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Evaluation of the Effects of Added Vitamin D_3 in Maternal Diets on Sow and Pig Performance[1]

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Summary

A total of 84 sows (PIC 1050) and their litters were used to determine the effects of supplementing high levels of dietary maternal vitamin D_3 on sow and pig performance, serum 25(OH)D_3, milk vitamin D_3, neonatal bone mineralization, and neonatal tissue vitamin D_3. After breeding, sows were randomly assigned to 1 of 3 dietary vitamin D_3 treatments (680, 1,360, or 2,720 IU/lb of complete diets). Sows were bled on d 0 and 100 of gestation, and at farrowing and weaning (d 21). Pig BW was recorded at birth and weaning, and serum was collected from 2 pigs/litter at birth, on d 10, and at weaning. A total of 54 piglets (18/treatment) were euthanized at birth and necropsied to sample bones and tissues. Sow and suckling pig performance and neonatal bone ash and bone density did not differ ($P > 0.10$) among maternal vitamin D_3 treatments, but sow serum 25(OH)D_3 and milk vitamin D_3 increased (linear, $P < 0.01$) with increasing maternal vitamin D_3 supplementation. Piglet serum 25(OH)D_3 increased (quadratic, $P < 0.03$) with increased maternal vitamin D_3. Neonatal kidney vitamin D_3 tended (quadratic, $P = 0.08$) to decrease with increasing maternal vitamin D_3, but liver vitamin D_3 tended (linear, $P = 0.09$) to increase with increasing maternal vitamin D_3; however, physiological concentrations of vitamin D within these tissues were low regardless of statistical tendencies.

At weaning, a subsample of 180 pigs (PIC 327 × 1050) were used in a 3 × 2 split plot design for 35 d to determine the effects of maternal vitamin D_3 and 2 levels of dietary vitamin D_3 (816 or 8,160 IU/lb) from d 0 to 10 postweaning on piglet growth and serum 25(OH)D_3. Overall (d 0 to 35), nursery ADG and F/G were not affected by either source of vitamin D_3, but ADFI tended (quadratic, $P < 0.06$) to decrease with increasing maternal vitamin D_3 because pigs from sows fed 1,360 IU of vitamin D_3/lb had lower ADFI compared with pigs from sows fed 680 or 2,720 IU vitamin D_3/lb. Nursery pig serum 25(OH)D_3 increased (linear, $P < 0.01$) with increasing maternal vitamin D_3 on d 0 (weaning), and maternal × diet interactions ($P < 0.01$) were observed on d 10 and 21 because pigs from sows fed 680 IU vitamin D_3/lb had greater increases in serum 25(OH)D_3 when fed 8,160 IU vitamin D_3/lb compared with pigs from sows fed 1,360 IU vitamin D_3/lb. In conclusion, sow and pig serum 25(OH)D_3 and milk vitamin D_3 can be increased by increasing maternal vitamin D_3, and nursery pig serum 25(OH)D_3 can be increased by increasing dietary vitamin D_3; however, sow and pig performance and neonatal bone mineralization was not influenced by increasing vitamin D_3 dietary levels.

[1] Appreciation is expressed to Heartland Assays, DSM Nutritional Products, and Iowa State University College of Veterinary Medicine for providing funding and laboratory analysis for this project.
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Introduction

Speculation has surfaced recently about serum 25(OH)D_3 concentrations of nursery pigs reared in modern swine production facilities, mainly because of documented cases in which vitamin D_3 has been absent from vitamin premixes fed to pigs (Feedstuffs, 2010[4]). In these cases, large percentages of pigs developed 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. In an effort to reduce these signs, guidelines for serum 25(OH)D_3 concentrations have been advocated. A recent survey of swine across different classes indicate that a significant proportion of pigs have serum 25(OH)D_3 concentrations below these guidelines (Madson, 2011[5]). Because most pigs are housed and raised in confinement facilities, pigs no longer have access to direct sunlight, which is needed for the endogenous production of vitamin D_3; therefore, these surveys seem to indicate additional vitamin D_3 supplementation is warranted, but little direct evidence characterizes these levels with production parameters such as weaning performance, subsequent nursery performance, or metabolic indicators such as bone ash or density.

For the suckling pig, vitamin D is supplied from maternal sources until after weaning. Previous research by Goff et al. (1984[6]) reported increased piglet serum 25(OH)D_3 concentrations in newborn pigs from sows dosed with vitamin D_3 intramuscularly 20 d prior to farrowing, suggesting vitamin D and its metabolites are transferred transplacentally. Surprisingly little research has quantified the effects of maternal feeding vitamin D_3 on piglet serum 25(OH)D_3 concentration. In addition, previous research conducted at Kansas State University (Flohr et al., 2011[7] and 2012[8]) concluded that supplementing vitamin D_3 to the suckling and nursery pig can increase serum 25(OH)D_3 concentrations but observed no effects on bone mineralization or growth performance. Finally, because feed is a low-cost method of D_3 supplementation, maternal supplementation may be a lower-cost and less labor-intensive method of manipulating serum 25(OH)D_3 concentrations in offspring compared with oral dosing. Therefore, the objectives in this experiment were to evaluate the effects of supplementing high levels of vitamin D_3 to sows on maternal performance, milk vitamin D_3 concentrations, sow and pig serum 25(OH)D_3, Ca and P concentrations, subsequent pig performance, neonatal bone mineralization, and neonatal tissue (liver and kidney) vitamin D_3 concentrations.

Procedures

Experimental procedures and animal care were approved by the K-State Institutional Animal Care and Use Committee. This experiment was conducted at the K-State Swine Teaching and Research Facility in Manhattan, KS, and was conducted from the months of January through August of 2012.

