Title: Novel feed processing methods of cold pelleting and fine ground corn segregation to maximize feed efficiency, nutrient utilization and economic return – **NPB #15-052**

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Industry summary: Swine producers continue to grind to extremely fine particle sizes, which inherently produces a significant portion of the diet that is fine powder. The fine particles (< 150 microns) create problems in the feed manufacturing and delivery processes and feeder management at the farm. Removal of the fine particles will improve the flow characteristics of the ground grains and feed. However, the fine particles must be incorporated back into the feed at some point during the manufacturing process to prevent feed mill shrink. One process used to change the physical form of a meal is pelleting. Traditional pelleting, however, requires a substantial investment in equipment, both for production of the actual pellets and for the steam necessary for the conditioning process. Cold pelleting is an alternative method of pelleting, which does not require the use of steam or a boiler. This somewhat novel technology provides an economical and practical option for pelleting the fine particles removed from the ground grains or even complete diets. This study was designed to evaluate the economic returns of utilizing the novel feed processing technology to improve feed efficiency with direct field application.

Key Findings:

Removal of particles less than 150 microns improved flowability in mash diets.

Cold pelleting was a viable option for pelleting complete animal feed.

Cold pelleting could optimize the performance of nursery pigs consuming pelleted feeds.

Keywords: pelleting, thermal processing, cold pelleting, particle size

Scientific abstract: A total of 320 pigs (DNA 241 × 600; initially 22.5 lb BW) were utilized in a 21-d experiment to determine the effects of corn fractionation and pelleting technique on nursery pig growth performance during the third feeding phase. There were 5 pigs per pen and 8 pens per treatment. Diets were manufactured with either ground corn (400 microns), ground corn with fines (<150 microns) removed, or ground corn with the fines (<150 microns) pelleted. Diets were then fed as a mash or pelleted using a traditional vertical die pellet mill equipped with a steam conditioner or a horizontal pellet die with hot water conditioning prior to pelleting. There were eight total treatments in a random block design. Overall, cold pelleting improved ADG, regardless of corn particle size, when compared to steam pelleting ($P<0.05$). BW remained comparable to the meal diets, but was decreased when pellets were steam conditioned. There was no significant difference in G:F among treatments, with the exception of the diets containing pelleted fines, which had significantly lower G:F due to observed increased feed wastage. Finally, corn particle size appeared to have little effect on pig growth performance; however, there were processing implications. Removal of fines less than 150 microns from the corn improved the flowability characteristics of the diets as indicated by improved composite flow index (CFI) values. The best flow was achieved when fines were pelleted and added back to the mash diets. More research is warranted on how best to process and utilize the removed fines to maximize pig growth.

Introduction: Reducing the particle size of cereal grains is well understood to be a means to improve the efficiency of gain in swine (Goodband and Hines, 1988; Giesemann et al., 1990; Wondra et al., 1995). Opinions vary somewhat among swine producers regarding the optimum particle size of cereal grains for animal production and feed manufacturing economics. None the less, a major shift has occurred over the past 5 years resulting in mills routinely grinding cereal grains as fine as possible for swine diets. Fine grinding grains, however, can result in 'flouring' where a large portion of the material is ground to a fine powder. These 'grinding fines' are traditionally less than 150 microns, and have been shown to have an adverse effect on feed flowability, making grain handling and feeder management more challenging when fed in meal form. This poses a problem for swine producers because when feed bridges in the feeding system, out of feed events occur which result in decreased performance and increased potential of ulceration, overall stress, and ultimately mortality. Thus a means to remove the finest particles and return them into the diet in a free flowing form would be highly beneficial to feed manufacturers, owners, and swine producers. Pelleting is a feed processing method shown to improve handling and transportation characteristics of feeds, while reducing ingredient segregation during handling, decreasing dust levels, and improving feed utilization in swine (Vanschoubroek et al., 1971). The pelleting process, however, is complex and producing pellets of high quality takes a fundamental understanding of steam quality, frictional die characteristics, and the inherent variability of diets. The perceived challenges often deter many swine producers from utilizing pelleting technology and capitalizing on the associated benefits. The use of flat die technology (cold pelleting) has received little attention at this point compared to thermal pelleting for commercial feed applications. Its unique advantage of layout (flat-bed compared to standard ring die) requires only a hot water heater compared to boiler, which dramatically minimizes equipment maintenance while still providing the frictional energy required for high pellet quality (Thomas et al., 1996). The main components are a flat die press and pan grinder rollers, where the rotating pan grinder rollers press product into a flat die to force it into a pelleted form (Jacobson et al., 2001). The die width establishes frictional heat to bind pellets together, and knives cut the strands into the desired length of pellets (Sears et al., 2001). This process is typically utilized for products that are highly fibrous or bulky, such as straw, wood, or biomass, but has been used in Europe for pelleting broiler diets with whole wheat instead of ground wheat (Svihus et al., 2004, Sultana et al., 2010). However, no peer-reviewed literature exists to compare the flat die technology to standard pelleting with steam conditioning and a ring die for animal diets. Though the technology has never been evaluated before, it may hold great promise as an alternative method of pelleting animal feed.

