The effects of dietary soybean hulls particle size and diet form on nursery and finishing pig performance[1]

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ABSTRACT: Two experiments were conducted to investigate increasing unground and finely ground soybean hulls fed in meal or pelleted form on nursery and finishing pig performance. In experiment 1, 1,100 nursery pigs (initially 6.8 ± 0.1 kg and 28 d of age) were used in a 42-d study with 11 replicates per treatment. Treatments were arranged in a 2 × 2 × 2 factorial with main effects of soybean hulls (10% vs. 20%), grind type (unground, 617 µ vs. ground, 398 µ), and diet type (pelleted vs. meal form). No three-way or soybean hull level × grind type interactions were observed. Overall, average daily gain (ADG) was increased ($P < 0.05$) by pelleting, decreased ($P < 0.05$) by grinding, but unaffected by soybean hull levels. Grind type × diet form interactions were observed ($P < 0.05$) for gain:feed ratio (G:F) and a tendency for average daily feed intake (ADFI; $P < 0.10$). This was because grinding soybean hulls decreased ($P < 0.05$) ADFI and increased ($P < 0.05$) G:F when fed in meal form; however, grinding did not affect ADFI and decreased ($P < 0.05$) G:F when diets were pelleted. Increasing soybean hulls increased ($P < 0.05$) ADFI and decreased ($P < 0.05$) G:F when diets were fed in meal form, but these effects were not observed when diets were pelleted (diet form × soybean hull level interaction, $P < 0.06$). In experiment 2, 1,215 pigs (initially 21.1 ± 0.1 kg) were used in a 118-d study with nine replications per treatment. Treatments were a corn–soybean meal–based control diet and four diets arranged in a 2 × 2 factorial with the main effects of soybean hulls (7.5% vs. 15%) and grind type (unground, 787 µ vs. ground, 370 µ). All diets were fed in meal form. No soybean hull level × grind type interactions were observed for any growth or carcass responses. Increasing dietary soybean hulls from 0% to 15%, regardless of particle size, did not affect ADG or ADFI, but decreased (linear, $P < 0.02$) G:F. Carcass yield, hot carcass weight, and backfat depth decreased (linear, $P < 0.03$) whereas percentage lean increased (linear, $P < 0.01$) with increasing soybean hulls. Pigs fed ground soybean hulls had increased backfat depth ($P < 0.01$) and decreased ($P < 0.01$) percentage lean and fat-free lean index. In summary, increasing soybean hulls up to 20% decreased G:F in nursery and finishing pigs, whereas pelleting nursery diets improved ADG and eliminated the negative effect of increasing soybean hulls on G:F. Grinding soybean hulls reduced growth performance in nursery and finishing pigs.

Key words: finishing pig, growth, nursery pig, particle size, pelleting, soybean hulls

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INTRODUCTION

Soybean hulls are a feed coproduct resulting from the cracking and dehulling process in soybean oil extraction. Due to its low energy value (net energy [NE] = 1,003 kcal/kg; Institut National de la Recherche Agronomique (INRA), 2004) and high crude fiber concentration (35.75%; NRC, 2012), they are not typically used in swine diets. Furthermore, use of fibrous ingredients has been shown to have different effects depending on pig age. As pigs grow, they substantially increase gastrointestinal tract size, consequently slowing the rate of passage of digesta and increasing fiber fermentation capabilities (Fernandez and Jorgensen, 1986; Noblet and Le Goff, 2001; Noblet and Van Milgen, 2004). Therefore, nursery and finishing pigs may respond to soybean hulls differently.

Kornegay (1978), Gore et al. (1986), and Kornegay et al. (1995) observed nursery pigs fed dietary soybean hulls have reduced gain:feed ratio (G:F). However, including soybean hulls at 3% to 10% of diet has been shown to improve (DeCamp et al., 2001) or not affect finishing pig performance (Bowers et al., 2000). However, at high levels of soybean hulls (24% to 30%), Kornegay (1978) and Stewart et al. (2013) observed reduced gain, with no changes or slight increases in intake. This would suggest that diet bulk density of low energy diets can affect intake and performance in nursery and finishing pigs. Therefore, feed-processing techniques such as pelleting to increase diet bulk density or fine grinding to improve digestibility of soybean hulls may mitigate its negative growth effects. Moreira et al. (2009) found that grinding soybean hulls (751 to 430 µ) increased metabolizable energy (ME) for growing and finishing pigs; however, pig growth performance was not measured in that study.

Therefore, the objectives of this study were to evaluate the effects of 1) added soybean hulls, soybean hull particle size, and complete diet form on growth performance of nursery pigs, and 2) increasing amounts of soybean hulls and soybean hull particle size on the growth performance and carcass characteristics of finishing pigs.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. The ME and NE values of corn, soybean hulls, and other major ingredients from NRC (1998, 2012) and INRA (2004) were evaluated and selected for use in diet formulation (Table 1). Caloric efficiencies of pigs in both experiments were determined on both an ME and NE basis. Caloric efficiency was calculated by multiplying total feed intake by energy in the diet (kcal/kg) and dividing by total gain.

