

Evaluation of Conditioning Temperature and Die Specifications on Nursery Pig Performance

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Summary

The objective of this study was to determine the effects on growth performance in nursery pigs that is linked to the conditioning temperature and die specifications used during the feed pelleting process. A total of 315 barrows (DNA; 200 × 400; initial BW 13.2 lb) were used in a 35-d growth trial. Upon arrival, pigs were weighed and assigned to pens in a completely randomized design with 5 pigs per pen, and each pen was randomly assigned to 1 of 7 dietary treatments with 9 replications per treatment. Treatments consisted of a mash control (MC) and 6 pelleted diets manufactured using 2 different pellet dies (length/diameter [L:D]: 6.7 and 2.7) and 3 different conditioning temperatures (low, medium, high). Conditioning temperatures for Phase 1 diets pelleted using the 6.7 L:D die were 80, 100, and 120°F and for the die with a L:D 2.7 were 100, 120, and 140°F for the low, medium, and high, respectively. Phase 2 conditioning temperatures for diets pelleted using the die with a L:D of 6.7 were approximately 120, 140, and 160°F and for the 2.7 L:D die were 140, 160, and 180°F for the low, medium, and high, respectively. Diets were fed in three phases as follows, Phase 1: d 0 to 10, Phase 2: d 10 to 25, and Phase 3: d 25 to 35. During Phase 3 all pigs were fed a common mash diet. Overall from d 0 to 35, similar ADG was observed for pigs fed the MC or pelleted diets with the exception of the diet pelleted at the low conditioning temperature using the 6.7 L:D die, which had decreased ($P < 0.05$) ADG compared to MC. When pelleting diets using the 2.7 L:D die, there was a tendency for increased (quadratic, $P = 0.077$) ADG in pigs fed diets conditioned at increasing temperatures, with the medium temperature having the greatest ADG. There was a tendency for increased ($P = 0.088$) ADG in pigs fed diets pelleted using the 2.7 L:D die compared to the 6.7 L:D die. Pigs fed pelleted diets, with the exception of the medium temperature on the 2.7 L:D die, had decreased ($P < 0.05$) ADFI compared to the MC. However, diets pelleted using the 6.7 L:D die as well as the diet manufactured at the medium conditioning temperature on the 2.7 L:D die had improved ($P < 0.05$) F/G compared to the MC diet. Additionally, pigs fed diets manufactured using the 6.7 L:D die had decreased ($P = 0.030$) ADFI compared to those fed diets pelleted using the 2.7 L:D die. In summary, pelleted diets showed poorer ADG but decreased ADFI and improved F/G, and no differences in final BW compared to the MC. Additionally, there was a

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numerical decrease in pellet quality when treatments were manufactured on the 2.7 L:D die; however, these differences did not result in a growth performance response due to conditioning temperature or die. Overall increasing conditioning temperature decreased the available lysine, and pigs fed pelleted diets had poorer ADG but decreased ADFI and improved F/G compared to those fed the MC.

Introduction

Pelleting of swine feed is a common industry practice as it typically improves growth performance and feed handling throughout production. During the pelleting process mash feed is exposed to moisture and heat via steam in the conditioner before it is pushed through the die to form pellets. Multiple variables during this process can be changed to influence pellet mill throughput and pellet quality. Conditioning temperature, the amount of time feed is retained in the conditioner and exposed to steam (retention time), and die selection are some factors that can be manipulated during the pelleting process. The die length to diameter (L:D) ratio plays a key role in the quality of pellets produced. A larger L:D ratio indicates a thicker die, allowing for more compression, which correlates with improved pellet quality. In addition to pelleting parameters, individual ingredient specifications can also vary greatly and influence the pelleting process.

It has been widely reported that pelleted feed can improve the feed efficiency of nursery pigs when compared to mash. Nursery pig diets also contain specialty ingredients, such as dried whey, that reduce flowability of the diets. These diets are pelleted to negate the flowability concerns. A variety of factors, such as pellet mill model, die specification, and diet composition can influence the conditioning temperature at which nursery pig diets are pelleted. Traditionally, nursery pig diets are pelleted at lower conditioning temperatures, ranging from approximately 140°F to 160°F, because of the increased levels of specialty proteins included in the diet. Whey products specifically require a lower conditioning temperature as milk-based products tend to absorb more moisture at higher temperatures, which creates a sticky consistency and risks plugging the equipment. Therefore, the objective of this study was to determine the effects of conditioning temperature and die specifications used when pelleting diets on the growth performance of nursery pigs.

