RESEARCH REPORT

ANIMAL SCIENCE

Title: Evaluating the use of long-term conditioning or extrusion to extract nutrients from low energy feedstuffs – **NPB #14-057** revised

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Industry summary: A shift in three major issues affecting feed manufacturing for pork production has occurred simultaneously in recent years. First, high ingredient costs have resulted in increased utilization of low energy, high fiber by-product ingredients in grow-finish diets. Second, these high ingredient costs have altered the cost:benefit ratio of pelleting, causing more producers to pellet grow-finish diets. Third, feed has recently been implicated as a potential vector of Porcine Epidemic Diarrhea Virus, a virus that is known to be thermally sensitive. All three of these issues aligned to emphasize that more research is needed to assess the economic benefits of feed processing conditions in low energy, high by-product diets for grow-finish pigs. This study aimed to determine the influence of processing a low energy, high by-product diet via pelleting with a standard 45 s conditioning time, pelleting with a 90 s conditioning time, or extrusion on grow-finish pig growth performance, nutrient digestibility, and carcass characteristics. Thermal processing, regardless of type, improved gain, feed efficiency, and carcass weight without affecting feed intake. While thermal processing did not affect percentage yield, backfat, or loin depth, pigs fed thermally-processed diets had poorer fat quality than those fed mash diets. There were few differences between diets pelleted for the standard 45 s and diets that were either extruded or pelleted with long-term conditioning times, suggesting that subjecting low energy diets to harsh thermal processing conditions is neither advantageous nor deleterious to grow-finish performance compared to traditional pelleting.

Key Findings:

- Thermal processing, regardless of type, improved overall ADG and G:F, but did not affect ADFI in finishing pigs.
- Pigs fed any thermally-processed treatment had greater hot carcass weight and jowl iodine value compared to those fed the mash diet.
- There were few differences between diets pelleted for the standard 45 s and diets that were either extruded or pelleted with long-term conditioning times.
- Subjecting low energy diets to harsh thermal processing conditions is neither advantageous nor deleterious to grow-finish performance compared to traditional pelleting.

Keywords: digestibility, extruding, pelleting, thermal processing

Scientific abstract: A total of 270 pigs (PIC 337 × 1050; initially 52.2 kg BW) were utilized 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 1) negative control: non-processed mash, 2) positive control: pelleted with 45 s conditioner retention time, 3) pelleted with 90 s conditioner retention time, and 4) extruded. Diets were fed in 3 phases with the same low energy diet formulation fed across treatments, containing 30% corn dried distillers grains with solubles and 19% wheat middlings. Thermal processing, regardless of type, improved ADG and G:F ($P < 0.05$), but did not affect ADFI ($P > 0.10$). Extruded diets tended to improve G:F compared to pelleted diets ($P < 0.10$). Interestingly, HCW was greater when pigs were fed pelleted diets compared to extruded diets, regardless of conditioning time ($P < 0.05$). However, pigs fed any thermally-processed treatment had greater HCW compared to those fed the negative control mash ($P < 0.05$). Thermal processing did not influence percentage yield, backfat, or loin depth when HCW was used as a covariate ($P > 0.10$). However, pigs fed thermally-processed diets had greater jowl iodine value compared to those fed mash diets ($P < 0.05$). This experiment again confirms the benefits of thermally processing feeds to improve ADG and G:F, but neither extended conditioning nor extrusion extracted additional nutrients from low energy feedstuffs compared to traditional pelleting. However, this research suggests that more extreme thermal processing conditions may be used without hindering nutrient utilization.