Experiment 1

A total of 1,100 pigs (C-29 × 359; PIC, Hendersonville, TN; initially 6.8 ± 0.1 kg body weight [BW] and 28 d of age) were used in a 42-d growth experiment to evaluate the effect of increasing dietary soybean hulls and soybean hull particle size in nursery pig diets fed in both meal and pelleted forms. Pigs were allotted to pen by initial BW, and pens of pigs were randomly allotted to one of eight dietary treatments. There were 10 pigs per pen

Table 1. Nutrient loading values for major ingredients used in diet formulation

	Corn	Soy hulls	Soybean meal	Fish meal	Spray dried whey
Crude protein, %	8.50	9.80	46.50	62.90	12.10
Lysine	0.26 (78)[1]	0.67 (61)	3.02 (90)	4.81 (95)	0.90 (87)
Isoleucine	0.28 (87)	0.43 (62)	2.16 (89)	2.57 (94)	0.62 (83)
Leucine	0.99 (92)	0.90 (63)	3.66 (89)	4.54 (94)	1.08 (87)
Methionine	0.17 (90)	0.11 (69)	0.67 (91)	1.77 (94)	0.17 (81)
Cysteine	0.19 (86)	0.11 (69)	0.74 (87)	0.57 (88)	0.25 (85)
Threonine	0.29 (82)	0.35 (62)	1.85 (87)	2.64 (88)	0.72 (79)
Tryptophan	0.06 (84)	0.11 (63)	0.65 (90)	0.66 (90)	0.18 (79)
Valine	0.39 (87)	0.43 (62)	2.27 (88)	3.03 (93)	0.60 (77)
Metabolizable energy, kcal/kg	3,420	1,864	3,380	3,360	3,190
Net energy, kcal/kg	2,650	1,003	2,020	2,335	2,215
Crude fiber, %	2.2	33.3	3.9	—	—
Calcium, %	0.03	0.54	0.34	5.21	0.75
Phosphorus, %	0.28 (14)	0.11 (30)	0.69 (23)	3.04 (94)	0.72 (97)

[1]Numbers in parenthesis are digestibility and availability coefficients for amino acids and phosphorous, respectively.

(five barrows and five gilts) and 11 replications per treatments. All pigs were fed a common pelleted starter diet for 10 d after weaning. Starting on day 10 postweaning (day 0 of the experiment), pigs were fed the experimental diets. The eight experimental diets were fed in two phases from day 0 to 14 and 14 to 42 (Table 2). Treatments were arranged in a 2 × 2 × 2 factorial with main effects of soybean hulls (10% or 20%), soybean hull grind type (unground or ground), and diet form (pelleted or meal form).

This experiment was conducted at the Cooperative Research Farm's Swine Research Nursery (Sycamore, OH), which is owned and managed by Kalmbach Feeds, Inc. (Upper Sandusky, OH). Each pen had slatted metal floors and was equipped with a four-hole stainless-steel feeder and one nipple-cup waterer for ad libitum access to feed and water. Individual pen weight and feed disappearance were measured weekly to determine average daily gain (ADG), average daily feed intake (ADFI), and G:F. Samples of each dietary treatment were collected from every feeder for each phase and subsampled.

A single lot of soybean hulls was used for the study with 50% used as received, whereas the other 50% was ground through a hammer mill (P-250D Pulverator; Jacobson Machine Works, Minneapolis, MN) equipped with a 1.59-mm screen at Kansas State University Grain Science Feed Mill (Manhattan, KS). The resulting particle sizes were 617 and 398 μ for unground and ground soybean hulls, respectively. All soybean hulls were then shipped to Kalmbach Feeds, Inc. (Upper Sandusky, OH) for feed manufacturing. All diets within each phase were formulated on a common standardized ileal digestible (SID) lysine concentration. The SID lysine levels fed were selected based on the required level for the diets without soybean hulls. All phase 1 diets contained 4% fish meal and 10% spray-dried whey. Phase 2 diets contained no specialty protein or lactose sources.

The ASAE (1983) standard method was used to determine the particle size of soybean hulls and complete meal diets. Tyler sieves, with numbers 6, 8, 12, 16, 20, 30, 40, 50, 70, 100, 140, 200, 270, and a pan were used for particle size determination. A Ro-Tap shaker (W. S. Tyler, Mentor, OH) was used to sift the 100 g samples for 10 min. A geometric mean particle size and the log normal standard deviation were calculated by measuring the amount of ground grain remaining on each screen. Pellet quality was measured using a tumbling box (procedure S269.4; ASAE, 1991) and results were reported as the pellet durability index (PDI). Two standard and two modified (inclusion of five 12.7 mm hex nuts in the tumbling box) PDI tests were conducted for each diet in each phase and an average value for each was determined.

