The Effects of Maternal Dietary Supplementation of Cholecalciferol (Vitamin D_3) and 25(OH)D_3 on Sow and Progeny Performance[1]

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Summary

A total of 69 sows (DNA Line 200 × 400) and their progeny were used to determine if feeding a combination of vitamin D_3 (Rovimix D_3, 500,000 IU/g; DSM Nutritional Products, Parsippany, NJ) and 25(OH)D_3 (Hy-D, DSM Nutritional Products, Parsippany, NJ) influences neonatal and sow vitamin D_3 status, muscle fiber morphometrics and development of the piglets, and subsequent growth performance to market. Within 3 days of breeding, sows were allotted to 1 of 3 dietary treatments fortified with 680 IU/lb vitamin D_3 (CON), 227 IU/lb vitamin D_3 + 11.3 µg/lb 25(OH)D_3 (DL), or 680 IU/lb vitamin D_3 + 22.7 µg/lb 25(OH)D_3 (DH). Differences in sow productivity and growth performance of progeny due to dietary treatment were not observed ($P > 0.050$). When pigs were sacrificed at birth, there were no treatment effects for all fiber morphometric measures ($P > 0.170$), except primary fiber number and the ratio of secondary to primary muscle fibers ($P < 0.016$). Pigs from CON fed sows had fewer primary fibers than pigs from sows fed the DH treatment ($P = 0.014$), with pigs from sows fed DL treatment not differing from either ($P > 0.104$). Pigs from the CON and DL fed sows had a greater secondary to primary muscle fiber ratio compared to pigs from DH sows ($P < 0.022$) but did not differ from each other ($P = 0.994$). There were treatment × time interactions for all sow and pig serum metabolites ($P < 0.001$). Therefore, we further compared treatment means within time period. At all time periods, sow serum 25(OH)D_3 concentrations differed for all treatments with the magnitude of difference largest at weaning ($P < 0.011$). On all three collection days, DH fed sows contained the greatest serum levels of 25(OH)D_3. For pig vitamin D_3 status at birth, the interaction was because serum concentrations of 25(OH)D_3 in pigs from sows fed CON and DL were not different from each other. But at weaning, pigs from all sow treatments differed. At both sampling days, progeny from DH fed sows contained the

[1]The authors express appreciation to DSM for providing financial support for this study which also includes the Hy-D, Rovimix D, and vitamin premix products used, as well as feed, serum, and milk analyses.

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greatest serum levels of 25(OH)D_3. There was no interaction for 25(OH)D_3 concentration in colostrum and milk; however, a main effect of dietary treatment ($P < 0.001$) and of time ($P = 0.001$) existed. Within maternal dietary treatment, colostrum collected within 12 h contained less ($P = 0.001$) 25(OH)D_3 compared to milk collected on d 21. Within sampling time, 12 h for colostrum and 21 d for milk, sows from all treatments were different ($P < 0.030$), with the largest 25(OH)D_3 concentration from DH fed sows, followed by DL and then CON. In conclusion, combining vitamin D_3 and 25(OH)D_3 in the maternal diet improves the vitamin D_3 status of the dam and progeny and it increases primary muscle fibers at birth.

Introduction

Vitamin D_3 plays a major role in regulating Ca and P absorption and metabolism in animals, especially for bone. This is important for the growth and maintenance of a functional skeleton to sustain health and improve welfare and longevity. On modern farms, especially the majority of swine and poultry farms in North America, animals are housed in environmentally-controlled barns with artificial lighting to maintain their comfort and productivity. Without access to direct sunlight and its ultraviolet UVB radiation, the endogenous production of vitamin D_3 in the animals' skin is limited and insufficient. Therefore, vitamin D_3 is recognized to be an essential nutrient, and is the most common form of vitamin D used to supplement swine diets today.

After ingestion and absorption of vitamin D_3, the 25th carbon of vitamin D_3 is hydroxylated in the liver to form calcidiol (25(OH)D_3). This metabolite is then transported through the blood to the kidney where additional hydroxylation occurs to form different metabolites of vitamin D_3, including 24,25$(OH)_2D_3$ and the active hormone form of vitamin D_3 calcitriol (1,25$(OH)_2D_3$), each with its own function in the body. The level of calcidiol found in blood serum is considered a good indicator of an animal's vitamin D_3 status (i.e. deficient, adequate, toxic).[5]

Using swine, Zhou et al.[6] investigated the effects of maternal vitamin D_3 nutrition and status on the sow and her offspring. They evaluated muscle fiber characteristics of newborn and weanling piglets whose mothers were fed 25(OH)D_3 in addition to vitamin D_3 and observed increased total muscle fiber numbers in newborn and weanling pigs, as well as an increased muscle fiber cross-sectional area in weanling pigs. The differences in skeletal muscle development found after the piglets were born indicates there is potential for enhancing lean development and growth performance when dams were fed greater levels of dietary vitamin D from supplementing 25(OH)D_3 to an existing level of vitamin D_3.

