Evaluating the Effects of Maternal Vitamin D Supplementation on the Subsequent Growth Performance and Carcass Characteristics of a Subsample Population of Growing Pigs

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Summary

A subsample of 448 growing pigs (PIC 327 × 1050), or approximately 50% of pigs weaned from sows fed varying dietary vitamin D regimens, were used in a split-plot design to determine the influence of maternal and nursery vitamin D regimens on growth performance. Sows were previously administered diets containing vitamin D as either: 1) low vitamin D_3 (363 IU/lb); 2) medium vitamin D_3 (907 IU/lb); 3) high vitamin D_3 (4,354 IU/lb); or 4) 23 µg 25(OH)D_3/lb (Hy-D, DSM Nutritional Products Inc, Parsippany, NJ) as described by Flohr et al. (2015[3]) throughout gestation and lactation. A total of 52 total litters from 2 consecutive weaning groups were represented in the subsample population for growth performance. Once weaned, pigs were allotted to pens in the nursery based on previously administered maternal vitamin D regimens, then pens were randomly assigned to 1 of 2 nursery vitamin D regimens (907 IU of vitamin D_3/lb, or 23 µg 25(OH)D_3/lb). Pigs remained on nursery vitamin D regimens for 35 d, then they were provided common growing and finishing diets until market. One pig per pen was bled at weaning and on d 17, 35, and 70 post-weaning to determine growing pig serum vitamin metabolites. At weaning, pig BW was increased (quadratic, $P = 0.001$) with increased maternal vitamin D_3 supplementation. This was because pigs from sows fed the medium concentration of vitamin D_3 were heavier at weaning compared to pigs from sows fed the low or high concentration of vitamin D_3. Overall from d 0 to 35 in the nursery, pigs from sows fed increasing vitamin D_3 had increased (quadratic, $P < 0.003$) ADG and ADFI, but F/G was similar regardless of maternal Vitamin D regimen. Pigs from sows fed the low concentration of vitamin D_3 had poorer

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[3] Flohr, J. R., J. C. Woodworth, M. D. Tokach, S. S. Dritz, R. D. Goodband, J. M. DeRouchey, and J. R. Bergstrom. 2015. Evaluating the impact of maternal vitamin D supplementation on sow performance, serum vitamin metabolites, neonatal muscle and bone characteristics, and subsequent pre-weaning pig performance. Kansas Agricultural Experiment Station Research Reports, Vol. 1: Iss. 7.

($P < 0.002$) ADG and final nursery BW compared to those from sows fed 25(OH)D_3. Throughout finishing (d 35 post-weaning until market), ADG was increased (quadratic, $P = 0.005$) and ADFI tended to increase (quadratic, $P = 0.055$) with increasing maternal vitamin D_3 supplementation because pigs from sows fed the medium concentration of vitamin D_3 had greater ADG and numerically greater ADFI compared to pigs from sows fed the low or high concentration of vitamin D_3. Average daily gain of pigs from sows fed the low concentration of vitamin D_3 was lower ($P < 0.004$) compared to those from sows fed 25(OH)D_3. Carcass data were also collected from 734 pigs (approximately 65% of pigs weaned from sows administered vitamin D regimens) from 3 out of the 4 weaning groups used for the experiment. At marketing, live BW and HCW were heavier ($P < 0.030$) for pigs from sows fed 25(OH)D_3 compared to pigs from sows fed the high concentration of vitamin D_3. Also, percentage carcass yield increased (quadratic, $P = 0.003$) with increasing maternal vitamin D_3 supplementation. Loin depth (linear $P = 0.047$) and BF (quadratic, $P = 0.031$) were both decreased with increasing vitamin D_3 supplementation. Overall, it appears that vitamin D_3 and 25(OH)D_3, whether through maternal supplementation or through the diet, are useful sources of vitamin D to increase serum 25(OH)D_3 concentrations in growing pigs. Additionally, 25(OH)D_3 (in the nursery diet) can increase serum 25(OH)D_3 of nursery pigs more than feeding the same international unit equivalency of vitamin D_3. Pigs from sows fed the medium concentration of vitamin D_3 performed better after weaning compared to pigs from sows fed the low or high concentrations of vitamin D_3; however, this difference may have been confounded with the variance in weaning weight associated with the subsample population used for the growth portion of the study. Also, it is perceived that pigs from sows fed 25(OH)D_3 had increased live weight and HCW compared to pigs from sows fed the high concentration of vitamin D_3.

Key words: 25(OH)D_3, growth, finishing pig, nursery pig, vitamin D

Introduction

Within the last five years, the swine industry has seen a rise in interest and speculation associated with vitamin D supplementation. This was largely due to several documented cases in which vitamin D_3 was absent from vitamin premixes fed to pigs (Feedstuffs, 2010[4]). Deficiency of the vitamin can lead to metabolic bone disease, which is categorized as a disturbance of normal bone formation and remodeling, and can lead to bone fractures and clinical signs of rickets. Additionally, human nutrition has experienced a resurgence of interest in vitamin D's role due to increasing genomic data, which has identified the presence of vitamin D receptors within tissue not typically associated with normal Ca and P homeostasis (Norman and Bouillon, 2010[5]). One specific tissue that has been identified is skeletal muscle cells.