Experiment 2

A total of 1,235 pigs (1050 × 337; PIC, Hendersonville, TN; initially 31.1 ± 0.1 kg BW) were used in a 118-d growth trial to determine the effects of feeding 7.5% and 15% ground or unground soybean hulls on growth performance and carcass characteristics of finishing pigs raised in a commercial environment. Pens of pigs were balanced by initial BW and randomly allotted to one of five dietary treatments in a completely randomized design with 26 to 28 pigs per pen and nine replications per treatment. Treatments were arranged in a 2 × 2 + 1 factorial with a control diet. Main effects were soybean hull grind type (unground, 787 μ vs. ground, 370 μ) and amount of soybean hulls (7.5% or 15%) in corn–soybean meal–based diets. The fifth treatment was a positive control, corn–soybean meal–based diet. Diets were fed in meal form and pigs were fed in four phases from days 0 to 118 with approximate BW ranges of 31 to 42, 42 to 77, 77 to 109, and 109 to 128 kg (Table 3). Treatment diets were formulated to a constant SID lysine concentration within each phase.

This experiment was conducted at a commercial research facility in southwestern Minnesota. The barns were naturally ventilated and double-curtain sided. Pens had completely slatted flooring and deep pits for manure storage. The research barn contained 48 pens (3.05 × 5.49 m) equipped with a five-hole conventional dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer, which afforded ad libitum consumption of feed and water. Daily feed additions to each pen were accomplished and recorded through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN). All soybean hulls were sourced from the same location (South Dakota Soybean Processors, Volga, SD). Each lot of soybean hulls was split into equal portions, and half was transported to the South Dakota State University Feed Mill (Brookings, SD) and ground through a hammer mill (G7HFS Prater-Sterling, Bolingbrook, IL) equipped with a 1.59-mm screen. After grinding, soybean hulls were transported along with the unground soybean hulls to the feed mill (New Horizon Farm; Pipestone, MN) for diet manufacturing. Pens of pigs were weighed and feed disappearance was recorded on days 0, 14, 28, 42, 53, 66, 82, 94, and 118 to determine ADG, ADFI, and G:F.

Table 2. Diet composition, experiment 1 (as-fed basis)[1]

	Phase[2] 1			Phase 2		
Soybean hulls, %[3]	0	10	20	0	10	20
Ingredient, %						
Corn	53.87	44.43	35.00	62.88	53.34	43.81
Soybean meal (46.5% crude protein)	28.43	28.00	27.55	32.86	32.50	32.15
Soybean hulls	—	10.00	20.00	—	10.00	20.00
Select menhaden fish meal	4.00	4.00	4.00	—	—	—
Spray-dried whey	10.00	10.00	10.00	—	—	—
Monocalcium P (21% P)	0.50	0.50	0.50	1.05	1.05	1.05
Limestone	0.81	0.68	0.55	0.95	0.83	0.70
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	—	—	—
Vitamin E (20,000 IU)	0.06	0.06	0.06	0.06	0.06	0.06
Vitamin premix[4]	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix[5]	0.09	0.09	0.09	0.09	0.09	0.09
Selenium	0.02	0.02	0.02	0.02	0.02	0.02
L-Lysine HCl	0.23	0.21	0.20	0.33	0.32	0.30
DL-Methionine	0.12	0.14	0.16	0.13	0.15	0.17
L-Threonine	0.12	0.12	0.12	0.13	0.14	0.15
Phytase[6]	0.02	0.02	0.02	0.02	0.02	0.02
Medication	0.58	0.58	0.58	0.58	0.58	0.58
Pellet binder[7]	0.50	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
SID amino acids, %						
Lysine	1.32	1.32	1.32	1.28	1.28	1.28
Isoleucine:lysine	63	62	62	61	61	61
Leucine:lysine	127	124	121	128	125	122
Methionine:lysine	35	35	36	33	34	35
Methionine and cysteine:lysine	58	58	58	58	58	58
Threonine:lysine	64	64	64	63	63	63
Tryptophan:lysine	18	18	18	17	18	18
Valine:lysine	69	68	67	68	67	66
Total lysine, %	1.46	1.48	1.50	1.42	1.43	1.45
Metabolizable energy, Mcal/kg	3.28	3.08	2.89	3.29	3.09	2.90
Net energy, Mcal/kg	2.39	2.25	2.09	2.35	2.21	2.05
Crude protein, %	21.90	21.87	21.85	21.11	21.12	21.13
Crude fiber, %	2.21	5.40	8.50	2.52	5.80	8.90
Acid detergent fiber, %	3.1	6.80	10.60	3.6	7.30	11.00
Neutral detergent fiber, %	7.8	12.50	17.20	9.1	13.70	18.40
Calcium, %	0.80	0.80	0.80	0.69	0.69	0.69
Phosphorous, %	0.65	0.63	0.61	0.62	0.61	0.59
Available P, %	0.46	0.46	0.46	0.40	0.40	0.40

[1]Diets were fed in either meal or pelleted forms.

[2]Soybean hulls were either ground to 389 μ or unground at 617 μ.

[3]Phase 1 diets were fed from 6.8 to 9.3 kg BW and from 9.3 to 27 kg BW for phase 2.

