Title: Evaluating Moderate to Severe Feed Processes in Light of Increasing Use of Wheat in Swine Diets. **NPB #13-069**

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Industry Summary:

The overriding objective of this research was to improve the industry-wide lack of knowledge of how wheat particle size and pelleting of complete diets containing wheat for nursery and finishing pigs can improve performance and economic return for swine producers. In order to accomplish this overall objective, two experiments were conducted to evaluate the effects of fine grinding and pelleting wheat on growth performance, nutrient digestibility, carcass characteristics, and economic return of grow-finish pigs. In Exp. 1, hard red or soft white winter wheat was ground to approximately 600, 400, or 200 µ and fed in pelleted wheat-soybean meal diets to grow-finish pigs to measure pig performance and economic costs of particle size reduction and pelleting. In Exp. 2, hard red winter wheat was ground to approximately 800, 600, or 400 µ and fed in meal diets in a similar trial.

Pigs fed hard red winter wheat consumed more feed, grew faster, and had greater DM digestibility than pigs fed soft white winter wheat with no appreciable differences due to grinding finer than 600 µ when fed in pelleted diets. For meal diets, grinding wheat less than 800 microns linearly improved feed efficiency and nutrient digestibility to the smallest micron size fed. Grinding the wheat for meal diets improved the caloric content of the wheat by 100 kcal of NE/lb or approximately 25 kcal NE per 100 microns.

When pelleting, reducing particle size from 600 to 200 µ of both wheat sources increased pellet durability index. Although the impact on cost of production was modest, electrical needs per ton were reduced with fine grinding of soft white winter wheat, but increased with grinding of hard red winter wheat. This difference may be related to the greater pellet durability index achieved with hard red than soft white winter wheat.

Producer bottom line;

- Similar to recent research at Kansas State University with corn, feed efficiency appears to improve as wheat particle size is reduced to less than 600 μ when fed in meal diets, but not when fed in pelleted diets.
- Pigs fed hard red winter wheat had superior daily gain and feed intake compared to pigs fed soft white winter wheat, but feed efficiency was similar between wheat sources.
- It is recommended that wheat be ground to a particle size under 400 μ when feeding hard red winter wheat in meal diets for maximum nutrient digestibility.

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Scientific Abstract:

A total of 864 pigs (PIC 327 × 1050; initially 96 lb) were used in two studies to determine the effects of hard red and soft white winter wheat particle size on finishing pig growth performance, diet digestibility and caloric efficiency. Pens of pigs were balanced by initial BW and randomly allotted to treatments with 8 pigs per pen and 12 pens per treatment in each experiment. In each study, the same basal wheat-soybean meal–based diets were used for all treatments with diets fed in three phases.

In Exp. 1, the 6 experimental diets were based on hard red winter wheat ground to 200, 400, or 600 μ or soft white winter wheat ground to 200, 400, or 600 μ. All diets were fed in pelleted form. Overall, feeding hard red winter wheat improved ($P < 0.05$) ADG, ADFI, and caloric efficiency on both an ME and NE basis when compared to soft white winter wheat. There was a tendency ($P < 0.07$) for a quadratic particle size × wheat source interaction for ADG, ADFI, and both DM and GE digestibility. This was due to ADG, ADFI, and both DM and GE digestibility having the lowest values at 400 μ for hard red winter wheat while they were all the highest at 400 μ for soft white winter wheat. There were no significant ($P > 0.10$) main effects of particle size, or particle size within wheat source. Finally, dietary treatments did not impact carcass characteristics. In conclusion, decreasing wheat particle size from 600 to 200 μ in pelleted diets had no effect on growth performance. Feeding hard red winter wheat improved ADG, ADFI, and caloric efficiency when compared to feeding soft white winter wheat.

In Exp. 2, the 3 dietary treatments were hard red winter wheat ground with a hammer mill to 730, 580, or 330 μ. From d 0 to 40, decreasing wheat particle size decreased (linear; $P < 0.05$), ADFI, but improved (quadratic; $P < 0.05$) F/G and caloric efficiency (CE), with no change in ADG. From d 40 to 83, decreasing wheat particle size increased (quadratic; $P < 0.05$) ADG, and improved (linear; $P < 0.05$) F/G and CE, with no change in ADFI. Overall from d 0 to 83, decreasing wheat particle size improved (linear; $P < 0.05$) F/G, and CE on both an ME and NE basis, with no difference in ADG or ADFI. Finally, reducing wheat particle size improved (linear; $P < 0.05$) DM and GE digestibility. In summary, fine grinding hard red winter wheat was detrimental to feed intake in early finishing, but improved ADG in late finishing and improved F/G in both periods and overall. Dry matter and GE digestibility as well as CE were all improved for the overall period with fine grinding wheat. Grinding wheat from 730 to 330 improved the caloric content on a NE basis by 100 kcal/lb.