Objectives: 1) Evaluate the novel technology of cold pelleting diets and its effect on animal growth performance, nutrient digestibility, and economic return compared to traditional pelleting. 2) Determine the role of fine particle (< 150 μm) inclusion or exclusion from mash or pelleted diets on flow characteristics, nutrient composition, pig growth performance, nutrient digestibility and economic return.

Materials and Methods:

Diet manufacturing

All dietary treatments were manufactured in accordance with cGMP's (current Good Manufacturing Practices) at Kansas State University O. H. Kruse Feed Technology Innovation Center in Manhattan, Kansas. The diets (Table 1) were based on the same corn-soybean meal formulation and the treatments were formed by changing the corn processing and the final form of the feed. The 8 treatments were: 1) ground corn diet fed as mash (GCM), 2) ground corn diet steam pelleted (GCSP), 3) ground corn diet cold pelleted (GCCP), 4) ground corn with fines less than 150 microns removed diet fed as mash (FRM), 5) ground corn with fines less than 150 microns removed diet steam pelleted (FRSP), 6) ground corn with fines less than 150 microns removed diet cold pelleted (FRCP), 7) sifted fines less than 150 microns steam pelleted then proportionally added back to ground corn (FPSP), and 8) sifted fines less than 150 microns cold pelleted then proportionally added back to ground corn (FPCP). Corn was initially ground to approximately 400 microns with a roller mill (RMS Model #924, Sioux Falls, SD). A portion of this ground corn (GC) was used to manufacture dietary treatments 1, 2, and 3, while the remainder of the ground corn was sifted using a rotary horizontal sifter to remove any particles less than 150 microns. The resulting ground corn with the fines removed (FR) averaged 600 microns and was included in dietary treatments 4, 5, and 6. The sifted fines were retained and pelleted (FP) prior to being proportionally added back to the ground corn from which they were previously removed (FR). The FP ground corn was included in treatments 7 and 8. Diets were fed either as a mash (M), a steam conditioned pellet (SP), or a cold conditioned pellet (CP). Steam conditioned pellets were manufactured on a traditional pellet mill (California Pellet Mill Model #1112-2, Crawfordsville, IN) equipped with a 1/4" x 2 1/2" vertical die. Mash was conditioned at 175°F for approximately 30 seconds prior to pelleting. Cold conditioned pellets were manufactured on a flat-face pellet mill (Amandus Kahl Model # 33-390, Reinbek, GER) equipped with a 1/4" x 1 3/16" horizontal die. Prior to pelleting with the flat bed pellet mill, mash feed passed through a blending screw where warm water (130°F) was added at a rate of 4%. Moisture and heat were removed with ambient air in a counter-flow cooler prior to packaging.

Electrical energy use on the main pellet mill motor and production rates were recorded during the steam and cold conditioned pellet runs and averaged to determine the overall production rate for each treatment (Table 2).

Samples of each treatment were collected and analyzed by Ward Laboratories (Kearney, NE) for DM (AOAC Official Methods 934.01), CP (AOAC Official Methods 990.01), ADF (AOAC Official Methods 973.18), TDN (Van Soest et al., 1991), Ca (AOAC Official Methods 927.02), P (AOAC Official Methods 964.06), 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 three ¾" hex nuts were added to each tumbling compartment (Table 2). The composite flow index was calculated for meal and meal/pellet combination diets according to the process described by Taylor et al. (2006).

Growth experiment

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.