[4]Provided per kg of the diet: 14,330 IU vitamin A; 2,205 IU vitamin D_3; 77.2 IU vitamin E; 8.8 mg vitamin K; 7.7 mg riboflavin; 33.1 mg pantothenic acid; 55.1 mg niacin; 0.40 mg vitamin B_{12}; and 0.30 mg selenium.

[5]Provided per kg of the diet: 25 mg Mn from manganese oxide, 88 mg Fe from iron sulfate, 2,000 mg Zn from zinc sulfate, 264 g Cu from copper sulfate, 1.36 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[6]Ronozyme CT 10,000 (DSM Nutritional Products, Inc., Parsippany, NJ) provided 1,848 phytase units (FTU)/kg, with a release of 0.10% available P.

[7]Ameri-Bond (LignoTech USA, Inc., Rothschild, WI).

Table 3. Diet composition, experiment 2, (as-fed basis)

	Phase[1] 1			Phase 2			Phase 3			Phase 4		
Soybean hulls, %[2]	0	7.5	15	0	7.5	15	0	7.5	15	0	7.5	15
Ingredient, %												
Corn	73.03	66.03	58.92	78.70	71.54	64.57	82.95	75.77	68.69	75.18	67.97	60.87
Soybean meal, 46.5% (crude protein)	24.44	24.02	23.71	18.97	18.75	18.33	14.89	14.67	14.36	22.63	22.41	22.10
Soybean hulls	—	7.50	15.00	—	7.50	15.00	—	7.50	15.00	—	7.50	15.00
Monocalcium P (21% P)	0.62	0.63	0.65	0.51	0.50	0.48	0.40	0.40	0.40	0.25	0.28	0.28
Limestone	0.95	0.85	0.75	0.95	0.85	0.75	0.93	0.83	0.73	0.90	0.80	0.70
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
VTM premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.03	0.05	0.06	0.01	0.02	0.03	0.00	0.01	0.01	0.05	0.06	0.08
L-Threonine	0.05	0.05	0.05	0.02	0.02	0.03	0.03	0.04	0.04	0.07	0.08	0.08
Biolys[4]	0.37	0.36	0.35	0.33	0.31	0.30	0.29	0.27	0.26	0.36	0.34	0.33
Phytase[5]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Paylean[6]	—	—	—	—	—	—	—	—	—	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition												
SID amino acids, %												
Lysine	1.00	1.00	1.00	0.84	0.84	0.84	0.72	0.72	0.72	0.95	0.95	0.95
Isoleucine:lysine	65	64	64	66	66	66	68	68	67	65	65	65
Leucine:lysine	146	143	140	159	156	151	173	168	164	150	147	143
Methionine:lysine	29	30	31	29	29	29	30	30	30	32	32	33
Met and Cys:lysine	57	57	57	59	58	57	63	61	60	60	60	60
Threonine:lysine	61	61	61	61	61	61	65	65	65	65	65	65
Tryptophan:lysine	18	18	18	18	18	18	18	18	18	18	18	18
Valine:lysine	74	73	72	77	76	75	81	79	78	75	74	73
Total lysine, %	1.04	1.06	1.08	0.87	0.89	0.91	0.75	0.77	0.79	0.99	1.01	1.02
Metabolizable energy, Mcal/kg	3.34	3.19	3.04	3.35	3.20	3.05	3.35	3.20	3.06	3.36	3.21	3.06
Net energy, Mcal/kg	2.26	2.16	2.06	2.28	2.18	2.08	2.30	2.20	2.10	2.27	2.17	2.07
Crude protein, %	17.90	17.85	17.84	15.77	15.79	15.74	14.21	14.23	14.21	17.26	17.28	17.27
Crude fiber, %	2.56	4.89	7.22	2.47	4.80	7.13	2.41	4.74	7.07	2.54	4.87	7.20
Acid detergent fiber, %	3.40	6.20	9.00	3.20	6.10	8.90	3.10	6.00	8.80	3.30	6.20	9.00
Neutral detergent fiber, %	9.20	12.70	16.20	9.30	12.80	16.30	9.30	12.80	16.30	9.20	12.80	16.30
Calcium, %	0.58	0.58	0.58	0.54	0.54	0.54	0.50	0.50	0.50	0.49	0.49	0.49
Phosphorous, %	0.50	0.49	0.48	0.46	0.44	0.42	0.42	0.41	0.39	0.42	0.41	0.40
Available P, %	0.29	0.29	0.29	0.25	0.25	0.25	0.23	0.23	0.23	0.21	0.21	0.21

[1]Phase 1 diets fed from days 0 to 14, phase 2 from days 14 to 53, phase 3 from days 53 to 94, and phase 4 from days 94 to 118.

[2]Soybean hulls were either ground to 370 μ or unground at 787 μ.

[3]Provided per kg of premix: 4,508,182 IU vitamin A; 701,273 IU vitamin D3; 24,043 IU vitamin E; 1,402 mg vitamin K; 3,006 mg riboflavin; 12,023 mg pantothenic acid; 18,033 mg niacin; 15.03 mg vitamin B12; 40.1 g Mn from manganous oxide; 90.2 g Fe from ferrous sulfate; 100.2 g Zn from zinc oxide; 10.0 g Cu from copper sulfate; 0.5 g I from ethylenediamine dihydroiodide; 0.3 g Se from sodium selenite.

