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Effects of Adding Cracked Corn to a Pelleted Supplement for Nursery and Finishing Pigs

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Summary
Three experiments were conducted to determine the effects of supplementing cracked corn into diets of nursery and finishing pigs. In Exp. 1, 144 pigs were used in a 28-d trial. Pigs (PIC TR4 × 1050; initially 16.5 lb) were weaned and allotted with 6 pigs per pen (3 barrows and 3 gilts) and 6 pens per treatment. All pigs were fed a common diet for 7 d postweaning and the experimental diets for the next 28 d. Treatments were corn-soybean meal-based in the form of mash, pellets, and pellets with 100% of the corn either ground (618 μm) or cracked (3,444 μm) and blended into the diet after the rest of the formulation (the supplement) had been pelleted. Overall (d 0 to 28), ADG and F/G improved when pigs were fed the mash control compared to the pelleted diets ($P < 0.001$); however, this response was caused by the poor performance of pigs fed the supplement treatments, with the pigs fed the complete pellets having improved ($P < 0.01$) ADG and F/G compared with pigs fed the pelleted supplement blended with ground and cracked corn. Finally, pigs fed the supplement blended with cracked corn had numerically lower ($P < 0.11$) ADG and poorer ($P < 0.001$) F/G compared to those fed the supplement blended with ground corn.

In Exp. 2, 224 nursery pigs (initially 16.3 lb) were used with 7 barrows or 7 gilts per pen and 8 pens per treatment. Treatments were corn-soybean meal-based and fed as mash, pellets, and pellets with 50% of the corn either ground (445 μm) or cracked (2,142 μm) and blended with the pelleted supplement. Pigs fed mash had improved ($P < 0.03$) ADG and F/G compared with pigs fed the other treatments; however, this resulted from adding ground or cracked corn outside the pellets (complete pellets vs. pelleted supplement with corn, $P < 0.01$).

In Exp. 3, 252 finishing pigs (initially 88.2 lb) were used with 7 pigs per pen and 9 pens per treatment. The treatments were the same as Exp. 2. Pigs fed mash had lower ($P < 0.004$) ADG compared with pigs fed diets with pellets. Pigs fed complete pellets had improved ($P < 0.03$) ADG and F/G compared with pigs fed corn and the pelleted supplement. Also, pigs fed the supplement blended with cracked corn had greater ($P < 0.02$) ADG than pigs fed the supplement blended with ground corn. Pelleting the diet led to an increase ($P < 0.05$) in ulceration scores; however, these negative effects on ulcer scores were reduced ($P < 0.001$) by cracking 50% of the corn and adding it post-pellet.

Key words: corn, cracked corn, feed processing, pelleting, nursery pig, finishing pig

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Introduction

From 2008 to present, historically high grain prices have pressured swine producers to strive for maximizing efficiency of gain by pigs as never before. An effective means of reducing high feed costs is improving nutrient utilization through feed processing. Previous research at Kansas State University has demonstrated that grinding and pelleting grains leads to improvements in nutrient digestibility and efficiency of gain in pigs; however, these feed manufacturing practices also have negative impacts. Fine grinding of cereals decreases bulk density, production rate, and flowability of feed while also increasing dustiness and the amount of energy required for processing. Pelleting can be used to reduce or eliminate bridging and dustiness and restore bulk density, but it adds energy costs for feed processing and often becomes the limiting factor in feed mill throughput. Additionally, fine grinding and pelleting have been shown to increase the incidence and severity of ulceration of the pars esophagea region of the pigs' stomach.

Colleagues in the poultry industry have suggested that feeding whole and cracked grain can improve gut health and reduce milling cost without negatively affecting growth performance in broilers. Thus, we designed 3 experiments to determine the effects of adding cracked corn to diets on growth performance and milling efficiency while preparing diets for nursery and finishing pigs.

Procedures

All animal use in these experiments was approved by the Kansas State University Animal Care and Use Committee.