Procedures

A total of 315 barrows (DNA 200 × 400; initial BW of 13.2 lb) were used in a 35-d growth trial at the Kansas State University Segregated Early Weaning (SEW) facility. Pigs were housed in 4- × 4-ft pens containing a three-hole dry self-feeder and one cup waterer to provide *ad libitum* access to feed and water. Pigs were weaned at approximately 21 d of age. Upon arrival, pigs were weighed and assigned to pens in a completely randomized design with 5 pigs per pen, and each pen was assigned to 1 of 7 treatments. There were 9 replications per treatment.

Dietary treatments consisted of a basal diet fed as a mash control (MC) or 6 diets pelleted with different pelleting parameters. The mash control diet was mixed at Hubbard Feeds (Beloit, KS) and transferred to Kansas State University, Manhattan, KS, and pelleted using the CL-5 experimental pellet mill (Model CL-5 California Pellet

Mill Co., Crawfordsville, IN). Diets were steam conditioned (5 in diameter × 36 in length) to 3 target conditioning temperatures for approximately 30 s and pelleted using 1 of 2 pellet dies. Both pellet dies had holes that were 3/16 inches in diameter and two different die thicknesses, to create length:diameter (L:D), of 2.7 and 6.7. Phase 1 feed was conditioned to approximately 80 (Low), 100 (Medium), and 120°F (High) using the 6.7 L:D die and 100 (Low), 120 (Medium), and 140°F (High) using 2.7 L:D die. The feeder was set at a constant rate to achieve approximately 120 lb per hour. Phase 2 feed was conditioned to approximately 120 (Low), 140 (Medium), and 160°F (High) using the 6.7 L:D die and 140 (Low), 160 (Medium), and 180°F (High) using the 2.7 L:D die. The feeder was set at a constant rate to achieve approximately 240 lb per hour for Phase 2. Pellets were then cooled in an experimental cooler for 15 minutes. After pelleting, pellets were sifted to remove fines to mitigate effects of pellet quality on pig performance. Pellet samples were taken at the die as well as after cooling and analyzed for pellet quality using a Holmen NHP100 (TekPro Ltd, Norfolk, UK) for 60 seconds. The basal diet formulation was a standard nursery diet that was formulated to meet or exceed the recommended nutrient requirement estimates for nursery pigs.² Diets were fed in three phases (Phase 1: d 0 to 10; Phase 2: d 10 to 25; Phase 3: d 25 to 35).

Pens of pigs were weighed, and feed disappearance calculated on d 0, 10, 17, 25, and 35 of the experiment to determine average daily gain (ADG), average daily feed intake (ADFI), and feed/gain ratio (F/G). Feed additions were recorded for each individual pen. Feed samples were taken from the feeders and appropriately stored until proximate analysis was performed (Ward Laboratories, Kearney, NE). Total and available lysine analysis was performed using official analytical methods at the Agricultural Experiment Station Chemical Laboratories at the University of Missouri.

Data were analyzed using the PROC-GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, NC) with pen serving as the experimental unit. Analysis was performed using Dunnett's multiple comparison test to compare each pelleted diet to the MC. Contrasts were used to separate treatment means with comparison of die (6.7 vs. 2.7), and linear and quadratic polynomials were used to test increasing conditioning temperature within each die. Results were considered significant at $P \leq 0.05$, and marginally significant at $P \leq 0.10$.

Results and Discussion

All treatment diets were analyzed for crude protein, fiber, fat, phytase content, as well as total and available lysine. Phase 1 diets pelleted using the 6.7 L:D die had an approximately 10% decrease in available lysine as conditioning temperature increased. Diets pelleted using the 2.7 L:D die had an even larger 25% decrease in the available lysine of Phase 1 diets as conditioning temperature increased. A similar trend was seen in Phase 2 diets pelleted using the 2.7 L:D die, where available lysine decreased by 15% as conditioning temperature increased. However, Phase 2 diets pelleted with the 6.7 L:D die had similar available lysine at all of the conditioning temperatures evaluated in this experiment. The increasingly harsh conditions with increased conditioning temperature and frictional heat across the die may have caused the reduction in available lysine.

² NRC, 2012. Nutrient Requirement for Swine, 11th rev. ed. National Academy Press, Washington, DC.