[4]Lysine product (Evonik INC., Kennesaw, GA).

[5]Optiphos 2000 (Enzyva LLC, Sheridan, IN), providing 375.23 phytase units (FTU)/kg, with a release of 0.10% available P.

[6]Paylean (Elanco Animal Health, Greenfield, IN).

On day 94 of the experiment, the four heaviest pigs (two barrows and two gilts, determined visually) per pen were weighed and sold according to the farm's normal marketing procedure. At the end of the trial (day 118), pigs were transported to a commercial packing plant (JBS Swift and Company; Worthington, MN) for processing and carcass data collection. Pigs were individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the abattoir. Hot carcass weights (HCW) were measured immediately after evisceration and each carcass was evaluated for percentage yield, backfat, and loin depth. Percentage yield was calculated by dividing HCW by live weight obtained at the plant. Backfat depth and loin depth were measured with an optical probe (SFK; Herlev, Denmark) inserted between the third and fourth ribs located anterior to the last rib at a distance approximately 7 cm from the dorsal midline. Fat-free lean index (FFLI) was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meter.

Chemical Analyses

Soybean hull samples were collected from both experiments for analysis of moisture (method 934.01; AOAC, 2006), crude protein (method 990.03; AOAC, 2006), acid detergent fiber (ANKOM Technology, 1998a), neutral detergent fiber (ANKOM Technology, 1998b), crude fiber (method 978.10; AOAC, 2006), Ca (method 965.14/985.01; AOAC, 2006.), and P (method 965.17/985.01; AOAC, 2006; Ward Laboratories, Inc., Kearney, NE) . For both experiments, soybean hulls and composite diet samples by treatment for each phase were measured for bulk density using a Seedburo test weight apparatus and computerized grain scale (Seedburo Model 8800, Seedburo Equipment, Chicago, IL).

Statistical Analyses

In both experiments, data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. In experiment 1, the statistical model contained the fixed effects of soybean hull level, grind type, diet form, and their interactions. In experiment 2, preplanned polynomial contrasts were used to determine linear and quadratic effects of increasing soybean hulls as well as the main effect of soybean hulls grind type and the level × grind type interaction. In both experiments, least-squares means were reported and results were considered significant at $P < 0.05$ and a trend at $0.05 < P \le 0.10$.

RESULTS

Chemical Analysis

In both trials, soybean hull samples were verified to be similar to those used in formulation and values were similar to NRC (2012) values (Table 4). The minor differences, particularly the crude protein values, would not be expected to influence results of the experiments. Unground soybean hulls were 617 and 787 μ for experiments 1 and 2, respectively. By grinding the soybean hulls through a hammer mill equipped with a 1.59-mm screen, they were reduced to 398 and 370 μ for experiments 1 and 2, respectively. Grinding soybean hulls increased its bulk density by approximately 66 g/L in both trials (Table 4).

For complete diets, increasing soybean hulls in both nursery and finishing diets increased dietary fiber as expected. As soybean hulls increased, bulk density of complete diets decreased (Tables 5 and 6). Pelleting diets increased bulk density. Grinding soybean hulls increased bulk density, particularly when

Table 4. Chemical analysis and bulk density of soybean hulls (as-fed basis)

Item	Experiment 1		Experiment 2[1]	
Dry matter, %	91.91		91.51	
Crude protein, %	9.8		10.61	
Acid detergent fiber, %	40.1		43.6	
Neutral detergent fiber, %	55.3		55.9	
Crude fiber, %	32.7		36.3	
Calcium, %	0.54		0.58	
Phosphorous, %	0.11		0.11	
	Ground	Unground	Ground	Unground
Bulk density, g/L	490	421	531	468
Particle size, D_{gw} (μ)	398	617	370	787

[1]Samples from every batch of soybean hulls used were composited, analyzed, and means are reported.

Table 5. Bulk density and particle size of experimental diets, experiment 1 (as-fed basis)[1]

	Treatments							
Soybean hulls grind type	Unground	Unground	Ground	Ground	Unground	Unground	Ground	Ground
Diet form	Meal	Meal	Meal	Meal	Pellet	Pellet	Pellet	Pellet
Item Soybean hulls, %:	10	20	10	20	10	20	10	20
Bulk density, g/L								
Phase 1	617	575	624	600	767	717	740	732
Phase 2	699	632	702	646	772	753	772	774
Particle size, µ								
Phase 1	355	400	360	364	—	—	—	—
Phase 2	430	558	423	500	—	—	—	—
Standard PDI, %[2]								
Phase 1	—	—	—	—	95	95	94	95
Phase 2	—	—	—	—	97	97	95	94
Modified PDI, %[3]								
Phase 1	—	—	—	—	93	92	89	92
Phase 2	—	—	—	—	94	95	92	92
Fines, %								
Phase 1	—	—	—	—	7.6	0.5	6.6	3.6
Phase 2	—	—	—	—	6.1	1.5	1.8	0.8

[1]Diet samples collected from the tops of each feeder during each phase.

