 3 (as-fed basis)[1]

	Phase 3				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Ingredient, %					
Corn	81.22	80.78	80.35	79.87	78.99
Soybean meal, 46.5% crude protein	16.83	16.86	16.89	16.92	16.99
Beef tallow	0.50	0.65	0.80	1.00	1.30
Monocalcium phosphate, 21% P	0.15	0.15	0.15	0.15	0.15
Limestone	0.31	0.57	0.82	1.07	1.58
Sodium chloride	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.04	0.04	0.04	0.04	0.05
L-threonine	0.10	0.10	0.10	0.10	0.10
L-tryptophan	0.02	0.02	0.02	0.02	0.02
Phytase[2]	0.04	0.04	0.04	0.04	0.04
Vitamin and trace mineral premix					
Total	100.00	100.00	100.00	100.00	100.00

continued

Table 4. Diet formulation, Phase 3 (as-fed basis)[1]

	Phase 3				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.83	0.83	0.83	0.83	0.83
Isoleucine:lysine	61	61	61	61	61
Leucine:lysine	146	146	146	145	145
Methionine:lysine	31	31	31	31	32
Methionine and cysteine:lysine	58	58	58	58	58
Threonine:lysine	65	65	65	65	65
Tryptophan:lysine	18.7	18.7	18.7	18.7	18.6
Valine:lysine	70	70	70	70	69
Total lysine, %	0.94	0.94	0.94	0.94	0.94
Net energy, kcal/lb	1,166	1,166	1,166	1,166	1,166
SID lysine:ME,[3] g/Mcal	2.46	2.46	2.46	2.46	2.46
Crude protein, %	14.1	14.1	14.1	14.0	14.0
Calcium,[4] %	0.27	0.36	0.45	0.54	0.72
STTD Ca,[5] %	0.28	0.35	0.42	0.48	0.62
Phosphorus,[4] %	0.36	0.36	0.36	0.36	0.36
STTD P,[6] %	0.29	0.29	0.29	0.29	0.29
Available phosphorus, %	0.24	0.24	0.24	0.24	0.24
Calcium:phosphorus[4]	0.75	1.00	1.25	1.50	2.00
STTD Ca:STTD P	0.96	1.20	1.44	1.68	2.17

[1]Phase 3 diets were fed from d 59 to 87 (164.1 to 227.1 lb).
[2]Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) was included at 1,000 FYT/kg releasing an assumed 0.15% aP and 0.132% STTD P.
[3]ME = metabolizable energy.
[4]These values represent analyzed Ca and analyzed P.
[5]Standardized total tract digestible calcium.
[6]Standardized total tract digestible phosphorus.

Table 5. Diet formulation, Phase 4 (as-fed basis)[1]

	Phase 4				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Ingredient, %					
Corn	81.56	81.15	80.73	80.32	79.50
Soybean meal, 46.5% crude protein	16.77	16.80	16.83	16.86	16.92
Beef tallow	0.50	0.65	0.80	0.95	1.25
Monocalcium phosphate, 21% P	0.00	0.00	0.00	0.00	0.00
Limestone	0.32	0.55	0.79	1.02	1.48
Sodium chloride	0.35	0.35	0.35	0.35	0.35
L-lysine HCl	0.23	0.23	0.23	0.23	0.23
DL-methionine	0.01	0.01	0.01	0.02	0.02
L-threonine	0.08	0.08	0.08	0.08	0.08
L-tryptophan	0.01	0.01	0.01	0.01	0.01
Phytase[2]	0.04	0.04	0.04	0.04	0.04
Vitamin and trace mineral premix	0.15	0.15	0.15	0.15	0.15
Total	100.00	100.00	100.00	100.00	100.00

Table 5. Diet formulation, Phase 4 (as-fed basis)[1]