A total of 84 sows (PIC 1050) from 3 consecutive farrowing groups and their litters were used in this study. Following breeding, sows were randomly assigned to 1 of 3

[4] Feedstuffs. 2010. Kent feeds recalls certain swine feeds. Accessed April 4, 2011. http://www.feedstuffs.com.
[5] Madson, D.M. 2011. Metabolic bone disease in swine: a diagnostic dilemma. Pages 8–18 in Proc. 52nd Ann. George A. Young Swine Health and Management Conference. Sioux City, NE.
[6] Goff, J.P., R.L. Horst, and E.T. Littledike. 1984. Effect of sow vitamin D status at parturition on the vitamin D status of neonatal piglet. J. Nutr. 114:163–169.
[7] Flohr et al. Swine Day 2011. Report of Progress 1056, pp. 34–45.
[8] Flohr et al. Swine Day 2012. Report of Progress 1074, pp. 35–47.

dietary vitamin D_3 treatments (680, 1,360, or 2,720 IU/lb) throughout 3 consecutive farrowing groups. There were 27 sows per treatment and 7 to 11 replications per farrowing group. During d 0 through 100 of gestation, sows were fed 4.4 lb/d of the gestation diets. From d 100 to farrowing, sows were fed 5.5 lb/d of the gestation diets. During d 0 through 110, sows were housed in gestation stalls (7.0 × 2.0 ft). On d 110, sows were transported to the farrowing house and were housed in farrowing crates. Both the gestation and farrowing barns were totally enclosed, environmentally controlled, and mechanically ventilated buildings. The farrowing barn contained 29 farrowing crates (7.0 × 2.0 ft for the sow and 7.0 × 3.2 ft for the pigs) that were each equipped with a single feeder and nipple waterer. After farrowing, sows were switched to lactation diets. Gestation and lactation diets were formulated to contain 0.56% and 0.94% standardized ileal digestible (SID) lysine, respectively (Table 1), and contained 40% and 20% dried distillers grains with solubles (DDGS), respectively. For the first 3 d after farrowing, sows were gradually provided increased feed according to appetite. After d 3, all sows were allowed ad libitum access to the lactation diet. Temperature in the farrowing house was maintained at a minimum of 68°F, and supplemental heat was provided to piglets with heat lamps.

Lactation feed intake was determined by measuring feed disappearance on d 0, 7, 14, and 21 (weaning). Sow BW was measured at breeding, d 110 of gestation, within 24 h after farrowing, and at weaning to determine gestation weight gain and lactation weight loss. Sows were bled on d 0 and 100 of gestation, within 12 h after farrowing, and on d 10 and 21 (weaning) in lactation to determine serum 25(OH)D_3, Ca, and P concentrations. Milk samples were collected within 12 h after farrowing, and on d 10 and d 21 (weaning) to determine milk vitamin D_3 concentrations. Milk samples were obtained by an intravenous injection of oxytocin (1 mL, Agrilabs, St. Joseph, MO), and milk was collected from all functional glands.

At birth, all piglets were weighed individually and ear tagged for identification. The second and fifth pigs born within each litter were bled prior to suckling on d 0, on d 10, and at weaning to determine piglet serum 25(OH)D_3, Ca, and P. The seventh pig born from 54 litters (18 pigs per treatment, 6 replications per farrowing group) was euthanized prior to suckling and necropsied for bone and tissue sample analysis to determine neonatal pig bone ash content, bone density, and tissue vitamin D_3 concentrations. Mummified and stillborn pigs were recorded to calculate total born and live born piglets. Although minimal, cross-fostering was conducted within 24 h postfarrowing to help standardize litter size within vitamin D_3 dietary treatments. Pigs were weighed after fostering to measure fostered litter weight. At weaning, piglet weights and piglet counts were recorded to determine individual and litter weight gains, along with survivability.

At weaning, a subsample of 180 multi-sex pigs (PIC 327 × 1050) from the first sow group were used in a 3 × 2 split plot design for 35 d to determine the effects of maternal vitamin D_3 concentration and 2 levels of dietary vitamin D_3 (816 or 8,160 IU/lb; from d 0 to 10 postweaning) on growth performance and serum 25(OH)D_3, Ca, and P. At weaning, pigs were allotted to pens based on their previously administered maternal vitamin D_3 treatments to maintain the integrity of weaning weights consistent with maternal vitamin D_3 effects. Pens were then randomly assigned to dietary vitamin D_3 treatments. There were 6 pigs/pen and 5 pens per treatment. Dietary vitamin D_3 treat-

ments were provided from d 0 to 10 in the nursery and were fed in a pellet form (Table 2). Common Phase 2 and 3 diets were provided to pigs from d 10 to 21 and d 21 to 35, respectively. Common diets were formulated to contain 1,800 IU/kg vitamin D_3 and were fed in a meal form. All pens (4 × 5 ft) had woven wire flooring, one 3-hole, dry self-feeder, and a nipple waterer to allow for ad libitum access to feed and water. All pigs and feeders were weighed on d 0, 5, 10, 17, 21, 28, and 35 after weaning to determine ADG, ADFI, and F/G. Blood samples were collected from 10 pigs/treatment on d 0, 10, 24, and 35 to determine serum 25(OH)D_3, Ca, and P. All blood, milk, and tissue sample analyses was conducted by Heartland Assays (Ames, IA) to determine serum 25(OH)D_3, Ca and P, and milk and tissue vitamin D_3 concentrations.

To achieve the dietary vitamin D_3 concentrations, a premix was made containing a vitamin D_3 supplement (Rovimix D_3, 500,000 IU/g; DSM Nutritional Products Inc., Parsippany, NJ). This supplement was then mixed into a rice hull carrier to form the premix and was added to the control diet (625 IU vitamin D_3/lb) by replacing corn. Vitamin premixes and complete diet samples were analyzed for vitamin D_3 concentration by DSM Nutritional Products.