Experiment 1. A total of 144 pigs (PIC TR4 × 1050, initially 16.5 lb) were weaned at 21 d of age, sorted by sex and ancestry, blocked by weight, and assigned to pens, with 3 barrows and 3 gilts per pen and 6 pens per treatment. The pigs were housed in an environmentally controlled nursery with pens (4 ft × 5 ft) having woven wire flooring. Animal level temperature was initially 90°F and was decreased by 3°F each week. Each pen had a self-feeder and nipple water to allow ad libitum consumption of feed and water. Pigs were fed a common pelleted diet (Rapid Start N/T; Suther Feeds Inc., Frankfort, KS) for the first 7 d postweaning, then used in a 28-d growth assay. Treatments were corn-soybean meal-based and fed in the form of mash, pellets, and pellets with 100% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted. The experimental diets (Table 1) were fed in 2 phases, with Phase 1 fed from d 0 to 14 and Phase 2 from d 14 to 28 of the experiment. All diets were formulated to meet or exceed the nutrient requirement estimates suggested by the National Research Council (NRC, 1998[4]). Pigs and feeders were weighed on d 0, 14, and 28 of the experiment to allow calculation of ADG, ADFI, and F/G.

All feed processing was completed at the K-State Grain Science Pilot Feed Mill. The corn was milled using a three-high roller mill (1:1, 1.5:1, 1.5:1 differential drives; 3.2, 4.7, and 6.3 corrugations per centimeter; and 0, 8.3, and 8.3 cm of spiral per meter of roller, Model K, Roskamp Manufacturing, Cedar Falls, IA). Particle size of the ground and cracked corn was determined using Tyler sieves (numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, 270, and a pan) and Ro-Tap shaker (W. S. Tyler, Mentor, OH).

[4] NRC. 1998. Nutrient Requirements of Swine.10th ed. Natl. Acad. Press, Washington, DC.

One hundred-gram samples were sifted for 10 min and the weight of the residue on each screen was used to calculate geometric mean particle size (d_{gw}) and the log normal standard deviation (s_{gw}). A 30 horsepower pellet mill (30 HD Master Model, California Pellet Mill, San Francisco, CA) equipped with a 5/32-in. × 7/8-in. die was used to pellet the complete pellets and the pelleted supplement. Feed was steam conditioned to approximately 160 and 180°F prior to pelleting for Phase 1 and 2, respectively. To preserve pellet quality, added fat exceeding 2% was applied postpellet. Pellet durability index (PDI) was determined using the standard tumbling-box technique. Finally, an amp-volt meter (Model DM-II, Amprobe Instrument, Lynbrook, NY) was used to calculate energy consumption during the grinding and pelleting processes.

Experiment 2. A total of 224 pigs (PIC TR4 × 1050, initially 16.3 lb) were weaned at 21 d of age, sorted by sex and ancestry, blocked by weight, and assigned to pens, with 7 barrows and 7 gilts per pen and 8 pens per treatment. Animal housing and management were identical to procedures used in Exp. 1. Treatments were corn-soybean meal-based and fed as mash, pellets, and pellets with 50% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted. The experimental treatments (Table 1) were fed in 2 phases, with Phase 1 d 0 to 13 of the experiment and Phase 2 d 13 to 28. All diets were formulated to meet or exceed the nutrient concentrations suggested by the National Research Council (NRC, 1998).

Pigs and feeders were weighed on d 0, 13, and 28 of the experiment to allow calculation of ADG, ADFI, and F/G. All feed processing was completed at the K-State Grain Science Pilot Feed Mill. All diets were processed as in Exp. 1, but added fat exceeding 5% was applied postpellet in Exp. 2. Grain particle size, PDI, and energy consumption were also determined as described for Exp. 1. A modified PDI was also determined by adding 5 hexagonal nuts into the tumbling box.

Experiment 3. Two hundred fifty-two finishing pigs (PIC TR4 × 1050; average initial BW of 88.8 lb) were sorted by weight, sex, and ancestry and assigned to pens and treatments were randomly assigned. Pigs were housed in an environmentally controlled finishing facility with a complete slatted concrete floor and adjustable gates to allow for 10 ft^2/pig. Each pen contained a self-feeder and cup waterer to allow ad libitum consumption of feed and water. An automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) was used to feed individual pens and record feed weights for each pen. The 80-d experiment had 7 pigs per pen (4 barrows and 3 gilts) and 9 pens per treatment. Treatments were the same as described in Exp. 2. The automated feeding system was used to blend ground or cracked corn with the pelleted supplement. Diets were fed in 3 phases (Table 3). Diets were formulated to meet or exceed all nutrient requirement estimates by the National Research Council (NRC, 1998).