Introduction: Pelleting is not a novel concept to improve nutrient utilization or mitigate high feed costs. In 1971, Vanschoubroek et al. summarized 66 experiments evaluating the effects of pelleting swine diets on production costs, handling characteristics, and pig performance. Not surprisingly, the advantages of pelleting included increasing bulk density; improving transportation characteristics of feeds; reducing ingredient segregation during handling; decreasing dust levels; reducing feed intake; increased weight gain; and improving feed utilization. The listed disadvantages included higher manufacturing costs; reduced carcass quality; and increased incidences of stomach ulceration. With this information available, the advantages of pelleting grow-finish diets did not outweigh the disadvantage of higher manufacturing costs until the relatively recent escalation of feed ingredient costs. However, pelleting is now an economic option in finishing, as outlined by De Jong et al. (2013). Thus, various methods of pelleting or diet form manipulation, including long-term conditioning and extrusion should be reevaluated, particularly with the utilization of high by-product ingredients and modern genotypes. The growth advantages from pelleting and extrusion are thought to be a result of the combination of increased starch gelatinization and increased susceptibility to enzymatic hydrolysis (Chiang and Johnson, 1977). Hancock (1992) outlined that more extreme methods of thermal processing, such as elongated conditioning or extrusion, provide further nutritional advantages such as feed sterilization, protein denaturation, increased fat stability, and decreased activity of antinutritional compounds. More extreme processing conditions are timely to evaluate because the FDA recently announced that it considers a commercial heat step, such as pelleting or extrusion, an effective Salmonella mitigation strategy. However, standard conditioning times are expected to only destroy 80% of pathogenic bacteria; longer conditioning times or extrusion is thought to be necessary for complete pathogen destruction. As pork producers begin evaluating the potential benefit and capability of producing Salmonella-free feed, it is pertinent to include the advantages or disadvantages of long-term conditioning or extrusion on nutritional characteristics, such as fiber solubility and potential amino acid degradation. While elongated conditioning or extrusion is beneficial to digestibility of some nutrients, such as fiber solubility, it may actually be detrimental to others, such as lysine or fatty acid concentrations. Lysine availability or reactivity has been demonstrated to be influenced by the drying process in DDGS (Pahm et al., 2008). Other research has demonstrated pelleting negatively influences carcass fat iodine value (De Jong et al., 2013). Thus, the digestibility of dry matter, crude protein, crude fat, crude fiber, ash, fiber fractions, fatty acid, amino acid, and reactive Lys levels should all be analyzed to best quantify potential nutritional implications from extreme processing conditions.

Objectives: 1) Determine the influence of processing a low energy, high by-product diet via pelleting with a standard 45 s conditioning time, pelleting with a 90 s conditioning time, or extrusion on diet fiber fraction, fatty acid, and amino acid concentrations. 2) Assess if the extreme processing conditions outlined above for low energy diets improve grow-finish pig growth, digestibility, or carcass characteristics compared to mash diets or standard pelleting.

Materials and Methods:

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

<u>Diet manufacturing</u>

Four dietary treatments were manufactured for this experiment: 1) negative control: non-processed mash, 2) positive control: pelleted with 45 s conditioner retention time, 3) pelleted with 90 s conditioner retention time, and 4) extruded. 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 (Tables 1 and 2). 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 82°C and pelleted using a pellet mill (California Pellet Mill Model # 3016-4, Crawfordsville, IN) fit with a 4-mm die. The conditioner motor speed was decreased to manufacture Treatment 3 with a longer conditioning time to mimic the time of a double-pass conditioner. Meanwhile, the basal diet was transported to Wenger Manufacturing, Inc. in Sabetha, KS where Treatment 4 was extruded using a Universal Pellet Cooker (Model UP/C, Wenger Manufacturing, Sabetha, KS) with 130°C preconditioning temperature. Electrical energy use and production rates were recorded during thermal processing twice during the production of each of the three phases and averaged to determine the overall production rate per phase. Mash diets were given values of zero. A standard price of $0.12 per kilowatt hour was utilized to calculate electrical energy costs for thermal processing and added to overall feed cost per pig (Table 2).

Samples of each treatment were collected and analyzed for proximate analysis (AOAC Official Methods 990.03, 942.05, 920.39, 978.10, and 934.01), NDF (Van Soest et al., 1991), ADF (AOAC Official Method 973.18), cellulose (AOAC Official Method 973.18), beta-glucan (AOAC Official Method 995.16), fatty acid profile (AOAC Official Methods 996.06, Ce 2-66), amino acid composition (AOAC Official Method 982.30), available Lys (AOAC Official Method 975.44) and pellet durability (Tables 3 and 4). Pellet durability was determined according to the standard and modified ASAE Standard S269.4 as described by Fahrenholz (2012) where five hex nuts were added to the each tumbling compartment (Table 2).