	Phase 4				
	Analyzed Ca:P ratio				
Item	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lysine	0.77	0.77	0.77	0.77	0.77
Isoleucine:lysine	66	66	66	66	66
Leucine:lysine	158	158	157	157	156
Methionine:lysine	30	30	30	31	30
Methionine and cysteine:lysine	59	59	59	59	59
Threonine:lysine	67	67	67	67	67
Tryptophan:lysine	18.8	18.8	18.8	18.8	18.8
Valine:lysine	75	75	75	75	75
Total lysine, %	0.88	0.88	0.88	0.88	0.88
Net energy, kcal/lb	1,168	1,168	1,168	1,168	1,168
SID lysine:ME,[3] g/Mcal	2.28	2.28	2.28	2.28	2.28
Crude protein, %	14.0	14.0	13.9	13.9	13.9
Calcium,[4] %	0.25	0.33	0.41	0.50	0.66
STTD Ca,[5] %	0.26	0.32	0.39	0.45	0.57
Phosphorus,[4] %	0.33	0.33	0.33	0.33	0.33
STTD P,[6] %	0.26	0.26	0.26	0.26	0.26
Available phosphorus, %	0.21	0.21	0.21	0.21	0.21
Calcium:phosphorus[4]	0.75	1.00	1.25	1.50	2.00
STTD Ca:STTD P	0.98	1.23	1.48	1.72	2.20

[1]Phase 4 diets were fed from d 88 to 114 (227.2 to 279 lb).
[2]Phytase (Ronozyme HiPhos, DSM Nutritional Products, Parsippany, NJ) was included at 1,000 FYT/kg releasing an assumed 0.15% aP and 0.132% STTD P.
[3]ME = metabolizable energy.
[4]These values represent analyzed Ca and analyzed P.
[5]Standardized total tract digestible calcium.
[6]Standardized total tract digestible phosphorus.

Table 6. Analyzed composition of experimental diets (as-fed-basis)[1]

	Phase 1				
	Analyzed Ca:P ratio				
Item, %	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Dry matter	87.25	87.29	87.41	87.54	87.73
Crude protein	21.14	20.91	20.86	21.19	20.61
Crude fiber	2.15	2.44	2.60	2.69	2.69
Ether extract	3.55	3.52	3.63	3.83	4.06
Ash	3.83	3.97	4.43	4.78	5.00
Calcium	0.47	0.53	0.70	0.84	0.97
Phosphorus	0.54	0.53	0.53	0.54	0.52
Ca:P ratio	0.87	1.00	1.32	1.56	1.87
	Phase 2				
Dry matter	86.43	86.60	86.74	86.95	86.94
Crude protein	17.58	17.83	17.76	17.66	17.75
Crude fiber	2.51	2.61	2.66	2.71	2.44
Ether extract	3.12	3.08	3.02	3.29	3.73
Ash	3.44	3.54	3.72	4.10	4.42
Calcium	0.33	0.38	0.56	0.69	0.87
Phosphorus	0.45	0.45	0.46	0.47	0.46
Ca:P ratio	0.73	0.84	1.22	1.47	1.89

[1]Representative samples of treatment diets were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of the phase and stored at -4°F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and Midwest Laboratories (Omaha, NE) and were analyzed for dry matter, crude protein, crude fiber, ash, ether extract, calcium, and phosphorus. Values represent the average across laboratories.

Table 7. Analyzed composition of experimental diets (as-fed-basis)[1]

	Phase 3				
	Analyzed Ca:P ratio				
Item, %	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1
Dry matter	86.83	87.32	87.36	86.86	87.43
Crude protein	15.40	15.00	15.20	16.79	15.99
Crude fiber	2.08	2.20	2.41	2.44	2.18
Ether extract	3.33	4.04	3.79	3.41	3.57
Ash	2.66	3.89	3.19	3.05	3.05
Calcium	0.30	0.41	0.54	0.62	0.87
Phosphorus	0.39	0.41	0.39	0.41	0.40
Ca:P ratio	0.77	1.00	1.38	1.51	2.18
	Phase 4				
Dry matter	86.89	86.89	87.00	87.29	87.22
Crude protein	15.16	14.94	15.73	14.99	15.09
Crude fiber	2.24	2.46	2.58	2.70	2.46
Ether extract	3.68	3.61	3.53	3.85	3.56
Ash	2.46	2.49	2.99	2.83	3.62
Calcium	0.27	0.36	0.50	0.48	0.81
Phosphorus	0.36	0.35	0.38	0.35	0.36
Ca:P ratio	0.75	1.03	1.32	1.37	2.25

[1]Representative samples of treatment diets were taken from 6 feeders per dietary treatment 3 d after the beginning and 3 d before the end of the phase and stored at -4°F. After blending, subsamples were submitted to Ward Laboratories, Inc. (Kearney, NE) and Midwest Laboratories (Omaha, NE) and were analyzed for dry matter, crude protein, crude fiber, ash, ether extract, calcium, and phosphorus. Values represent the average across laboratories.