A total of 320 nursery pigs (DNA 241 × 600; initially 22.5 lb. BW) were utilized in a 21-d experiment. There were 5 pigs per pen and 8 pens per dietary treatment. Pigs were provided *ad libitum* access to feed and water for the duration of the trial. Each pen was equipped with one nipple waterer and dry self-feeder. On d 0 of the trial, pens were weighed and randomly assigned to one of the eight dietary treatments. Pen weights and feed intake, determined by feed disappearance, were collected on d 0, 7, 14, and 21 to calculate Average Daily Gain (ADG), Average Daily Feed Intake (ADFI), and Gain to Feed Ratio (G:F).

Economic Analyses

At the conclusion of the trial an economic analysis was performed to determine the financial impact of the treatments. Ingredient prices from April 2016 were used for all economic calculations with corn valued at $128/ton and soybean meal at $343/ton. The cost of feed ($/ton) included ingredients, kwh, and boiler fuel usage when applicable. A standard price of $0.12 per kilowatt hour was used to calculate electrical energy costs for thermal processing and added to overall feed cost. The total feed cost per pig was calculated by multiplying the ADFI by the number of days on trial and the diet cost. The cost per pound of gain was calculated by dividing the total feed cost per pig by the average pounds gained per pig. Total revenue per pig was calculated by multiplying the ADG by the number of days on trial and the assumed live price of $0.52 per pound. Finally, the total feed cost per pig was subtracted from the total revenue per pig to calculate the income over feed cost.

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. Results were considered significant if $P \leq 0.05$, and a trend if $0.05 < P < 0.10$. Orthogonal contrasts were used to evaluate interactions between steam vs. cold pelleted diets, pelleted vs. mash diets, and diets excluding the fines vs. diets where the fines were pelleted and proportionally added back to the corn fraction.

Results and Discussion (see attached tables):

Diet Manufacturing

The flowability of the mash diets were evaluated based on the composite flow index, which characterized flow property by integrating the results of several different flow tests, such as the angle of repose, percent compressibility, and critical orifice diameter (Taylor et al., 2006). In general, a CFI value above 45 is considered acceptable, while CFI values between 30-45 characterize a poor flowing product. Applying this methodology and scale to the data (Table 2), flowability of the diets that contained the ground corn with the fines (GCM) had a CFI of 38. Whereas, removal of corn particles less than 150 microns (FRM), improved the overall flowability of the mash diet (CFI = 43). The results of this study were similar to other research that corroborated the hypothesis that the increased fines resulting from current fine grinding practices may result in poor flowability of feed both in the manufacturing process and on the farm. Ultimately the greatest flowability was achieved through pelleting of the fines and returning them to the mash diets (>50 CFI for FPSP and FPCP). This method was ideal for feed manufacturers, as it resulted in no grain waste in the feed mill and an overall improvement in flowability when compared to both mash diets.

The electrical consumption per ton was different for steam and cold conditioned pelleting (25 versus 13.5, respectively). The lower energy usage of the cold conditioned pellets was likely due to the thinner die used on the flat bed pelleter, which also resulted in poorer quality pellets, likely due to less die compression. While production rate was more stable during steam pelleting, it required more kWh/ton compared to cold pelleting. The cold pelleting, however, had the lowest energy use per ton, and as expected the increased production rate and thinner die required less energy compared to steam pelleting. The electrical energy use was higher when pelleting the fine particles (<150 um) with both pellet mills. The fines were difficult to pellet and the throughput was decreased in an effort to improve pellet quality. Increased hot pellet temperatures measured after the die and before cooling indicated increased friction between the material and surface of the die hole. This slowed throughput and in extreme cases, overloaded the pellet mill motor. Differences in pellet durability (PDI) were also observed based on conditioning and pelleting method. Cold condition pelleting resulted in lower standard and modified PDIs compared to steam pelleting. The lower PDI values could be a result of a lower effective length to pellet die hole diameter ratio (L:D) of the die, which would have resulted in less compression in the die. Additionally, the lack of steam likely reduced the binding potential of the protein and starch components in the diet. Subsequent studies are needed to further examine die specifications and conditioning on pellet quality. The PDI of the pelleted fines was low for both the steam and cold conditioned pellet methods (62.2 and 25.8, respectively). The low L:D ratio (4.8) of the die used to pellet the cold conditioned fines resulted in weak pellets, but another die was not available at the time of manufacturing and this lack of available equipment is a notable hurdle for wide-scale implementation of cold pelleting . Subsequent studies are needed to determine the optimal die specifications when pelleting fine corn particles with the horizontal die pellet mill.