Growth experiment

A total of 270 finisher pigs (PIC 337 × 1050; initially 52.2 kg) were utilized in this 79-d experiment. There were 7 to 8 pigs per pen and 9 pens per treatment. All pens contained one waterer and self-feeder allowing ad libitum access to feed and water. On d 0, pens were weighed and randomly assigned one of four dietary treatments. Pen weights and feed disappearance were collected on d 0, 25, 46, 60, and 79 to calculate the ADG, ADFI, and G:F. Phase 3 diets included 0.4% titanium dioxide and fecal samples were collected from three pigs per pen between d 66 and 68. 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 79 d. Pigs were slaughtered and carcass data collected in a single run at Triumph Foods in St. Joseph, Missouri. 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 using the equation by Cocciardi et al. (2009). Economic value was calculated with market values at the time of pig slaughter in September 2014. Specifically, corn $253/tonne, soybean meal $467/tonne, DDGS $227/tonne, wheat midds $218/tonne, and pig live weight $107.97/cwt.

Nutrient Digestibility Analyses

Fecal samples were dried according to AOAC Official Method 934.01 and analyzed for proximate analysis (AOAC Official Methods 990.03, 942.05, 920.39, 978.10, and 934.01), NDF (Van Soest et al., 1991), ADF (AOAC Official Method 973.18), cellulose (AOAC Official Method 973.18), beta-glucan (AOAC Official Method 995.16), fatty acid profile (AOAC Official Methods 996.06, Ce 2-66), amino acid composition (AOAC Official Method 982.30), and available Lys (AOAC Official Method 975.44). Digestibility coefficients were calculated according to Stein et al. (2006).

Statistical Analyses

Data were analyzed using the GLIMMIX procedure in SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit as a completely randomized design. 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 interactions between pelleted vs. extruded diets, pelleted vs. control diets, and thermally-processed vs. control diets.

Results and Discussion (see attached figures and tables):

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, so the pelleted diet with a 45-s conditioning time was manufactured at 66.2, 84.8, and 80.8% of the production rate of the pelleted diet with a 90-s conditioning time in phase 1, 2, and 3, respectively. The extruded diet was manufactured at a lower production rate, but was more stable throughout the varying phases as it could be held at a constant 1,200 kg/hr. The electrical energy consumption of the thermal processing equipment was as predicted, with pelleted diets having lesser energy usage than extruded diets and shorter conditioning time resulting in reduced electricity consumption. The differences in equipment also influenced pellet durability index. The longer conditioning time in the pelleted diets improved pellet quality between 1.6 and 5.2%. Extruded diets are also commonly evaluated for durability with the modified tumbling box method used to evaluate pellet quality, so durability between pellets and extrudates can be compared directly. The extruded treatment had substantially greater durability index than either pelleted treatment. It is possible that the mechanical pressure from extrusion causes increased starch gelatinization. Starch, in its native form, has less binding potential than gelatinized starch (Kaliyan and Morey, 2009) Wood (1987) found that diets manufactured with pre-gelatinized starch had greater pellet hardness and durability than those manufactured with raw starch. Interestingly, Gilpin et al. (2002) found that increased retention time by using the same method of altering the variable frequency drive significantly improved pellet durability.

Table 3 displays the analyzed diet composition after processing. While many nutrients are consistent with formulated values, differences exist between treatments. Notably, the pelleted diets conditioned for 90 s have the greatest DM. It is likely that the slight increase in moisture was added to the diet during steam conditioning. 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 diet because they have a low propensity for starch gelatinization and pelleting, and were therefore not utilized in the analysis of the pelleted diets. Adding increasing concentrations of distillers dried grains with solubles to diets has been demonstrated to cause a linear increase in pellet fines production (Min et al., 2008). There are conflicting reports regarding the effect of extrusion on dietary fiber solubility, but it appears that moderate extrusion conditions improve fiber solubility, while extreme temperatures (150 to 200°C) actually increase percentage fiber due to an alteration of starch chemistry (Silijestrom et al., 1986, Wang & Klopfenstein, 1993). The extruded diets had the lowest CF concentration in phase 1 and 2, but was intermediate in phase 3. Interestingly, both cellulose and beta-glucan concentrations were greatest in the extruded diet in phase 3, but were intermediate in phase 1 and 2. Based on our findings, 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, we evaluated the role of feed processing on both fatty acid and amino acid composition (Table 4). Previous research has suggested that pelleting results softer carcass fat, potentially due to greater digestibility dietary lipids that are more unsaturated in nature (De Jong et al., 2013). Unsurprisingly, the majority of fatty acids in the diet were linoleic, oleic, palmitic, and linolenic acids. 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 slightly decreased with increasingly harsh thermal processing conditions. Thermal processing is known to alter protein availability, and particularly Lys reactivity. Reactive lysine values are highest in mash diets and lowest in extruded diets in all but the last phase. This is different from research that found the lowest value of reactive occurred in three of four pellets, rather than in the extruded diets (Tran and Hendriks, 2007). 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 (Fastinger and Mahan, 2006; Stein et al., 2006). 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 (Finot and Magnenat, 1981;

Pahm et al., 2008). Interestingly, the pelleted diet conditioned for 90 s had the greatest lysine availability in phases 1 and 3. However, extruded diets had among the lowest lysine availability in all three phases.

