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Evaluation of Extreme Thermal Processing Methods to Improve Nutrient Utilization of Low-Energy Diets for Finishing Pigs

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Abstract

A total of 270 pigs (PIC 337 × 1050; initially 115.7 lb) were used in a 79-d experiment to determine the effects of long-term conditioning or extrusion on finishing pig nutrient digestibility, growth performance, and carcass characteristics. There were 7 or 8 pigs per pen and 9 pens per treatment. Treatments included the same basal diet processed as: 1) nonprocessed mash; 2) pelleted with 45-s conditioner retention time; 3) pelleted with 90-s conditioner retention time; or 4) extruded. Diets were fed in three phases with the same low-energy diet formulation fed across treatments, containing 30% corn dried distillers grains with solubles and 19% wheat middlings. Pigs fed thermally processed feed, regardless of method, had improved ADG, F/G, ether extract, and crude fiber apparent total tract digestibility ($P < 0.05$) compared to those fed the mash diet, but thermal processing did not affect ADFI . Extruded diets tended to improve F/G compared to pelleted diets ($P = 0.09$). Pigs fed any thermally processed treatment had greater HCW compared to those fed mash ($P < 0.05$). Improvements in fat and crude fiber digestibility ($P < 0.05$) led to improved caloric efficiency in pigs fed thermally processed diets. Thermal processing did not influence percentage yield, backfat, or loin depth when HCW was used as a covariate. However, pigs fed thermally processed diets had greater jowl fat iodine value compared to those fed mash diets ($P < 0.05$). Electrical energy usage during thermal processing was recorded. Pigs fed mash diets had greater ($P < 0.05$) cost per lb of gain, as well as reduced gain value and income over feed costs, compared to those fed thermally processed diets. This experiment confirms the benefits of thermally processing feeds to improve ADG and F/G, but compromises carcass fat iodine value. Additionally, this research suggests that more extreme thermal processing conditions may be used without hindering nutrient utilization.

Keywords

carcass fat quality, extrude, pellet, performance, pig

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Evaluation of Extreme Thermal Processing Methods to Improve Nutrient Utilization of Low-Energy Diets for Finishing Pigs[1,2]

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Summary

A total of 270 pigs (PIC 337 × 1050; initially 115.7 lb) were used in a 79-d experiment to determine the effects of long-term conditioning or extrusion on finishing pig nutrient digestibility, growth performance, and carcass characteristics. There were 7 or 8 pigs per pen and 9 pens per treatment. Treatments included the same basal diet processed as: 1) nonprocessed mash; 2) pelleted with 45-s conditioner retention time; 3) pelleted with 90-s conditioner retention time; or 4) extruded. Diets were fed in three phases with the same low-energy diet formulation fed across treatments, containing 30% corn dried distillers grains with solubles and 19% wheat middlings. Pigs fed thermally processed feed, regardless of method, had improved ADG, F/G, ether extract, and crude fiber apparent total tract digestibility ($P < 0.05$) compared to those fed the mash diet, but thermal processing did not affect ADFI . Extruded diets tended to improve F/G compared to pelleted diets ($P = 0.09$). Pigs fed any thermally processed treatment had greater HCW compared to those fed mash ($P < 0.05$). Improvements in fat and crude fiber digestibility ($P < 0.05$) led to improved caloric efficiency in pigs fed thermally processed diets. Thermal processing did not influence percentage yield, backfat, or loin depth when HCW was used as a covariate. However, pigs fed thermally processed diets had greater jowl fat iodine value compared to those fed mash diets ($P < 0.05$). Electrical energy usage during thermal processing was recorded. Pigs fed mash diets had greater ($P < 0.05$) cost per lb of gain, as well as reduced gain value and income over feed costs, compared to those fed thermally processed diets. This experiment confirms the benefits of thermally processing feeds to improve ADG and F/G, but compromises carcass fat iodine value. Additionally, this research suggests that more extreme thermal processing conditions may be used without hindering nutrient utilization.