All diet compositions were analyzed after processing (Table 3). Analyses were consistent with formulated values and were similar across treatments. ADF values were the most variable, however, there is no clear explanation for why these values were increased with steam pelleting when compared to the meal and cold pelleted diets. It is interesting to note that removal of the corn fines fraction did not change the nutrient composition of the diets, suggesting the material was simply finely ground corn and not a segregated portion of the germ or endosperm.

Growth Performance

From d 0 to 7, there were no differences in ADG or BW ($P > 0.10$), but a trend in G:F ($P = 0.061$) was detected based on increased feed disappearance ($P = 0.037$) of mash diets: GCM and FRM, as well as mash diets with pelleted fines: FPSP and FPCP (Table 5). The increased feed disappearance is likely due to observed feed wastage, which was difficult to control due to differences in the flowability and quality of the mash and pellet diets, respectively. In particular, the FPSP and FPCP presented the greatest challenge for proper feeder management. It was necessary to set feeder gaps that allowed passage of the ¼" diameter pellet, which, in turn, increased the mash flow. Rooting behavior was also observed in these diets as the pigs sorted through the mash for the pellets. These observed challenges in pig behavior and feeder management were likely the cause of higher feed disappearance in both mash and pelleted fines diets. A similar problem was observed in the feeders that contained mash diets that had ground corn with the fines removed (FRM). This diet had good flowability and tended to flood pans, which resulted in increased feed wastage.

By d 14, pigs consuming the mash diets weighed more than their counterparts consuming steam pelleted feed (P = 0.03), while a similar trend was observed in those pigs consuming cold pelleted feed (P = 0.06). Among the pelleted treatments from 7 to 14 d, pigs fed cold pelleted diets had improved (P < 0.05) ADG, regardless of the ground corn used, compared to steam pelleting. Furthermore, reduced ADFI was observed in both steam and cold conditioned diets when compared to mash (P =0.01 and P =0.04, respectively). The low intake of the steam comditioned diets (GCSP an FRSP) may have been a result of the increased pellet hardness associated with the steam conditioning discussed previously. ADFI was the greatest for FPSP and FPCP, where values appeared inflated due to increased wastage at the feeder. Excluding these two treatments, there was no significant difference in G:F among the remaining treatments.

From d 14 to 21 the ADG was significantly lowered by steam and cold pelleting as shown by the planned contrasts (P < 0.05). Further, pigs receiving the steam pelleted diets had lower ADG than those on cold pelleted diets (P < 0.05). Though gain was reduced, the older pigs appeared to have less of a palatability issue with the steam pelleted diets, reflected by the similar ADFI when compared to cold pelleted treatments during the period. Feed wastage remained problematic for FPSP and FPCP diets as shown by increased ADFI and low G:F when compared to the other treatments. Based on direct contrasts, the steam pelleted diets maintained similar G:F to the mash (P = 0.99), while G:F was reduced when compared to the cold pelleted diets alone (P = 0.02). Overall, however, diets showed no significant difference in G:F when analyzed together, with the exception of FPSP and FPCP diets (P < 0.01). The ground corn type had no effect on ADG, ADFI, or G:F.

The overall (d 0 to 21) ADG of the pigs was significantly impacted by the pelleting process (P < 0.05), with mash treatments GCM and FRM resulting in the greatest ADG (1.23 and 1.25, respectively), followed by the cold pelleted diets GCCP and FRCP (1.10 and 1.15), while the steam pelleted diets GCSP and FRSP had the lowest ADG (0.97 and 0.98, respectively). Assuming that increased feed disappearance in FPSP and FPCP is due to increased wastage, the greatest ADFI remained in the mash diets. Pigs consuming the steam pelleted diets had similar ADFI to those receiving the cold pelleted diets overall (P = 0.07). The G:F was similar among all treatments, excluding the highly wasted FPSP and FPCP diets. There was no overall effect of steam or cold conditioning pellets on G:F when compared to mash (P = 0.82 and P = 0.68, respectively). This indicates that cold pelleting technology is a viable alternative to traditional steam pelleting. In addition, the type of ground corn included in the diet had no impact on ADG, ADFI, or G:F.