[2]PDI measured using a tumbling box.

[3]PDI measured using modified procedure by including five 12.7-mm hex nuts in the tumbling box.

high levels of soybean hulls were used. In both phases of experiment 1, grinding soybean hulls had a limited impact on diet particle size when 10% soybean hulls were used; however, using ground soybean hulls at 20% of the diet reduced the particle size of the diet to a greater extent. In all phases of experiment 2, grinding soybean hulls reduced particle size of complete diets regardless of soybean hull inclusion. Pellet quality in experiment 1 was exceptional in both phases and soybean hulls did not affect pellet durability, regardless of inclusion or particle size. However, diets with 20% soybean hulls had fewer percentage of fines.

Experiment 1

From day 0 to 14, there were no evidences for any three-way or two-way interactions for any growth responses ($P > 0.19$; Table 7). Therefore, main effects were presented in Table 8. Increasing soybean hulls from 10% to 20% of the diet improved ($P < 0.01$) ADG, G:F, and caloric efficiency on both ME and NE basis. Fine-grinding soybean hulls worsened ($P < 0.01$) ADG, G:F, and caloric efficiency, whereas pelleting soybean hull diets increased ($P < 0.01$) ADG and ADFI but did not affect G:F or caloric efficiency.

Table 6. Bulk density and particle size of experimental diets, experiment 2 (as-fed basis)[1]

	Treatments				
Grind type	—	Unground	Unground	Ground	Ground
Item Soybean hulls, %:	0	7.5	15	7.5	15
Bulk density, g/L					
Phase 1	672	679	645	699	655
Phase 2	706	647	604	670	652
Phase 3	664	629	589	625	629
Phase 4	674	638	603	653	633
Particle size, µ					
Phase 1	583	573	582	566	551
Phase 2	491	567	590	524	529
Phase 3	540	573	615	555	540
Phase 4	588	577	594	537	552

[1]Diet samples collected from each feeder during each phase.

Table 7. Interactions of soybean hulls level, particle size, and diet form on nursery pig performance, experiment 1[1]

Grind type	Unground	Unground	Ground	Ground	Unground	Unground	Ground	Ground		Probability[2], *P* <	
Diet form	Meal	Meal	Meal	Meal	Pellet	Pellet	Pellet	Pellet			
Soybean hulls, %	10%	20%	10%	20%	10%	20%	10%	20%	SEM	Grind type × diet form	Diet form × soybean hull level
Days 0 to 14											
ADG, g	159	182	151	166	204	206	176	196	28	0.35	0.33
ADFI, g	276	293	273	282	337	316	325	335	28	0.45	0.19
G:F	0.567	0.619	0.539	0.583	0.613	0.650	0.538	0.586	0.042	0.21	0.88
Caloric efficiency, Mcal/kg gain											
ME	5.62	4.91	5.96	5.18	5.34	4.65	6.14	5.24	0.44	0.23	0.90
NE	4.02	3.43	4.26	3.62	3.82	3.25	4.39	3.66	0.31	0.23	0.90
Days 14 to 42											
ADG, g	634	625	614	619	651	639	630	637	14.5	0.86	0.96
ADFI, g	924	956	879	922	951	946	922	947	30.6	0.10	0.07
G:F	0.687	0.653	0.699	0.671	0.686	0.646	0.684	0.675	0.012	0.18	0.09
Caloric efficiency, Mcal/kg gain											
ME	4.60	4.60	4.52	4.49	4.61	4.45	4.62	4.47	0.08	0.19	0.10
NE	3.22	3.14	3.16	3.06	3.23	3.04	3.23	3.05	0.06	0.19	0.10
Days 0 to 42											
ADG, g	475	477	460	467	502	494	478	490	18	0.91	0.79
ADFI, g	708	735	677	708	746	736	722	743	29	0.10	0.06
G:F	0.672	0.649	0.679	0.660	0.673	0.673	0.662	0.661	0.007	0.05	0.06
Caloric efficiency, Mcal/kg gain											
ME	4.70	4.64	4.65	4.56	4.69	4.47	4.77	4.56	0.05	0.05	0.06
NE	3.29	3.17	3.26	3.12	3.29	3.06	3.34	3.12	0.04	0.05	0.06
Body weight, kg											
Day 0	6.8	6.8	6.7	6.8	6.8	6.8	6.9	6.8	0.1	0.22	0.52
Day 14	9.0	9.4	8.9	9.1	9.6	9.7	9.3	9.5	0.4	0.80	0.36
Day 42	26.8	26.9	26.1	26.4	27.9	27.6	26.9	27.4	0.8	0.96	0.73

[1]A total of 1,100 pigs (PIC C-29 × 359, initially 6.8 ± 0.1 kg) were used in a 42-d study with 11 replications per treatment.

[2]No soybean hull × grind type × diet form interactions ($P > 0.37$) or soybean hull × grind type interaction ($P > 0.17$).