Key words: carcass fat quality, extrude, pellet, performance, pig

Introduction

High-fiber byproduct ingredients often price into least-cost formulas. However, their inclusion may have negative consequences, including increased nutrient variability, and

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decreased growth performance, carcass yield, and fat quality.[2,3] In addition, the physical characteristics of these ingredients often create handling challenges because they have decreased bulk density compared to the original grain or oilseed. It is often difficult to produce a high quality pellet due to the increased fracture points and poor starch gelatinization potential because of their high fiber content.

Still, if thermal processing parameters are manipulated so a high-quality pellet is produced, advantages in diet quality may be captured. Increasing conditioning time during the pelleting process improves pellet quality and increases the diet's propensity for starch gelatinization and susceptibility to enzymatic hydrolysis.[4] While extended processing is beneficial for some nutrients, others may be negatively affected. Furthermore, pelleting is already an energetically expensive process that reduces feed mill throughput, and harsher processing conditions exacerbate these disadvantages.[5] It is important to evaluate the effects of pelleting diets that include low-energy byproducts to calculate the cost:benefit ratio of these harsh thermal processing methods in pork production. The objective of this experiment was to assess how long-term conditioning or extrusion of low-energy diets impacts nutrient digestibility, growth performance, and carcass characteristics in finishing pigs.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used for this experiment. The experiment was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan.

Diet Manufacturing

Four treatments were manufactured for this experiment by varying the same diet with different thermal processing methods: 1) nonprocessed mash, 2) pelleted with 45-s conditioner retention time, 3) pelleted with 90-s conditioner retention time, and 4) extruded. The 45-s conditioner retention time would be typical of what is used in commercial pellet diet production. Diets were fed in 3 phases with the same low-energy diet formulation fed across treatments with 30% corn dried distillers grains with solubles and 19% wheat middlings (Table 1). The basal diets, as well as treatments 1, 2, and 3, were manufactured at the Kansas State University O. H. Kruse Feed Technology Innovation Center in Manhattan. Treatments 2 and 3 were conditioned at 180°F and pelleted using a pellet mill (California Pellet Mill Model #3016-4, Crawfordsville, IN) fit with a 0.17 × 1.13-in. die. The conditioner motor speed was decreased to manufacture treatment 3 with a longer conditioning time to mimic the time of a double-pass

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[2] Stein, H. H., and G. C. Shurson. 2009. Board invited review: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87(4): 1292-1303.

[3] Coble, K. F. 2015. Influence of dietary fiber and copper on growth performance and carcass characteristics of finishing pigs and utilizing linear programming to determine pig flow. PhD Diss. Kansas State University.

[4] Lundblad, K. K., S. Issa, J. D. Hancock, K. C. Behnke, L. J. McKinney, S. Alavi, E. Preslokken, J. F. Fledderus, and M. Sorensen. 2011. Effects of steam conditioning at low and high temperature, expander conditioning and extruder processing prior to pelleting on growth performance and nutrient digestibility in nursery pigs and broiler chickens. Anim. Feed Sci. Technol. 169(3): 208-217.

[5] Fahrenholz, A. C. 2012. Evaluating factors affecting pellet durability and energy consumption in a pilot feed mill and comparing methods for evaluating pellet durability. PhD Diss. Kansas State Univ., Manhattan.

conditioner. Meanwhile, the basal diet was transported to Wenger Manufacturing, Inc. in Sabetha, KS, where treatment 4 was manufactured using a Universal Pellet Cooker (Model UP/C, Wenger Manufacturing, Sabetha, KS) with 338°F preconditioning temperature. Pellet durability was determined according to the standard and modified ASAE Standard S269.4 where five ½-in. hex nuts were added to the each tumbling compartment (Table 2).