Historically, vitamin D_3 has been the most common form of vitamin D supplemented to livestock. This metabolite must undergo two steps of hydroxylation to become the active 1, 25 dihydroxycholecalciferol which is commonly involved in gut Ca and P absorption, and bone resorption pathways. The first step of hydroxylation occurs in the

[4] Feedstuffs. 2010. Kent feeds recalls certain swine feeds. Accessed April 4, 2011. http://www.feedstuffs.com.

[5] Norman, A. W. and R. Bouillon. 2010. Vitamin D nutritional policy needs a vision for the future. Experimental Biology and Medicine. 235: 1034-1045.

liver while the second has notably occurred in the kidney. A synthetically produced 25 hydroxycholecalciferol (25(OH)D_3; Hy-D; DSM Nutritional Products, Parsippany, NJ) metabolite is also available for use in the domestic poultry industry and internationally and is recognized as being more readily available to the animal since it has already undergone the first step of metabolism.

Hines et al. (2013[6]) evaluated muscle development of fetuses (90 d of age) from gestating gilts fed diets containing either vitamin D_3 (1,113 IU/lb) or vitamin D_3 plus 25(OH)D_3 (227 IU/lb of D_3 and 23 µg/lb of 25(OH)D_3) with both treatments resulting in similar vitamin D on an international units equivalency in the diet. They observed an increase in the number of muscle fibers, within longissimus muscles of fetuses from gilts fed 25(OH)D_3 compared to those fetuses from gilts only fed vitamin D_3. Also the authors observed increased 25(OH)D_3 concentrations in fetuses from gilts fed 25(OH)D_3 compared to those fetuses from gilts only fed vitamin D_3. The study suggests that when evaluating vitamin D_3 and 25(OH)D_3 at an international unit equivalency, 25(OH)D_3 is more available and efficiently utilized. Additionally, the potential changes or alterations in fetal muscle development resulting from different maternal vitamin D supplementation strategies could result in additional lean tissue deposition post parturition and more efficient utilization of nutrients.

With this information, the goal of this study was to evaluate the impact of maternal and nursery vitamin D supplementation strategies on post-weaning growth performance and serum vitamin metabolites and carcass characteristics.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved these experimental procedures and animal care. These experiments were conducted at the K-State Swine Teaching and Research Facility in Manhattan, KS, from September 2014 to May 2015.

All nursery and finishing facilities were totally enclosed, environmentally controlled, and mechanically ventilated buildings. Pigs in the first weaning group were housed in 4 × 5 ft nursery pens, each with a 4-hole dry self-feeder and a single nipple waterer to provide ad libitum access to feed and water. Pens had wire mesh flooring and allowed approximately 3 ft^2/pig. On d 55 after weaning, pigs were moved to the finishing barn into pens that were 5 × 10 ft with totally slatted concrete flooring. Each pen was equipped with a 2-hole dry self-feeder and 2 nipple waterers to provide ad libitum access to feed and water. Pigs in the second weaning group were housed in nursery pens that were 5 × 5 ft with tri-bar flooring. Each pen was equipped with a 3-hole dry self-feeder and a nipple waterer to allow for ad libitum access to feed and water. These pigs were moved to the finishing pens (8 × 10 ft) with totally slatted flooring. Each pen was equipped with a 2-hole dry self-feeder and bowl waterer to allow ad libitum access to feed and water. Feed was delivered to each pen individually by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

[6] Hines, E. A., J. D. Coffey, C. W. Starkey, T. K. Chung and J. D. Starkey. 2013. Improvement of maternal vitamin D status with 25-hydroxycholecalciferol positively impacts porcine fetal skeletal muscle development and myoblast activity. J. Anim. Sci. 91:9 4116–4122.

A total of 448 pigs (PIC 327 × 1050) from 52 litters (from 2 consecutive weaned pig groups; approximately 50% of pigs weaned from the maternal trial) were used as a subsample of the weaned pig population in a 4 × 2 split plot design to determine the effects of maternal vitamin D regimen and nursery vitamin D regimen on growth performance. At weaning, pigs were allotted to pens based on their previously administered maternal vitamin D regimens. Pens were then randomly assigned to the nursery dietary vitamin D regimens (either 907 IU vitamin D_3 or 23 µg 25(OH)D_3/lb). There were 7 pigs per pen and 4 pens per treatment in the first wean group, and 4 pigs per pen and 8 or 9 pens per treatment in the second wean group. Dietary vitamin D regimens remained consistent in three nursery diets, which were fed from d 0 to 10, d 10 to 21, and d 21 to 35 for phases 1, 2, and 3, respectively. The nursery diets were formulated to contain 1.40, 1.34, and 1.22% standardized ileal digestible (SID) lysine (Table 2) for phases 1, 2, and 3, respectively. Pigs and feeders were weighed on d 0, 10, 21, and 35 to determine ADG, ADFI, and F/G.

After d 35 post-weaning, pigs were switched to a common growing pig diet (Phase 4) and then were transported to the finisher approximately 55 d after weaning. Pigs remained penned by maternal and dietary nursery regimens in the finisher; however, because the pen sizes changed from the nursery to the finisher, pigs were remixed within treatments and were allotted to finishing pens. In finishing, all pigs received common diets formulated to contain 375, 313, and 250 IU of vitamin D_3/lb for phases 4, 5, and 6, respectively. Pigs were weighed and feed disappearance was calculated every 28 d until marketing.