The objective of this study was to determine if feeding a combination of vitamin D_3 (Rovimix D3, 500,000 IU/g; DSM Nutritional Products, Parsippany, NJ) and its more available metabolite, 25(OH)D_3 (Hy-D, DSM), influences sow and pig performance. Performance parameters included sow reproductive and litter performance, sow and pig

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[5]Soares, J. H., J. M. Kerr, and R. W. Gray. 1995. 25-hydroxycholecalciferol in poultry nutrition. Poult. Sci. 74:1919–1934.

[6]Zhou, H., Y. Chen, G. Lv, Y. Zhuo, Y. Lin, B. Feng, Z. Fang, L. Che, J. Li, S. Xu, and D. Wu. 2016. Improving maternal vitamin D status promotes prenatal and postnatal skeletal muscle development of pig offspring. Nutrition. 32:1144–1152. doi:10.1016/j.nut.2016.03.004

vitamin D status, muscle fiber morphometrics of the progeny, and subsequent growth performance of the piglets.

Procedures

The protocol for this experiment was approved by the Kansas State University Institutional Animal Care and Use Committee. The study was conducted at the K-State Swine Teaching and Research Center (Manhattan, KS). All serum, colostrum, and milk sample testing were performed by Heartland Assays LLC (Ames, IA).

A total of 69 sows (DNA Line 200 × 400) and their progeny from 3 consecutive farrowing groups were used in this study. Within 3 days of breeding, each sow was weighed and assigned to 1 of 3 dietary treatments equalized for parity and body weight (BW). Treatments were gestation and lactation diets fortified with either 680 IU/lb vitamin D_3 (CON); 227 IU/lb vitamin D_3 + 11.3 μg/lb 25(OH)D_3 (DL); or 680 IU/lb vitamin D_3 + 22.7 μg/lb 25(OH)D_3 (DH). The total intended vitamin D_3 activities for the CON, DL, and DH diets were 680 IU, 680 IU, and 1,588 IU/lb of the diet, respectively. For all other nutrients, the experimental diets (Table 1) were equally formulated to meet or exceed the dietary requirements suggested by the Swine National Research Council.[7]

During gestation, sows were housed in individual gestation stalls equipped with individual water nipples and a feed trough. From d 0 to 74 of gestation, sows were fed 4.4 lb of feed once per day at 0800 h. Feed allowance increased to 5.5 lb/d from d 75 to 110. After consuming gestation feed on d 110, sows were moved into farrowing crates equipped with individual water nipples, and water misters. Sows were fed the gestation diet 4 times throughout the day using an electronic feeding system (Gestal Solo; JYGA Technologies, Quebec, Canada) until the sow farrowed. Once the sows gave birth, they were weighed, transitioned to lactation diets, and placed on an individual feeding curve determined by parity. Lactation feed intake was determined from the recordings of feed disappearance on d 7, 14, and 21. Individual sow and piglet weights were recorded within 24 h of birth and at weaning on d 21 of lactation.

The progeny from one farrowing group was double ear-tagged and monitored through the nursery and finisher until harvest. For the nursery, a total of 216 pigs weaned from one of the groups were randomly placed in 36 pens within maternal dietary treatment with 6 pigs per pen. Nursery pens allowed 3.27 ft^2 of floor space per pig and were equipped with a 4-hole feeder and a nipple waterer for *ad libitum* access. Nursery diets were fed in 2 phases and pigs maintained the same treatment as their mother. All diets were formulated to meet or exceed the dietary requirements suggested by the Swine National Research Council[7] (Table 2). Phase 1 diets were fed in meal form from d 0 to 14 postweaning. Phase 2 diets were fed in meal form from d 14 to 59 postweaning. Individual pen weights and feeder weights were measured on d 7, 14, 21, 28, 35, 42, 49, and 59 to determine average daily gain (ADG), average daily feed intake (ADFI), and feed to gain ratio (F/G).

[7]NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

Pigs were transferred from the nursery to the finisher on d 59 postweaning. All pigs maintained the same pen-mates after their transfer to maintain pen integrity throughout the trial.