Growth Experiment

A total of 270 finisher pigs (PIC 337 × 1050; initially 115.7 lb) were used in this 79-d experiment. There were 7 to 8 pigs per pen and 9 pens per treatment. All pens contained 1 waterer and self-feeder allowing ad libitum access to feed and water. On d 0, pens were weighed and randomly assigned 1 of the 4 dietary treatments. Pen weights and feed disappearance were collected on d 0, 25, 46, 60, and 79 to calculate the ADG, ADFI, and F/G. Phase 3 diets (60 to 79 d) included 0.4% titanium dioxide, and fecal samples were collected between d 66 and 68 from 3 pigs or more and combined to make 1 composite sample per pen. Prior to slaughter, pigs were individually tattooed for identification purposes at the packing plant. Individual pig weights were collected at the farm before slaughter on d 79. Pigs were slaughtered and carcass data collected in a single run at Triumph Foods in St. Joseph, MO. Hot carcass weights were measured immediately after evisceration and each carcass evaluated for carcass yield, backfat depth, loin depth, and jowl iodine value. Carcass yield was calculated by dividing the HCW at the packing plant by the live weight at the farm. Fat depth and loin depth were measured by optical probe insertion between the third and fourth rib from the proximal end. Jowl fat samples were analyzed by near infrared spectroscopy (Bruker MPA, Breman, Germany) for iodine value.

Nutrient Digestibility Analysis

All feed and fecal samples were analyzed for proximate analysis, NDF, ADF, cellulose, beta-glucan, fatty acid profile, amino acid composition, and available Lys at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Colombia. Digestibility coefficients were calculated according to Stein et al. (2006).[6]

Statistical Analysis

Data were analyzed as a completely randomized design using the GLIMMIX procedure in SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Hot carcass weight was used as a covariate for backfat and loin depth. Results were considered significant if $P < 0.05$, and a trend if $0.05 < P < 0.10$. Orthogonal contrasts were used to evaluate differences between pelleted vs. extruded diets, pelleted vs. control diets, 45-s pellet vs. 90-s pellet, and thermally processed vs. control diets.

Results and Discussion

Diet Manufacturing

Post-mixing production rate varied widely among treatments due to differences in equipment (Table 2). Both pelleted diets were manufactured using the same model pellet mill with a variable frequency drive to control conditioner speed. The extruded

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[6] Stein, H. H., M. L. Gibson, C. Pedersen, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs. J. Anim. Sci. 84(4): 853-860.

diet was manufactured at a lower production rate, but was more stable throughout the phases and was held at a constant 2,650 lb/h. The electrical energy consumption of the thermal processing equipment was as predicted, with the pelleted diets having lower energy usage than extruded diets, and 45-s conditioning time having less energy usage than the 90-s conditioning time for pelleted diets. The differences in equipment also influenced pellet durability index (PDI). The longer conditioning time in the pelleted diets improved standard and modified PDI, by 1.6 and 5.2%, respectively. The extruded treatment had substantially higher PDI than either pelleted treatment. This is likely due to greater starch gelatinization in the extruded diet due to the higher moisture and heat.

While many nutrients are consistent with formulated values, differences existed between treatments (Table 3). Notably, the pelleted diets conditioned for 90-s had the greatest DM. It is likely that the reduction in production rate for the 90-s pellets resulted in longer time spent in the cooler, where more water was pulled off the pellets. In addition, mash diets had greater ADF concentrations and much greater NDF concentrations than the thermally processed diets. Potentially, more of the fibrous particles from wheat middlings or distillers dried grains with solubles were part of the fines separated from the complete pelleted diet because they have a low propensity for starch gelatinization and pelleting and were not used in the pelleted diets analysis. The extruded diet had the lowest crude fiber concentration in phases 1 and 2, but was intermediate in phase 3. Both cellulose and beta-glucan concentrations were greatest in the extruded diet in phase 3, but were intermediate in phases 1 and 2. Future research should include evaluating the nutritional composition of fines compared to pelleted diets, which may explain some of the differences in nutrient concentration between the mash and thermally processed feeds.