One pig per pen (randomly selected) was bled via jugular venipuncture at weaning, d 17, 35, and 70 post-weaning to determine serum vitamin metabolites. All blood samples were collected in serum separator tubes and refrigerated for at least 6 h after collection. Blood was centrifuged at 2,800 rpm for 25 min. Serum was extracted and stored in 2-mL vials and frozen in a freezer at -4°F. All vitamin metabolite testing (25(OH)D_3, vitamin D_3, α-tocopherol, and retinol) from Exp. 2 was conducted by the DSM Nutritional Laboratory (Kaiseraugst, Switzerland).

Carcass data were collected from approximately 75% (3 of the 4 groups) of the weaned progeny from the maternal regimens. Because carcass data included animals that were not part of the growth performance portion of the study, carcass results are only reported within the maternal vitamin D regimens. Pigs were individually weighed and tattooed for carcass data collection at a commercial abattoir (Triumph Foods, St. Joseph, MO). Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage carcass yield, backfat, and loin depth. Percentage carcass yield was calculated by dividing HCW at the plant by live weight at the farm.

Statistical Analysis

All growth data were analyzed as a split plot design using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, NC). Maternal vitamin D treatment acted as the whole plot unit and nursery vitamin D treatment as the split plot unit. Pen was the experimental unit and weaning group was included in the model as a random effect. Contrast statements tested for maternal vitamin D treatments included: (1) increasing maternal vitamin D_3 linear and quadratic polynomials; and (2) 363 IU vitamin D_3 vs. 23 µg

25(OH)D_3; (3) 907 IU vitamin D_3 vs. 23 µg 25(OH)D_3; and (4) 4,354 IU vitamin D_3 vs. 23 µg 25(OH)D_3. Due to unbalanced sample sizes for maternal treatments, a Tukey-Kramer multiple comparison adjustment was used for the maternal vitamin D pair-wise comparison tests. Repeated measures analysis was performed on the serum vitamin metabolite responses, and day of collection was included as a fixed effect to determine serum changes to dietary treatments over time. For carcass data, maternal vitamin D treatment served as the fixed effect, and weaning group acted as a random effect in the model. The percentage yield was analyzed using a beta distribution. Results were considered significant at $P \leq 0.05$ and a tendency at $P \leq 0.10$.

Results and discussion

Analysis of nursery diets (Table 2) suggested that CP and P concentrations were similar to formulated values. The Ca concentrations analyzed greater than formulated but all diets were above the animals' requirement. All vitamin D analysis showed nursery diets were within 25% of their formulated targets. Although there is no reference for analytical variation of vitamin D within animal feed, a recovery rate within 25% of the formulated value is viewed as an accepted analytical recovery of other vitamins within animal feeds (AAFCO, 2015[7]); therefore, the formulated concentrations were used for statistical analyses and the reported results.

At weaning, BW of pigs subsampled for the nursery portion of the study increased (quadratic, $P = 0.001$; Table 3) with increasing maternal vitamin D_3. This was because pigs subsampled from sows fed the medium concentration of vitamin D_3 were heavier (14.9 lb) compared to pigs from sows fed either the low (14.2 lb) or the high (14.6 lb) concentrations of vitamin D_3. The mean BW of pigs within maternal regimens used in the subsample were numerically different than the average BW of pigs within regimen weaned from the entire study. Analysis showed that over the entire maternal study, pig BW at weaning was not different among maternal vitamin D regimens. No nursery × maternal vitamin D interactions were observed for growth performance. During Phase 1 in the nursery (d 0 to 10), pigs from sows fed 25(OH)D_3 had greater ($P < 0.023$) ADG compared to pigs from sows fed the low, medium, or high concentration of vitamin D_3. Average daily feed intake and F/G were not influenced during the first phase. From d 10 to 21, ADG and ADFI increased (quadratic, $P < 0.014$) with increasing vitamin D_3 supplementation. Feed efficiency worsened with increasing (quadratic, $P = 0.044$) maternal vitamin D_3 supplementation. Pigs from sows fed 25(OH)D_3 had higher ($P = 0.028$) ADFI compared to pigs from sows fed the low concentration of vitamin D_3, and pigs from sows fed 25(OH)D_3 had poorer ($P = 0.017$) F/G compared to pigs from sows fed the high concentration of vitamin D_3. During the third phase (d 21 to 35), increasing maternal vitamin D_3 increased (quadratic, $P < 0.018$) ADG and ADFI. Pigs from sows fed 25(OH)D_3 tended to have higher ($P = 0.091$) ADG compared to pigs from sows fed the low concentration of vitamin D_3. Pigs fed vitamin D_3 in the nursery tended ($P < 0.070$) to have increased ADG and ADFI compared to pigs fed 25(OH)D_3. Overall, from d 0 to 35, increasing maternal vitamin D_3 increased (quadratic, $P < 0.003$) ADG and ADFI, but F/G was similar regardless of maternal or nursery vitamin D regimen. Pigs from sows fed 25(OH)D_3 had higher ($P = 0.002$) ADG and tended to have higher ($P = 0.066$) ADFI compared to pigs from sows fed the

[7] AAFCO. 2015. 2015 Official publication, Association of American Feed Control Officials Incorporated. p. 302.

low concentration of vitamin D_3. Final BW at the end of the nursery period (d 35) was increased (quadratic, $P = 0.001$) with increased maternal vitamin D_3. Also, pigs from sows fed 25(OH)D_3 had higher ($P = 0.001$) d 10, 21, and final BW compared to pigs from sows fed the low concentration of vitamin D_3. Nursery vitamin D regimen did not impact nursery growth performance (Table 4).