Introduction:

Reducing the particle size of cereal grains has been shown to improve the efficiency of gain in swine. Opinions vary regarding the optimum particle size of cereal grains for animal production and feed manufacturing economics. Most experiments exploring optimal particle size of grain have been conducted in meal diets. In corn-soybean meal- based diets, reducing corn particle size below 400 μ can improve F/G in finishing pigs (De Jong et al. 2013) fed mash diets. In wheat-based diets, Kim et al. (2005) observed that decreasing wheat particle size from 929 to 580 μ improved starch digestibility. In addition, Mavromichalis et al. (2000) observed improved feed efficiency when wheat was ground from 600 to 400 μ. While much data exists with corn ground below 400 μ, little data is available that illustrates the impacts of feeding diets containing finely ground wheat.

In addition to fine grinding cereal grains, pelleting has also been shown to consistently improve performance in finishing pigs through reduced intake and improved feed efficiency. Reducing particle size of cereal grains can improve pellet quality by increasing the surface area of the grains during the pelleting process and improving adhesion of the pellet. However, Murphy et al. (2009) reported no differences in growth performance in growing pigs as wheat particle size of pelleted diets was reduced from 639 to 552 μ.

Therefore the objective of this study was to determine the effects of wheat source and particle size on finishing pig growth performance, diet digestibility, caloric efficiency, and carcass characteristics.

Objectives:

The overriding objective is to improve the industry-wide lack of knowledge of how wheat particle size and pelleting of complete diets containing wheat for finishing pigs can improve performance and economic return for swine producers. In order to accomplish this overall objective, the specific objectives to be studied:

1) To quantify relative costs associated with different degrees of feed processing of wheat (i.e., grinding and pelleting).

2) To evaluate the effects of fine grinding and pelleting wheat on growth performance, nutrient digestibility, carcass characteristics, and economic return of grow-finish pigs.

Materials & Methods:

Two separate experiments were conducted to answer our objectives. The first experiment was a 2 × 3 factorial with hard red or soft white winter wheat ground to approximately 200, 400, and 600 microns with all 6 diets pelleted. In the second experiment, hard red winter wheat was ground to target particle sizes of 400, 600, and 800 microns and fed in meal form.

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in both experiments. The studies were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. The barn used for the studies had completely slatted flooring and deep pits. Each pen was equipped with a 2-hole stainless steel feeder and bowl waterer for ad libitum access to feed and water. Feed was delivered to each individual pen by a robotic feeding system (FeedPro; Feedlogic Corp., Wilmar, MN).

Exp. 1

A total of 576 pigs (PIC 327 × 1050, initially 96 lb BW) from two consecutive finishing groups were used to determine the effects of wheat source and particle size of pelleted diets on finishing pig growth performance, caloric efficiency, and carcass characteristics. Pigs were allotted randomly to pens upon entry into the finisher and remained in the experiment for 75 and 89 d respectively for each group. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 6 dietary treatments with 12 replications per treatment and 8 pigs per pen. The 6 basal diets consisted of the same wheat-soybean meal-formulation (Table 1). The experimental treatments were arranged as a 2 × 3 factorial with 2 wheat sources (hard red winter wheat or soft white winter wheat) and 3 particle sizes (200, 400, or 600 μ). All diets were fed in pelleted form.

Pigs and feeders were weighed approximately every 2 weeks to determine ADG, ADFI, and F/G. Caloric efficiencies of pens were determined on both an ME and NE basis. Efficiencies were calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Feed ingredients were assigned an ME and NE value taken from the NRC (2012).

Composite samples of the wheat used in the diets were collected prior to feed manufacturing and analyzed for DM, CP, fat, NDF, ADF, ash and amino acids (Table 2). Nutrient analyses were than used in diet formulation. Feed samples were taken from each feeder during each phase and then combined within treatment and phase for analysis (Table 3, 4, and 5). Bulk density, PDI, and percent fines were determined for all diets (Table 6). Particle size, angle of repose, and bulk density was determined for each wheat source at the three different particle sizes. Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 100-g samples for 10 min. Particle size was conducted with and without a flow agent (Amorphous silica powder, Gilson Company Inc., Middleton, WI) which was added at 0.001 oz to 3.52 oz of feed. Angle of repose was measured by allowing feed to flow freely over a flat circular platform of a known diameter. The diameter of the platform and height of the resulting pile were used to calculate the angle of repose.