In phase 2 (days 14 to 42), no three-way or two-way interactions were observed for ADG ($P > 0.86$; Table 7). ADG was not influenced by soybean hull level, but tended to decrease ($P < 0.06$) by fine grinding, and was increased ($P < 0.01$) by feeding pelleted diets (Table 8). There was a tendency for grind type × diet form interaction ($P < 0.10$) for ADFI. Fine-grinding soybean hulls reduced ADFI in pigs fed meal diets but had less of an effect on ADFI of pigs fed pelleted diets. Similarly, increasing soybean hulls from 10% to 20% increased ADFI and worsened G:F in meal diets but had no effect on G:F and a smaller increase in ADFI in pelleted diets (diet form × soybean hull level interaction, $P < 0.10$). In addition, there were tendencies for diet form × soybean hull level interactions ($P < 0.10$) for ME and NE caloric efficiencies in which increasing soybean hull level improved caloric efficiency to a greater extent in pelleted diets than in meal diets.

Overall (days 0 to 42), there were no three-way or two-way interactions observed for ADG ($P > 0.10$; Table 7). ADG was not influenced by soybean hull level, decreased ($P < 0.01$) by fine-grinding soybean hulls, but increased ($P < 0.01$) by feeding pelleted diets (Table 8). Grind type × diet form interactions were observed for ADFI ($P < 0.10$) and G:F ($P < 0.05$). This was the result of pigs fed ground soybean hulls having reduced ADFI and improved G:F in meal diets, but ADFI was unaffected and G:F decreased when diets were pelleted. In addition, a tendency for a diet form × soybean hull level interactions ($P < 0.06$) was observed for ADFI and G:F. This was the result of pigs fed increased soybean hulls having increased ADFI and decreased G:F in meal diets, but did not affect G:F and had less effect on ADFI when diets were pelleted. Grind type × diet form interactions ($P < 0.05$) were observed for caloric efficiency on an ME and NE basis, where grinding soybean hulls improved caloric efficiency on an ME and NE basis in meal diets, but not in pelleted diets. Furthermore, tendencies for diet form × soybean hulls level

Table 8. Main effects of soybean hulls, particle size, and complete diet form on nursery pig performance, experiment 1[1]

	Soybean hulls		Soybean hulls grind type		Diet form			Probability, $P <$		
Item	10%	20%	Unground	Ground	Meal	Pellet	SEM	Diet Form	Soybean hulls grind type	Soybean hulls level
Days 0 to 14										
ADG, g	172	188	188	172	164	195	27	0.01	0.01	0.01
ADFI, g	303	306	305	304	281	328	26	0.01	0.84	0.58
G:F	0.564	0.610	0.612	0.562	0.577	0.597	0.039	0.63	0.01	0.01
Caloric efficiency, Mcal/kg gain										
ME	5.76	5.00	5.13	5.63	5.42	5.34	0.39	0.63	0.01	0.01
NE	4.12	3.49	3.63	3.98	3.83	3.78	0.28	0.63	0.01	0.01
Days 14 to 42										
ADG, g	632	630	637	625	623	639	12	0.01	0.06	0.71
ADFI, g	919	943	944	918	921	941	29	0.01	0.01	0.01
G:F	0.689	0.669	0.676	0.682	0.677	0.680	0.009	0.70	0.31	0.01
Caloric efficiency, Mcal/kg gain										
ME	4.59	4.50	4.57	4.52	4.55	4.54	0.06	0.74	0.30	0.04
NE	3.21	3.07	3.16	3.13	3.15	3.14	0.04	0.75	0.30	0.01
Days 0 to 42										
ADG, g	479	482	487	474	470	491	17	0.01	0.01	0.45
ADFI, g	713	731	731	713	707	737	28	0.01	0.01	0.01
G:F	0.672	0.661	0.667	0.666	0.665	0.667	0.004	0.69	0.82	0.03
Caloric efficiency, Mcal/kg gain										
ME	4.70	4.55	4.62	4.63	4.63	4.62	0.03	0.76	0.83	0.01
NE	3.30	3.12	3.21	3.21	3.21	3.20	0.02	0.78	0.82	0.01
Body weight, kg										
Day 0	6.8	6.8	6.8	6.8	6.8	6.8	0.10	0.71	0.87	0.83
Day 14	9.2	9.4	9.4	9.2	9.1	9.5	0.40	0.01	0.01	0.01
Day 42	26.9	27.1	27.3	26.7	26.5	27.4	0.80	0.01	0.08	0.42

[1]A total of 1,100 pigs (PIC C-29 × 359, initially 6.8 ± 0.1 kg) were used in a 42-d study with 11 replications per treatment.

interactions ($P < 0.06$) were also observed for caloric efficiency on an ME and NE basis. Increasing soybean hulls improved caloric efficiency on an ME an NE basis to a greater extent in pelleted diets than in meal diets.

Experiment 2

Overall (days 0 to 118), there were no evidences of soybean hull level × grind type interactions for any growth and carcass responses ($P > 0.18$). Increasing dietary soybean hull level did not affect ADG, ADFI, or final BW but decreased ($P < 0.02$) G:F (Table 9). Caloric efficiency improved ($P < 0.01$) on both ME and NE basis as more soybean hulls were added. Feeding finely ground soybean hulls did not influence ADG or ADFI, but resulted in poorer ($P < 0.04$) G:F and caloric efficiency on both ME and NE basis.