Finisher pens allowed for 9.00 ft^2 of slatted floor space per pig and were equipped with a 2-hole, dry self-feeder and a cup waterer for *ad libitum* access. The finisher dietary treatments were fed in 3 phases. Phase 1 diets were fed until about 134 lb of body weight, then phase 2 diets were fed until about 220 lb of body weight. The third and final phase diets were fed from 220 lb of body weight until market. Finisher phase 1 and 2 diets contained the same added levels of vitamin D within each treatment and were fortified with 454 IU/lb vitamin D_3 (CON), 11.3 µg/lb 25(OH)D_3 (DL), or 22.7 µg/lb 25(OH)D_3 (DH). The total vitamin D_3 activities of the CON, DL, and DH diets were 454 IU, 454 IU, and 907 IU/lb of the diet, respectively. For finisher phase 3, diets were fortified with 363 IU/lb vitamin D_3 (CON), 9 µg/lb 25(OH)D_3 (DL), or 18 µg/lb 25(OH)D_3 (DH). The total vitamin D_3 activity of the CON, DL, and DH diets were 363 IU, 363 IU, and 726 IU/lb of the diet, respectively. All diets were formulated to meet or exceed the dietary requirements suggested by the Swine National Research Council[7] (Table 3). Feed was distributed and recorded by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) 4 times a day. Individual pen weights and feeder weights were measured approximately every 16 d to determine ADG, ADFI, and F/G ratio. Final live weight was collected on individual pigs one day before marketing. Hot carcass weight was collected on individual pigs at Triumph Foods (St. Joseph, MO).

Data were analyzed as a completely randomized design using the GLIMMIX procedure in SAS 9.4 (SAS Institute, Inc., Cary, NC) with sow or pen as the experimental unit. Dietary treatment was the fixed effect. For sow and litter performance, muscle fiber morphometrics, whole body piglet measurements, nursery and finisher performance, and hot carcass weight (HCW) data were analyzed as a completely randomized design. Normal distribution was used for symmetrically distributed numeric responses, whereas Beta or Gamma distributions were used to model percentage responses such as stillborn percentage with logit or log link function respectively. Count responses were analyzed under Negative Binomial distribution and log link. Serum metabolite and milk analyses were analyzed as a completely randomized design with repeated measures on time controlled for baseline measures at gestation d 0. Fixed effects included treatment, time, and their interaction. Time served as the repeated measure, sow/pig as the subject, and ANTE(1) as the covariance structure as the best fit based on Bayesian Information Criterion. Differences were considered significant at $P \leq 0.05$ and trends at $0.05 > P \leq 0.10$.

Results and Discussion

According to the most recent survey of current vitamin and trace minerals fed in the U.S. swine industry, Flohr et al.[8] found that the median concentration of vitamin D_3 fed to gestating and lactating sows that represented about 40% of the industry was 799 IU/lb. The maximum level of dietary vitamin D_3 allowed for pigs in Canada is

[8]Flohr, J. R., J. M. DeRouchey, J. C. Woodworth, M. D. Tokach, R. D. Goodband, and S. S. Dritz. 2016. A survey of current feeding regimens for vitamins and trace minerals in the US swine industry. J. Swine Health Prod. 24:290–303.

680 IU/lb. Therefore, we chose to use 680 IU vitamin D_3/lb diet for the CON treatment in this study.

There were no treatment effects on sow and preweaned pig performance ($P > 0.283$; Table 4). For pigs sacrificed at birth, there were no treatment effects for fiber morphometric measures ($P > 0.170$; Table 5), except primary fiber number and the ratio of secondary to primary muscle fibers ($P < 0.016$). Pigs from CON fed sows had fewer primary fibers than pigs from sows fed the DH treatment ($P = 0.014$), with pigs from sows fed DL treatment not differing from either ($P > 0.104$). Pigs from the CON and DL fed sows had greater secondary to primary muscle fiber ratios compared to pigs from sows fed the DH treatment ($P < 0.022$) but did not differ from each other ($P = 0.994$). When pigs were sacrificed at weaning, there were no treatment effects for fiber morphometric measures ($P > 0.129$; Table 6).

All pig serum samples analyzed for vitamin D_3 had concentrations that were not above the detectable limit of 1.5 ng/mL. There were treatment × time interactions for all other sow and pig serum metabolites ($P < 0.001$; Table 7). Therefore, treatment means were compared within time period. At all time periods, sow serum 25(OH)D_3 concentrations differed for all treatments with the magnitude of difference largest at weaning ($P < 0.011$), and serum 25(OH)D_3 concentration was always the greatest when sows were fed the DH diet.