Necropsies were performed onsite and in compliance with the college's standard operating procedures. Pigs were euthanized with an intravenous overdose of sodium pentobarbital (Fatal Plus, Vortech Pharmaceuticals, Dearborn, MI). Right femurs and second ribs were collected to determine bone ash content, and left second ribs were used to determine bone density. Whole liver and kidney tissues were collected and frozen immediately at -4°F until samples were prepared for specific analysis.

Bone densities were determined at the Iowa State University College of Veterinary Medicine (Ames, IA). All left second ribs were stripped to the periosteum, submerged in water for 4 h under 12.09 psi vacuum, and blotted dry prior to recording bone weight. Bone volume was determined using weight in air minus weight under water according to the Archimedes principle. Bone density values were then expressed as ounces of bone/in.^{3} volume.

Bone ash analysis, which was performed on the right femurs and right second rib, was conducted at the K-State Swine Nutrition Laboratory in Manhattan, KS. Bones were cleaned to the periosteum and were split perpendicular to the long axis of the diaphysis. Fat extraction was conducted by placing bones in cellulose thimbles and inserting thimbles in the main chambers of soxhlet extractors. The extraction solvent was petroleum ether. Fat extraction was conducted for 7 d. At the completion of the extraction period, bone samples were dried in a forced-air oven at 212°F until a consistent dry weight was achieved. Then bones were ashed at 1,112°F for 24 h. Ash weights were recorded and expressed as a percentage of dry fat-free bone.

Data were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). Maternal performance data were analyzed with sow as the experimental unit, treatment as a fixed effect, and farrowing group as a random effect. Nursery performance was analyzed as a 3 × 2 split plot design, and pen was used as the experimental unit. Additional contrasts were used to determine the effects of early nursery vitamin D_3 treatments and the interaction of maternal vitamin D_3 and early nursery dietary vitamin D_3 treatments. Serum 25(OH)D_3, Ca, P, and milk vitamin D_3 data were analyzed

using the repeated measures function to determine the effects of treatment variables over time, and individual pig was the experimental unit. Bone ash, bone density, and tissue vitamin D_3 concentrations were analyzed using individual pig as the experimental unit. Differences among treatments were considered significant with $P \leq 0.05$ and trends if $P > 0.05$ and ≤ 0.10.

Results and Discussion

Analysis of vitamin D_3 concentrations in the diets verified that they were within acceptable analytical variation of formulated dietary values (Table 3). For maternal performance, increasing supplementation of vitamin D_3 from 680 to 2,720 IU/lb of the complete diet did not influence ($P > 0.05$; Table 4) sow BW gain in gestation, lactation ADFI, or sow BW loss in lactation. In addition, maternal vitamin D_3 treatments used in this study did not affect ($P > 0.05$) litter performance criteria or piglet BW at birth or weaning.

A maternal × day interaction ($P < 0.01$; Table 5) was observed for sow serum 25(OH)D_3 because 25(OH)D_3 was not different among sows on d 0 of gestation serum, but increasing maternal vitamin D_3 increased (linear, $P < 0.01$) serum 25(OH)D_3 on d 100 of gestation, at farrowing, and at weaning. Milk vitamin D_3 concentrations were not influenced by sampling day ($P = 0.56$); however, milk vitamin D_3 increased (linear, $P < 0.01$) with increasing maternal dietary vitamin D_3 at farrowing, on d 10 in lactation, and at weaning. A day effect was observed ($P < 0.01$) for piglet serum 25(OH)D_3 as serum concentrations increased through time from birth to weaning, and serum 25(OH)D_3 increased (quadratic, $P < 0.03$) with increasing maternal vitamin D_3 at birth, on d 10 in lactation, and at weaning.

No differences ($P > 0.05$) in neonatal bone ash values were observed for femurs or second ribs. Rib bone density was not influenced ($P > 0.05$) by maternal vitamin D_3 concentrations. Kidney vitamin D_3 concentrations tended to decrease (quadratic, $P = 0.09$) with increasing maternal vitamin D_3 because pigs from sows fed 1,360 IU vitamin D_3/lb had much lower tissue vitamin D_3 concentrations compared with pigs from sows fed 680 or 2,720 IU vitamin D_3/lb. Liver tissue vitamin D_3 concentrations tended to increase (linear, $P = 0.08$) with increased maternal dietary vitamin D_3. Overall, means associated with tissue vitamin D_3 concentrations were low because many samples were below the lower detectable limit of 0.001 ng/mg, which suggests that the neonatal liver and kidney are not high in vitamin D_3 content at birth and that newborn pigs do not store vitamin D_3 in the liver and kidney, perhaps the result of little to no hepatic or renal fat development within the newborn animal. Previous research (Clements and Fraser, 1988[9]) concluded that fetal rats store 25(OH)D_3 in muscle tissue at birth, and this is the primary source of vitamin D available to the animal for the first 3 weeks of its life.

During the nursery portion of the study, no interactions between maternal vitamin D_3 and dietary vitamin D_3 were observed ($P > 0.05$; Table 6) in growth performance. Overall (d 0 to 35), ADFI tended (quadratic, $P = 0.06$) to decrease with increasing vitamin D_3, with pigs from sows fed 1,360 IU vitamin D_3/lb having lower ADFI compared with pigs

[9] Clements, M.R., and D.R. Fraser. 1988. Vitamin D supply to the rat fetus and neonate. J. Clin. Invest. 81:1768–1773.

from sows fed either 680 or 2,720 IU vitamin D_3/lb; however, maternal and nursery vitamin D_3 supplementation did not influence ($P > 0.05$) overall (d 0 to 35) ADG or F/G.