Growth Performance

Feed processing method had a large impact on finishing pig growth performance overall, but particularly during the early stages of growth (Table 5). Diet form affected ADG and G:F from d 0 to 25, 25 to 46, and overall, where thermally processed diets were improved 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 ($P > 0.10$). As described above, the PDI of the extruded diets was substantially greater than 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 effected. An alternative theory is that because extruded diets expand due to pressure changes from moisture flash-off after the die, their larger size made for more challenging feeder management that was resolved after the first phase. Williams (2010) also found that pigs fed extruded diets manufactured with 30% DDGS had poorer ADFI than those fed mash or pelleted diets that was overcome with time. Regardless, the effect was not carried though other phases.

Overall, thermal processing improved pig ADG by 3.1 to 5.9% and G:F by 5.6 to 8.1% without affecting overall ADFI. Ultimately, these growth performance improvements resulted in a pig that was to 3.1 to 5.2 kg 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.

While these results in ADG and G:F from thermal processing are similar to those previously reported (Lundblad et al, 2011; De Jong et al., 2013), there is still disagreement as to the reasoning for this improvement. Pelleting is known to increase hydrogen bonding of starch molecules and starch gelatinization, which then improves starch and subsequent energy digestibility (Fahrenholz, 2012). Hancock (1992) outlined that thermal processing methods provide both nutritional and non-nutritional advantages, including feed sterilization, increased fat stability, decreased activity of antinutritional compounds, decreased feed wastage, and increased bulk density decreasing feed wastage. Amornthewaphat et al. (2008) suggested that greater bulk density of extruded maize had reduced water solubility of the diet and increased viscosity and transit time in the digestive tract. Nevertheless, 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 nutrient manipulation (Table 8). Pigs fed pelleted diets conditioned for 90 s had the greatest ATTD CP, EE, Ash, NDF, and ADG concentration ($P < 0.05$). Most notably, however, is the overwhelming EE and CF digestibility improvement in pigs fed thermally-processed diets compared to those fed mash diets ($P < 0.05$). Past research suggests that harsh thermal processing of swine diets, such as extrusion, improves ileal DM digestibility (Muley et al., 2007) , NFE in nursery pigs (Van Der Poel et al., 1989), and starch digestibility in growing pigs (Sun et al. 2006). Alterations in nutrient digestibility led to improved caloric efficiency in pigs fed thermally-processed diets than those fed mash diets and, ultimately, greater HCW ($P < 0.05$).

Feed processing method did not affect carcass yield, backfat depth, or loin depth (P > 0.10), but was an important factor in jowl iodine value. This finding confirms that reported previously by De Jong (2013) and Nemechek (2014), who described a previously unknown interaction between thermal processing and lipid utilization. During finishing pig growth experiments, they observed that pelleting diets resulted in pigs depositing more unsaturated fat. Potentially, thermal processing increases the digestibility of dietary lipids, which are predominantly from grain and therefore relatively unsaturated in nature. We can therefore link the effects of thermal processing on carcass iodine value with dietary fatty acid concentrations. The iodine value regression equation is built upon the proportion of fatty acids present in a fat sample (Benz et al., 2010). The fatty acids included in the equation include C16:1, C18:1, C18:2, C18:3, C20:1, and C22:1, with C18:3 having the greatest influence on the equation (AOCS, 1998). 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 in order 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 ingredient inclusion an important factor in carcass fat quality. Whitney et al. (2006) reported that, while feeding 10 to 30% distillers dried grains with solubles does affect carcass lean characteristics, the ingredient addition in a diet results in an increase in unsaturated carcass fat and the likelihood of soft bellies. The tested diets were high fiber diets that were somewhat limited in dietary fat compared to diets with lower by-product 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.