Table 8. Effects of analyzed Ca:P ratio with the inclusion of phytase on growth performance, carcass characteristics, and economics of growing-finishing pigs [1]

	Analyzed Ca:P ratio[2,3]						Probability, *P*	
Item[4]	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1	SEM	Linear	Quadratic
Grower period (d 0 to 58)								
ADG, lb	1.81	1.85	1.83	1.88	1.83	0.027	0.390	0.061
ADFI, lb	3.73	3.75	3.74	3.84	3.76	0.083	0.349	0.289
F/G	2.06	2.03	2.04	2.05	2.05	0.023	0.998	0.173
Finisher period (d 59 to 114)								
ADG, lb	1.97	2.10	2.16	2.17	2.19	0.026	<0.001	0.001
ADFI, lb	5.92	6.10	6.20	6.23	6.21	0.092	0.011	0.044
F/G	3.00	2.92	2.87	2.88	2.83	0.047	0.002	0.193
Overall (d 0 to 114)								
ADG, lb	1.90	1.98	1.99	2.02	2.01	0.019	<0.001	0.001
ADFI, lb	4.79	4.89	4.91	5.00	4.95	0.082	0.025	0.090
F/G	2.52	2.47	2.46	2.47	2.46	0.029	0.017	0.104
Body weight, lb								
d 0	55.7	55.7	55.9	55.7	55.7	2.06	0.924	0.766
d 58	162.2	164.3	163.8	166.2	163.5	3.42	0.427	0.096
d 114	268.5	280.5	281.7	283.7	280.7	3.97	0.001	<0.001
Carcass characteristics[5]								
Pig count	144	164	157	158	146	---	---	---
HCW, lb	199.6	204.9	206.4	208.4	206.7	2.99	0.007	0.015
Yield, %	74.4	73.1	73.2	73.5	73.6	0.42	0.550	0.090
Backfat, mm[6]	16.1	16.0	16.5	16.2	16.2	---[7]	0.855	0.604
Fat-free lean, %[6]	57.4	57.5	57.2	57.2	57.3	---[7]	0.650	0.615
Loin depth, mm[6]	69.5	70.2	69.8	68.7	69.2	---[7]	0.406	0.984

continued

Table 8. Effects of analyzed Ca:P ratio with the inclusion of phytase on growth performance, carcass characteristics, and economics of growing-finishing pigs [1]

	Analyzed Ca:P ratio[2,3]						Probability, *P*	
Item[4]	0.75:1	1.00:1	1.25:1	1.50:1	2.00:1	SEM	Linear	Quadratic
Economics								
Feed cost, $/pig	58.64	60.23	60.75	62.18	62.22	1.019	<0.001	0.102
Feed cost/lb gain, $[8]	0.271	0.267	0.267	0.269	0.271	0.0031	0.521	0.101
Gain value, $/pig[9]	92.11	95.20	95.96	97.21	96.21	1.089	0.005	0.013
IOFC, $/pig[10]	33.47	34.97	35.21	35.04	33.99	0.774	0.853	0.068
Bone characteristics[11,12]								
Ash, %[13,14]	60.52	61.10	61.90	61.79	61.82	0.188	<0.001	0.001