A day effect ($P < 0.01$) was observed for nursery pig serum 25(OH)D_3. At weaning (d 0), pig serum 25(OH)D_3 increased (linear, $P < 0.01$) with increasing maternal vitamin D_3. Maternal × diet interactions ($P < 0.01$) were observed on d 10 and 21 because pigs from sows fed 680 IU vitamin D_3/lb had greater increases in serum 25(OH)D_3 when fed 8,160 IU vitamin D_3/lb compared with pigs from sows fed 1,360 IU vitamin D_3/lb. On d 35, serum 25(OH)D_3 concentrations did not differ among maternal treatments, but a diet effect ($P < 0.04$) was observed with increased nursery diet vitamin D_3 increasing serum 25(OH)D_3.

A day effect ($P < 0.01$; Figure 1) was observed for sow serum Ca. Sow serum Ca tended (linear, $P = 0.07$) to be higher on d 0 of gestation for sows assigned to the 2,720 IU vitamin D_3/lb treatment compared with sows assigned to lower maternal vitamin D_3 treatments, which reflects potential differences prior to initiation of maternal vitamin D_3 treatments. On d 100 of gestation, increasing maternal dietary vitamin D_3 tended to decrease (quadratic, $P = 0.09$) serum Ca. Serum P concentrations were not influenced ($P > 0.10$) by maternal vitamin D_3 treatments or by sampling day ($P = 0.18$). In terms of piglet serum Ca, a day effect was observed ($P < 0.01$; Figure 2) for serum Ca concentrations. Serum Ca also tended to decrease (linear, $P = 0.08$) with increasing maternal vitamin D_3 on d 10 of lactation. Serum P concentrations were not influenced ($P > 0.10$) by maternal vitamin D_3 treatments, but they tended to be different based on day of sampling ($P = 0.08$). Nursery pig serum Ca concentrations were not influenced by maternal or nursery vitamin D_3 concentrations, but for serum P a tendency was observed (quadratic, $P = 0.08$; Figure 3) for P concentrations to increase within increasing maternal vitamin D_3 on d 10 after weaning was observed, and day of blood collection influenced serum P concentrations ($P < 0.01$). Although several statistical tendencies were observed within several collection days, all serum Ca and P means collected fell within previously described physiological ranges (Friendship et al., 1984[10]) associated with normal healthy pigs of similar stages of production.

In summary, supplementing vitamin D_3 via the maternal diet is an effective way to increase serum 25(OH)D_3 of the young pig by increasing transplacental transfer of 25(OH)D_3 from the sow to the fetus, along with increased transfer during lactation from the increased milk vitamin D_3 concentrations. In addition, maternal supplementation and increased vitamin D_3 in nursery diets can increase nursery pig serum 25(OH)D_3 concentrations, but the increase in maternal supplementation did not influence sow or pig performance, sow or pig serum Ca and P, or neonatal bone traits. Future research is needed to determine optimal serum 25(OH)D_3 levels for proper bone development and ideal Ca and P absorption in pigs. More work examining potential impacts of vitamin D on the immune system or other novel biological processes in pigs may offer additional insights into possible benefits of vitamin D supplements for pigs.

[10] Friendship et al. 1984. Hematology and biochemistry reference values for Ontario swine. Can. J. Comp. Med. 48:390–393.

Table 1. Composition of sow diets (as-fed basis)[1,2]

Item	Gestation	Lactation
Ingredient, %		
Corn	52.96	52.19
Soybean meal (46.5% CP)	2.99	23.88
Dried distillers grains with solubles	40.00	20.00
Monocalcium P (21% P)	0.65	0.90
Limestone	1.90	1.60
Salt	0.50	0.50
Vitamin premix[3]	0.50	0.50
Trace mineral premix	0.15	0.15
L-lysine HCl	0.23	0.15
Phytase[4]	0.13	0.13
Total	100	100
Calculated analysis		
ME, kcal/lb	1,492	1,488
CP, %	17.0	21.1
Total lysine, %	0.72	1.13
Standardized ileal digestible lysine, %	0.56	0.97
Ca, %	0.88	0.88
P, %	0.59	0.64
Available P, %[5]	0.50	0.48

[1] A total of 84 sows and litters were used to determine the effects of supplemental vitamin D_3 on maternal performance, subsequent pig performance, sow and piglet serum 25(OH)D_3, Ca and P, milk vitamin D_3, neonatal bone mineralization, and piglet tissue vitamin D_3 concentrations.

[2] Vitamin D_3 premixes were mixed to contain 1,000,000 IU vitamin D_3/lb of premix by blending vitamin D_3 (Rovimix D; DSM Nutritional Products, Parsippany, NJ) with rice hulls. Premix replaced a percentage of corn to achieve the desired treatment vitamin D_3 concentrations.

[3] Vitamin premix provided 625 IU vitamin D_3/lb of the complete diet.

[4] Natuphos 600, BASF, Florham Park, NJ. Provided 341 phytase units (FTU)/lb of diet.

[5] Phytase provided 0.12% available P to gestation and lactation diets.