In addition to crude nutrients, the role of feed processing on both fatty acid and amino acid composition was evaluated (Table 4). The majority of fatty acids in the diet were linoleic, oleic, palmitic, and linolenic acids. Based on our findings, feed processing method did not appear to alter fatty acid concentrations within the diet. Amino acids also did not seem altered by dietary treatment, but lysine availability, as measured by chemical analysis, was slightly decreased with increasingly harsh thermal processing conditions compared to mash. Thermal processing is known to alter protein availability, and particularly Lys reactivity. Reactive lysine values were greatest in mash diets and lowest in extruded diets in all but the last phase. It is logical that extruded diets would have the least reactive Lys due to the formation of Maillard reactions. Maillard reactions brought on during conditioning or preconditioning irreversibly bind the free ε-NH_2 group of Lys and other amino acids to a reducing sugar. Only Lys that retains its reactivity, and thus has not undergone this binding chemical process, is bioavailable to the animal but is still present in nutrient analyses for total Lys.

Growth Performance

Feed processing method had a large impact on finishing pig growth performance overall, but particularly during the early stages of the study (Table 5). There were no differences between pelleted diets, but diet form affected ADG and F/G from d 0 to 25, 25 to 46, and overall, where thermally processed diets improved growth performance compared to mash diets ($P < 0.05$). Interestingly, ADFI was impaired when pigs were fed extruded diets from d 0 to 25 ($P < 0.05$), but was not affected after the initial phase.

As described above, the PDI of the extruded diets was substantially greater than that of the pelleted diets in all phases. This feed hardness may have contributed to the poor ADFI of pigs during the first phase, but then they became acclimated to the physical characteristics of the diet and intake was no longer affected.

Overall, thermal processing improved pig ADG by 3.1 to 5.9% and F/G by 5.6 to 8.1% without affecting overall ADFI. Ultimately, these growth performance improvements resulted in pigs that were 6.8 to 11.5 lb heavier at market compared to those fed mash diets, with the greatest weight increase coming from those fed pelleted diets that had been conditioned for 90-s. Thermal processing had a substantial impact on pig growth performance, but there was little differentiation among the thermal processing methods themselves.

Nutrient Digestibility and Carcass Quality

While some of the differences in growth performance may be attributed to changing physical diet form, broad differences in nutrient digestibility due to differences in feed manufacturing method suggest the bulk of differences are due to digestibility (Table 6). Pigs fed pelleted diets conditioned for 90-s had the greatest CP, and NDF digestibility ($P < 0.05$) compared to all other treatments, and the extruded diet had the lowest ($P < 0.05$) ash digestibility. Additionally, pigs fed thermally processed diets had improved ether extract, crude fiber, and cellulose digestibility compared to those fed mash diets ($P < 0.05$). Alterations in nutrient digestibility led to improved caloric efficiency in pigs fed thermally processed diets compared to those fed mash diets.

Feed processing method did not affect percentage carcass yield or backfat depth but tended ($P = 0.08$) to increase loin depth compared to pigs fed the mash diets. While the quantity of pork fat did not change significantly, the composition of fat was altered. Jowl fat iodine value was increased ($P < 0.05$) when pigs were fed diets that were thermally processed. While the 2 points in iodine value shift is important, it is not necessarily dramatic. Still the mode of action driving this shift is unknown. Potentially, thermal processing increases the digestibility of dietary lipids, which are predominantly from grain and therefore relatively unsaturated in nature. Therefore, we can link the effects of thermal processing on carcass iodine value with dietary fatty acid concentrations. Since more dietary lipids are available for deposition, pigs potentially have reduced de novo fatty acid synthesis. The fatty acids created during de novo fatty acid synthesis are highly saturated to maximize energetic efficiency. Thus, thermally processing diets likely shifts fat deposition from saturated de novo products to more unsaturated dietary lipids. This makes the interaction with thermal processing and ingredient inclusion an important factor in carcass fat quality. The diets used in this study were high in fiber compared to diets with low byproduct inclusion levels. Still, the relationship between thermal processing, fatty acid digestibility, and the degree of unsaturation in carcass fat deposition is important to continue to evaluate.