<u>Economic Analyses</u>

Finally, at the conclusion of the trial economic analyses were performed to determine the value of thermal processing and its potential to increase profit through improved growth performance and feed efficiency (Table 6). As expected, the cost of feed was increased by pelleting, with steam conditioning requiring the greatest investment. Differences in feed intake resulted in lower feed cost per pig in the pelleted diets and similar cost per pound of gain throughout. Overall, however, the greatest IOFC was achieved with the mash diets requiring no additional processing cost, followed by the cold pelleted diets. The steam pelleted diets had the lowest IOFC, due to the increased cost of steam for processing. While the IOFC is an economic tool to gauge dietary efficiency, it does not take into account any additional benefits that further processing may achieve, such as improved flowability. It is also important to note that the IOFC is strongly correlated to ingredient and market prices, which can fluctuate over time.

Conclusions: The results of this study indicate that removing particles less than 150 microns improved the flowabiltiy of a mash diet. Additionally, cold pelleting was a viable option to steam pelleting, but will require more research to determine the optimal die specifications to achieve a similar pellet quality. The results also confirmed that feeder management is critical, especially when there are differences in the physical form of the feed that cause the pigs to root and sort feed. Further research is required to determine if pelleting the fines is a viable option in small scale feed mills.

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

Ingredient, %	Phase 3 Basal Diet
Corn[2]	62.92
Soybean meal, 48%	31.68
Monocalcium phosphate	1.15
Limestone	0.95
Salt	0.35
L-Lys-HCL	0.30
DL-Met	0.12
L-Thr	0.12
Trace mineral premix[3]	0.15
Vitamin premix[4]	0.25
Phytase[5]	0.02
Total	100.00
Calculated analysis	
Standardized ileal digestible (SID) amino acids, %	
Lysine	1.24
Isoleucine:lysine	63
Leucine:lysine	129
Methionine:lysine	33
Methionine & cysteine:lysine	57
Threonine:lysine	63
Tryptophan:lysine	18.7
Valine:lysine	69
Total lysine, %	1.39
ME, kcal/lb	674
SID lysine:ME, g/Mcal	3.79
CP, %	21.7
Ca, %	0.70
P, %	0.65
Available P, %	0.43

[1]A single diet formulation was manufactured using specified corn fractions and then processed using different pelleting techniques to create 8 dietary treatments.

[2] Dependent on treatment, the entire corn fraction, the upper corn fraction with fines removed, or the entire corn fraction with fines pelleted was used.

[3]Provided per lb of premix: 2,004,182 IU vitamin A; 250,523 IU vitamin D_3; 8,017 IU Vitamin E; 802 mg vitamin K; 1,503 mg riboflavin; 5,010 mg pantothenic acid; 9,019 mg niacin; and 7 mg vitamin B_{12}.

[4]Provided per lb of premix: 12 g Mn from manganese oxide, 50 g Fe from iron sulfate, 50 g Zn from zinc sulphate, 5 g Cu from copper sulfate, 90 mg I from calcium iodate, and 90 mg Se from sodium selenite.

[5]Provided 355 phytase units (FTU)/lb, with a release of 0.11% available P.

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

Corn :	Ground Corn [2]			Ground Corn with Fines Removed[3]			Ground Corn with Fines Pelleted[4]	
Feed Form:	Mash	Steam Pellet	Cold Pellet	Mash	Steam Pellet	Cold Pellet	Mash with Steam Pelleted Fines	Mash with Cold Pelleted Fines
Production rate, lb/h	---	1200	3024	---	1200	3480	600	2496
Electrical energy, Kw/ton	---	25.3	14.1	---	24.7	12.8	70.7	19.4
Electrical energy, kwh	---	15.2	21.3	---	14.8	22.3	21.2	24.2
Conditioner temp, °F	---	175	---	---	175	---	160	---
Hot pellet temp, °F	---	185	123	---	183	120	175	135
Composite flow index	38	---	---	43	---	---	59.3	56.7
Pellet durability index								
Standard	---	90.1	86.6	---	89.7	84.9	74.0	34.8
Modified[5]	---	84.6	78.3	---	80.9	79.4	62.2	25.6

[1] A single diet formulation was manufactured using specified ground corn fractions and then processed using different pelleting techniques to create 8 dietary treatments.