Feed was manufactured at the O.H. Kruse Feed Technology Innovation Center on the Kansas State University north campus. Wheat was ground to three particle sizes (245; 465; 693 and 258; 402; 710) for both the hard red and soft white wheat, respectively. The three particle sizes of the hard red wheat were created utilizing a hammer-mill equipped with either a # 2, 10, or 16 screen (0.03, 0.16, 0.25 in), respectively. The hard red wheat ground to 245 μ was first ground through a roller mill to ensure a fine enough grind was achieved through the hammer-mill. Soft white wheat was ground through a #4, 12, and 16 hammer-mill screen (0.06, 0.19, 0.25 in), respectively. During feed manufacturing, electrical consumption and throughput were measured (Table 7).

Fecal samples were collected on d 7 of phase 3 (d 61 and 59 respectively for group 1 and 2) via rectal massage from 2 pigs per pen. The phase 3 diets contained 0.5% titanium dioxide as an inert digestibility marker. After collection, fecal samples were then dried in a 50˚C forced air drying oven and then ground for measurement of energy by bomb calorimetry and titanium concentration. The digestibility values were calculated using the indirect method (Table 8).

Prior to marketing, all pigs were individually weighed and tattooed for carcass data collection and transported to Triumph Foods LLC (St. Joseph, MO). Standard carcass characteristics were measured and jowl fat samples were collected and analyzed at the plant by NIR for IV.

Data were analyzed as a completely randomized design (CRD) using the PROC-Mixed procedure in SAS with pen serving as the experimental unit. Linear and quadratic contrasts were completed to determine the main effects of decreasing wheat particle size as well as the interaction with wheat source. The main effects of wheat source were also determined. Lastly, linear and quadratic contrasts within wheat source for particle size were also tested. Results were considered significant at $P \leq 0.05$ and tendencies between $P > 0.05$ and $P \leq 0.10$.

Exp. 2

A total of 288 pigs (PIC 327 × 1050; initially 96.4 lb) were used in an 83-d study. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 3 treatments with 8 pigs per pen and 12 pens per treatment. The same basal wheat-soybean meal–based diets were used for all treatments. Diets were fed in three phases from d 0 to 27, 27 to 60, and 60 to 83 (Table 9). The 3 dietary treatments included hard red winter wheat ground with a hammermill to approximately 730, 580, or 330 µ. Pigs and feeders were weighed approximately every 2 weeks to determine ADG, ADFI, and F/G. Caloric efficiency was determined on both an ME and NE basis. Caloric efficiency was calculated by multiplying total feed intake × energy in the diet (kcal/lb) and dividing by total gain. Feed ingredients were assigned ME values from the NRC (2012). For NE, values were for the growing pig by INRA (2004).

Feed was manufactured at the O.H. Kruse Feed Technology Innovation Center on the Kansas State University. Wheat was ground to three particle sizes (728; 579; 326) utilizing a hammer-mill equipped with either a # 4, 8, or 12 screen (0.06, 0.13, 0.19 in.) respectively.

Composite samples of the wheat used in the diets were collected prior to feed manufacturing and analyzed for DM, CP, fat, NDF, ADF, ash and amino acids (Table 10). Analyzed values were than used in diet formulation. Feed samples were taken from each feeder during each phase and then combined within treatment and phase for analysis (Table 11). Bulk density, particle size, and angle of repose of major ingredients and all diets were measured (Table 12). Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 100-g samples for 10 min. Particle size was conducted with and without a flow agent (Amorphous silica powder, Gilson Company Inc., Middleton, WI) which was added at 0.001 oz to 3.52 oz of wheat. Particle size of complete diets was conducted without a flow agent. Angle of repose was measured by allowing feed to flow freely over a flat circular platform of a known diameter. The diameter of the platform and height of the resulting pile were used to calculate the angle of repose.

Fecal samples were collected on d 7 of phase 3 (d 67 of the study) from 2 pigs per pen. The phase 3 diets contained 0.5% titanium dioxide as an indigestible marker. After collection, fecal samples were then dried in a 50˚C forced air drying oven and then ground for analysis of gross energy and titanium concentration. The digestibility values were calculated using the indirect method (Table 13).