Feed processing was completed at a commercial feed mill (Key Feeds, Clay Center, KS). For the complete mash, complete pellet, and pelleted supplement with ground corn treatments, corn was milled through a hammer mill (Jacobson P24209 series 2) equipped with a full circle screen with 1/8-in.-diameter openings. For the cracked corn treatment, the corn was processed using a 40 horsepower two-high roller mill (1.5:1, 1.5:1 differential drives; 1.55 and 1.55 corrugations per centimeter; and 6 and 16 cm of spiral/meter of roller, Ferrell Ross 10 × 36, Hereford, TX). The geometric mean

particle size, log normal standard deviation, PDI, modified PDI, and energy consumption were determined as described in Exp. 1. The complete pellet and the pelleted supplement were pelleted in a 125 horsepower pellet mill (Century, California Pellet Mill, San Francisco, CA) with 3/16-in. die. All supplemental fat was added in the mixer before conditioning with steam at 167°F before pelleting.

Pigs and feeders were weighed on day 0, 26, 54, and 80 to allow calculation of ADG, ADFI, and F/G. On d 80, the pigs were tattooed and shipped to a commercial abattoir (Farmland Foods Inc., Crete, NE) for collection of carcass data and stomachs. The esophageal region of the stomachs was removed and scored for ulcers and keranitization by a trained veterinary pathologist. For keratinization, the non-glandular mucosa of the esophageal region that was not ulcerated was scored on the scale of 1 = none (normal or no keratinization), 2 = mild (keratin covering < 25% of the non-glandular mucosa), 3 = moderate (keratin covering 25 to 75% of the non-glandular mucosa), and 4 = severe (keratin covering > 75% of the non-glandular mucosa). Because keratinization is a precursor to ulceration, stomachs that were fully ulcerated and thus had no remaining squamous epithelium were assumed to have been fully keratinized prior to ulcer development and given a score of 4 for keratinization. For ulceration, the esophageal region was scored as 1 = none, 2 = mild (ulceration present but affecting < 25% of the non-glandular mucosa), 3 = moderate (ulceration of 25-75% of the non-glandular mucosa), and 4 = severe (ulceration of > 75% of non-glandular mucosa).

Statistical analysis. Data in Exp. 1 and 2 were analyzed as a randomized complete block design and data in Exp. 3 were analyzed as a completely randomized design using the MIXED procedure of SAS (v9.2; SAS Institute Inc., Cary, NC). In Exp. 1, BW at d 7 (the initiation of the growth assay) was used as a covariate. Orthogonal contrasts were used to separate treatment means in all experiments with comparisons of: (1) mash vs. treatments with pellets, (2) complete pellets vs. pelleted supplement with ground and cracked corn, and (3) pelleted supplement with ground vs. cracked corn. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.15$.

For Exp. 3, HCW was used as a covariate for analyses of backfat thickness, loin depth, and fat-free lean index (FFLI).

Results and Discussion

Experiment 1. The particle sizes of the ground and cracked corn were 618 and 3,444 μm, respectively. The difference in milling procedure resulted in 7.6 times more energy (6.8 vs. 0.9 kWh/ton) required to fine-grind corn in the hammermill vs. cracking corn in the roller mill. Fine-grinding corn in the hammer mill also reduced throughput from 4.3 to 1.1 ton/h compared with cracking corn in the roller mill.

Energy required for pelleting the complete pellet and the pelleted supplement was 14.3 and 13.0 kWh/ton, respectively (Table 3). The supplement and complete diet for Phase 1 had similar PDI, but for Phase 2 the PDI for the supplement was 7% points greater than the PDI for the complete diet.

Grinding and pelleting the complete diet required 5 times more energy (17.3 vs 3.5 kWh/ton) than simply grinding the mash (Table 4); however, total energy required to

produce the pelleted supplement with ground or cracked corn was reduced by 7.4 and 10 kWh/ton, respectively, when compared with pelleting the entire diet.