In summary, thermal processing, regardless of type, improved overall ADG and F/G, but not ADFI in finishing pigs. Pigs fed any thermally processed treatment had greater jowl fat iodine value compared to those fed the mash diet. This experiment again confirms the benefits of thermally processing feeds to improve ADG and F/G, but neither extended conditioning nor extrusion extracted additional nutrients from low-energy feedstuffs compared to traditional pelleting.

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	37.14	40.35	42.59
Soybean meal, 46.5% CP	11.60	8.55	6.05
Corn distillers dried grains with solubles	30.00	30.00	30.00
Wheat middlings	19.00	19.00	19.00
Monocalcium P, 21% P	0.00	0.00	0.00
Limestone	1.30	1.20	1.20
Salt	0.35	0.35	0.35
L-lysine HCL	0.29	0.27	0.23
Trace mineral premix	0.15	0.13	0.08
Vitamin premix	0.15	0.13	0.08
Phytase[2]	0.02	0.02	0.02
Titanium dioxide[3]	0.00	0.00	0.40
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lys	0.86	0.77	0.68
Ile:lys	73	75	78
Leu:lys	192	206	224
Met:lys	35	38	41
Met & cys:lys	67	71	77
Thr:lys	64	66	69
Trp:lys	18.5	18.5	18.9
Val:lys	89	93	99
SID lys:ME, g/Mcal	2.66	2.37	2.10
ME, kcal/lb	1,468	1,473	1,466
Total lys, %	1.05	0.96	0.86
CP, %	20.1	18.9	17.8
Ca, %	0.58	0.53	0.52
P, %	0.55	0.53	0.52
Available P, %	0.35	0.34	0.34

[1] A single diet formulation for each of three phases of a 79-d finishing pig experiment was manufactured and then processed according to different parameters to create four dietary treatments.

[2] HiPhos 2700 (DSM Nutritional Products, Inc., Parsippany, NJ), provided an estimated release of 0.10% available P.

[3] Used as an indigestible marker for calculating digestibility of nutrients.

Table 2. Physical analysis of diets, (as-fed basis)[1]

	Phase 1				Phase 2				Phase 3			
Item	Mash	45-s pellet	90-s pellet	Extrude	Mash	45-s pellet	90-s pellet	Extrude	Mash	45-s pellet	90-s pellet	Extrude
Production rate, lb/h	---	4,398	2,945	2,645	---	4,784	2,987	2,645	---	14,255	7,500	2,645
Electrical, kilowatt/h	---	14.13	18.9	26.5	---	9.78	17.3	26.0	---	9.2	16.8	24.5
Durability index[2]												
Standard	---	91.9	93.6	99.8	---	87.7	92.9	99.1	---	91.0	92.6	99.0
Modified	---	84.6	87.3	99.3	---	80.9	85.6	98.0	---	82.2	86.2	97.8

[1] A single diet formulation for each of three phases of a 79-d finishing pig experiment was manufactured and then processed according to different parameters to create four dietary treatments.

[2] Determined according to ASAE S269.4, 2003 with a modification to include five hex nuts in the tumbling chamber.