Conditioning and hot pellet temperatures were recorded periodically throughout each pelleting run and the difference (ΔT) was calculated. Conditioning temperatures averaged within 5°F of the target and the ΔT decreased as conditioning temperature increased. This is an expected result as frictional heat will decrease when conditioning temperature increases, as steam provides moisture and therefore lubrication while feed passes through the die. All pelleted diets were evaluated for pellet quality using a Holmen 100 for 60 seconds. There was approximately a 10% decrease in pellet durability index (PDI) of the Phase 1 diet when pelleted with the 2.7 L:D die compared the 6.7 L:D die, but no large differences in PDI were observed when comparing conditioning temperatures. However, the Phase 2 diet pelleted at the low or medium conditioning temperature on the 2.7 L:D die was analyzed to have a PDI value approximately 30% poorer than all other pelleted treatments.

From d 0 to 10 there were no differences in ADG, ADFI, or F/G for each pelleted treatment compared to the mash control diet. When diets were pelleted using the 6.7 L:D die, pigs fed diets conditioned at the medium temperature (100°F) tended to have increased (quadratic, $P = 0.077$) ADFI compared to the low and high temperatures. There was no difference in d 10 BW for any treatment.

From d 10 to 25, pigs fed the MC had increased ($P < 0.05$) ADG compared to those fed the diets pelleted using the low and medium conditioning temperatures on the 6.7 L:D die. Pigs fed all other pelleted diets had ADG similar to those fed the MC. When pelleting using the 6.7 L:D die, there was a tendency for a linear increase ($P = 0.098$) in ADG in pigs fed diets pelleted with increasing conditioning temperature. Pigs fed the MC or the diet pelleted at the medium conditioning temperature on the 2.7 L:D die had similar ADFI as those fed the MC, while pigs fed all other pelleted diets had decreased ($P = 0.001$) ADFI during this phase. Furthermore, pigs fed diets pelleted on the 6.7 L:D die had decreased ($P = 0.026$) ADFI compared to the 2.7 L:D die. There were no differences in F/G or d 25 BW during this period.

From d 25 to 35 all treatments were fed a common mash diet. There were no differences in ADG, ADFI, or F/G between pigs previously fed the MC and each pelleted diet. However, there was a tendency for increased ($P = 0.083$) ADG in pigs previously fed diets pelleted on the 2.7 L:D die compared to the 6.7 L:D die. Pigs fed diets pelleted using the die with a L:D of 2.7 also had increased ($P = 0.039$) ADFI compared to pigs fed diets manufactured with the L:D 6.7 die.

From d 0 to 25 there was no difference observed in ADG when comparing each pelleted treatment to the MC. Pigs fed diets pelleted on the 6.7 L:D die at any of the conditioning temperatures, and diets pelleted using the 2.7 L:D at the low and high conditioning temperatures had decreased ($P < 0.05$) ADFI during this phase, compared to those fed the MC and the medium conditioning temperature on the 2.7 L:D die. Pigs fed all pelleted diets manufactured on the 6.7 L:D die as well as the medium conditioning temperature on the 2.7 L:D die showed improved ($P < 0.05$) F/G compared to the MC and diets pelleted on the 2.7 L:D die at the low and high conditioning temperatures. There were no differences between pigs fed diets pelleted using the different dies.

Overall from d 0 to 35, pigs fed the MC had increased ($P < 0.05$) ADG compared to diet manufactured using the 6.7 L:D die at the low conditioning temperature with all other pelleted treatments performing similarly to the MC. When pelleting diets using the 2.7 L:D die, there was a tendency for increased (quadratic, $P = 0.077$) ADG in pigs fed diets conditioned at increasing temperatures, with the medium temperature having the greatest ADG. There was a tendency for increased ($P = 0.088$) ADG in pigs fed diets pelleted using the 2.7 L:D die compared to the 6.7 L:D die. Pigs fed diets pelleted on the 6.7 L:D die and diets pelleted using the 2.7 L:D at the low and high conditioning temperatures had decreased ($P < 0.05$) ADFI during this phase compared to the MC. Pigs fed pelleted diets using the 6.7 L:D die at any conditioning temperature or the 2.7 L:D die at the medium conditioning temperature had improved ($P < 0.05$) F/G compared to the MC diet. Additionally, pigs fed diets manufactured using the 6.7 L:D die had decreased ($P = 0.030$) ADFI compared to those fed diets pelleted using the 2.7 L:D die. There was a tendency for increased ($P = 0.088$) d 35 BW in pigs fed diets pelleted using the 2.7 L:D die compared to the 6.7 L:D die.