Overall (d 0 to 28), ADG, F/G, and final BW were improved when pigs were fed the mash control compared to the pelleted diets ($P < 0.001$), but this response was caused by the poor performance of pigs fed the supplement treatments with the pigs fed the complete pellets having improved ($P < 0.01$) ADG, F/G, and final BW compared with pigs fed the pelleted supplement blended with ground and cracked corn. Finally, pigs fed the supplement blended with cracked corn had numerically lower ($P < 0.11$) ADG, final BW, and poorer ($P < 0.001$) F/G compared with those fed the supplement blended with ground corn.

Experiment 2. The particle sizes of the ground and cracked corn were 445 and 2,412 μm, respectively. Grinding the corn using the hammer mill required 8.3 times the amount of energy (8.2 vs. 0.99 kWh/ton) as the roller mill used to crack corn (Table 5).

The average energy required to pellet the complete diet (8.14 kWh/ton) and the supplement (7.88 kWh/ton) were similar (Table 5). The PDI (96.6% and 96.7%) and modified PDI (95.8% and 95.8%) were almost identical for both the complete and supplement pellets for Phase 1, respectively. For Phase 2 diets, the PDI and modified PDI for the supplement were 1.6 and 3.5% points higher than the PDI and modified PDI for the complete pellets, respectively.

To grind and pellet the complete diet required 3 times more total energy (12.3 vs 4.2 kWh/ton) than simply grinding the mash (Table 6), but total energy required to produce the pelleted supplement with ground or cracked corn was reduced by 2.3 and 4.2 kWh/ton, respectively, compared with pelleting the entire diet.

For the 28-d experiment, pigs fed mash had improved ($P < 0.03$) ADG, F/G, and final BW compared to pigs fed the other treatments; however, pigs fed the supplement blended with ground or cracked corn had a trend for decreased ($P < 0.14$) ADG and final BW and increased ($P < 0.001$) ADFI and F/G compared with those fed the complete pellet.

Experiment 3. To pellet the supplement required 9% less energy (kWh/ton) but had a production rate 1% less than the complete diet (Table 7). This does not account for treatment differences due to removing 50% of the corn and adding it postpellet. PDIs and modified PDIs were similar between the complete pellet and the pelleted supplement. Milling of the corn using a roller mill and hammer mill (1/8-in. screen) achieved corn particle sizes of 2,841 μm and 493 μm, respectively. Grinding the corn using the hammer mill required 9 times the energy (kWh/ton) and reduced the production rate by 102% compared with cracking the corn with the roller mill.

The cost effects pelleting can have on a feed mill are also important to consider. To grind and pellet the complete diet, an additional 15.3 kWh/ton of energy was required compared to simply grinding the mash (Table 8); however, removing 50% of the corn from the pellet and either grinding or cracking it reduced total energy consumed by grinding and pelleting by 36 and 48%, respectively. Energy was based on $0.07/kWh when calculating energy cost. Pelleting the complete diet increased the electrical cost

alone from $0.39 to $1.46 compared with simply grinding the mash, but removing 50% of the corn from the pellet and cracking it can reduce diet cost by $0.70/ton compared with the pelleted complete diet.

Adding 50% of the corn after pelleting can reduce cost from $1.46/ton (complete pellet) to $0.93/ton (pelleted supplement with ground corn) or it can be further reduced to $0.76/ton (pellet supplement with cracked corn). A feed mill with the capability of producing 6 tons of pellets/h and running 50 h/wk could produce 300 ton/wk. Pelleting the complete diet would increase electrical cost from $117 to $438 per week, costing them an extra $321/wk for electrical cost alone. If 50% of the corn is removed from the pellet and cracked, it could reduce electrical cost from $438 (complete pellet) to $279 (pelleted supplement with ground corn) or $228 (pelleted supplement with cracked corn)/wk, saving the feed mill $159 or $210/wk, respectively. Applying this scenario to an integrated feed mill producing 10,000 ton/wk would reduce the electrical cost per week from $14,600 (complete pellet) to $9,300 (pellet supplement with ground corn) or $7,600 (pellet supplement with cracked corn), saving the feedmill $5,300 or $7,000/wk, respectively. However, energy is not the only factor that effects cost in the feed mill.