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

	Phase 1				Phase 2				Phase 3			
Item	Mash	45-s pellet	90-s pellet	Extrude	Mash	45-s pellet	90-s pellet	Extrude	Mash	45-s pellet	90-s pellet	Extrude
DM, %	87.5	87.6	89.0	86.5	89.6	89.8	91.5	89.2	88.6	88.4	88.7	90.3
CP, %	17.62	17.48	18.97	17.48	18.3	18.11	19.3	17.8	17.91	16.88	18.11	17.92
Ether extract, %	3.28	3.44	3.30	2.51	3.42	3.58	3.43	2.83	2.89	4.29	3.64	4.06
Crude fiber , %	4.80	3.97	3.97	3.80	5.11	3.99	3.73	3.74	4.09	3.85	3.81	4.01
Ash, %	4.17	4.22	4.65	4.43	4.46	4.31	4.93	4.48	5.13	4.46	4.78	4.34
ADF, %	6.88	6.13	5.62	5.04	7.22	6.02	5.41	5.56	6.58	5.67	6.30	6.21
NDF, %	17.78	13.86	13.91	14.71	19.29	15.2	14.44	14.62	17.5	15.54	15.27	16.23
Cellulose, %	4.49	4.45	2.29	2.40	4.90	4.31	3.74	3.95	3.47	3.86	3.32	4.37
Beta-glucan, %	0.29	0.63	0.56	0.47	1.01	0.95	0.99	1.27	0.70	0.94	0.72	1.42

[1] A single diet formulation for each of three phases of a 79-d finishing pig experiment was manufactured and then processed according to different parameters to create four dietary treatments.

Table 4. Analyzed fatty acid and amino acid composition of the diet (as-fed basis)[1]

	Phase 1				Phase 2				Phase 3			
Item	Mash	45-s pellet	90-s pellet	Extrude	Mash	45-s pellet	90-s pellet	Extrude	Mash	45-s pellet	90-s pellet	Extrude
Fatty acid, %												
Myristic (14:0)	0.09	0.12	0.12	0.10	0.12	0.07	0.08	0.09	0.12	0.10	0.12	0.10
Palmitic (16:0)	14.9	15.0	14.9	14.8	14.7	14.8	15.0	14.9	15.1	14.8	14.9	14.6
Palmitoleic (9c-16:1)	0.20	0.24	0.20	0.20	0.21	0.21	0.23	0.22	0.24	0.22	0.22	0.22
Margaric (17:0)	0.14	0.12	0.12	0.18	0.12	0.11	0.11	0.11	0.09	0.10	0.12	0.11
Stearic (18:0)	2.20	2.09	2.14	2.15	2.20	2.13	2.21	2.12	2.17	2.09	2.14	2.04
Oleic (9c-18:1)	22.7	22.7	22.7	23.0	23.4	23.3	23.0	23.9	23.0	22.9	22.6	23.5
Vaccenic (11c-18:1)	0.81	0.79	0.81	0.82	0.80	0.79	0.79	0.80	0.80	0.77	0.80	0.77
Linoleic (18:2n6)	54.9	55.1	55.2	54.9	54.8	55.0	54.8	54.4	54.7	55.3	55.0	55.1
Linolenic (18:3n3)	2.21	2.29	2.35	2.27	2.07	2.10	2.16	2.02	2.21	2.18	2.29	2.03
Gonodic (20:1n9)	0.36	0.36	0.37	0.32	0.31	0.37	0.38	0.37	0.38	0.40	0.38	0.31
Behenoic (22:0)	0.21	0.20	0.17	0.17	0.22	0.19	0.21	0.18	0.18	0.20	0.22	0.21
Lignoceric (24:0)	0.39	0.18	0.17	0.15	0.18	0.18	0.25	0.17	0.17	0.13	0.18	0.15
Amino acid, %												
Threonine	0.77	0.73	0.80	0.73	0.74	0.72	0.74	0.67	0.69	0.66	0.71	0.70
Valine	0.99	0.94	1.03	0.90	0.94	0.92	1.01	0.91	0.93	0.88	0.94	0.92
Methionine	0.37	0.38	0.40	0.35	0.38	0.36	0.37	0.35	0.37	0.34	0.37	0.37
Isoleucine	0.81	0.78	0.87	0.72	0.77	0.74	0.76	0.72	0.73	0.71	0.76	0.73
Leucine	2.01	1.99	2.18	1.97	1.95	1.97	2.13	1.86	1.99	1.87	1.97	1.97
Phenylalanine	0.99	0.95	1.06	0.92	0.95	0.94	0.98	0.88	0.92	0.87	0.93	0.92
Lysine	1.12	1.05	1.17	1.03	1.08	1.03	1.05	0.99	0.92	0.88	1.00	0.88
Lysine availability[2]	1.10	1.04	1.15	1.01	1.06	1.01	1.03	0.98	0.91	0.86	0.99	0.87
Histidine	0.54	0.52	0.56	0.52	0.51	0.51	0.54	0.49	0.50	0.48	0.51	0.50
Arginine	1.14	1.05	1.16	1.07	1.07	1.04	1.06	0.99	0.99	0.95	1.03	0.99
Tryptophan	0.21	0.20	0.22	0.22	0.19	0.20	0.20	0.19	0.18	0.19	0.20	0.19
Total amino acid	19.88	18.92	20.75	18.70	18.86	18.73	19.53	17.69	18.25	17.39	18.58	18.16