Both a maternal × day interaction ($P < 0.001$; Table 5) and a nursery × day interaction ($P < 0.001$; Table 6) were observed for growing pig serum 25(OH)D_3. At weaning, increasing maternal vitamin D_3 increased (linear, $P = 0.001$) serum 25(OH)D_3, and pigs from sows fed the high concentration of vitamin D_3 had greater ($P = 0.001$) serum 25(OH)D_3 compared to pigs from sows fed 25(OH)D_3. By d 17 in the nursery, pigs consuming diets with 25(OH)D_3 had greater ($P = 0.001$) serum 25(OH)D_3 concentrations compared to pigs consuming diets with vitamin D_3. Also, increasing maternal vitamin D_3 tended (quadratic; $P = 0.063$) to increase serum 25(OH)D_3. On d 35, pigs consuming diets with 25(OH)D_3 had greater ($P = 0.001$) serum 25(OH)D_3 concentrations compared to pigs consuming diets with vitamin D_3, and increasing maternal vitamin D_3 increased (quadratic, $P = 0.006$) serum 25(OH)D_3. Pigs from sows fed the medium concentration of vitamin D_3 had greater ($P = 0.002$) serum 25(OH)D_3 concentrations compared to pigs from sows fed 25(OH)D_3. By d 70, (35 d post nursery vitamin D regimens) serum 25(OH)D_3 was not influenced by maternal or nursery vitamin D regimens.

Both a maternal × day ($P < 0.001$) and a nursery × day ($P < 0.001$) interaction were observed for growing pig serum vitamin D_3. At weaning, increasing maternal vitamin D_3 increased (quadratic, $P = 0.013$) serum vitamin D_3 and pigs from sows fed the high concentration of vitamin D_3 had greater ($P = 0.001$) serum 25(OH)D_3 compared to pigs from sows fed 25(OH)D_3. Additionally, pigs in pens fed vitamin D_3 had greater ($P = 0.034$) initial vitamin D_3 serum concentrations compared to pigs in pens fed 25(OH)D_3. On d 17 and 35, pigs fed vitamin D_3 had increased ($P < 0.001$) serum vitamin D_3 compared to pigs fed 25(OH)D_3. By d 70, neither nursery nor maternal vitamin D regimen influenced serum vitamin D_3 concentrations.

A day effect ($P = 0.001$) was observed for serum α-tocopherol of growing pigs because the serum concentration varied over time. At weaning, pigs from sows fed 25(OH)D_3 had lower ($P = 0.001$) α-tocopherol compared to pigs from sows fed the low concentration of vitamin D_3. Also at weaning, pigs allotted to pens fed vitamin D_3 had reduced ($P = 0.015$) serum α-tocopherol concentrations compared to pigs allotted to pens fed 25(OH)D_3. Additionally, increasing maternal vitamin D_3 decreased (linear, $P = 0.037$) serum α-tocopherol. After weaning, neither maternal or nursery vitamin D regimen influenced serum α-tocopherol concentrations. A day effect ($P = 0.001$) was also observed for growing pig serum retinol because serum retinol increased over time. It appeared that increasing maternal vitamin D_3 increased (quadratic, $P < 0.037$) serum retinol in pigs at weaning and on d 17 after weaning. By d 35, serum retinol tended to increase (quadratic, $P = 0.063$) with increased maternal vitamin D_3 supplementation. On d 17, serum retinal was lower ($P = 0.038$) for pigs from sows fed the low concentration of vitamin D_3 compared to pigs from sows fed 25(OH)D_3. On d 70, neither maternal nor nursery vitamin D regimen influenced serum retinol concentrations.

Throughout the finisher portion of the study no nursery × maternal vitamin D interactions were observed. Upon entry into the finisher, BW was increased (quadratic, $P = 0.035$; Table 7) with increased maternal vitamin D_3 largely because pigs from sows fed the medium concentration of vitamin D_3 had heavier BW than pigs from sows fed the low or high concentration of vitamin D_3. Pigs from sows fed 25(OH)D_3 tended to have higher ($P = 0.056$) d 0 BW compared to pigs from sows fed the low concentration of vitamin D_3. Overall finisher ADG increased (quadratic, $P = 0.005$) with increased maternal vitamin D_3, which also led to increased (quadratic, $P = 0.006$) final BW. Feed efficiency tended (quadratic, $P = 0.055$) to improve with increasing maternal vitamin D_3. Pigs from sows fed 25(OH)D_3 had higher ($P = 0.004$) ADG compared to pigs from sows fed the low concentration of vitamin D_3, which resulted in a greater ($P = 0.003$) market BW. Nursery vitamin regimen did not impact finishing growth performance (Table 8).

For carcass characteristics, pigs from sows fed 25(OH)D_3 had heavier ($P < 0.047$; Table 9) final live BW and HCW compared to pigs from sows fed the high concentration of vitamin D_3. Yield percentage increased (quadratic, $P = 0.003$) with increasing maternal vitamin D_3 supplementation. Loin depth (linear, $P = 0.047$) and BF thickness (quadratic, $P = 0.031$) decreased with increasing maternal vitamin D_3 supplementation.