In the experiment reported herein, numerical decreases in available lysine were observed as conditioning temperature increased on both the 6.7 and 2.7 L:D dies. In addition, there was a decrease in pellet quality when treatments were manufactured on the 2.7 L:D die; however, pellet quality improved as conditioning temperature increased. These differences did not result in a growth performance response due to conditioning temperature or die. Furthermore, pigs fed pelleted diets had poorer ADG but decreased ADFI and improved F/G compared to those fed the MC. Overall, increasing the conditioning temperature decreased the available lysine, and pigs fed pelleted diets had poorer ADG but decreased ADFI and improved F/G compared to those fed the MC.

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Table 1. Diet composition (as-fed basis) ^{1,2,3}

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	38.81	56.91	65.47
Whey, spray dried	25.00	10.00	---
Soybean meal	17.65	25.95	28.30
DDGS	5.00	---	---
Fish meal, menhaden	4.50	2.50	---
Fat	3.00	1.00	2.00
Enzymatically treated soybean meal	2.50	---	---
MHA methionine	0.24	0.23	0.25
L-Threonine	0.18	0.21	0.23
L-Lysine	0.48	0.48	0.55
L-Valine	0.10	0.15	0.16
L-Tryptophan	0.05	0.04	0.05
Monocalcium P, 21%	0.40	0.60	1.10
Limestone	0.50	0.75	0.75
Sodium chloride	0.30	0.50	0.60
Vitamin premix	0.25	0.25	0.25
Trace mineral premix	0.15	0.15	0.15
Zinc oxide	0.39	0.25	---
Choline chloride	0.04	---	---
Sodium metabisulfite	0.25	---	---
Alltech Viligen	0.15	---	---
Vitamin E 20,000 IU/lb	0.05	---	---
Vitamin A:D 10:1	0.01	---	---
Phytase ⁶	0.02	0.03	---
Total	100	100	100

continued

Table 1. Diet composition (as-fed basis) ^{1,2,3}

Ingredient, %	Phase 1	Phase 2	Phase 3
Calculated analysis			
Standard ileal digestible (SID) AA, %			
Lysine	1.38	1.35	1.35
Isoleucine:lysine	56	54	60
Leucine:lysine	108	109	106
Methionine:lysine	37	37	37
Methionine and cysteine:lysine	58	56	54
Threonine:lysine	64	63	60
Tryptophan:lysine	18.4	18.9	18.0
Valine:lysine	68	70	67
Histidine:lysine	30	34	32
Total lysine, %	1.55	1.50	1.41
ME, kcal/lb	1,507	1,527	1,508
NE, kcal/lb	1,084	1,118	1,197
SID Lys:NE, g/Mcal	5.77	5.37	5.12
CP, %	19.5	20.9	19.0
Ca, %	0.70	0.75	0.80
P, %	0.60	0.60	0.50
Available P, %	0.47	0.47	0.32

¹Experimental diets were fed in 3 phases from d 0 to 10, 10 to 25, and 25 to 35. A common diet was fed from d 25 to 35.

²All treatment diets were mixed at Hubbard Feeds (Beloit, KS) and transported to be pelleted using the CL-5 experimental pellet mill at Kansas State University.

³AA = Amino acids. ME = metabolizable energy. NE = net energy.

⁴During Phase 1, Quantum Blue (AB Vista, Plantation, FL) was used as the phytase source supplying 333 FTU/g. Aextra PHY 2500 TPT (Dupont, Wilmington, DE) was used as the phytase source for Phase 2, supplying 434 FTU/g.

Table 2. Chemical analysis of experimental diets (as-fed basis)^{1,2}

Conditioning temperature ⁴ :	Pellet die ³ : MC ⁵	6.7			2.7		
		Low	Med	High	Low	Med	High
Phase 1							
Moisture, %	8.24	9.5	10.38	11.01	9.44	10.8	11.14
Crude protein, %	17.2	19.2	17.8	18.9	18.8	19.2	17.1
Crude fiber, %	2.2	1.9	1.7	1.7	2.0	2.2	1.9
Ether extract, %	5.5	5.9	5.4	5.1	6.0	6.2	5.1
Total lysine, %	1.42	1.40	1.32	1.32	1.47	1.33	1.25
Available lysine, % ⁶	1.18	1.37	1.29	1.26	1.44	1.30	1.21
Lysine:crude protein, %	7.20	7.29	7.41	6.98	7.81	6.92	7.30
Phase 2							
Moisture, %	10.45	10.93	11.48	11.51	11.56	11.66	12.06
Crude protein, %	18.3	19.5	20.0	19.5	20.3	19.2	18.1
Crude fiber, %	1.9	1.8	2.0	1.9	1.7	2.0	1.9
Ether extract, %	3.7	3.6	3.7	3.8	3.5	4.1	4.0
Total lysine, %	1.51	1.40	1.43	1.46	1.52	1.45	1.38
Available lysine, % ⁶	1.47	1.36	1.40	1.40	1.49	1.42	1.35
Lysine:crude protein, %	8.25	7.17	7.15	7.48	7.48	7.55	7.62