[1] A single diet formulation for each of three phases of a 79-d finishing pig experiment was manufactured and then processed according to different parameters to create four dietary treatments.

[2] Indicates the percentage of reactive lysine available after diet post-processing.

Table 5. Effects of feed processing method on finishing pig growth performance[1]

	Diet form					$P =$			
Item	Mash	45-s pellet	90-s pellet	Extrude	SEM	Processing method	Pelleted vs. extruded	Pelleted vs. Mash	Mash vs. thermally processed
d 0 to 25									
ADG, lb	2.05^{b}	2.18^{a}	2.20^{a}	2.11	0.018	< 0.001	< 0.001	< 0.001	< 0.001
ADFI, lb	5.65^{ab}	5.59^{b}	5.68^{a}	5.37^{c}	0.077	0.013	0.003	0.841	0.208
F/G	2.76^{b}	2.56^{a}	2.58^{a}	2.55^{a}	0.019	0.002	0.575	< 0.001	< 0.001
d 25 to 46									
ADG, lb	2.09^{b}	2.29^{a}	2.24^{a}	2.33^{a}	0.042	< 0.001	0.134	< 0.001	< 0.001
ADFI, lb	6.18	6.07	6.16	6.09	0.090	0.759	0.904	0.570	0.520
F/G	2.96^{b}	2.65^{a}	2.75^{a}	2.61^{a}	0.069	< 0.001	0.104	< 0.001	< 0.001
d 46 to 60									
ADG, lb	2.05	2.05	2.18	2.13	0.064	0.309	0.812	0.399	0.329
ADFI, lb	6.51	6.40	6.47	6.42	0.106	0.885	0.911	0.592	0.544
F/G	3.18	3.12	2.97	3.01	0.081	0.245	0.760	0.213	0.156
d 60 to 79									
ADG, lb	2.18	2.18	2.29	2.24	0.051	0.325	0.883	0.377	0.324
ADFI, lb	7.04	6.82	7.04	6.86	0.134	0.391	0.583	0.460	0.330
F/G	3.23	3.13	3.07	3.06	0.094	0.089	0.406	0.063	0.026
d 0 to 79									
ADG, lb	2.09^{b}	2.18^{a}	2.22^{a}	2.16^{a}	0.026	< 0.001	0.330	0.001	0.001
ADFI, lb	6.12	6.01	6.12	5.90	0.084	0.140	0.084	0.585	0.233
F/G	2.93^{b}	2.76^{a}	2.76^{a}	2.73^{a}	0.025	< 0.001	0.087	< 0.001	< 0.001
BW, lb									
d 0	115.5	115.7	115.7	115.7	0.913	0.997	0.949	0.871	0.845
d 25	166.3^{b}	169.4^{a}	169.9^{a}	165.4^{b}	1.283	< 0.001	< 0.001	0.001	0.034
d 46	209.7^{b}	216.9^{a}	216.9^{a}	214.3^{a}	1.863	0.001	0.121	<0.001	< 0.001
d 60	238.3^{b}	245.5^{a}	247.5^{a}	244.2^{a}	1.912	< 0.001	0.197	<0.001	< 0.001
d 79	279.6^{c}	286.4^{b}	291.1^{a}	286.7^{b}	2.515	0.008	0.444	0.002	0.002

[1] A total of 270 (PIC 327 × 1050) were used in a 79-d experiment to evaluate the effects of feed processing method on finishing pig performance. A single diet formulation was manufactured into four different dietary treatments. There were 7 to 8 pigs per pen with 9 replications per treatment.