Throughput is another key factor that affects milling cost. Pelleting is the limiting factor in feed mill production rates, so it will be the only thing considered when calculating the treatment effects on production rates. Key Feeds was able to pellet 6 ton/h. If a feed mill producing 6 ton/h needed to produce 300 ton/wk, the pellet mill would be required to run for 50 h/wk. Pulling 50% of the corn from the finishing pig diet resulted in an average of 60% of the diet as the pelleted supplement and 40% of the diet as corn outside of the pellet. Removing 50% of the corn would reduce the amount of pellets required from 300 ton/wk to 180 ton/wk, which would require the feed mill to run 30 h/wk instead of 50 h/wk. Assuming a feed mill of this size would cost $175/h to run, reducing the operating time by 20 h would save the feed mill approximately $3,500/wk.

For the overall experiment (d 0 to 80), pigs fed the diets with pellets had increased ($P < 0.02$) ADG and ADFI, with no difference in F/G compared with those fed the mash (Table 9); however, pigs fed the pelleted supplement with ground or cracked corn had poorer ($P < 0.03$) ADG and F/G and a trend for increased ADFI ($P < 0.08$) compared with those fed the complete pellet, with the pelleted supplement and ground corn causing the decrease (P < 0.02; the supplement plus ground corn vs. the supplement plus cracked corn) in ADG. Although the contrast statements did not directly compare the complete pellet with the mash, we observed a 6 and 4% improvement in ADG and F/G, respectively, when pigs were fed the complete diets in the pellet form compared with the mash form. No differences were measured in F/G when feeding the pelleted supplement with either ground or cracked corn. The difficulty of feeder management and sorting of feed was notably increased when adding either ground or cracked corn postpellet, but due to particle size of the cracked corn, it blended better with the supplement than the ground corn, which provided for easier feeder management and less sorting of feed than the ground corn plus the pelleted supplement treatment. We believe this is the reason feed efficiency was not better for the supplement with ground corn compared with cracked corn, but this conclusion was based on observation alone; feed wastage was not measured.

No differences were found in HCW, backfat thickness, or percentage FFLI among treatments (Table 9). Pigs fed the pelleted treatments had reduced ($P < 0.02$) percentage yield compared with those fed the mash, and pigs fed the pelleted supplement with cracked corn had decreased ($P < 0.002$) percentage yield compared with pelleted supplement with ground corn. Pigs fed the complete diet had decreased ($P < 0.03$) loin depth compared with those fed the pellet supplement and corn either ground or cracked.

Pigs fed the pelleted diets had similar keratinization scores as those fed the mash diet (Table 10), but pigs fed the pelleted supplement plus corn had improved ($P < 0.02$) stomach keratinization scores, with a majority of this reduction caused by adding cracked corn postpellet (P < 0.004; pellet supplement plus ground corn vs. pellet supplement plus cracked corn). Pelleting the diet led to an increase ($P < 0.05$) in ulceration scores; however, these negative effects on ulcer scores were reduced ($P < 0.001$) by cracking 50% of the corn and adding it postpellet, which resulted in the lowest stomach ulcer scores.

In conclusion, pelleting the complete diet for nursery pigs improved efficiency of gain in 1 of the 2 experiments, but adding a percentage of the corn after pelleting is not a viable option for nursery pigs. In finishing pigs, pelleting the complete diet led to improvements in performance, but pelleting the diet increased feed mill energy consumption and increased the incidence of pars esophageal lesions in the stomach. The negative effects of pelleting on stomach morphology and feed mill cost were alleviated by cracking 50% of the corn and adding it postpellet. Although finishing pigs fed the cracked corn achieved maximum rates of gain, feed efficiency was reduced by 6% compared with pigs fed the complete pellet; therefore, due to high feed cost, feeding cracked corn is not a viable option unless it is necessary for mortality reasons or to meet production rates.