Table 2. Composition of nursery diets (as-fed basis)[1]

Item	Phase 1[2]	Phase 2[3]	Phase 3[4]
Ingredient, %			
Corn	39.58	44.73	65.78
Soybean meal (46.5% CP)	17.33	23.41	30.67
Dried distillers grains with solubles	5.00	15.00	---
Spray-dried porcine plasma	5.00	---	---
Spray-dried blood cells	1.25	---	---
Spray-dried whey	25.00	10.00	---
Select menhaden fish meal	---	4.50	---
Soybean oil	3.00	---	---
Monocalcium P (21% P)	0.85	0.15	1.03
Limestone	1.00	0.70	0.98
Salt	0.30	0.30	0.35
Zinc oxide	0.39	0.25	---
Trace mineral premix	0.15	0.15	0.15
Vitamin premix[5]	0.25	0.25	0.25
L-lysine HCl	0.20	0.28	0.36
DL-methionine	0.13	0.05	0.13
L-threonine	0.05	0.05	0.13
L-isoleucine	0.10	---	---
Phytase[6]	0.13	0.17	0.17
Acidifier[7]	0.20	---	---
Vitamin E, 20,000 IU	0.05	---	---
Choline chloride 60%	0.04	---	---
Vitamin D_3 premix[8]	0.02	0.02	0.02
Total	100	100	100
Calculated analysis			
ME, kcal/lb	1,549	1,506	1,503
CP, %	21.2	23.1	20.4
Standardized ileal digestible lysine, %	1.35	1.30	1.25
Ca, %	0.80	0.70	0.68
P, %	0.71	0.63	0.61
Available P, %[9]	0.63	0.50	0.42

[1] A total of 180 pigs (PIC 327 × 1050; initially 21 d of age) were used in a 3 × 2 split plot design for 35 d to determine the effects of maternal vitamin D_3 and early nursery dietary vitamin D_3 on nursery growth performance and serum 25(OH) D_3 concentrations.

[2] Phase 1 diets were fed from d 0 to 10.

[3] Common Phase 2 diets were fed from d 10 to 24.

[4] Common Phase 3 diets were fed from d 24 to 35.

[5] Vitamin premix provided 625 IU vitamin D_3/lb of the complete diet.

[6] Natuphos 600 (BASF, Florham Park, NJ) provided 354, 463, and 463 phytase units (FTU)/lb of the complete diet for Phase 1, 2, and 3 diets, respectively.

[7] KemGest (Kemin Industries Inc., Des Moines, IA).

[8] Vitamin D_3 premixes were mixed to contain 1,000,000 IU vitamin D_3/lb of premix by blending vitamin D_3 (Rovimix D; DSM Nutritional Products, Parsippany, NJ) with rice hulls. Premix replaced a percentage of corn to achieve the desired treatment vitamin D_3 concentrations.

[9] Phytase provided 0.12, 0.13, and 0.12% available P for Phase 1, 2, and 3 diets, respectively.

Table 3. Analyzed dietary vitamin D_3 concentrations (as-fed)[1]

Maternal diets, IU/lb				
Formulated composition	680	1,360	2,720	
Analyzed composition				
Gestation	683	1,529	3,640	
Lactation	669	1,538	2,817	
	Phase 1[2]		Phase 2[3]	Phase 3[4]
Nursery diets, IU/lb				
Formulated composition	816	8,160	816	816
Analyzed composition	848	8,754	841	867

[1] Vitamin D_3 analysis was performed by DSM Nutritional Products (Parsippany, NJ), and values represent the average of 2 pooled samples per diet.
[2] Phase 1 diets were fed from d 0 to 10.
[3] Common Phase 2 diets were fed from d 10 to 24.
[4] Common Phase 3 diets were fed from d 24 to 35.

Table 4. The effects of high maternal vitamin D3 on sow and litter performance[1,2]

	Vitamin D_3, IU/lb				Probability, $P <$	
Item	680	1,360	2,720	SEM	Linear	Quadratic
Sows, n	28	26	26			
Sow BW, lb						
Gestation						
d 0	425.7	427.9	423.7	19.29	0.91	0.89
d 110	510.2	518.5	522.7	13.21	0.52	0.80
Change	+84.5	+90.6	+99.0	11.99	0.24	0.92
Lactation						
d 0	489.2	501.7	494.0	13.17	0.89	0.50
d 21 (weaning)	468.1	485.6	479.2	16.59	0.67	0.42
Change	-21.1	-16.1	-14.8	6.14	0.24	0.43
ADFI, lb						
d 0 to wean (d 21)	12.46	12.96	13.18	0.747	0.27	0.63
Piglets						
Litter size, n						
Mummies	0.3	0.2	0.3	0.12	0.88	0.86
Stillborn	0.6	0.4	0.8	0.34	0.60	0.37
Total born alive	13.0	12.5	13.2	0.88	0.74	0.57
Fostered	12.3	12.1	13.0	0.70	0.50	0.48
Weaned	11.2	10.8	11.5	0.652	0.48	0.32
Survivability, %[3]	91.2	89.2	88.5	2.02	0.88	0.58
Piglet BW, lb						
Birth	2.88	2.99	2.96	0.091	0.63	0.47
Weaning	11.71	12.23	12.18	0.364	0.43	0.42

[1] A total of 84 sows (PIC 1050) and their litters were used. Two sows were removed from the 1,360 IU/kg vitamin D_3 treatment because of lameness and illness, and two sows were removed from the 2,720 IU/kg vitamin D_3 treatment because of late-term abortion and farrowing complications.

[2] Sow group was used as a random effect in the statistical model.

[3] Survivability was calculated by dividing the weaned litter size by the fostered litter size.