At birth, piglets from DH fed sows had greater serum 25(OH)D_3 concentrations than piglets from sows fed the DL treatment ($P = 0.003$), with piglets from sows fed CON treatment intermediate ($P > 0.061$). At weaning, serum concentrations of 25(OH)D_3 in piglets from all sow treatments were different ($P < 0.001$), with the greatest concentration in piglets from DH sows, followed by CON, and followed by DL. At birth, serum concentrations of 24,25$(OH)_2D_3$ in pigs from all sow treatments were different ($P < 0.001$), with the greatest concentration in pigs from DH sows, followed by DL and then CON. At weaning, pigs from the CON and DL fed sows had serum 24,25$(OH)_2D_3$ concentrations less than pigs from sows fed the DH treatment ($P < 0.001$), but did not differ from each other ($P = 0.944$). During grower and finisher phases, pig serum 25(OH)D_3 concentrations for all treatments differed from each other with the magnitude of difference larger in grower pigs ($P < 0.001$).

There were no treatment × time interactions for any of the metabolites measured in milk and no treatment or time main effects for 24,25$(OH)_2D_3$ concentration ($P > 0.068$; Table 8). Colostrum collected within 12 h contained less ($P = 0.001$) 25(OH)D_3 than milk collected on d 21. Regardless of time, concentrations of 25(OH)D_3 in milk were different ($P < 0.030$), with the largest 25(OH)D_3 concentration from DH fed sows, followed by DL and then CON.

When pigs were in the nursery, there were no treatment effects for any of the growth performance measures ($P > 0.132$), except for feed efficiency from d 28 to 59 and d 0 to 59 ($P < 0.015$; Table 9). From d 28 to 59, DL pigs had a poorer feed efficiency than DH pigs ($P = 0.002$), with CON pigs not intermediate ($P > 0.107$). From d 0 to 59, DL pigs had a poorer feed efficiency than DH pigs ($P = 0.018$), with CON pigs intermediate ($P > 0.191$). When pigs were in the finishing barn, there were no treatment effects for any of the growth performance measures ($P > 0.171$; Table 10). Also, there were no treatment effects for live weight, HCW or dressing percentage in the pigs marketed ($P > 0.826$; Table 11).

In conclusion, combining vitamin D_3 and 25(OH)D_3 in the maternal diet did not affect sow or preweaned pig performance in the farrowing house. The combination did, however, improve the vitamin D status of the dam and progeny and increased primary muscle fibers at birth. Although improvements were observed in primary muscle fibers at birth, the total number of muscle fibers was not improved at birth or weaning, which may explain why there were no differences in progeny growth performance to market.

Table 1. Sow diet composition (as-fed basis)

Ingredient, %	Gestation[1]	Lactation[2]
Corn	80.33	63.04
Soybean meal	15.60	30.20
Monocalcium phosphate, 21% P	1.48	1.48
Limestone	1.15	1.05
Salt	0.50	0.50
L-Lysine-HCl	---	0.20
DL-Methionine	---	0.05
L-Threonine	0.03	0.075
Choice white grease	---	2.50
Trace mineral premix	0.15	0.15
Vitamin premix without vitamin D	0.25	0.25
Sow add pack	0.25	0.25
Phytase[3]	0.015	0.015
Vitamin D premix[4]	0.25	0.25
Total	100.00	100.00
Calculated analysis[5]		
Standard ileal digestible (SID) lysine, %	0.56	1.07
Net energy,[5] kcal/lb	1,123	1,137
Crude protein, %	14.10	19.90
Calcium, %	0.76	0.77
Available phosphorus, %	0.46	0.48
Standardized digestible phosphorus, %	0.48	0.52

[1]Diets were fed from within 3 days of breeding to parturition.
[2]Diets were fed from d 0 to 21 of lactation.
[3]Ronozyme Hiphos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ), with a release of 0.10% available P.
[4]Vitamin D premixes contain 680 or 1,588 IU of total vitamin D activity per lb of diet by adding a combination of vitamin D_3 (Rovimix D3-500, DSM Nutrition Products), 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products), and corn to achieve desired vitamin D concentrations for each treatment.
[5]NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

Table 2. Nursery diet composition (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2
Corn	41.04	47.14
Soybean meal	30.30	32.00
Blood meal	1.25	---
Corn DDGS, >6 and <9% oil	10.00	15.00
Fish meal combined	1.25	---
Milk, whey powder	10.00	---
Monocalcium phosphate, 21% P	0.80	1.00
Limestone	1.10	1.03
Salt	0.30	0.35
L-Lysine-HCl	0.30	0.30
DL-Methionine	0.18	0.12
L-Threonine	0.15	0.06
Choice white grease	2.00	2.00
Trace mineral premix	0.15	0.15
Vitamin premix without vitamin D	0.25	0.25
Zinc oxide	0.42	0.28
Copper sulfate	0.05	0.05
Acidifier[2]	0.20	---
Phytase[3]	0.02	0.02
Vitamin D premix[4]	0.25	0.25
Total	100.00	100.00
Calculated analysis[5]		
Standard ileal digestible (SID) lysine, %	1.40	1.24
Net energy,[5] kcal/lb	1,114	1,107
Crude protein, %	24.10	23.70
Calcium, %	0.79	0.69
Available phosphorus, %	0.53	0.49
Standardized digestible phosphorus, %	0.55	0.52