Data were analyzed as a completely randomized design (CRD) using the PROC-Mixed procedure in SAS with pen serving as the experimental unit. Linear and quadratic contrasts were completed to determine the effects of decreasing wheat particle size. Results were considered significant at $P \leq 0.05$ and tendencies between $P > 0.05$ and $P \leq 0.10$.

Results and Discussion:

Exp. 1

Analysis of dietary treatments showed that all values were similar to those used in formulation. Bulk density and percent fines were similar among treatments; however, PDI was lower for the soft white wheat diets compared to the hard red wheat. Decreasing the particle size of the wheat improved PDI as expected. Wheat particle sizes were close to target levels for hard red winter wheat (693, 465, 245 µ) and soft white winter wheat (710, 402, 258 µ). Reductions in particle size led to increases in angle of repose for both wheat sources, which would suggest decreased flow ability; however, no issues with diet flow ability in feed lines or feeders were realized during the trial. In addition, reducing wheat particle sizes decreased bulk density.

Grinding hard red winter wheat required more kWh compared to soft white winter wheat. For both sources, as wheat was ground finer, kWh increased as expected. Pelleting soft white winter wheat diets increased electrical consumption compared to hard red winter wheat. Finely ground wheat increased electrical consumption for hard red wheat during pelleting but decreased electrical consumption for soft white wheat. Throughput during pelleting was improved by increasing wheat particle size as well as by pelleting soft white wheat compared to hard red wheat.

Overall, feeding hard red winter wheat improved ($P < 0.05$) ADG, ADFI, and caloric efficiency on both an ME and NE basis when compared to soft white winter wheat. The improvement in caloric efficiency was reflective of source differences in the ME and NE values obtained from the NRC because there were no differences in F/G which suggests the energy value for the wheat sources was similar. There was a tendency ($P < 0.07$) for a quadratic particle size × wheat source interaction for ADG, ADFI, and both DM and GE digestibility. This was due to ADG, ADFI, and both DM and GE digestibility having the lowest values at 400 μ for hard red winter wheat while they were the highest at 400 μ for soft white winter wheat. There were no main effects ($P > 0.10$) of particle size, or particle size within wheat source. Finally, dietary treatments did not impact ($P > 0.10$) carcass characteristics.

Results from this study suggest that reducing the particle size of either hard red or soft white winter wheat from 600 to 200 μ does not improve growth performance when diets are pelleted. This is in contrast to previous work done with meal diets, but agrees with Nemechek et al. (2013) who showed that corn based diets had larger improvements to fine grinding when diets were fed in meal form compared to similar diets fed in pelleted form. Less electrical consumption is needed to create wheat at a particle size of 600 μ compared to 200 μ and, thus, should result in diets that are lower cost to manufacturer. Feeding hard red compared to soft white winter wheat improved performance of pigs fed pelleted diets

Exp. 2

Bulk density decreased (Table 12) as wheat particle size decreased. As expected, angle of repose increased as particle size decreased, which indicates poorer flow ability.

From d 0 to 40, decreasing wheat particle size decreased (linear; $P < 0.05$) ADFI but improved (quadratic; $P < 0.05$) F/G and CE, with no change ($P > 0.10$) in ADG (Table 13). From d 40 to 83, decreasing wheat particle size increased (quadratic; $P < 0.05$) ADG, and improved (linear; $P < 0.05$) F/G and CE, with no change ($P > 0.10$) in ADFI. Overall from d 0 to 83, reducing wheat particle size had no effect on ADG or ADFI, but improved (linear; $P < 0.05$) F/G, and CE on both an ME and NE basis. Finally, reducing wheat particle size improved (linear; $P < 0.05$) DM and GE digestibility.

In summary, fine grinding wheat was detrimental to feed intake in early finishing but this was not observed in late finishing. Fine grinding wheat improved ADG in late finishing and F/G for both periods and for the overall study period. In addition, DM and GE digestibility were also improved as wheat was ground finer. Caloric efficiency was also improved for the overall period as wheat was ground finer. The improvement in caloric efficiency can be attributed to the finer particle size of the wheat resulting in improved digestibility. Grinding the wheat from 728 to 326 μ improved the caloric content of the wheat by 100 kcal of NE/lb or approximately 25 kcal NE per 100 microns. It is recommended that wheat be ground to a particle size under 400 μ when feeding hard red winter wheat in meal diets for maximum nutrient digestibility.