Table 5. Effects of high maternal vitamin D_3 on sow and pig serum 25(OH)D_3, milk vitamin D_3, neonatal bone traits, and tissue vitamin D_3[1,2]

	Maternal vitamin D_3, IU/lb				Probability, $P <$	
	680	1,360	2,720	SEM	Linear	Quadratic
Sow						
Serum 25(OH)D_3, ng/mL						
d 0	30.1	26.2	32.0	4.65	0.54	0.27
d 100	33.2	36.5	57.9	4.65	0.01	0.23
Farrowing	30.1	35.4	56.9	4.65	0.01	0.38
Weaning	39.3	52.5	66.3	4.65	0.01	0.31
Milk vitamin D_3, ng/g						
Farrowing	1.02	2.33	3.97	0.31	0.01	0.37
d 10	0.78	2.33	3.73	0.31	0.01	0.13
Weaning	1.02	1.98	3.53	0.31	0.01	0.73
Piglet						
Serum 25(OH)D_3, ng/mL						
Birth	4.5	5.9	9.4	0.75	0.01	0.03
d 10	4.4	6.2	10.6	0.75	0.01	0.01
Weaning	5.6	8.0	14.0	0.81	0.01	0.01
Bone ash content, %						
2nd rib	43.6	43.6	43.5	0.80	0.95	0.96
Femur	44.9	44.5	44.8	0.55	0.76	0.66
Bone density, g/mL						
2nd rib	1.30	1.30	1.31	0.02	0.64	0.56
Tissue vitamin D_3, ng/g						
Kidney	1.68	0.10	1.37	0.842	0.99	0.09
Liver	0.04	0.04	0.19	0.050	0.08	0.16

[1] A total of 84 sows (PIC 1050) and their litters were used to determine the effects of high maternal vitamin D_3 on sow and pig serum 25(OH)D_3, milk vitamin D_3, and neonatal bone traits and tissue vitamin D_3.

[2] Day effects were $P < 0.01$, $P = 0.56$, and $P < 0.01$ for sow 25(OH)D_3, milk vitamin D_3, and piglet 25(OH)D_3, respectively. Maternal × day interactions were $P < 0.01$, $P = 0.87$, and $P = 0.13$ for sow 25(OH)D_3, milk vitamin D_3, and piglet 25(OH)D_3, respectively.

Table 6. The effects of maternal and early nursery vitamin D_3 supplementation on nursery pig growth performance and serum 25(OH)D_3[1]

	Maternal vitamin D_3, IU/lb						Probability, $P <$				
	680		1,360		2,720			Maternal × diet	Maternal		
Early nursery vitamin D_3:[2]	816	8,160	816	8,160	816	8,160	SEM	interaction	Linear	Quadratic	Diet
d 0 to 35											
ADG, lb	0.92	0.92	0.86	0.88	0.92	0.87	0.03	0.56	0.56	0.12	0.75
ADFI, lb	1.32	1.36	1.27	1.25	1.33	1.27	0.04	0.39	0.47	0.06	0.69
F/G	1.43	1.48	1.48	1.42	1.45	1.45	0.03	0.17	0.96	0.71	0.90
Serum 25(OH)D_3, ng/mL											
d 0	6.3		10.5		17.6		3.09		0.01	0.91	
d 10	20.0	53.5	21.9	49.6	24.0	60.9	2.16	0.01	0.01	0.04	0.01
d 21	13.2	26.7	13.6	23.9	14.4	31.6	2.16	0.01	0.16	0.15	0.01
d 35	16.7	18.0	14.5	19.3	14.9	19.5	2.16	0.42	0.94	0.83	0.04

[1] A total of 180 mixed-sex pigs (PIC 327 × 1050; initially 21 d of age) were weaned from the first sow group and used in a 3 × 2 split plot design for 35 d to determine the effects of maternal and early nursery dietary vitamin D_3 on growth performance.

[2] Dietary vitamin D_3 treatments were fed in Phase 1 diets from d 0 to 10. Common Phase 2 and 3 diets were fed from d 10 to 21 and d 21 to 35, respectively. Common diets were formulated to contain 1, 800 IU/kg vitamin D_3. Treatments are expressed as IU/kg of the complete diet.

[3] Ten pigs/treatment were bled to determine serum 25(OH)D_3. Day effect, $P < 0.01$ and maternal × diet × day interaction, $P = 0.32$.