[1]Phase 1 diets were fed from d 0 to 14 and phase 2 diets were fed from d 14 to 59 in the nursery.
DDGS = dried distillers grains with solubles.
[2]Kem-gest (Kemin Industries, Inc., Des Moines, IA).
[3]Ronozyme Hiphos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ), with a release of 0.10% available P.
[4]Vitamin D premixes contain 680 or 1,588 IU of total vitamin D activity per lb of diet by adding a combination of vitamin D_3 (Rovimix D3-500, DSM Nutrition Products), 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products), and corn to achieve desired vitamin D concentrations for each treatment.
[5]NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

Table 3. Finisher diet composition (as-fed basis)[1]

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	74.40	83.42	83.42
Soybean meal	22.85	14.30	14.30
Monocalcium phosphate, 21% P	0.55	0.33	0.33
Limestone	0.95	0.85	0.85
Salt	0.35	0.35	0.35
L-Lysine-HCl	0.31	0.25	0.25
DL-Methionine	0.06	0.02	0.02
L-Threonine	0.09	0.05	0.05
Trace mineral premix	0.15	0.13	0.13
Vitamin premix without vitamin D	0.15	0.15	0.15
Phytase[2]	0.015	0.015	0.015
Vitamin D premix[3]	0.15	0.15	0.15
Total	100.00	100.00	100.00
Calculated analysis[4]			
Standard ileal digestible (SID) lysine, %	0.98	0.73	0.73
Net energy,[4] kcal/lb	1,124	1,151	1,151
Crude protein, %	17.40	14.0	14.0
Calcium, %	0.55	0.45	0.45
Available phosphorus, %	0.27	0.21	0.21
Standardized digestible phosphorus, %	0.33	0.26	0.26

[1]Phase 1 diets were fed from d 0 to 35, phase 2 diets were fed from d 35 to 67, and phase 3 diets were fed from d 67 to 97 in the finisher.

[2]Ronozyme Hiphos (GT) 2700 (DSM Nutritional Products, Parsippany, NJ), with a release of 0.10% available P.

[3]Vitamin D premixes contain either vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) mixed with corn or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) mixed with corn to achieve desired vitamin D concentrations for each treatment.

[4]NRC. 2012. Nutrient Requirements of Swine. 11th ed. Natl. Acad. Press, Washington, DC.

Table 4. Effects of feeding vitamin D_3 alone or in combination with 25(OH)D_3 on sow and preweaned piglet performance[1]

	Diet[2]				
	1,500 IU D_3	500 IU D_3 and 25 µg 25(OH)D_3	1,500 IU D_3 and 50 µg 25(OH)D_3	SEM	Probability, $P <$
Sows, *n*	23	23	23	---	---
Parity	2.35	2.35	2.52	---	---
Lactation ADFI, lb	12.38	12.71	12.50	0.436	0.865
Sow BW, lb					
Gestation					
d 0	407.0	405.7	421.3	13.726	0.672
d 110	505.7	509.6	509. 9	10.300	0.950
BW gain, lb	98.70	103.91	88.61	8.584	0.444
Lactation					
d 0	467.8	473.9	477.3	10.214	0.801
d 21	458.6	464.4	464.4	11.014	0.912
BW loss, lb	-9.22	-9.57	-12.91	4.394	0.807
Litter characteristics					
Total born, *n*	17.28	16.73	17.86	0.881	0.652
Born alive, %	87.80	92.13	89.67	1.960	0.283
Stillborn, %	9.53	6.93	9.42	5.048	0.891
Mummies, %	3.90	2.27	2.86	2.771	0.864
Standardized litter size,[3] *n*	14.00	13.83	13.96	0.780	0.987
Weaning litter size, *n*	13.00	13.09	13.00	0.754	0.996
Survivability, %	93.08	95.07	93.57	1.766	0.706
Piglet BW, lb					
Birth	3.03	3.13	2.93	0.090	0.307
Weaning	12.40	12.00	11.75	0.341	0.409

[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and 25(OH)D_3 influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market.
[2]Three maternal dietary treatments were fed. Vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) were used to achieve desired vitamin D_3 concentrations for each treatment.
[3]Cross-fostering occurred within treatment and within 48 h to equalize litter size.
BW = body weight. ADFI = average daily feed intake.