¹Moisture, crude protein, crude fiber, and fat analysis was performed by Ward Laboratories, Inc. (Kearney, NE) on pooled diet samples collected from the feeders.

²Experimental diets were fed in 3 phases from d 0 to 10, d 10 to 25, and d 25 to 35.

³Diets pelleted at Kansas State University were manufactured using a model CL-5 experimental on two pellet dies with a pellet diameter of 4.7 mm with and length:diameter ratio of either 6.7 or 2.7.

⁴Conditioning temperatures for Phase 1 on the 6.7 L:D die were approximately 80, 100, and 120°F and 100, 120, and 140°C for the 2.7 L:D die for the low, medium, and high, respectively. Phase 2 conditioning temperatures for the 6.7 L:D die were approximately 120, 140, and 160°F and for the 2.7 L:D die were 140, 160, and 180°F for the low, med, and high respectively.

⁵MC = Mash control.

⁶Total and available lysine analysis was performed using official analytical methods at the University of Missouri Agricultural Experiment Station Chemical Laboratories, according to AOAC Official Method 975.44, chp. 45.4.03, 2006.

Table 3. Effect of pellet die and conditioning temperature on feed processing^{1,2}

Conditioning temperature ⁴ :	Pellet die ³ : MC ⁵	6.7			2.7		
		Low	Med	High	Low	Med	High
Phase 1							
Production rate, lb/min	---	2.15	2.26	2.37	2.12	2.12	2.02
Conditioning temp., °F	---	80.5	100.8	120.4	102.8	122.8	140.5
Hot pellet temp., °F	---	118.2	137.7	150.7	135.8	146.3	148.3
Δ T, °F ⁵	---	37.7	36.9	30.3	33.0	23.5	7.8
Pellet durability index, ¹ % ⁶	---	95.5	94.5	94.3	84.7	82.5	83.6
Phase 2							
Production rate, lb/min	---	3.94	4.27	3.62	3.66	3.92	4.15
Conditioning temp., °F	---	121.4	140.5	162.0	141.4	161.5	176.0
Hot pellet temp., °F	---	150.8	161.8	174.7	154.5	164.9	178.7
Δ T, °F	---	29.4	21.3	12.7	13.1	3.4	2.7
Pellet durability index, %	---	86.7	89.0	92.2	66.9	61.5	82.4

¹All diets were mixed at Hubbard Feeds (Beloit, KS) and transported to Kansas State University for further processing.

²Diets pelleted at K-State were manufactured on two pellet dies with a pellet diameter of 3/16 in with an L:D ratio of either 6.7 or 2.7 and sifted to control for differences in pellet quality.

³Conditioning temperatures for Phase 1 on the 6.7 L:D die were approximately 80, 100, and 120°F and 100, 120, and 140°F for the 2.7 L:D die for the low, med, and high respectively. Phase 2 conditioning temperatures for the 6.7 L:D die were approximately 120, 140, and 160°F and for the 2.7 L:D die were 140, 160, and 180°F for the low, medium, and high respectively.

⁴MC = Mash control.

⁵Δ T = Hot pellet temperature - conditioning temperature.

⁶Pellet durability analysis was performed using a Holmen 100 for 60 s for all pelleted samples.