For blood serum vitamin concentrations, overall the serum 25(OH)D_3 was not different for pigs from sows fed the low or medium concentration of vitamin D_3 or 25(OH)D_3; it was increased in pigs from sows fed the high concentration of vitamin D_3 at weaning. However, in the nursery, serum 25(OH)D_3 response was greater for pigs fed 25(OH)D_3 compared to vitamin D_3. These results indicate that maternal and nursery vitamin D supplementation strategy will impact serum 25(OH)D_3 response. Nursery vitamin D regimens did not influence growth performance. But, pigs from sows fed the medium concentration of vitamin D_3 performed better after weaning compared to pigs from sows fed the low or the high concentration of vitamin D_3. Still, it is unclear whether this was a result of maternal vitamin D regimen or a result of the increased BW at weaning, which was observed for pigs weaned from sows on those maternal regimens. During the nursery phase, pigs from sows fed 25(OH)D_3 performed better than those from sows fed the low concentration of vitamin D_3. Carcass data showed that pigs from sows fed 25(OH)D_3 had increased final BW and HCW compared to pigs from sows fed the high concentration of vitamin D_3. This response was not expected and is different from the conclusion of Hines et al. (2014), who observed increases in muscle fiber number for fetuses from gilts fed 25(OH)D_3 vs. vitamin D_3 at the same international unit equivalency. Ultimately, more research examining the potential effects of vitamin D supplementation form (vitamin D_3 or 25(OH)D_3) and concentration is needed to differentiate whether there is economic incentive to supplement the nutrient above current NRC (2012) requirements.

Table 1. Nursery and finishing diet composition (as-fed basis)[1]

	Nursery diets[2]			Finishing diets[3]		
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Ingredient, %						
Corn	35.68	46.01	56.39	71.50	78.44	82.86
Soybean meal, 46.5% CP	22.09	20.37	24.27	25.71	19.20	14.93
Corn DDGS[4]	5.00	15.00	15.00	---	---	---
Fish meal	5.00	5.00	---	---	---	---
Spray dried whey	25.00	10.00	---	---	---	---
Choice white grease	3.00	0.00	---	---	---	---
Monocalcium phosphate	0.15	0.23	0.88	0.55	0.33	0.30
Calcium carbonate	1.05	1.13	1.35	1.13	1.10	1.08
Sodium chloride	0.30	0.30	0.35	0.35	0.35	0.35
L-lysine HCl	0.40	0.45	0.50	0.31	0.25	0.22
DL-methionine	0.20	0.14	0.13	0.06	0.02	---
L-threonine	0.17	0.16	0.17	0.09	0.05	0.05
L-tryptophan	0.04	0.05	0.04	---	---	---
L-valine	0.09	0.03	0.03	---	---	---
Choline chloride, 60%	0.04	---	---	---	---	---
Zinc oxide	0.39	0.25	---	---	---	---
Mecadox 2.5	1.00	0.50	0.50			
Phytase[5]	0.02	0.02	0.02	0.02	0.02	0.02
Trace mineral premix[6]	0.15	0.15	0.15	0.15	0.13	0.10
Vitamin premix[7]	0.25	0.25	0.25	0.15	0.13	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00

continued

Table 1. Nursery and finishing diet composition (as-fed basis)[1]

	Nursery diets[2]			Finishing diets[3]		
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Calculated Analysis						
SID[8] amino acids, %						
Lys	1.40	1.34	1.22	1.05	0.85	0.72
Met & Cys:Lys	57	57	57	55	56	59
Thr:Lys	63	63	63	61	61	64
Trp:Lys	19	19	19	18	18	18
Val:Lys	68	68	68	69	73	76
NE, Mcal/lb	1.17	1.10	1.09	1.12	1.14	1.15
SID Lys:NE, g/Mcal	5.45	5.53	5.10	4.26	3.39	2.84
CP,%	21.6	22.6	21.0	18.5	15.9	14.2
Ca,%	0.86	0.81	0.74	0.62	0.55	0.52
P, %	0.63	0.62	0.60	0.49	0.41	0.39
Available P, %	0.51	0.47	0.42	0.29	0.23	0.22
STTD P, %	0.43	0.41	0.36	0.34	0.28	0.27
Ca:P	1.36	1.30	1.23	1.28	1.34	1.35

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial. There were a total of 7 pigs per pen and 4 pens per treatment in the first weaning group and 4 pigs per pen and either 8 or 9 pens per treatment in the second weaning group.

[2] Phase 1 diets were fed from d 0 (weaning) until d 10, Phase 2 diets from d 10 to d 21, and Phase 3 diets from day 21 to 35. Experimental treatments were made by adding either a vitamin D_3 premix (2,000,000 IU/lb of premix) in the diet replacing corn or 0.73 lb/ton of 25(OH)D_3 (Hy-D; DSM Nutritional Products, Parsippany, NJ) was added to the diet by replacing corn.

[3] Common finishing diets were fed from approximately 50 to 120 lb, 120 to 200 lb, and 200 lb until market for phases 4, 5, and 6, respectively. Common finishing diets were formulated to contain 375, 313, and 250 IU of vitamin D_3 per lb of complete diet for phasse 4, 5, and 6, respectively.

[4] Dried distillers grains with solubles.

[5] Ronozyme Hi-Phos, DSM Nutritional Products (Parsippany, NJ) provided 216 phytase units (FTU/lb) of diet with an expected release of 0.10% phytate P.

[6] Provided 11,000 ppm Cu, 198 ppm I, 73,413 ppm Fe, 22,046 ppm Mn, 198 ppm Se, and 74,413 ppm Zn per lb of premix.