Table 1. Composition of experimental diets (Exp. 1[1] and 2[2]; as-fed basis)

Item	Phase 1	Phase 2
Ingredient, %		
Corn	44.50	57.82
Soybean meal (46.5% CP)	29.00	33.10
Spray-dried whey	15.00	—
Spray-dried plasma	2.50	—
Menhaden fishmeal	3.00	—
Soybean oil	3.00	5.00
Monocalcium phosphate (21% P)	0.63	1.31
Limestone	0.86	1.11
Salt	0.30	0.37
L-Lysine HCl	0.21	0.32
DL-Methionine	0.13	0.13
L-Threonine	0.03	0.10
Vitamin premix	0.25	0.25
Mineral premix	0.15	0.15
Zinc oxide	0.19	—
Copper sulfate	—	0.09
Antibiotic[3]	0.25	0.25
Calculated analysis, %		
Standardized ileal digestible lysine	1.45	1.27
Ca	0.82	0.78
Available P	0.43	0.35

[1] Experimental treatments were fed as mash, pellets, and pellets with 100% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted.
[2] Experimental treatments were fed as mash, pellets, and pellets with 50% of the corn (ground or cracked) blended into with the pelleted supplement.
[3] To provide 154 g/ton oxytetracycline and 154 g/ton neomycin.

Table 2. Composition of experimental diets (Exp. 3; as-fed basis)[1]

Item	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn	74.04	79.25	84.70
Soybean meal (46.5% CP)	22.00	17.15	11.90
Choice white grease	1.00	1.00	1.00
L-Lysine HCl	0.35	0.34	0.35
DL-Methionine	0.074	0.070	0.048
L-Threonine	0.110	0.117	0.110
L-Tryptophan	0.019	0.023	0.037
Monocalcium phosphate (21% P)	0.91	0.720	0.540
Limestone	1.08	0.91	0.89
Salt	0.25	0.25	0.25
Vitamin premix	0.08	0.08	0.08
Mineral premix	0.04	0.04	0.04
Antibiotic[2]	0.05	0.050	0.05
Calculated analysis, %			
Standardized ileal digestible lysine	1.00	0.88	0.76
Ca	0.70	0.55	0.50
Available P	0.30	0.21	0.17

[1] Experimental treatments were fed as mash, pellets, and pellets with 50% of the corn (ground or cracked) blended into the diet after the rest of the formulation (the supplement) had been pelleted.
[2] Provided (per kilogram of diet) 9.1 mg/kg of tylosin.

Table 3. Processing characteristics (Exp. 1)

Item	Complete pellet	Supplement pellet	Ground corn[1]	Cracked corn[1]
Grinding				
Energy, kWh/t	N/A[2]	N/A	6.8	0.9
Production rate, t/h	N/A	N/A	1.1	4.3
Particle size				
dgw, µm[3]	N/A	N/A	618	3,444
sgw, µm[4]	N/A	N/A	2.16	1.4
Pelleting				
Phase 2				
Energy, kWh/ton	14.3	13.0	N/A	N/A
Production rate, ton/h	0.75	0.85	N/A	N/A
PDI, %[5]	97	98	N/A	N/A
Phase 3				
Energy, kWh/ton	13.3	13.0	N/A	N/A
Production rate, ton/h	0.83	0.85	N/A	N/A
PDI,%[5]	87	94	N/A	N/A

[1] Corn was milled using a three-high roller mill (Model K, Roskamp Manufacturing, Cedar Falls, IA).
[2] Not applicable.
[3] Geometric mean particle size.
[4] Log normal standard deviation.
[5] Pellet durability index.

Table 4. Effects of replacing 100% of ground corn in pellets with cracked corn in nursery pig diets (Exp. 1)[1]

Item	Complete mash	Complete pellet	Ground corn + supplement	Cracked corn + supplement	SE	Contrasts[2] 1	2	3
Energy kWh/ton[3]	3.5	17.3	9.9	7.3				
d 0 to 28								
ADG, lb	1.09	1.04	0.98	0.93	0.03	0.001	0.01	0.11
ADFI, lb	1.45	1.37	1.43	1.43	0.03	0.16	0.10	0.93
F/G	1.33	1.32	1.46	1.55	0.06	0.001	0.001	0.001
Final BW, lb	46.0	44.5	43.0	41.5	0.3	0.001	0.01	0.11

[1] A total 144 pigs (PIC TR4 × 1050, average initial BW of 16.5 lb) were used in the 28-d growth assay with 6 pigs per pen and 6 pens per treatment.
[2] Contrast were: (1) mash vs. treatments with pellets, (2) complete pellets vs. pellet supplement with ground or cracked corn, and (3) ground corn plus pellet supplement vs. cracked corn plus pellet supplement.
[3] Energy (kWh/ton) = (corn % * grinding energy (kWh/ton)) + (supplement % * pelleting energy (kWh/ton)).