[2] Ground corn particle size of 400 microns.

[3] Ground corn with fines (<150 microns) removed via sifting, remaining fraction particle size of 600 microns.

[4] Ground corn with fines (<150 microns) removed via sifting followed by pelleting prior to being proportionally added back.

[5] Modified with three ¾ inch hexagonal nuts.

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

Corn:	Ground Corn[2]			Ground Corn with Fines Removed[3]			Ground Corn with Fines Pelleted[4]	
Feed Form:	Mash	Steam Pellet	Cold Pellet	Mash	Steam Pellet	Cold Pellet	Mash with Fines Steam Pelleted	Mash with Fines Cold Pelleted
DM, %	88.57	88.58	88.92	88.07	88.91	88.77	89.14	89.18
CP, %	23.00	22.30	22.80	22.00	22.30	22.40	23.00	23.00
ADF, %	3.00	3.30	2.50	2.60	4.10	3.40	2.90	2.80
TDN, %	79.80	79.40	80.50	79.70	78.90	79.50	80.30	80.50
Calcium, %	0.83	0.85	0.85	0.97	0.85	0.90	0.92	0.86
Phosphorous, %	0.60	0.69	0.69	0.67	0.72	0.70	0.65	0.72

[1] A single diet formulation was manufactured using specified corn fractions and then processed using different pelleting techniques to create 8 dietary treatments.
[2] Ground corn particle size of 400 microns.
[3] Ground corn with fines (<150 microns) removed via sifting, remaining fraction particle size of 600 microns.
[4] Ground corn with fines (<150 microns) removed via sifting followed by pelleting prior to being proportionally added back.

Table 5. Effects of corn fraction and pelleting technique on nursery pig growth perfomance[1]

Corn:	Ground Corn[2]			Ground Corn with Fines Removed[3]			Ground Corn with Fines Pelleted [4]			Probability, *P* <			
Feed Form:	Mash	Steam Pellet	Cold Pellet	Mash	Steam Pellet	Cold Pellet	Mash with Fines Steam Pelleted	Mash with Fines Cold Pelleted	SEM	Trt	Steam vs cold pellet	Steam pellet vs mash	Cold pellet vs mash
BW, lb													
d 0	22.58	22.55	22.60	22.50	22.60	22.63	22.63	22.53	0.891	1.000	0.935	1.000	0.842
d 7	28.93	28.73	28.78	29.73	28.93	28.73	28.65	29.20	0.976	0.963	0.913	0.835	0.287
d 14	38.12	35.10	36.35	38.08	35.63	36.48	34.60	36.45	1.091	0.059	0.236	0.030	0.064
d 21	48.98^{a}	42.93^{c}	45.78^{abc}	48.80^{a}	43.15^{c}	46.83^{ab}	42.83^{c}	45.15^{bc}	1.388	0.0003	0.006	0.002	0.009
d 0 to 7													
ADG, lb	0.91	0.88	0.88	1.03	0.90	0.87	0.86	0.95	0.053	0.345	0.761	0.700	0.029
ADFI, lb	1.20^{abc}	1.14^{bc}	1.11^{c}	1.29^{ab}	1.13^{c}	1.15^{bc}	1.35^{abc}	1.21^{ab}	0.055	0.037	0.938	0.271	0.024
G:F	0.75	0.77	0.79	0.80	0.80	0.76	0.65	0.80	0.039	0.061	0.833	0.570	0.628
d 7 to 14													
ADG, lb	1.24^{a}	0.91^{ed}	1.08^{abc}	1.19^{ab}	0.96^{edc}	1.11^{abc}	0.85^{e}	1.04^{bdc}	0.059	0.0001	0.009	0.001	0.031
ADFI, lb	1.83^{bc}	1.52^{e}	1.62^{ced}	1.89^{b}	1.59^{ed}	1.76^{bcd}	2.26^{a}	2.17^{a}	0.085	<.0001	0.111	0.014	0.039
G:F	0.68^{a}	0.59^{b}	0.67^{ab}	0.63^{ab}	0.60^{ab}	0.63^{ab}	0.39^{d}	0.49^{c}	0.029	<.0001	0.084	0.202	0.655
d 14 to 21													
ADG, lb	1.55^{a}	1.12^{c}	1.35^{ab}	1.53^{a}	1.08^{c}	1.48^{a}	1.18^{bc}	1.24^{bc}	0.073	<.0001	<.0001	0.001	0.006
ADFI, lb	2.36^{c}	1.78^{d}	1.95^{dc}	2.31^{c}	1.76^{d}	2.13^{dc}	3.35^{a}	2.88^{b}	0.152	<.0001	0.083	0.010	0.053
G:F	0.66^{a}	0.63^{a}	0.69^{a}	0.66^{a}	0.61^{a}	0.69^{a}	0.37^{c}	0.46^{b}	0.031	<.0001	0.026	0.991	0.832
d 0 to 21													
ADG, lb	1.23^{a}	0.97^{c}	1.10^{b}	1.25^{a}	0.98^{c}	1.15^{ab}	0.96^{c}	1.08^{bc}	0.043	<.0001	0.001	0.001	0.001
ADFI, lb	1.79^{c}	1.48^{d}	1.56^{d}	1.83^{c}	1.49^{d}	1.68^{dc}	2.32^{a}	2.09^{b}	0.074	<.0001	0.073	0.004	0.008
G:F	0.69^{a}	0.65^{a}	0.71^{a}	0.68^{a}	0.66^{a}	0.69^{a}	0.43^{c}	0.53^{b}	0.023	<.0001	0.078	0.818	0.676