[1]A total of 1,214 pigs (PIC 337 × Camborough, initial pen average BW of 55.7 lb) were used in a 114-d growth trial with 27 pigs per pen and 9 pens per treatment.
[2]Treatments were formulated to be adequate in STTD P within phases, which corresponded to 0.38, 0.32, 0.29, and 0.26% STTD P for phases 1, 2, 3, and 4, respectively.
[3]Phytase (Ronozyme Hiphos, DSM Nutritional Products, Parsippany, NJ) was added to the diets at 1,000 FYT/kg feed with assumed release values of 0.15% avP and 0.132% STTD P.
[4]ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. IOFC = income over feed cost.
[5]907 pigs were transported to a commercial packing plant for processing and data collection (Swift and Company, Worthington, MN).
[6]Adjusted for hot carcass weight (HCW).
[7] EM for backfat were 0.38, 036, 0.37, and 0.38. SEM for fat-free lean were 0.25, 0.24, 0.25, 0.25, and 0.25. SEM for loin depth were 0.71, 0.68, 0.68, 0.68, and 0.70.
[8]Feed cost/lb gain = total feed cost divided by total gain per pig.
[9]Gain value = (HCW × $0.5835) – (d 0 BW × 0.75 × $0.5835).
[10]Income over feed cost = gain value – feed cost.
[11]90 pigs (2 pigs/pen, 1 barrow/1 gilt) visually assumed to represent the mean live weight of the pen were subsampled and shipped to a separate processing facility for bone collection (Natural Foods Holdings, Inc., Sioux Center, IA).
[12]A total of 90 third metacarpals were autoclaved for 1 h. After cleaning, bones were placed in Soxhlets containing petroleum ether for 7 d as a means of removing water and fat. They were then dried at 105°C for 7 d, and then ashed at 600°C for 24 h.
[13]Adjusted for HCW.
[14]The two-way interaction was tested and no evidence for significant interaction was observed. There was a marginal significant gender effect ($P < 0.10$) on percentage bone ash, with barrows having greater bone mineralization than gilts (61.55 and 61.30% for barrows and gilts, respectively).

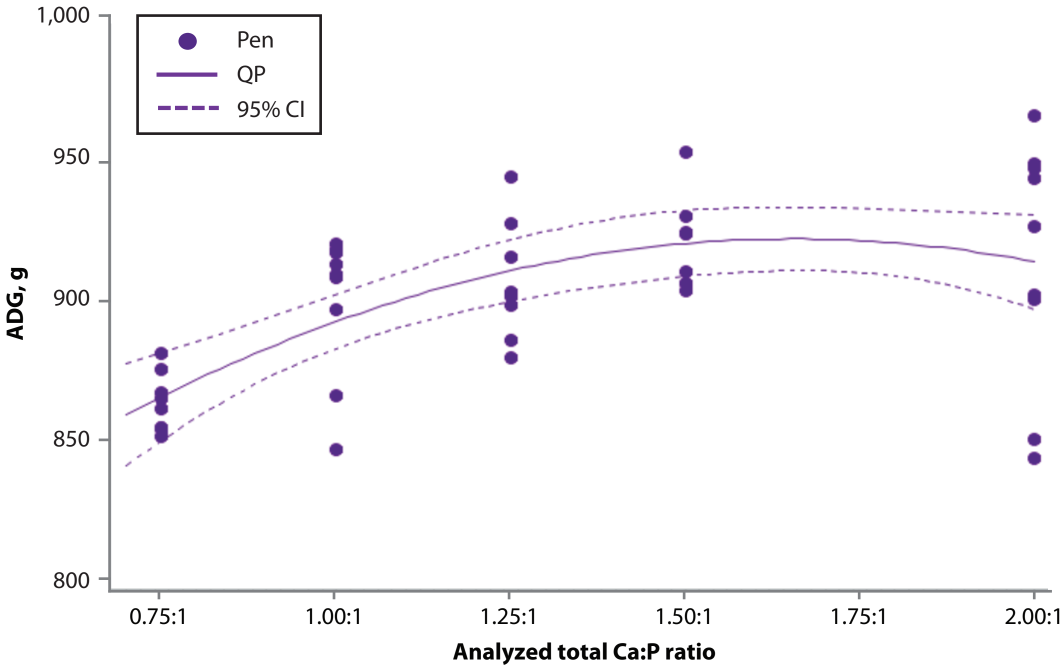

Figure 1. Fitted quadratic polynomial (QP) regression model on average daily gain (ADG) as a function of increasing analyzed calcium:phosphorus ratio in growing-finishing pigs fed diets containing 1,000 phytase units. The QP model estimated the maximum mean ADG at 1.63:1 analyzed Ca:P ratio (95% CI: [1.25:1, >2.00:1]), with 99% of the maximum response being achieved at 1.28:1. Based on the best fitting model, the estimated regression equation was ADG, g = 729.12 + 233.25 × (Ca:P) –71.3315 × (Ca:P)^2.