Table 5. Whole Longissimus lumborum and muscle fiber characteristics of pigs at birth from sows fed vitamin D_3 alone or in combination with $25(OH)D_3$[1]

	Diet[2]				
	1,500 IU D_3	500 IU D_3 and 25 µg $25(OH)D_3$	1,500 IU D_3 and 50 µg $25(OH)D_3$	SEM	Probability, *P* <
Pigs, *n*	12	12	12	---	---
Live birth weight, lb	3.14	3.17	2.97	0.134	0.517
Whole muscle CSA,[3] mm^2	192	195	186	11.7	0.838
All fiber characteristics[4]					
Number[5]	720,711	829,512	711,181	73,763	0.409
CSA, μm^2	108	106	103	6.7	0.875
Myonuclei	1.21	1.22	1.36	0.336	0.939
Satellite cells	0.06	0.06	0.07	0.078	0.988
Fiber type characteristics[6]					
Primary					
Number[7]	37,501[b]	44,111[b]	66,139[a]	8,914	0.016
CSA, μm^2	222	240	215	20.3	0.661
Secondary					
Number[7]	683,210	785,401	647,715	70,119	0.302
CSA, μm^2	101	99	93	6.4	0.614
Secondary fibers per primary fiber[8]	20.4[a]	20.0[a]	11.9[b]	2.05	0.009

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

[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and $25(OH)D_3$ influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market. Thirty-six piglets were sacrificed within 24 hours of birth.

[2]Three maternal dietary treatments were fed within 3 days of artificial insemination until weaning on d 21 of lactation. Vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or $25(OH)D_3$ (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) were used to achieve desired vitamin D concentrations for each treatment.

[3]CSA = cross-sectional area.

[4]Overall fiber characteristics independent of fiber type.

[5]Total number of muscle fibers was determined by the number of photomicrograph frames in the whole muscle CSA multiplied by the average number of fibers in a frame.

[6]Fibers that stained exclusively positive for BA-D5 were labeled as primary muscle fibers and fibers that stained negative for BA-D5 were labeled as secondary muscle fibers.

[7]Total number of a specific fiber isoforms was determined by the number of photomicrograph frames in the whole muscle CSA multiplied by the average number of the specific fiber isoforms in a frame.

[8]Ratio of secondary muscle fibers present per primary muscle fiber.

Table 6. Whole Longissimus lumborum and muscle fiber characteristics of pigs at weaning from sows fed vitamin D_3 alone or in combination with 25(OH)D_3[1]

	Diet[2]				
	1,500 IU D_3	500 IU D_3 and 25 µg 25(OH)D_3	1,500 IU D_3 and 50 µg 25(OH)D_3	SEM	Probability, *P* <
Pigs, *n*	11	12	12	---	---
Live birth weight, lb	3.22	3.16	2.83	0.200	0.323
Live weaning weight, lb	12.84	12.43	11.55	0.635	0.334
Whole muscle CSA,[3] mm^2	656	604	541	57.3	0.360
All fiber characteristics[4]					
Number[5]	754,550	753,211	684,633	66,665	0.657
CSA, μm^2	563	565	505	45.6	0.553
Myonuclei	1.59	1.48	1.38	0.380	0.916
Satellite cells	0.12	0.11	0.12	0.105	0.999
Fiber type characteristics[6]					
Type I					
Number[7]	91,248	93,984	79,139	9,894	0.468
Distribution,[8] %	12.2	12.7	11.6	0.83	0.646
CSA, μm^2	434	393	416	21.5	0.384
Type IIA					
Number[7]	117,943	132,715	119,140	12,253	0.616
Distribution,[8] %	15.7	17.7	17.9	0.81	0.129
CSA, μm^2	401	360	345	26.1	0.291
Type IIX					
Number[7]	200,114	206,098	175,679	23,920	0.584
Distribution,[8] %	26.8	26.3	24.6	1.42	0.498
CSA, μm^2	539	532	469	37.2	0.329
Type IIB					
Number[7]	345,264	320,416	310,674	29,229	0.658
Distribution,[8] %	45.7	42.9	45.8	1.44	0.256
CSA, μm^2	671	727	613	74.4	0.537

[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and 25(OH)D_3 influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market. Thirty-five piglets were sacrificed at weaning.
[2]Three maternal dietary treatments were fed within 3 days of artificial insemination until weaning on d 21 of lactation. Vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) were used to achieve desired vitamin D concentrations for each treatment.
[3]CSA = cross-sectional area.
[4]Overall fiber characteristics independent of fiber type.
[5]Total number of muscle fibers was determined by the number of photomicrograph frames in the whole muscle CSA multiplied by the average number of fibers in a frame.
[6]Fibers that stained exclusively positive for BA-D5, SC-71, and BF-F3 were labeled type I, type IIA, and IIB, respectively. Fibers that stained positive for both SC-71 and B-FF3 were labeled as type IIX fibers.
[7]Total number of a specific fiber isoforms was determined by the number of photomicrograph frames in the whole muscle CSA multiplied by the average number of the specific fiber isoforms in a frame.
[8]Distribution was calculated by the number of the specific fibers divided by the overall total fibers multiplied by 100%.