[7] Provided 1,600,000 IU vit. A, 8,000 IU vit. E, 800 mg vit. K, 7 mg vit. B_{12}, 15,000 mg niacin, 5,000 mg pantothenic acid, and 1,500 mg riboflavin per lb of premix.

[8] Standardized ileal digestible.

Table 2. Analyzed nursery diet composition (as-fed)[1]

	Nursery diets					
	Phase 1		Phase 2		Phase 3	
Item	Vit D_3	25(OH)D_3	Vit D_3	25(OH)D_3	Vit D_3	25(OH)D_3
Formulated						
CP, %	21.6	21.6	22.6	22.6	21	21
Ca, %	0.86	0.86	0.81	0.81	0.74	0.74
P, %	0.63	0.63	0.62	0.62	0.60	0.60
Vitamin D_3, IU/lb	907	---	907	---	907	---
25(OH)D_3, µg/lb	---	23	---	23	---	23
Analyzed[2,3]						
CP, %	21.8	22.4	24.2	23.2	23.1	22.4
Ca, %	1.04	1.04	1.03	1.02	0.80	0.9
P, %	0.65	0.64	0.71	0.70	0.61	0.61
Vitamin D_3, IU/lb	1,016	---	771	---	957	---
25(OH)D_3, µg/lb	---	18	---	17	---	18
% of formulated	112	79	85	75	106	77

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial. The treatment structure was a split-plot design with maternal treatment as the whole-plot unit and nursery treatment as the split-plot unit. For nursery performance, pen was the experimental unit. Random effect of group was used in the statistical model. There were a total of 7 pigs per pen and 4 pens per treatment in group 1 and 4 pigs per pen and either 8 or 9 pens per treatment in the second group.

[2] Means represent the average of two pooled samples.

[3] Crude protein, Ca, and P was determined at Ward Laboratories (Kearney, NE). Vitamin D_3 and 25(OH)D_3 analysis was performed by DSM Nutrition Products (Parsippany, NJ).

Table 3. Main effects of maternal vitamin D regimen on growth performance of nursery pigs[1]

	Maternal Vitamin D[2]					Probability, $P <$				
	Vitamin D_3					Vitamin D_3		Low D_3 vs.	Medium D_3 vs.	High D_3 vs.
Item	Low	Medium	High	25(OH)D_3	SEM	Lin	Quad	25(OH)D_3	25(OH)D_3	25(OH)D_3
Average BW, lb										
d 0	14.2	14.9	14.6	14.6	0.13	0.566	0.001	0.088	0.371	0.985
d 10	18.6	19.5	19.0	19.9	0.35	0.878	0.005	0.001	0.483	0.012
d 21	28.6	30.2	29.6	30.4	0.37	0.381	0.001	0.001	0.986	0.268
d 35	46.4	49.1	47.8	49.2	1.14	0.555	0.001	0.001	0.997	0.141
d 0 to 10										
ADG, lb	0.44	0.46	0.44	0.52	0.041	0.765	0.432	0.003	0.023	0.003
ADFI, lb	0.70	0.71	0.72	0.77	0.041	0.694	0.663	0.178	0.373	0.400
F/G	1.65	1.62	1.67	1.51	0.227	0.694	0.678	0.396	0.593	0.262
d 10 to 21										
ADG, lb	0.90	0.97	0.95	0.95	0.021	0.248	0.014	0.265	0.84	0.997
ADFI, lb	1.29	1.44	1.32	1.39	0.040	0.299	0.001	0.028	0.315	0.177
F/G	1.44	1.49	1.38	1.46	0.056	0.002	0.044	0.845	0.832	0.017
d 21 to 35										
ADG, lb	1.28	1.35	1.30	1.34	0.064	0.98	0.017	0.091	0.999	0.446
ADFI, lb	2.06	2.19	2.12	2.15	0.120	0.854	0.018	0.402	0.815	0.964
F/G	1.62	1.63	1.63	1.60	0.023	0.728	0.672	0.889	0.610	0.599
d 0 to 35										
ADG, lb	0.92	0.98	0.95	0.99	0.035	0.729	0.003	0.002	0.917	0.105
ADFI, lb	1.43	1.53	1.47	1.52	0.053	0.853	0.002	0.066	0.929	0.437
F/G	1.57	1.59	1.57	1.55	0.016	0.781	0.394	0.709	0.241	0.714

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial. The treatment structure was a split-plot design with maternal treatment as the whole-plot unit and nursery treatment as the split-plot unit. For nursery performance, pen was the experimental unit. Random effect of group was used in the statistical model. There were a total of 7 pigs per pen and 4 pens per treatment in group 1 and 4 pigs per pen and either 8 or 9 pens per treatment in the second group.

[2] Maternal vitamin D_3 concentrations of 363, 907, and 4,354 IU vitamin D_3 per lb of complete diet were fed for low, medium, and high treatments, respectively, and 23 µg of 25(OH)D_3/lb of the complete diet for the maternal 25(OH)D_3 treatment.