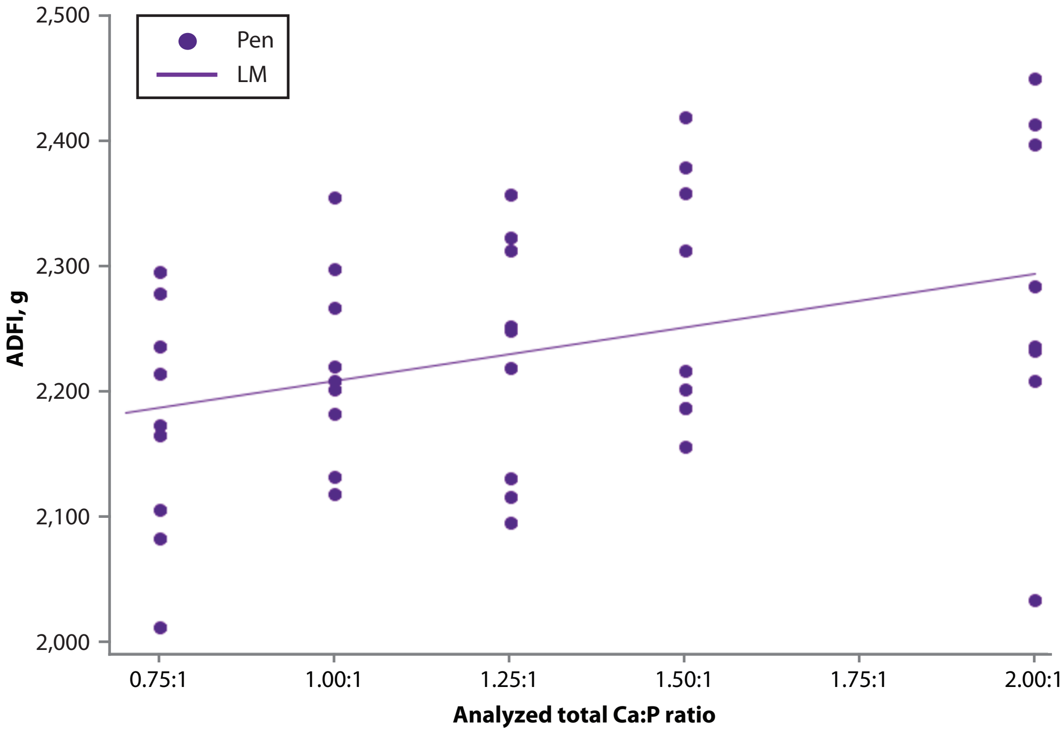

Figure 2. Fitted linear (LM) regression model on average daily feed intake (ADFI) as a function of increasing analyzed calcium:phosphorus ratio in growing-finishing pigs fed diets containing 1,000 phytase units. The LM model estimated the maximum mean ADFI at greater than 2.00:1 analyzed Ca:P ratio with added phytase. The estimated regression equation was average daily gain, g = 2109.55 + 98.8323 × (Ca:P).