[abc] Means within a row that do not share a common superscript differ, $P < 0.05$.

Table 6. Effects of feed processing method on finishing pig nutrient digestibility, caloric efficiency, and carcass characteristics[1]

	Diet form					*P* =			
Item	Mash	45-s pellet	90-s pellet	Extrude	SEM	Processing method	Pelleted vs. extruded	Pelleted vs. Mash	Mash vs. thermally processed
ATTD[2], %									
DM	82.7	81.3	84.8	82.6	0.83	0.379	0.820	0.837	0.891
GE	81.2	82.4	82.7	82.1	0.42	0.318	0.449	0.524	0.683
CP	80.1^{b}	79.7^{c}	83.4^{a}	79.3^{c}	0.78	0.003	0.027	0.141	0.442
Ether extract	36.3^{c}	66.7^{a}	65.4^{a}	60.4^{b}	2.36	< 0.001	0.063	< 0.001	< 0.001
Ash	53.7^{a}	41.0^{b}	52.7^{a}	38.9^{c}	1.78	< 0.001	0.0006	0.002	< 0.001
Crude fiber	38.8^{c}	70.5^{a}	63.0^{b}	69.5^{a}	3.26	< 0.001	0.484	< 0.001	< 0.001
NDF	40.5^{b}	35.9^{c}	45.1^{a}	34.1^{c}	2.33	0.010	0.031	0.997	0.422
ADF	44.8^{a}	33.4^{b}	46.5^{a}	36.3^{b}	3.26	0.023	0.368	0.232	0.115
Cellulose	30.5	40.0	36.3	39.1	3.12	0.157	0.801	0.056	0.036
Caloric efficiency									
ME, kcal/lb	4,304^{a}	4,047^{b}	4,040^{b}	3,989^{b}	60.6	< 0.001	0.102	< 0.001	< 0.001
NE, kcal/lb	3,144^{a}	2,956^{b}	2,951^{b}	2,915^{b}	33.8	< 0.001	0.105	< 0.001	< 0.001
Carcass characteristics									
HCW, lb	201.3^{b}	209.2^{a}	210.1^{a}	208.8^{a}	2.64	1.000	0.772	0.007	0.006
Carcass yield[3], %	72.2	72.6	72.3	72.6	0.12	0.205	0.564	0.222	0.136
Backfat depth[4], mm	20.5	19.7	20.9	20.6	0.56	0.524	0.700	0.730	0.817
Loin depth[4], mm	60.9	62.7	62.5	62.7	0.84	0.353	0.875	0.106	0.077
Jowl fat iodine value[5]	75.4^{b}	77.1^{a}	77.3^{a}	77.6^{a}	0.37	< 0.001	0.370	< 0.001	< 0.001

[1] A total of 270 (PIC 327 × 1050) were used in a 79-d experiment to evaluate the effects of feed processing method on finishing pig performance. A single diet formulation was manufactured into four different dietary treatments. There were 7 to 8 pigs per pen with 9 replications per treatment.

[2] Apparent total tract digestibility of nutrients.

[3] Carcass yield calculated by dividing HCW by live weight obtained at the farm prior to transportation to the packing plant.

[4] Adjusted by using HCW as a covariate.

[5] Jowl fat iodine value (g/100 g) was measured at the packing plant by near-infrared spectroscopy.

[abc] Means within a row that do not share a common superscript differ, $P < 0.05$.