Table 4. Main effects of nursery vitamin D regimen on nursery growth performance[1]

	Nursery source[2]			
	Vitamin D_3	25(OH)D_3	SEM	Probability, *P* <
Average BW, lb				
d 0	14.6	14.6	0.10	0.922
d 10	19.2	19.3	0.32	0.774
d 21	29.6	29.8	0.27	0.491
d 35	48.3	48.0	1.08	0.537
d 0 to 10				
ADG, lb	0.46	0.47	0.039	0.700
ADFI, lb	0.74	0.71	0.036	0.226
F/G	1.65	1.58	0.222	0.284
d 10 to 21				
ADG, lb	0.93	0.95	0.014	0.433
ADFI, lb	1.36	1.36	0.036	0.816
F/G	1.46	1.43	0.053	0.240
d 21 to 35				
ADG, lb	1.34	1.30	0.062	0.066
ADFI, lb	2.16	2.10	0.117	0.070
F/G	1.62	1.62	0.017	0.770
d 0 to 35				
ADG, lb	0.96	0.95	0.034	0.482
ADFI, lb	1.50	1.47	0.050	0.137
F/G	1.58	1.56	0.011	0.221

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial. The treatment structure was a split-plot design with maternal treatment as the whole-plot unit and nursery treatment as the split-plot unit. For nursery performance, pen was the experimental unit. Random effect of group was used in the statistical model. There were a total of 7 pigs per pen and 16 pens per treatment in group 1 and 4 pigs per pen and either 3 or 4 pens per treatment in the second group.

[2] Nursery vitamin D regimens provided 907 IU of vitamin D from vitamin D_3 or 23 µg of 25(OH)D_3 per lb of the complete diet.

Table 5. Main effects of maternal vitamin D regimen on growing pig serum vitamin metabolites[1]

	Maternal Vitamin D[2]					Probability, $P <$				
	Vitamin D_3					Vitamin D_3		Low D_3 vs.	Medium D_3 vs.	High D_3 vs.
Item	Low	Medium	High	$25(OH)D_3$	SEM	Lin	Quad	$25(OH)D_3$	$25(OH)D_3$	$25(OH)D_3$
Growing pig serum vitamin metabolites										
$25(OH)D_3$, ng/mL[3]										
Weaning	5.4	7.1	16.6	5.5	1.15	0.001	0.871	0.925	0.300	0.001
d 17	22.7	25.9	25.0	23.6	1.24	0.466	0.063	0.581	0.163	0.398
d 35	26.4	30.8	26.8	25.5	1.29	0.366	0.006	0.556	0.002	0.452
d 70	18.3	15.7	16.1	16.5	1.54	0.497	0.257	0.403	0.686	0.816
Vitamin D_3, ng/mL[4]										
Weaning	1.4	1.1	4.9	1.0	0.24	0.001	0.013	0.249	0.833	0.001
d 17	2.0	2.2	1.8	2.0	0.26	0.431	0.475	0.920	0.479	0.719
d 35	2.1	2.2	2.3	2.4	0.28	0.698	0.744	0.400	0.641	0.745
d 70	3.2	1.1	3.1	2.6	0.33	0.760	0.988	0.187	0.209	0.275
α-tocopherol, mg/L[5]										
Weaning	5,304	4,769	4,591	4,331	197.5	0.037	0.086	0.001	0.101	0.340
d 17	982	829	804	924	207.4	0.641	0.629	0.837	0.738	0.679
d 35	1,521	1,401	1,242	1,291	216.4	0.374	0.758	0.417	0.698	0.869
d 70	1,799	1,566	1,784	1,631	258.8	0.796	0.498	0.632	0.856	0.646
Retinol, ng/mL[6]										
Weaning	254	301	286	283	19.9	0.464	0.037	0.176	0.427	0.907
d 17	366	419	397	413	21.0	0.599	0.023	0.038	0.795	0.491
d 35	389	435	431	421	21.6	0.242	0.063	0.158	0.553	0.667
d 70	379	393	373	360	24.8	0.635	0.585	0.507	0.250	0.631

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial and followed through finishing. The treatment structure was a split-plot design with maternal treatment as the whole-plot unit and nursery treatment as the split-plot unit.

[2] Maternal vitamin D_3 concentrations of 363, 907, and 4,354 IU vitamin D_3 per lb of complete diet were fed for low, medium, and high treatments, respectively, and 23 μg of $25(OH)D_3$ /lb of the complete diet for the maternal $25(OH)D_3$ treatment.

[3] A maternal × day ($P < 0.001$) interaction and a nursery × day ($P < 0.001$) interaction were observed for growing pig serum $25(OH)D_3$ concentrations.

[4] A maternal × day ($P < 0.001$) interaction and a nursery × day ($P < 0.001$) interaction were observed for growing pig serum vitamin D_3 concentrations.

[5] A day effect ($P < 0.001$) was observed for growing pig serum α-tocopherol concentrations.

[6] A day effect ($P < 0.001$) was observed for growing pig serum retinol concentrations.

Table 6. Main effects of nursery vitamin D regimen on growing pig serum vitamin metabolites[1]

	Nursery source[2]			
Item	Vitamin D_3	25(OH)D_3	SEM	Probability, P <
Growing pig serum vitamin metabolites				
25(OH)D_3, ng/mL[3]				
Weaning	9.3	8.0	0.84	0.229
d 17	11.3	37.3	0.89	0.001
d 35	16.1	38.7	0.91	0.001
d 70	16.8	16.6	1.10	0.889
Vitamin D_3, ng/mL[4]				
Weaning	2.3	1.8	0.17	0.034
d 17	3.0	1.0	0.18	0.001
d 35	3.5	1.0	0.19	0.001
d 70	2.9	3.1	0.23	0.656
α-tocopherol, mg/L[5]				
Weaning	4,512	4,984	137.7	0.015
d 17	902	868	144.5	0.868
d 35	1,404	1,324	147.7	0.695
d 70	1,680	1,710	177.9	0.901
Retinol, ng/mL[6]				
Weaning	284	278	16.7	0.663
d 17	408	390	17.2	0.260
d 35	423	415	17.4	0.660
d 70	373	379	19.6	0.800

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial and followed through finishing. The treatment structure was a split-plot design with maternal treatment as the whole-plot unit and nursery treatment as the split-plot unit.