Table 1. Diet composition in Exp. 1(as-fed basis)[1]

	Source:	Hard red winter wheat			Soft white winter wheat		
Item	Phase:	1	2	3	1	2	3
Ingredient, %							
Wheat		78.45	85.02	89.45	78.45	85.02	89.45
Soybean meal (46.5% CP)		17.31	11.19	6.33	17.31	11.19	6.33
Choice white grease		1.50	1.50	1.50	1.50	1.50	1.50
Monocalcium phosphate (21% P)		0.25	---	---	0.25	---	---
Limestone		1.38	1.28	1.25	1.38	1.28	1.25
Salt		0.35	0.35	0.35	0.35	0.35	0.35
L-lysine HCl		0.29	0.30	0.32	0.29	0.30	0.32
DL-methionine		0.05	0.05	0.01	0.05	0.05	0.01
L-threonine		0.09	0.08	0.10	0.09	0.08	0.10
Trace mineral premix		0.13	0.10	0.08	0.13	0.10	0.08
Vitamin premix		0.13	0.10	0.08	0.13	0.10	0.08
Phytase[2]		0.08	0.08	0.05	0.08	0.08	0.05
Titanium[3]		---	---	0.50	---	---	0.50
Total		100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis							
Standard ileal digestible (SID) amino acids, %							
Lysine		0.94	0.81	0.71	0.94	0.81	0.71
Isoleucine:lysine		66	65	63	68	67	67
Leucine:lysine		121	122	123	120	121	121
Methionine:lysine		31	30	30	30	30	30
Met & Cys:lysine		62	63	66	62	64	66
Threonine:lysine		63	63	66	62	63	66
Tryptophan:lysine		23.5	24.0	24.3	22.1	22.1	22.1
Valine:lysine		70	70	70	74	75	75
Total lysine, %		1.05	0.91	0.80	1.05	0.91	0.80
ME, kcal/lb[4]		1,467	1,470	1,470	1,491	1,497	1,498
NE. kcal/lb[4]		1,099	1,114	1,123	1,143	1,161	1,174
SID Lysine:ME, g/Mcal		2.91	2.50	2.19	2.86	2.45	2.15
CP, %		17.8	15.6	13.9	17.4	15.2	13.5
Crude fiber, %		2.7	2.6	2.6	0.7	0.4	0.2
Ca, %		0.65	0.55	0.53	0.65	0.55	0.53
P, %		0.48	0.41	0.40	0.48	0.41	0.40
Available P, %		0.28	0.23	0.22	0.28	0.23	0.22

[1] Treatment diets fed for 79 and 85 d for groups 1 and 2, respectively.

[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 340.5 phytase units (FTU)/lb, with a release of 0.12% available P.

[3] Titanium was included in diets fed from day 7 to 14 in group 1 at a level of 0.5%, at the expense of corn.

[4] NRC. 2012. Nutrient Requirements of Swine, 10th ed. Natl. Acad. Press, Washington DC.

Table 2. Chemical analysis of wheat sources in Exp. 1 (as-fed basis)[1]

Item	Hard red winter wheat	Soft white winter wheat
DM, %	90.86	91.80
CP, %	11.8	11.2
ADF, %	3.2	2.8
NDF, %	8.1	8.6
NFE, %	72.9	74.8
Ca, %	0.07	0.13
P, %	0.38	0.40
Fat, %	1.8	1.6
Ash, %	1.81	1.89
Starch, %	55.4	56.9

[1] A composite sample consisting of 6 subsamples was used for analysis.

Table 3. Chemical analysis of diets during phase 1 in Exp. 1 (as-fed basis)[1,2]

	Source:	Hard red winter wheat			Soft white winter wheat		
Item	Particle size:	200	400	600	200	400	600
DM, %		89.68	89.69	90.19	91.16	91.73	91.48
CP, %		20.1	20.2	20.5	19.1	20.3	19.5
ADF, %		2.7	2.7	2.2	2.3	3.5	3.1
NDF, %		7.6	8.1	7.5	6.9	9.9	8.9
NFE, %		60.8	60.8	61.5	63.5	61.8	62.6
Ca, %		0.72	0.69	0.76	0.87	0.76	0.80
P, %		0.49	0.52	0.50	0.46	0.51	0.52
Fat, %		2.8	2.7	2.6	2.6	2.6	2.6
Ash, %		3.78	3.85	3.88	4.10	4.20	4.21
Starch, %		39.8	39.9	39.9	42.7	41.0	41.8

[1] A composite sample consisting of 3 subsamples was used for analysis.

[2] All values are averages of the two finishing groups feed.