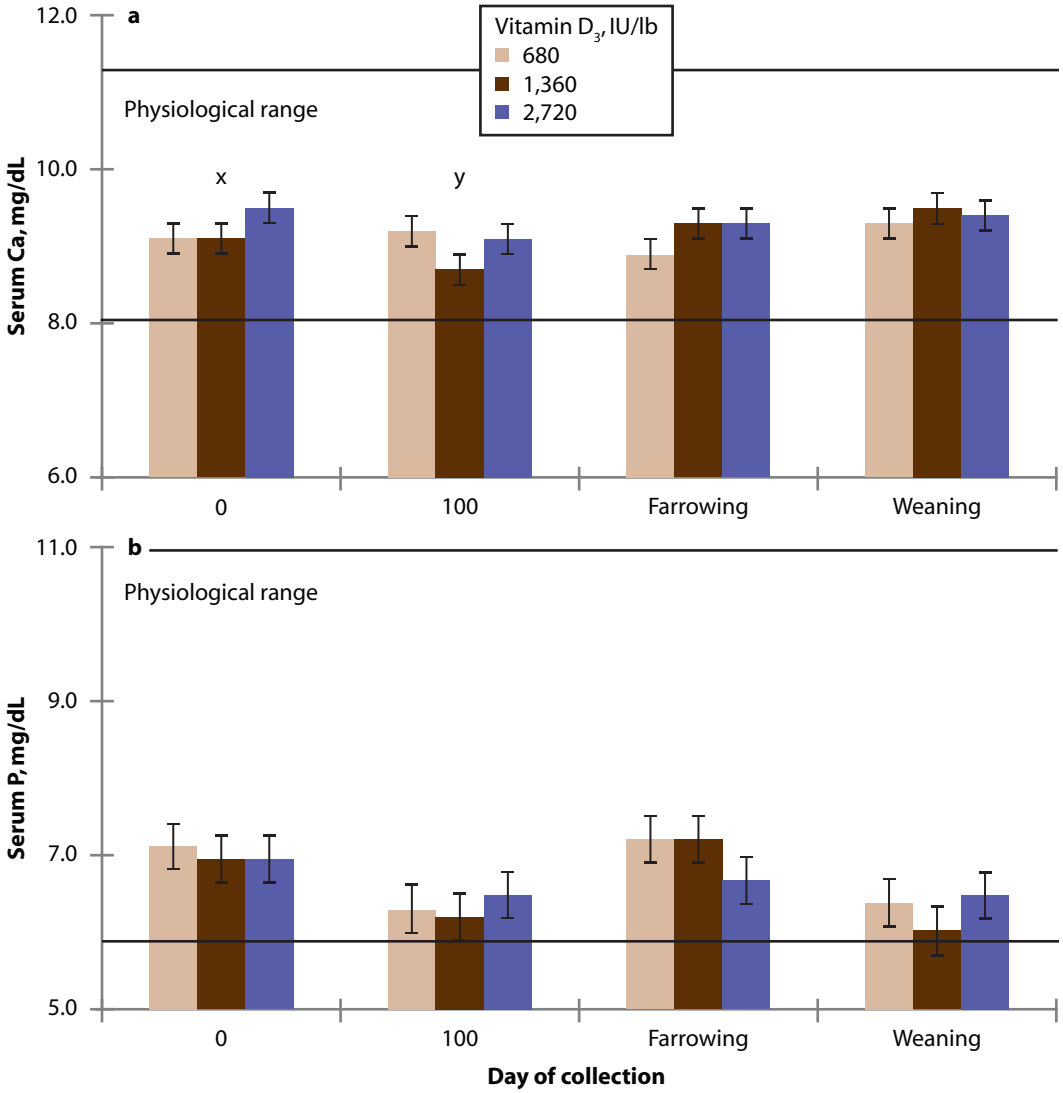

Figure 1. Serum Ca and P concentrations (mg/dL) at d 0 and 100 of gestation, farrowing, and weaning (d 21 of lactation) in sows fed diets formulated to supply 680, 1,320, or 2,720 IU vitamin D_3/lb of the complete diet. Superscripts denote differences ($P < 0.05$) due to: a, linear dietary effect; and b, a quadratic dietary effect. Superscripts denote tendencies ($0.05 < P \leq 0.10$) due to: x, linear dietary effects; and y, quadratic dietary effects. Physiological range based on Friendship et al. (1984).