Table 5. Processing characteristics (Exp. 2)

Item	Complete pellet	Supplement pellet	Ground corn[1]	Cracked corn[2]
Grinding				
Energy, kWh/ton	N/A[3]	N/A	8.20	0.99
Production rate, ton/h	N/A	N/A	2.30	5.01
Particle size				
dgw, µm[4]	N/A	N/A	445	2,412
sgw, µm[5]	N/A	N/A	2.63	2.14
Pelleting				
Phase 2				
Energy, kWh/ton	6.20	5.51	N/A	N/A
Production rate, ton/h	1.55	1.46	N/A	N/A
PDI, %[6]	96.6	96.7	N/A	N/A
Modified PDI, %[7]	95.8	95.8	N/A	N/A
Phase 3				
Energy, kWh/ton	10.08	10.25	N/A	N/A
Production rate, ton/h	1.00	1.00	N/A	N/A
PDI, %[6]	88.9	90.5	N/A	N/A
Modified PDI, %[7]	82.6	86.1	N/A	N/A

[1] Corn was milled using a hammer mill (Jacobson P240D) with a screen size of 1/8 in. (teardrop full circle screen).
[2] Corn was milled using a three-high roller mill (Model K, Roskamp Manufacturing, Cedar Falls, IA).
[3] Not applicable.
[4] Geometric mean particle size.
[5] Log normal standard deviation.
[6] Pellet durability index.
[7] Modified by adding 5 ½-in. hexagonal nuts prior to tumbling.

Table 6. Effects of replacing 50% of ground corn in pellets with cracked corn in nursery pig diets (Exp. 2)

Item	Complete mash	Complete pellet	Ground corn + pelleted supplement	Cracked corn + pelleted supplement	SE	Contrasts[2]		
						1	2	3
Energy kWh/ton[3]	4.2	12.3	9.98	8.1				
d 0 to 28								
ADG, lb	1.12	1.10	1.07	1.04	0.03	0.03	0.12	0.26
ADFI, lb	1.56	1.45	1.63	1.62	0.04	0.96	0.001	0.78
F/G	1.39	1.32	1.52	1.56	0.03	0.01	0.001	0.25
Final BW, lb	48.03	47.09	46.18	45.61	1.29	0.03	0.14	0.53

[1] A total 224 pigs (PIC TR4 × 1050, average initial BW of 16.5 lb) were used in the 28-d growth assay with 7 pigs per pen and 8 pens per treatment.
[2] Contrasts were: (1) mash vs. treatments with pellets, (2) complete pellets vs. pellet supplement with ground or cracked corn, and (3) ground corn plus pelleted supplement vs. cracked corn plus pelleted supplement.
[3] Energy (kWh/ton) = (corn % * grinding energy (kWh/ton)) + (supplement % * pelleting energy (kWh/ton)).

Table 7. Processing characteristics of grinding or cracking corn and pelleting the complete diet or supplement (Exp. 3)

Item	Complete pellet	Supplement pellet	Ground corn[1]	Cracked corn[2]
Grinding				
Energy, kWh/ton	N/A[3]	N/A	6.95	0.76
Production rate, ton/h	N/A	N/A	6.0	13.2
dgw, µm[4]	N/A	N/A	493	2,841
sgw, µm[5]	N/A	N/A	2.64	1.97
Pelleting				
Energy, kWh/ton	15.27	13.91	N/A	N/A
Production rate, ton/h	6.05	5.98	N/A	N/A
PDI, %[6]	89.3	90.4	N/A	N/A
Modified PDI, %[7]	84.9	85.5	N/A	N/A

[1] Corn was milled using a hammer mill (JacobseenP24209 Series 2) with a screen size of 1/8 in. (full circle screen).
[2] Corn was milled using a two-high roller mill (Ferrell Ross 10 × 30, Hereford, TX).
[3] Not applicable.
[4] Geometric mean particle size.
[5] Log normal standard deviation.
[6] Pellet durability index.
[7] Modified by adding 5 ½-in. hexagonal nuts prior to tumbling.