Table 4. Chemical analysis of diets during phase 2 in Exp. 1 (as-fed basis)[1,2]

	Source:	Hard red winter wheat			Soft white winter wheat		
Item	Particle size:	200	400	600	200	400	600
DM, %		90.63	90.26	90.66	91.6	91.54	91.54
CP, %		18.5	18.0	18.4	18.2	17.0	17.4
ADF, %		2.2	2.9	1.9	3.0	2.9	2.9
NDF, %		7.4	8.3	6.2	8.1	7.4	9.7
NFE, %		64.4	63.9	64.8	64.5	66.1	65.5
Ca, %		0.66	0.72	0.67	0.69	0.64	0.67
P, %		0.45	0.44	0.41	0.39	0.44	0.42
Fat, %		2.5	2.7	2.6	2.7	2.6	2.7
Ash, %		3.47	3.44	3.32	3.76	3.50	3.62
Starch, %		45.1	44.4	46.6	45.3	45.0	43.9

[1] A composite sample consisting of 3 subsamples was used for analysis.

[2] All values are averages of the two finishing groups feed.

Table 5. Chemical analysis of diets during phase 3 in Exp. 1 (as-fed basis)[1,2]

	Source:	Hard red winter wheat			Soft white winter wheat		
Item	Particle size:	200	400	600	200	400	600
DM, %		90.24	89.83	89.92	89.98	90.82	90.64
CP, %		15.7	15.8	16.5	16.8	14.2	15.1
ADF, %		2.04	1.7	1.9	2.3	1.4	2.9
NDF, %		7.3	6.9	6.6	7.7	6.5	8.7
NFE, %		67.3	68.3	66.1	65.6	69.5	67.2
Ca, %		0.63	0.63	0.61	0.62	0.65	0.62
P, %		0.43	0.46	0.45	0.46	0.35	0.42
Fat, %		2.4	2.4	2.4	2.2	2.5	2.5
Ash, %		4.16	3.61	3.45	3.54	3.63	3.57
Starch, %		48.4	47.9	46.1	46.6	53.7	47.6

[1] A composite sample consisting of 3 subsamples was used for analysis.

[2] All values are averages of the two finishing groups feed.

Table 6. Physical analysis of diets and wheat in Exp. 1[1]

	Source:	Hard red winter wheat			Soft white winter wheat		
Item	Particle size, μ:	200	400	600	200	400	600
Diet[2]							
Bulk density, lb/bu		68.0	66.8	67.5	68.6	68.0	66.3
PDI, %		88.5	81.2	74.2	54.5	50.9	48.7
Percent fines, %		24.0	22.9	26.9	22.2	27.2	24.1
Wheat							
Particle size (no flow agent)[3], μ		245	465	693	258	402	710
Particle size (flow agent), μ		201	415	631	210	341	638
Angle of repose, °		50.8	49.5	45.8	58.1	58.2	43.6
Bulk density, lb/bu		54.3	55.0	56.6	56.1	56.5	59.4

[1] A composite sample consisting of 6 subsamples was used for analysis.

[2] Diet samples from phases were averaged as no differences existed between phases.

[3] Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 3.52 oz samples for 10 min. Particle sizes were ran with and without flow agent which was used at an inclusion level of 0.001 oz.

Table 7. Electrical consumption and throughput during feed manufacturing in Exp. 1[1]

Item	Source:	Hard red winter wheat			Soft white winter wheat		
	Particle size, μ:	200	400	600	200	400	600
Wheat grinding							
Kilowatts[2], kW		11.04	9.33	8.37	8.58	8.47	7.59
Kilowatt hours[3], kW		7.88	7.00	6.98	5.00	4.94	4.43
Cost/ton[4], $		0.32	0.28	0.28	0.20	0.20	0.18
Throughput, lb/hr		7,200	8,000	9,000	10,285	10,285	10,285
Pelleting							
Kilowatts, kW		20.64	20.57	20.99	22.56	22.80	22.68
Kilowatt hours, kWh		14.07	12.66	12.25	13.63	13.83	14.88
Cost/ton, $		2.25	2.03	1.96	2.18	2.21	2.38
Throughput, lb/hr		5,033	5,443	5,804	5,862	5,961	5,909

[1] Voltage was recorded during each manufacturing run and then averaged across the phases and between the groups.

[2] kW was calculated by the formula kW = amperage × voltage / 1000.

[3] kWh was calculated by the formula kWh = kW × hours used.