<u>Economic Analyses</u>

Finally, the ultimate measure of the value of thermal processing is if the potential income it generates by improving growth performance and feed efficiency is greater than the extra feed cost due to processing (Table 9). Notably, feed costs included the electricity utilized by various thermal processing equipment, but not the cost of steam or changes in production capacity. Thus, the feed cost for pelleted diets with a 90 s conditioning time were greatest, but all four diets were relatively similar in diet price overall. Previously, Stark (2009) reported that an increase in pellet mill throughput led to a linear increase in pellet mill efficiency and linear reduction in pellet durability. While feed cost did not vary greatly on a per pig basis across treatments ($P >$ 0.10), we can observe differences when the values are placed on a basis of cost of gain. Pigs fed mash diets had greater cost per kg of gain, as well as reduced gain value and income over feed costs, which was driven by a greater overall ADFI ($P < 0.05$). Ultimately, thermal processing improved income over feed cost by \$8.82 to \$10.03 compared to feeding pigs mash diets. Fahrenholz (2012) has explained that it is possible to manipulate energy efficiency in such a way as to preserve pellet durability while maintaining the lowest possible energy consumption. Fahrenholz (2012) predicted that lowest overall feed cost had both a mid-range energy consumption (9.1 kWh/tonne) and pelleting cost (\$8.21/tonne). As ingredient prices continue to fluctuate, it is important for individual production systems to evaluate their costs of pelleting relative to their value of nutrient extraction.

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

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

Ingredient, %	Phase 1	Phase 2	Phase 3
Corn	37.15	40.35	42.50
Soybean meal, 48%	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 phosphate	0.00	0.00	0.00
Limestone	1.30	1.20	1.20
Salt	0.35	0.35	0.35
L-Lys-HCL	0.29	0.27	0.23
Trace mineral premix[2]	0.15	0.13	0.08
Vitamin premix[3]	0.15	0.13	0.08
Phytase[4]	0.02	0.02	0.02
Titanium Dioxide[5]	0.00	0.00	0.40
Total	100.00	100.00	100.00
Calculated analysis			
Standardized ileal digestible (SID) amino acids, %			
Lysine	0.86	0.77	0.68
Isoleucine:lysine	73	75	78
Leucine:lysine	192	206	224
Methionine:lysine	35	38	41
Methionine & cysteine:lysine	67	71	77
Threonine:lysine	64	66	69
Tryptophan:lysine	18.5	18.5	18.9
Valine:lysine	89	93	99
Total lysine, %	1.05	0.96	0.86
ME, kcal/kg	666	668	665
SID lysine:ME, g/Mcal	2.66	2.37	2.10
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 4 dietary treatments.

[2]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU Vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[3]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[4]Provided 780 phytase units (FTU)/kg, with a release of 0.11% available P.

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

Phase:	1				2				3			
Treatment:	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, kg/h	---	1,995	1.336	1,200	---	2,170	1,355	1,200	---	6,466	3,402	1,200
Electrical energy, kilowatt hour	---		18.9	26.5	---	9.78	17.3	26.0	---	9.2	16.8	24.5
Pellet durability index												
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 4 dietary treatments.

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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
GE, kcal/kg	3,500	3,510	3,530	3,400	3,580	3,600	3,630	3,520	3,480	3,580	3,540	3,650
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
EE, %	3.28	3.44	3.30	2.51	3.42	3.58	3.43	2.83	2.89	4.29	3.64	4.06
CF, %	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 4 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 avail.	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 4 dietary treatments.