Table 7. Effects of feeding 25(OH)D_3 on serum concentrations of vitamin D_3 metabolites[1]

	Maternal diet[2]				Probability, P <		
	1,500 IU D_3	500 IU D_3 and 25 µg 25(OH)D_3	1,500 IU D_3 and 50 µg 25(OH)D_3	SEM	Treatment	Time	Treatment × time
Sow serum[3]							
25(OH)D_3, ng/mL					<0.001	<0.001	<0.001
Gestation, d 100	21.2[c]	31.4[b]	52.1[a]	1.90			
Farrowing	17.8[c]	25.3[b]	43.3[a]	1.46			
Weaning	27.6[c]	48.8[b]	82.3[a]	2.82			
Piglet serum[4]							
25(OH)D_3, ng/mL					<0.001	<0.001	<0.001
Birth	2.1[ab]	2.0[b]	3.0[a]	0.27			
Weaning	4.7[b]	3.6[c]	7.6[a]	0.19			
24,25(OH)$_2$$D_3$, ng/mL					<0.001	<0.001	<0.001
Birth	1.9[c]	2.8[b]	4.8[a]	0.15			
Weaning	0.9[b]	1.1[b]	2.4[a]	0.09			
Pig serum							
25(OH)D_3, ng/mL					<0.001	<0.001	<0.001
Grower[5]	16.6[c]	36.4[b]	61.3[a]	1.63			
Finisher[6]	17.8[c]	30.0[b]	53.4[a]	1.76			

[a,b,c]Means within a row with different superscripts differ (P < 0.05) within the row's respective time.
[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and 25(OH)D_3 influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market.
[2]Three dietary treatments were fed using vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) to achieve desired vitamin D_3 concentrations for each maternal treatment.
[3]Sow serum 25(OH)D_3 was analyzed using gestation d 0 as a covariate.
[5]Grower serum was collected immediately after pigs were transferred to the finisher, 59 d postweaning.
[6]Finisher serum was collected the day before marketing, 156 d postweaning.

Table 8. Effects of feeding 25(OH)D_3 on colostrum and milk concentrations of vitamin D_3 metabolites[1,2]

	Maternal diet[3]				Probability, *P* <		
	1,500 IU D_3	500 IU D_3 and 25 µg 25(OH)D_3	1,500 IU D_3 and 50 µg 25(OH)D_3	SEM	Treatment	Time	Treatment × time
25(OH)D_3, ng/g					<0.001	0.001	0.518
Colostrum, d 0	0.333	0.537	0.852	0.091			
Milk, d 21	0.487	0.728	1.180	0.070			
24,25$(OH)_2D_3$, ng/g					0.619	0.166	0.068
Colostrum, d 0	0.118	0.262	0.382	0.081			
Milk, d 21	0.242	0.211	0.114	0.048			

[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and 25(OH)D_3 influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market.

[2]Colostrum means represent the average metabolite from a total 36 sows. Milk means represent the average metabolite from a total 34 sows.

[3]Three dietary treatments were fed using vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) to achieve desired vitamin D_3 concentrations for each maternal treatment.

Table 9. Effects of feeding 25(OH)D_3 on nursery pig growth performance [1, 2]

	Diet [3]				
	1,500 IU D_3	500 IU D_3 and 25 µg 25(OH)D_3	1,500 IU D_3 and 50 µg 25(OH)D_3	SEM	Probability, *P* <
d 0 to 14					
ADG, lb	0.316	0.354	0.345	0.020	0.385
ADFI, lb	0.474	0.492	0.473	0.021	0.762
F/G	1.514	1.425	1.389	0.046	0.163
d 0 to 21					
ADG, lb	0.506	0.553	0.514	0.021	0.242
ADFI, lb	0.844	0.876	0.830	0.021	0.287
F/G	1.673	1.617	1.625	0.050	0.702
d 21 to 28					
ADG, lb	1.107	1.148	1.152	0.030	0.513
ADFI, lb	1.595	1.654	1.599	0.035	0.421
F/G	1.450	1.445	1.390	0.028	0.258
d 28 to 59					
ADG, lb	1.548	1.489	1.571	0.030	0.149
ADFI, lb	2.682	2.671	2.637	0.047	0.773
F/G	1.734[ab]	1.801[b]	1.679[a]	0.023	0.002
d 0 to 59					
ADG, lb	1.119	1.111	1.140	0.022	0.643
ADFI, lb	1.891	1.903	1.862	0.032	0.649
F/G	1.688[ab]	1.723[b]	1.633[a]	0.022	0.023
BW, lb					
d 0	12.59	12.49	12.59	0.128	0.827
d 7	12.97	13.22	13.26	0.194	0.522
d 14	17.01	17.60	17.42	0.343	0.472
d 21	23.59	24.31	23.39	0.496	0.398
d 28	31.34	32.51	31.64	0.578	0.341
d 59	79.31	78.66	80.66	1.267	0.529