[4] Cost per kWh was $0.12

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Table 8. Interactive effects of wheat source and particle size of pelleted diets on finishing pig growth performance, caloric efficiency and carcass characteristics in Exp. 1[1]

Item	Source:	Hard red winter wheat			Soft white winter wheat					
	Particle size, µ:	200	400	600	200	400	600	SEM	Quadratic particle size × source[2]	Source main effect
ADG, lb		2.26	2.21	2.26	2.14	2.20	2.18	0.03	0.075	0.004
ADFI, lb		5.85	5.70	5.88	5.58	5.67	5.63	0.08	0.068	0.003
F/G		2.58	2.58	2.61	2.61	2.58	2.58	0.02	0.994	0.948
Initial wt, lb		95.6	95.6	95.6	95.6	95.5	95.6	8.3	0.983	0.978
Final wt, lb		281.9	276.8	280.5	271.5	277.1	276.1	7.03	0.289	0.129
Caloric efficiency[3]										
ME		3,796	3,783	3,829	3,903	3,851	3,859	28	0.985	0.041
NE		2,098	2,087	2,121	2,189	2,164	2,140	114	0.447	0.001
Digestibility										
DM, %		87.67	87.00	87.95	85.80	87.73	85.14	0.80	0.030	0.048
GE, %		68.28	64.52	66.31	62.34	67.47	64.90	1.94	0.053	0.360
Carcass traits										
Feed/carcass gain[4]		3.53	3.57	3.69	3.58	3.77	3.76	0.09	0.454	0.065
HCW, lb		201.4	199.1	202.3	197.1	200.8	199.3	3.2	0.331	0.479
Yield, %		73.0	72.8	72.9	73.0	73.1	73.1	73.1	0.241	0.167
BF, in		0.77	0.76	0.75	0.75	0.77	0.78	0.02	0.945	0.466
Loin depth, in		2.28	2.28	2.31	2.21	2.29	2.27	0.05	0.474	0.447
FFL, %		0.52	0.53	0.53	0.52	0.53	0.52	0.02	0.792	0.397
Jowl IV, mg/100 g		69.1	69.0	68.6	68.4	68.6	68.3	0.4	0.928	0.210

[1]A total of 576 pigs (PIC 327 × 1050, initially 96 lb BW) in 2 groups were used in a 75 and 89-d study with 8 pigs per pen and 12 replications per treatment.

[2] No source × particle size interactions; main effects of particle size; linear or quadratic effects of particle size within wheat source.

[3] Caloric efficiency is expressed as kcal/lb of gain.

[4] Feed/carcass gain is expressed as total intake / lb carcass gain with an assumed initial yield of 75%.

Table 9. Composition of experimental diets in Exp. 2 (as-fed basis)

	Phase[1]:		
Item	1	2	3
Ingredient, %			
Hard red winter wheat	81.29	87.46	92.69
Soybean meal, 46.5% CP	15.84	10.14	4.94
Monocalcium P, 21%	0.28	0.03	---
Limestone	1.43	1.28	1.30
Salt	0.35	0.35	0.35
L-lysine HCl	0.33	0.33	0.35
DL-methionine	0.04	0.02	0.02
L-threonine	0.09	0.09	0.11
Trace mineral premix	0.15	0.13	0.10
Vitamin premix	0.15	0.13	0.10
Phytase[2]	0.08	0.08	0.05
Titanium dioxide	---	---	0.50
Total	100.00	100.00	100.00
Calculated analysis			
Standard ileal digestible (SID) amino acids, %			
Lysine	0.94	0.81	0.71
Isoleucine:lysine	64	63	61
Leucine:lysine	118	121	120
Methionine:lysine	30	30	30
Met & Cys:lysine	61	63	66
Threonine:lysine	62	63	66
Tryptophan:lysine	23.1	23.7	23.7
Valine:lysine	68	69	67
SID lysine:ME, g/Mcal	2.98	2.56	2.24
ME, kcal/lb	1,431	1,435	1,435
Total lysine, %	1.05	0.91	0.79
CP, %	19.7	17.9	16.2
Ca, %	0.67	0.56	0.55
P, %	0.50	0.44	0.42
Available P, %	0.30	0.25	0.24
Crude fiber, %	2.70	2.60	2.60

[1] Phase 1 diets were fed from approximately 85 to 140 lb; Phase 2 diets were fed from 140 to 182 lb and Phase 3 from 182 to 265 lb.

[2] Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 204.3 phytase units (FTU)/lb, with a release of 0.11% available P.