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	Diet form	Pelleted vs. extruded	Pelleted vs. control	Control vs. thermally processed
d 0 to 25									
ADG, kg	0.93^{b}	0.99^{a}	1.00^{a}	0.96^{b}	0.008	< 0.001	< 0.001	< 0.001	< 0.001
ADFI, kg	2.57^{ab}	2.54^{b}	2.58^{a}	2.44^{c}	0.035	0.013	0.003	0.841	0.208
G:F	0.40	0.42	0.42	0.42	0.005	0.002	0.575	< 0.001	< 0.001
d 25 to 46									
ADG, kg	0.95^{b}	1.04^{a}	1.02^{a}	1.06^{a}	0.019	< 0.001	0.134	< 0.001	< 0.001
ADFI, kg	2.81	2.76	2.80	2.77	0.041	0.759	0.904	0.570	0.520
G:F	0.34^{b}	0.38^{a}	0.36^{a}	0.38^{a}	0.006	< 0.001	0.104	< 0.001	< 0.001
d 46 to 60									
ADG, kg	0.93	0.93	0.99	0.97	0.029	0.309	0.812	0.399	0.329
ADFI, kg	2.96	2.91	2.94	2.92	0.048	0.885	0.911	0.592	0.544
G:F	0.32	0.32	0.34	0.33	0.008	0.245	0.760	0.213	0.156
d 60 to 79									
ADG, kg	0.99^{b}	0.99^{b}	1.04^{a}	1.02^{a}	0.023	0.325	0.883	0.377	0.324
ADFI, kg	3.20	3.10	3.20	3.12	0.061	0.391	0.583	0.460	0.330
G:F	0.31	0.32	0.33	0.33	0.006	0.089	0.406	0.063	0.026
d 0 to 79									
ADG, kg	0.95^{b}	0.99^{a}	1.01^{a}	0.98^{a}	0.012	< 0.001	0.330	0.001	0.001
ADFI, kg	2.78	2.73	2.78	2.68	0.038	0.140	0.084	0.585	0.233
G:F	0.34^{b}	0.36^{a}	0.36^{a}	0.37^{a}	0.003	< 0.001	0.087	< 0.001	< 0.001
BW, kg									
d 0	52.5	52.6	52.6	52.6	0.415	0.997	0.949	0.871	0.845
d 25	75.6^{b}	77.0^{a}	77.23^{a}	75.2^{b}	0.583	< 0.001	< 0.001	0.001	0.034
d 46	95.3^{b}	98.6^{a}	98.6^{a}	97.4^{a}	0.847	0.001	0.121	<0.001	< 0.001
d 60	108.3^{b}	111.6^{a}	112.5^{a}	111.0^{a}	0.869	< 0.001	0.197	<0.001	< 0.001
d 79	127.1^{c}	130.2^{b}	132.3^{a}	130.3^{b}	1.143	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 4 different dietary treatments.

^{ab}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 charactersitcs[1]

	Diet form					*P* =			
Item;	Mash	45 s pellet	90 s pellet	Extrude	SEM	Diet form	Pelleted vs. extruded	Pelleted vs. control	Control vs. thermally processed
ATTD, %									
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
EE	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
CF	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[2]									
ME, kcal/kg	9,509	8,940	8,925	8,813	64.3	< 0.001	0.102	< 0.001	< 0.001
NE, kcal/kg	6,947	6,530	6,519	6,439	47.0	< 0.001	0.105	< 0.001	< 0.001
Carcass characteristics									
HCW, kg	91.5	95.1[a]	95.5[a]	94.9[a]	1.20	1.000	0.772	0.007	0.006
Carcass yield[2], %	72.2	72.6	72.3	72.6	0.12	0.205	0.564	0.222	0.136
Backfat depth[3], mm	20.5	19.7	20.9	20.6	0.56	0.524	0.700	0.730	0.817
Loin depth[3], mm	60.9	62.7	62.5	62.7	0.84	0.353	0.875	0.106	0.077
Jowl iodine value[4]	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 4 different dietary treatments.
[2]Carcass yield calculated by dividing HCW by live weight obtained at the farm prior to transportation to the packing plant.
[3]Adjusted by using HCW as a covariate
[4]Jowl iodine value (g/100 g) was measured at the packing plant by near-infrared spectroscopy.

Table 7. Effects of feed processing method on overall (d 0 to 79) pig and carcass value[1,2]

	Diet form				*P* =			
Item;	Mash	45 s pellet	90 s pellet	Extrude	Diet form	Pelleted vs. extruded	Pelleted vs. control	Control vs. thermally processed
Cost analysis								
Feed cost[2], $/pig	68.56	68.09	69.09	66.86	0.299	0.104	0.977	0.577
Cost, $/kg of gain[2]	0.92	0.87	0.87	0.86	< 0.001	0.185	< 0.001	< 0.001
Gain value[2], $/kg gain	122.12	130.47	132.12	130.44	0.003	0.701	< 0.001	< 0.001
Income over feed cost, $	53.56	62.38	63.04	63.59	< 0.001	0.606	< 0.001	< 0.001

[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 4 dietary treatments.

[2]Used standardized costs for time when pigs were marketed (September 2014): corn $253/tonne, soybean meal $467/tonne, DDGS $227/tonne, wheat midds $218/tonne, electricity $0.12/kilowatt hour, pig live weight $107.97/cwt