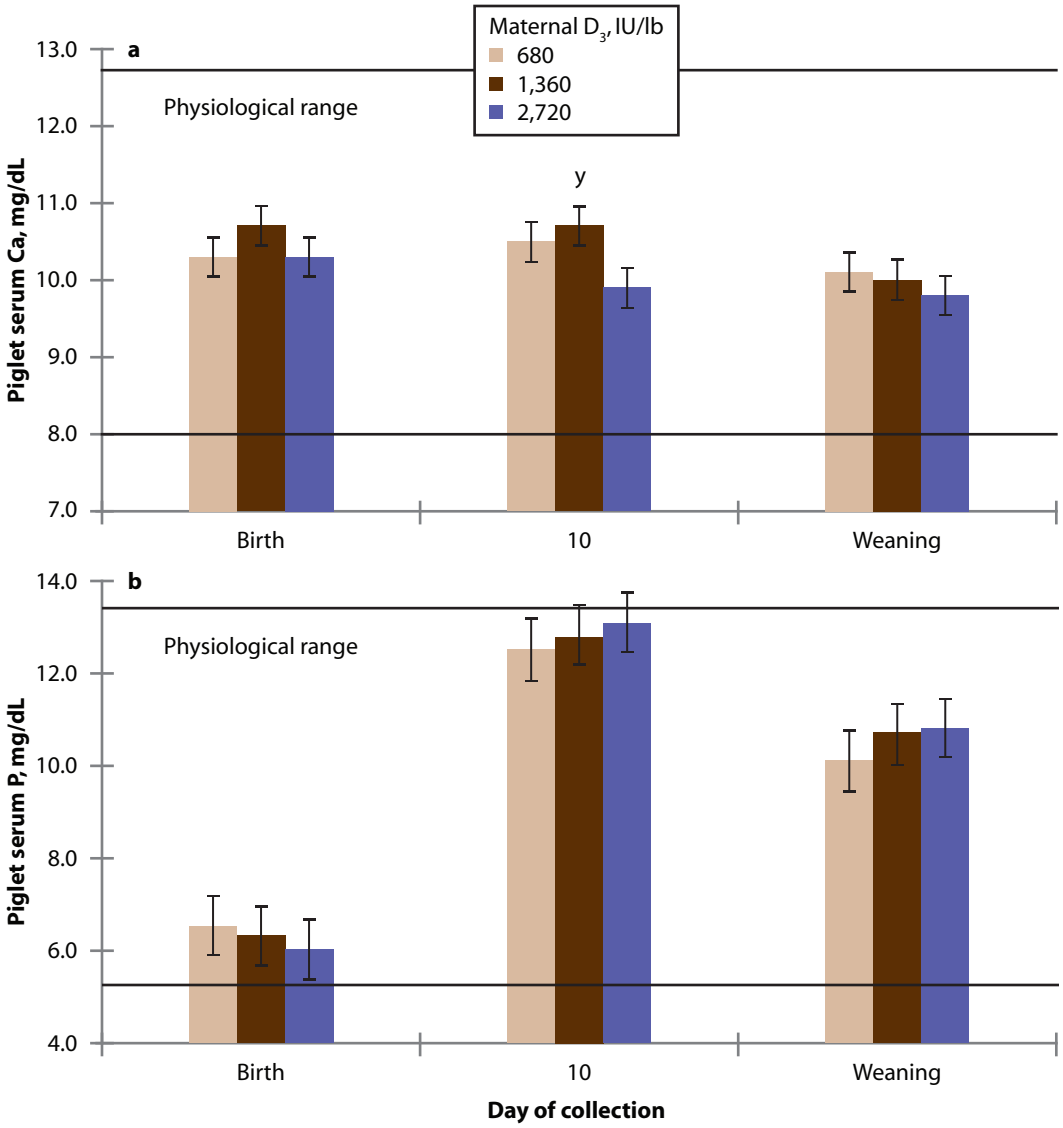

Figure 2. Serum Ca and P concentrations (mg/dL) at birth, d 10, and weaning (d 21) in pigs from sows fed diets formulated to supply 680, 1,320, or 2,720 IU vitamin D_3/lb of the complete diet. Superscripts denote differences ($P < 0.05$) due to: a, linear maternal diet effect; and b, quadratic maternal diet effect. Superscripts denote tendencies ($0.05 < P \leq 0.10$) due to: x, linear maternal diet effect; and y, quadratic maternal diet effect. Physiological range is based on Friendship et al. (1984).

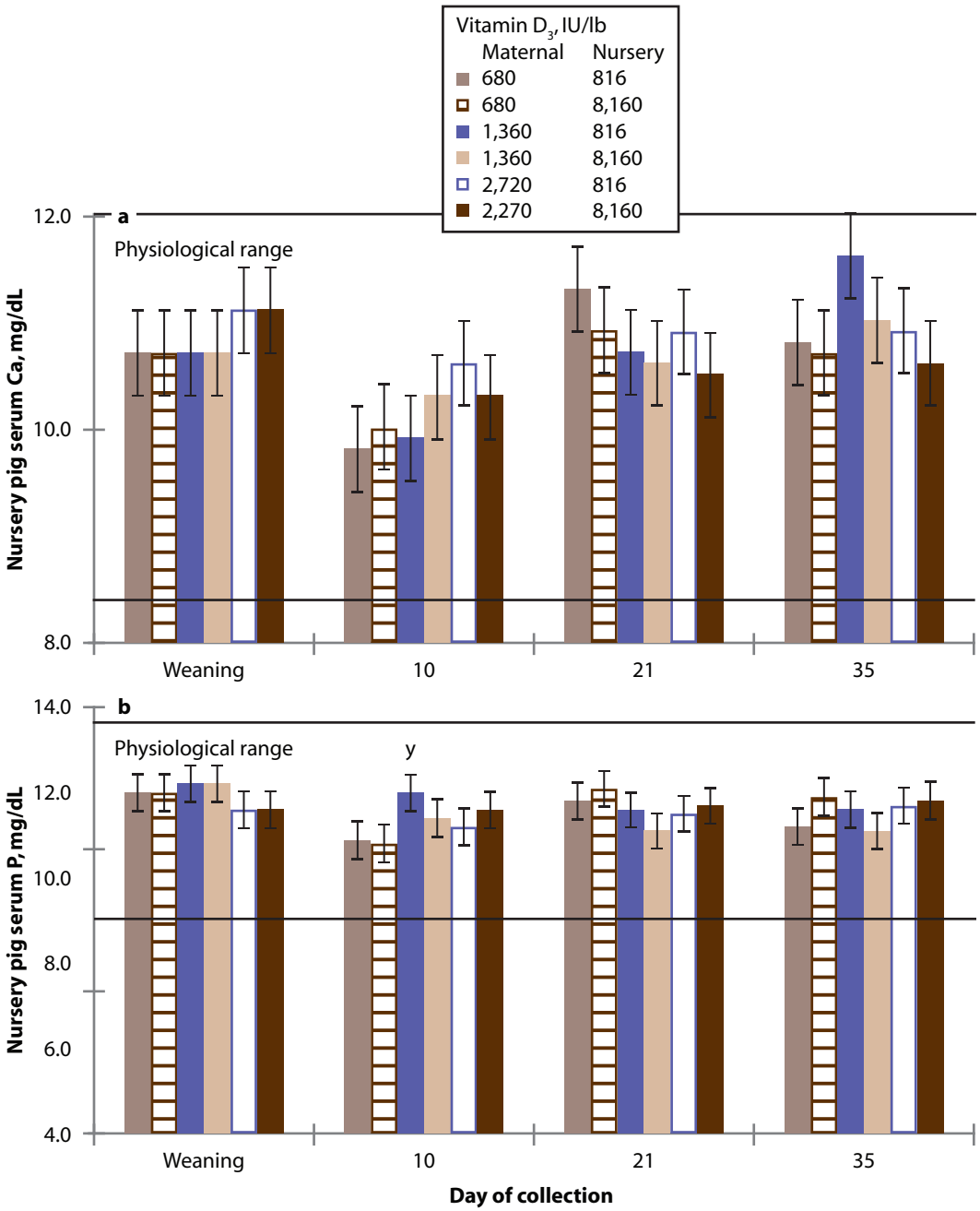

Figure 3. Serum Ca and P concentrations (mg/dL) at weaning, d 10, d 21, and d 35 in nursery pigs from sows fed diets formulated to supply either 680, 1,320 or 2,720 IU vitamin D_3/lb of the complete diet, and fed diets formulated to either 816 or 8,160 IU vitamin D_3/lb from weaning until d 10. Superscripts denote differences ($P < 0.05$) due to: a, linear maternal diet effect; b, a quadratic maternal diet effect; and c, diet effect. Superscripts denote tendencies ($0.05 < P \leq 0.10$) due to: x, linear maternal diet effect; and y, quadratic maternal diet effect; z, diet effect. Physiological range is based on Friendship et al. (1984).