Table 8. Electrical consumption and cost for experimental treatments (Exp. 3)

Item	Complete mash	Complete pellet	Ground corn + pelleted supplement	Cracked corn + pelleted supplement
Energy, kWh/ton[1]	5.5	20.8	13.3	10.9
Electrical cost, $/ton[2]	0.39	1.46	0.93	0.76
Hammer mill	0.39	0.39	0.39	0.20
Roller mill	0.00	0.00	0.00	0.02
Pellet mill	0.00	1.07	0.54	0.54

[1] Energy (kWh/ton) = (corn % * grinding energy (kWh/ton)) + (supplement % * pelleting energy (kWh/ton)).
[2] Energy cost was based on $0.07/kWh.

Table 9. Effects of replacing 50% of ground corn in pellets with cracked corn in finishing pig diets (Exp. 3)[1]

Item	Complete mash	Complete pellet	Ground corn + pelleted supplement	Cracked corn + pelleted supplement	SE	Contrast[2] 1	2	3
d 0 to 80								
ADG, lb	2.30	2.44	2.33	2.41	0.03	0.004	0.03	0.02
ADFI, lb	5.86	5.99	6.07	6.36	0.10	0.02	0.08	0.06
F/G	2.55	2.46	2.61	2.64	0.04	0.62	0.001	0.61
Carcass characteristics								
HCW, lb	204.2	210.8	205.4	208.3	2.4	0.17	0.19	0.41
Carcass yield, %	74.4	74.0	74.4	73.7	0.1	0.02	0.78	0.001
Backfat thickness, in.[3]	0.73	0.79	0.78	0.74	0.02	0.15	0.33	0.22
Loin depth, in.[3]	2.69	2.60	2.70	2.66	0.03	0.29	0.03	0.36
FFLI, %[3,4]	52.39	51.51	51.64	52.12	0.32	0.10	0.37	0.29

[1] A total 252 pigs (PIC TR4 × 1050, average initial BW of 89 lb) were used in the 80-d growth assay.
[2] Contrasts are: (1) mash vs. treatments with pellets, (2) complete pellets vs. pelleted supplement with ground and cracked corn, and (3) pelleted supplement with ground vs. pelleted supplement with cracked corn.
[3] HCW used as a covariate.
[4] Fat-free lean index.

Table 10. Effects of cracked corn on stomach morphology in finishing pigs (Exp. 3)[1]

Item	Complete mash	Complete pellet	Ground corn + pellet supplement	Cracked corn + pellet supplement	SE	Contrast[2] 1	2	3
Stomach keratinization[3]								
No. observations	44	41	45	46				
Normal	8	3	3	16				
Mild	11	13	12	14				
Moderate	12	2	10	4				
Severe	13	23	20	12				
Mean	2.67	3.22	3.08	2.25	0.26	0.43	0.02	0.004
Stomach ulceration[4]								
No. observations	44	41	45	46				
Normal	29	16	19	36				
Erosions	8	15	12	6				
Ulcers	6	5	12	2				
Severe ulcers	1	5	2	2				
Mean	1.53	2.05	2.02	1.36	0.12	0.05	0.02	0.001

[1] A total 252 pigs were used in the 80-d growth assay with an average initial BW of 89 lb and an average final BW of 279 lb.
[2] Contrasts are: (1) mash vs. treatments with pellets, (2) complete pellets vs. pelleted supplement with ground and cracked corn, and (3) pelleted supplement with ground vs. cracked corn.
[3] Scored on scale: 1 = none, 2 = mild, 3 = moderate, and 4 = severe.
[4] Scored on scale: 1 = none, 2 = mild, 3 = moderate, and 4 = severe.