[1] A total of 340 pigs (DNA 241 x 600) were used in a 21-d experiment to evaluate the effects of corn fraction and pelleting technique on nursery pig performance.

[2] Ground corn particle size of 400 microns.

[3] Ground corn with fines (<150 microns) removed via sifting, remaining fraction particle size of 600 microns.

[4] Ground corn with fines (<150 microns) removed via sifting followed by pelleting prior to being proportionally added back

[a-e] Means with different superscripts are significantly different ($P \leq 0.05$).

Table 6. Effects of corn fraction and pelleting technique on nursery pig value[1]

Corn:	Ground Corn[2]			Ground Corn with Fines Removed[3]			Ground Corn with Fines Pelleted[4]			Probability, *P* <				
Feed Form:	Mash	Steam Pellet	Cold Pellet	Mash	Steam Pellet	Cold Pellet	Mash with Fines Steam Pelleted	Mash with Fines Cold Pelleted	SEM	Trt	Steam vs cold pellet	Pellet vs mash	Fines excluded vs fines pelleted
Cost analysis													
Feed cost[5], \$/ton	222.83	226.46	225.38	222.83	226.41	225.50	227.18	225.73	---	---	---	---	---
Total feed cost[6], \$/pig	4.20[c]	3.53[d]	3.70[d]	4.29[c]	3.55[d]	3.97[dc]	5.53[a]	4.95[b]	0.176	<.0001	0.089	0.008	0.016
Cost[7], \$/lb of gain	0.16[c]	0.17[c]	0.16[c]	0.16[c]	0.17[c]	0.16[c]	0.27[a]	0.22[b]	0.011	<.0001	0.311	0.726	0.682
Total revenue[8], \$/pig	13.43[a]	10.60[c]	12.05[b]	13.68[a]	10.69[c]	12.58[ab]	10.50[c]	11.77[bc]	0.466	<.0001	0.001	0.001	0.001
Income over feed cost[9], \$	9.23[a]	7.07[c]	8.35[ab]	9.39[a]	7.14[bc]	8.61[a]	4.98[d]	6.82[c]	0.453	<.0001	0.004	0.008	0.009

[1] A single diet formulation was manufactured using specified corn fractions and then processed using different pelleting techniques to create 8 dietary treatments.
[2] Composite corn fraction particle size of 400 microns.
[3] Ground corn with fines (<150 microns) removed via sifting, remaining fraction particle size of 600 microns.
[4] Ground corn with fines (<150 microns) removed via sifting followed by pelleting prior to being proportionally added back.
[5] Standardized cost for time of feed manufacture: corn \$128/ton, soybean meal \$343/ton, electricity \$0.12/kwh
[6] Total feed cost = feed cost * feed consumed per pig
[7] Cost = total feed cost divided by total gain per pig.
[8] One lb. of live weight gain was estimated to be worth \$0.63.
[9] Income over feed cost = total revenue per pig – feed cost per pig.