[3] Titanium was included in the phase 3 diet as an indigestible marker for the first 7 d of the phase at a level of 0.5%, at the expense of corn.

Table 10. Chemical analysis of ingredients in Exp. 2 (as-fed basis)[1]

Item	Hard red winter wheat	Soybean meal
DM, %	90.86	90.14
CP, %	11.8	45.8
ADF, %	3.2	6.2
NDF, %	8.1	6.8
NFE, %	72.9	33.6
Ca, %	0.07	0.40
P, %	0.38	0.70
Fat, %	1.8	1.2
Ash, %	1.81	6.11
Starch	55.4	1.5
Particle size (no flow agent), µ	728; 579; 326[2]	942
Particle size (flow agent), µ	714; 554; 284[3]	
Bulk density, lb/bu	60.7; 60.7; 59.3[4]	60.8

[1] A composite sample consisting of 3 subsamples was used for analysis.
[2] Particle sizes were determined using Tyler sieves, with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap shaker (W.S. Tyler, Mentor, OH) was used to sift the 3.52 oz samples for 10 min.
[3] Particle sizes were ran with and without flow agent which was used at an inclusion level of 0.001 oz.
[4] Wheat for treatments 1, 2, and 3 respectively.

Table 11. Chemical analysis of diets in Exp. 2 (as-fed basis)[1]

Item[2]	Phase 1	Phase 2	Phase 3
DM, %	90.28	89.91	89.16
CP, %	19.7	18.4	16.1
ADF, %	2.9	2.8	2.5
NDF, %	9.3	8.2	7.8
Crude fiber, %	2.6	2.2	2.3
NFE, %	62.4	62.9	65.7
Ca, %	0.74	0.89	0.74
P, %	0.51	0.48	0.41
Fat, %	1.4	1.5	1.6
Ash, %	4.41	4.79	3.70
Starch, %	44.1	45.0	51.3

[1] A composite sample consisting of 6 subsamples was used for analysis.
[2] All treatments were analyzed and values were averaged as all treatments were formulated identically.

Table 12. Analysis of diets in Exp. 2[1]

	Wheat particle size, μ		
Item	728	579	326
Bulk density, lb/bu			
Phase 1	59.6	59.4	57.6
Phase 2	59.9	59.7	57.8
Phase 3	59.1	59.1	56.1
Particle size, μ[2]			
Phase 1	634	527	432
Phase 2	665	493	354
Phase 3	650	492	336
Angle of repose, °			
Phase 1	44.4	45.6	51.4
Phase 2	44.0	44.1	49.0
Phase 3	45.8	50.3	51.8

[1] A composite sample of four subsamples was used for analysis.
[2] Analysis were run without flow agent.

Table 13. Effects of wheat particle size on finishing pig performance in Exp. 2[1]

	Wheat particle size, μ				Probability, *P* <	
Item	728	579	326	SEM	Linear	Quadratic
d 0 to 40						
ADG, lb	2.02	2.04	1.98	0.03	0.349	0.247
ADFI, lb	5.04	4.94	4.84	0.06	0.033	0.966
F/G	2.50	2.42	2.44	0.02	0.015	0.014
d 40 to 83						
ADG, lb	2.02	1.99	2.10	0.02	0.015	0.014
ADFI, lb	6.33	6.18	6.25	0.08	0.484	0.228
F/G	3.14	3.11	2.98	0.03	0.001	0.180
d 0 to 83						
ADG, lb	2.02	2.01	2.04	0.02	0.470	0.470
ADFI, lb	5.71	5.58	5.57	0.06	0.130	0.434
F/G	2.83	2.77	2.73	0.02	0.001	0.824
Caloric efficiency[2]						
ME	4,056	3,973	3,913	28.7	0.001	0.755
NE	3,024	2,963	2,919	21.5	0.001	0.746
Digestibility[3]						
DM, %	88.95	91.15	91.46	0.64	0.013	0.246
GE, %	65.47	70.33	73.46	1.71	0.004	0.685
BW, lb						
d 0	96.5	96.5	96.5	1.1	0.996	0.998
d 40	177.2	177.9	176.2	1.8	0.716	0.586
d 83	264.0	263.4	266.9	2.5	0.414	0.511

[1] A total of 288 pigs (PIC 327 ×1050) were used with 12 pens per treatment and 8 pigs per pen.
[2] Caloric efficiency is expressed as kcal/lb of gain and represents the d 0 to 83 data.
[3] Fecal samples were taken on d 67 of the study via rectal massage from two pigs per pen.