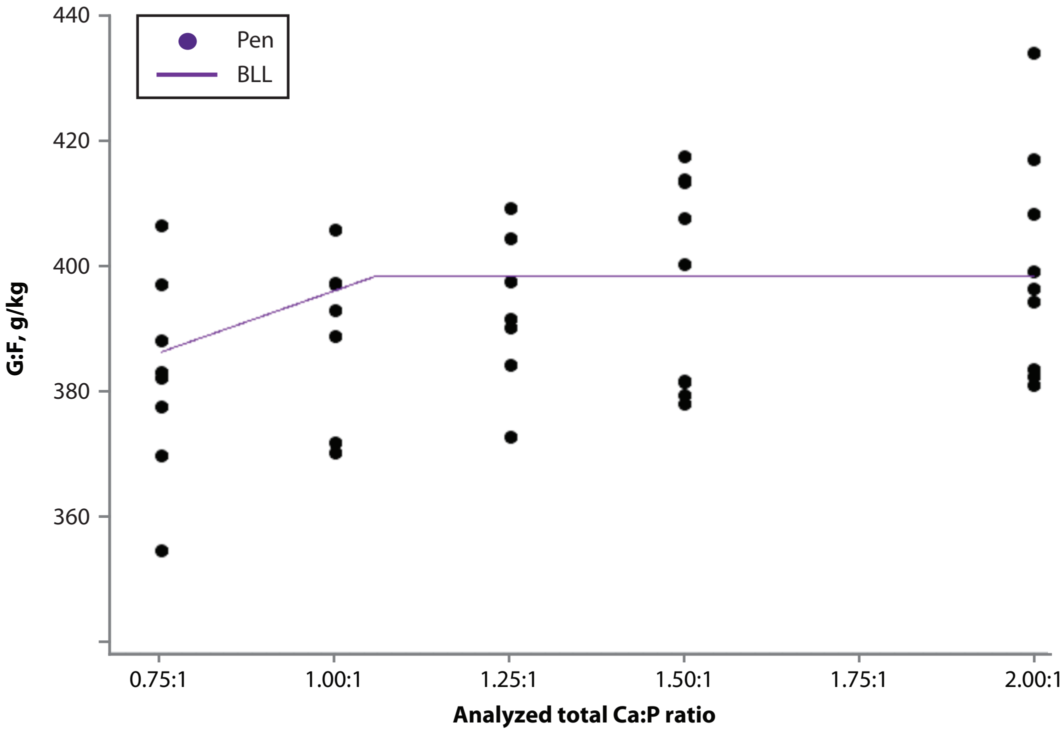

Figure 3. Fitted broken-line linear (BLL) regression model on gain to feed ratio (G:F) as a function of increasing analyzed calcium:phosphorus ratio in growing-finishing pigs fed diets containing 1,000 phytase units. The BLL model estimated the maximum mean G:F at 1.05:1 analyzed Ca:P ratio (95% CI: [0.81:1, 1.30:1]). The estimated regression equation was G:F, g/kg = 406.43 - 31.4661 × (1.0543 - Ca:P) if analyzed Ca:P ratio < 1.05:1, and G:F, g/kg = 406.43 if analyzed Ca:P ratio ≥ 1.05:1.