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

[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and 25(OH)D_3 influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market. A total of 216 weaned pigs were used in a 59-d nursery growth trial with 6 pigs per pen and 12 pens per treatment.

[2]Experimental diets were fed from d 0 to 59 in 2 phases.

[3]Three dietary treatments were fed using vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) to achieve desired vitamin D_3 concentrations for each treatment.

ADG = average daily gain. ADFI = average daily feed intake. F/G = feed to gain ratio. BW = body weight.

Table 10. Effects of feeding 25(OH)D_3 on finishing pig growth performance [1,2]

	Diet [3]				
	1,500 IU D_3	500 IU D_3 and 25 µg 25(OH)D_3	1,500 IU D_3 and 50 µg 25(OH)D_3	SEM	Probability, P <
d 0 to 35					
ADG, lb	2.14	2.13	2.16	0.030	0.802
ADFI, lb	4.77	4.64	4.73	0.076	0.479
F/G	2.23	2.18	2.19	0.021	0.189
d 35 to 67					
ADG, lb	2.30	2.29	2.21	0.040	0.249
ADFI, lb	6.40	6.40	6.29	0.098	0.647
F/G	2.78	2.80	2.84	0.031	0.383
d 67 to 97					
ADG, lb	2.25	2.28	2.28	0.029	0.809
ADFI, lb	6.78	7.06	6.93	0.103	0.171
F/G	3.01	3.10	3.05	0.036	0.215
d 0 to 97					
ADG, lb	2.22	2.23	2.21	0.024	0.894
ADFI, lb	5.90	5.96	5.92	0.079	0.878
F/G	2.66	2.67	2.68	0.021	0.816
BW, lb					
d 0	79.31	78.66	80.66	1.267	0.529
d 35	154.21	157.41	153.89	2.429	0.533
d 67	227.19	227.96	227.03	2.542	0.963
d 97	294.83	296.31	295.30	2.794	0.929

[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and 25(OH)D_3 influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market. A total of 216 weaned pigs were used to continue the nursery growth trial into the finisher with consistent pen integrity of 6 pigs per pen and 12 pens per treatment.

[2]Experimental diets were fed from finisher d 0 to 97 in 3 phases.

[3]Three dietary treatments were fed using vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) to achieve desired vitamin D_3 concentrations for each treatment. Columns are divided into maternal dietary treatments from which the progeny inherited their treatment. Finishing pigs were fed 3 phases of diets with different concentrations of vitamin D_3 and 25(OH)D_3 than the dams.

ADG = average daily gain. ADFI = average daily feed intake. F/G = feed to gain ratio. BW = body weight.

Table 11. Effects of feeding 25(OH)D_3 on HCW [1]

	Diet [2]				
	1,500 IU D_3	500 IU D_3 and 25 µg 25(OH)D_3	1,500 IU D_3 and 50 µg 25(OH)D_3	SEM	Probability, P <
Live weight, lb	295.4	295.4	296.4	3.05	0.967
HCW, lb[3]	223.4	223.0	223.6	2.75	0.987
Dressing %[4]	75.6	75.4	75.4	0.29	0.826

[1]A total of 69 sows (DNA Line 200 × 400) and their progeny over 3 consecutive farrowing groups were used to determine if feeding a combination of vitamin D_3 and 25(OH)D_3 influences neonatal and sow performance and vitamin D_3 status, muscle fiber morphometrics, and subsequent growth performance of the piglets to market. A total of 168 market pigs were used for these calculations out of the 202 pigs that made it to the plant. The remaining pigs either could not be identified or were skinned, causing incorrect recording of HCW.

[2]Three dietary treatments were fed using vitamin D_3 (Rovimix D3-500, DSM Nutrition Products) and/or 25(OH)D_3 (Hy-D Premix 62.5 mg/lb, DSM Nutritional Products) to achieve desired vitamin D_3 concentrations for each treatment.

[3]HCW = hot carcass weight.

[4]Dressing percentage was calculated by taking the HCW divided by the live weight of that animal times 100%.