[2] Nursery vitamin D regimens provided 907 IU of vitamin D from vitamin D_3 or 23 μg of 25(OH)D_3 per lb of the complete diet.

[3] A nursery × day ($P < 0.001$) interaction was observed for growing pig serum 25(OH)D_3 concentrations.

[4] A nursery × day ($P < 0.001$) interaction was observed for growing pig serum vitamin D_3 concentrations.

[5] A day effect ($P < 0.001$) was observed for growing pig serum α-tocopherol concentrations.

[6] A day effect ($P < 0.001$) was observed for growing pig serum retinol concentrations.

Table 7. Main effects of maternal vitamin D regimen and nursery vitamin D regimen on growth performance of finishing pigs[1]

	Maternal Vitamin D[2]					Probability, $P <$				
	Vitamin D_3					Vitamin D_3		Low D_3 vs.	Medium D_3 vs.	High D_3 vs.
Item	Low	Medium	High	25(OH)D_3	SEM	Lin	Quad	25(OH)D_3	25(OH)D_3	25(OH)D_3
Average BW, lb										
d 0	46.8	48.9	47.7	49.3	1.10	0.891	0.035	0.056	0.970	0.372
Market	292.2	300.9	297.5	303.1	6.50	0.480	0.006	0.003	0.866	0.240
Finishing pig growth										
ADG, lb	2.04	2.11	2.08	2.12	0.022	0.602	0.005	0.004	0.916	0.220
ADFI, lb	5.65	5.7	5.67	5.79	0.053	0.981	0.492	0.216	0.558	0.327
F/G	2.72	2.66	2.68	2.69	0.047	0.534	0.055	0.701	0.777	0.994

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial and followed through finishing. The treatment structure was a split-plot design with maternal treatment as the whole-plot unit and nursery treatment as the split-plot unit. For finishing performance pen was the experimental unit. Random effect of group was used in the statistical model. There were a total of 5 to 7 pigs per pen and 9 or 10 finishing pens per treatment.

[2] Maternal vitamin D_3 concentrations of 363, 907, and 4,354 IU vitamin D_3 per lb of complete diet were fed for low, medium, and high treatments, respectively; and 23 µg of 25(OH)D_3 /lb of the complete diet for the maternal 25(OH)D_3 treatment.

Table 8. Main effect of nursery vitamin D regimen on growth performance of finishing pigs[1]

	Nursery source[2]			
Item	Vitamin D_3	25(OH)D_3	SEM	Probability, *P* <
Average BW, lb				
d 0	48.4	47.9	0.98	0.432
Market	298.3	298.6	6.31	0.911
Finishing pig growth				
ADG, lb	2.08	2.09	0.018	0.577
ADFI, lb	5.66	5.74	0.037	0.126
F/G	2.68	2.7	0.043	0.453

[1] A total of 448 pigs from 52 litters in 2 farrowing groups were used in a 35-d nursery trial and followed through finishing. The treatment structure was a split-plot design with maternal treatment as the whole-plot unit and nursery treatment as the split-plot unit. For finishing performance pen was the experimental unit. Random effect of group was used in the statistical model. There were a total of 5 to 7 pigs per pen and 38 finishing pens per treatment.

[2] Subsequent nursery treatments consisted of supplementing vitamin D in phase 1, 2, and 3 diets from either vitamin D_3 (907 IU/lb) or from 25(OH)D_3 (23 µg/lb).

Table 9. The effect of maternal vitamin D regimen on subsequent pig carcass data[1]

	Maternal vitamin D[2]					Probability, *P* <				
	Vitamin D_3					Vitamin D_3		Low D_3 vs.	Medium D_3 vs.	High D_3 vs.
Item	Low	Medium	High	25(OH)D_3	SEM	Lin	Quad	25(OH)D_3	25(OH)D_3	25(OH)D_3
Live weight, lb	297.2	298.6	295.0	302.1	7.00	0.264	0.534	0.266	0.574	0.047
HCW, lb	220.1	222.1	218.1	224.0	7.38	0.155	0.288	0.276	0.830	0.037
Yield, %	73.9	74.3	73.8	74.0	0.76	0.077	0.002	0.521	0.339	0.298
Loin depth, in[3]	2.37	2.39	2.32	2.34	0.161	0.047	0.470	0.743	0.459	0.933
BF, in[3]	0.82	0.77	0.80	0.79	0.035	0.959	0.031	0.407	0.898	0.928

[1] Means represent data collected from 642 finishing pigs within 3 consecutive finishing groups. Group and finishing treatment within group were used as random effects. Wean age was included in the model as a covariate.

[2] Maternal vitamin D_3 concentrations of 363, 907, and 4,354 IU vitamin D_3 per lb of complete diet were fed for low, medium, and high treatments, respectively; and 23 μg of 25(OH)D_3/lb of the complete diet for the maternal 25(OH)D_3 treatment.

[3] Hot carcass weight was used as a covariate in the statistical model.