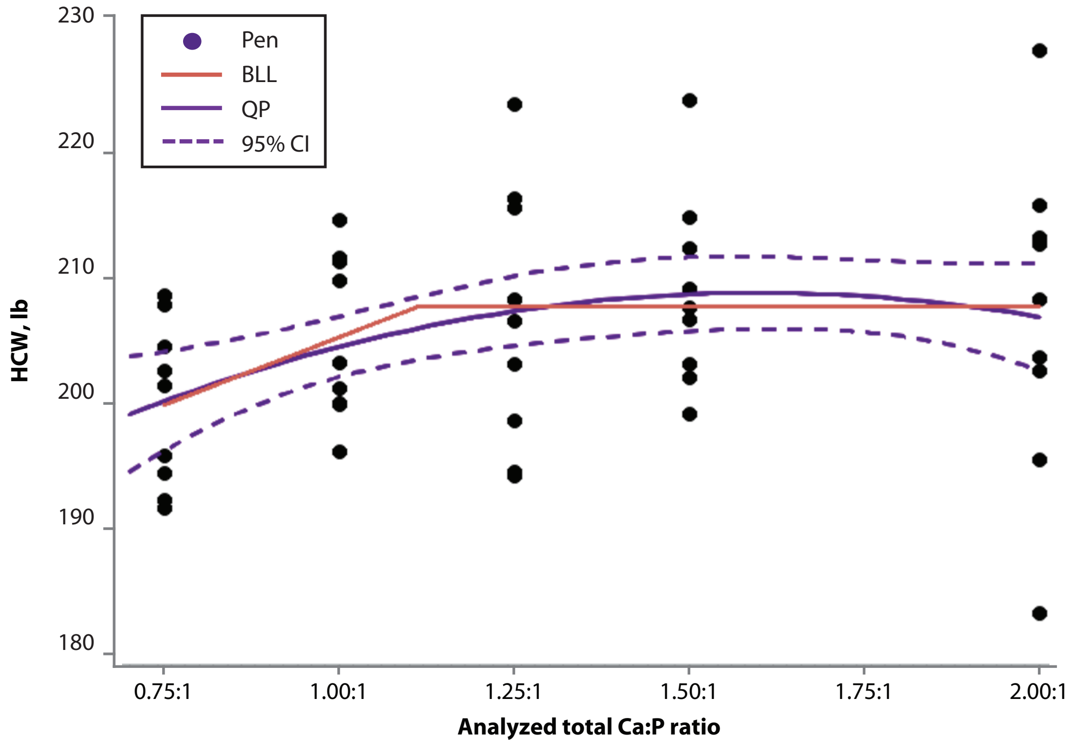

Figure 4. Fitted quadratic polynomial (QP) regression model and broken-line linear (BLL) model on hot carcass weight (HCW) as a function of increasing analyzed calcium:phosphorus ratio in growing-finishing pigs fed diets containing 1,000 phytase units. The QP model estimated the maximum mean HCW at 1.60:1 analyzed Ca:P ratio (95% CI: [1.14:1, >2.00:1]). The estimated regression equation was HCW, lb = 178.27 + 37.7255 × (Ca:P) – 11.7964 × $(Ca:P)^2$. The BLL plateau was estimated at 1.11:1 analyzed Ca:P ratio (95% CI: [0.87:1, 1.36:1]). The estimated regression equation was HCW, lb = 207.30 – 21.2124 × (1.11 – Ca:P) if analyzed Ca:P < 1.11:1, and HCW, lb = 207.30 if analyzed Ca:P ≥ 1.11:1.

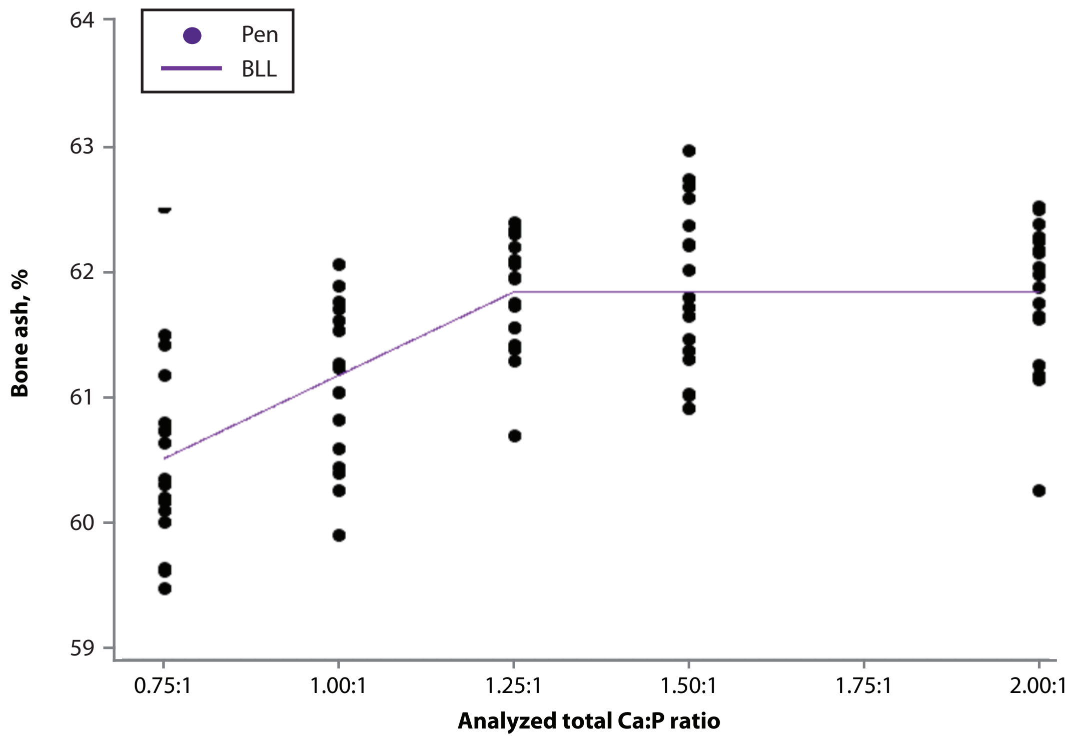

Figure 5. Fitted broken-line linear (BLL) regression model on percentage bone ash as a function of increasing analyzed calcium:phosphorus ratio in growing-finishing pigs fed diets containing 1,000 phytase units. The BLL model estimated the maximum mean percentage bone ash at 1.25 analyzed Ca:P ratio (95% CI: [1.10:1, 1.40:1]). The estimated regression equation was bone ash, % = 61.83 – 2.65158 × (Ca:P) if analyzed Ca:P ratio < 1.25:1. If analyzed Ca:P ≥ 1.25:1, then bone ash, % = 61.83.