Table 4. Effect of conditioning temperature and die specifications on nursery pig performance^{1,2,3}

Cond temp. ^{5:}	Die ^{4:} MC ⁶										Probability, $P <^{7,8}$				
		6.7			2.7			SEM	Dunnett's	6.7		2.7		6.7 vs. 2.7	
		Low	Med	High	Low	Med	High			Linear	Quadratic	Linear	Quadratic		
BW, lb															
d 0	13.1	13.1	13.2	13.2	13.2	13.2	13.2	13.2	0.25	0.997	0.828	0.817	0.877	0.810	0.700
d 10	16.4	16.3	16.8	16.2	16.4	16.8	16.2	0.39	0.731	0.778	0.180	0.693	0.230	0.955	
d 25	31.7	29.8	30.5	30.5	30.5	31.3	30.5	0.77	0.419	0.453	0.646	0.921	0.283	0.298	
d 35	43.5	40.7	41.6	41.5	42.3	43.2	41.7	0.98	0.183	0.531	0.579	0.629	0.216	0.088	
d 0 to 10															
ADG, lb	0.32	0.32	0.36	0.30	0.32	0.35	0.30	0.03	0.654	0.672	0.155	0.601	0.209	0.907	
ADFI, lb	0.39	0.32	0.38	0.32	0.34	0.35	0.32	0.02	0.249	0.933	0.077	0.475	0.429	0.997	
F/G	1.21	1.04	1.05	1.07	1.12	1.02	1.09	0.05	0.176	0.677	0.916	0.609	0.180	0.547	
d 10 to 25															
ADG, lb	1.01	0.88*	0.89*	0.95	0.92	0.96	0.95	0.03	0.021	0.098	0.553	0.435	0.327	0.128	
ADFI, lb	1.38	1.15*	1.16*	1.21*	1.21*	1.26	1.23*	0.04	0.001	0.211	0.353	0.334	0.308	0.026	
F/G	1.35	1.30	1.29	1.27	1.31	1.30	1.30	0.02	0.405	0.356	0.860	0.655	0.978	0.460	
d 25 to 35 ⁸															
ADG, lb	1.18	1.09	1.11	1.09	1.17	1.19	1.12	0.04	0.458	0.913	0.697	0.445	0.423	0.083	
ADFI, lb	1.82	1.62	1.71	1.68	1.75	1.79	1.74	0.05	0.121	0.394	0.358	0.922	0.477	0.039	
F/G	1.54	1.49	1.55	1.54	1.49	1.51	1.56	0.03	0.654	0.314	0.474	0.161	0.588	0.838	
d 0 to 25															
ADG, lb	0.74	0.66	0.68	0.69	0.66	0.72	0.69	0.02	0.169	0.329	0.846	0.514	0.131	0.384	
ADFI, lb	0.98	0.81*	0.84*	0.85*	0.85*	0.90	0.86*	0.03	0.001	0.304	0.805	0.636	0.196	0.126	
F/G	1.33	1.24*	1.24*	1.23*	1.27	1.25*	1.25	0.01	0.020	0.927	0.901	0.624	0.537	0.219	
d 0 to 35															
ADG, lb	0.86	0.78*	0.80	0.80	0.80	0.85	0.81	0.02	0.049	0.362	0.726	0.827	0.077	0.088	
ADFI, lb	1.22	1.04*	1.09*	1.09*	1.10*	1.15	1.11*	0.02	0.001	0.201	0.517	0.627	0.153	0.030	
F/G	1.41	1.33*	1.35*	1.35*	1.36	1.35*	1.37	0.01	0.019	0.439	0.496	0.476	0.311	0.273	

¹ A total of 360 barrows (DNA 200 × 400) with initial body weight (BW) of 13.2 lb, were used in a 35-d growth trial at the Kansas State University Segregated Early Weaning Facility.

² All diets were mixed at Hubbard Feeds (Beloit, KS) and transported to K-State for further processing.

³ Diets were fed as follows, Phase 1 from d 0 to 10, Phase 2 from d 10 to 25, and a common mash diet was fed to all test pigs from d 25 until the end of the study on d 35.

⁴ Pelleted diets were manufactured on two pellet dies with a pellet diameter of 3/16 in with an L:D ratio of either 6.7 or 2.7.

⁵ Conditioning temperatures for Phase 1 on the 6.7 L:D die were approximately 80, 100, and 120°F and 100, 120, and 140°F for the 2.7 L:D die for the low, medium, and high, respectively. Phase 2 conditioning temperatures for the 6.7 L:D die were approximately 120, 140, and 160°F and for the 2.7 L:D die were 140, 160, and 180°F for the low, medium, and high, respectively.

⁶ MC = Mash control

⁷ Analysis was performed using Dunnett's multiple comparison for all parameters and contrasts were used to separate treatment means with comparison of die (6.7 vs. 2.7) and temperature within die.

⁸ The * denotes a $P < 0.05$ significant difference from the MC diet.

SEM = standard error of the mean. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed efficiency.