For carcass characteristics, increasing soybean hulls, regardless of soybean hull particle size, reduced (linear, $P < 0.03$) carcass yield, HCW, and backfat. Because of the reduction in backfat depth, percent lean and FFLI increased (linear, $P < 0.01$) as soybean hull level increased in the diets. Reducing the particle size of soybean hulls increased ($P < 0.01$) backfat depth and decreased ($P < 0.01$) percentage lean and FFLI.

DISCUSSION

The impact of dietary fiber on pig performance is dependent on age. Research has shown that when fibrous ingredients are included in a swine diet, the pigs' hindgut becomes more active, digesting the majority of the fiber (Fernandez and Jorgensen, 1986; Noblet et al., 1994; Jorgensen et al., 1996). Fernandez and Jorgensen (1986) observed that increasing dietary fiber decreased digestibility in young pigs, but as pigs aged and increased BW, fiber digestibility significantly improved. These findings have been replicated by Noblet and Le Goff (2001), Noblet and van Milgen (2004), and Stewart et al. (2013). As the pig matures and increases BW, the gastrointestinal tract increases in size, resulting in decreased passage rate of digesta and greater

Table 9. Effects of ground and unground soy hulls on growth performance and carcass characteristics, experiment 2[1]

							Probability[2], $P <$		
Soybean hulls grind type:	—	Unground	Unground	Ground	Ground		Soybean hull	Soybean hulls	
Soybean hulls, %	0	7.5	15	7.5	15	SEM	grind type	Linear	Quadratic
Days 0 to 118									
ADG, kg	0.837	0.839	0.845	0.843	0.822	0.010	0.34	0.78	0.53
ADFI, kg	2.13	2.15	2.18	2.21	2.18	0.024	0.31	0.11	0.31
G:F	0.391	0.387	0.384	0.381	0.375	0.004	0.04	0.02	0.75
Caloric efficiency, Mcal/kg gain									
ME	8.54	8.32	8.08	8.49	8.29	0.090	0.03	0.01	0.60
NE	6.33	6.07	5.80	6.20	5.95	0.060	0.03	0.01	0.61
Body weight, kg									
Day 0	31.0	31.0	31.1	31.1	31.1	0.79	0.99	0.96	0.99
Day 118	128.3	127.7	128.9	128.8	126.5	1.39	0.64	0.73	0.83
Carcass characteristics									
Plant carcass yield, %	76.26	75.42	74.96	75.23	75.16	0.361	0.55	0.01	0.13
Hot carcass weight, kg	94.7	92.9	91.9	94.0	91.8	1.05	0.62	0.03	0.83
Backfat depth, mm	15.6	14.2	13.5	15.1	14.5	0.29	0.01	0.01	0.38
Loin depth, mm	67.4	66.0	64.8	65.5	65.6	0.81	0.84	0.32	0.25
Lean, %	57.44	58.06	58.39	57.54	57.82	0.186	0.01	0.01	0.89
FFLI[3]	54.12	54.75	55.07	54.28	54.50	0.168	0.01	0.01	0.63

[1]A total of 1,235 pigs (PIC 337 × 1050; initially 31.1 ± 0.06 kg) were used in a 118-d study with 9 replications per treatment.

[2]No soybean hull level × grind type interactions ($P > 0.18$).

[3]FFLI was calculated using NPPC (2000) guidelines for carcasses measured with the Fat-O-Meter.

fermentation capacity in hindgut; as a result, more volatile fatty acids are produced and used, and dietary fiber becomes more digestible (Fernandez and Jorgensen, 1986; Noblet and Le Goff, 2001). Therefore, many studies have suggested that NE values of high-fiber ingredients are greater in heavy vs. light pigs (Noblet et al., 1994; Noblet and Le Goff, 2001; Le Gall et al., 2009). Stewart et al. (2013) reported that 30% soybean hulls had no effect on growth performance in finishing pigs (85 to 127 kg BW) but did decrease G:F in growing pigs (25 to 55 kg BW). In this study, increasing dietary soybean hulls did not affect ADG but decreased G:F to a similar extent (approximately 3%) in both nursery and finishing pigs.

Just (1982), Noblet and Perez (1993), and Noblet et al. (1994) illustrated that dietary fiber acts as a diluent to NE as fermentation of fiber increases N losses. However, increased pig BW reduces these effects on N loss. In both experiments 1 and 2, the ME and NE of the diets decreased with increasing soybean hulls. However, interestingly, increasing soybean hulls improved ME and NE caloric efficiency in both experiments. It is theorized that pigs were more efficient than expected with increasing soybean hulls. A possible reason for this observation is that the soybean hull NE value used in diet formulation was underestimated by INRA (2004). Contrary to this study, Stewart et al. (2013) suggested that the NE (603 kcal/kg) of soybean hulls determined using a comparative slaughter procedure was lower than the NE calculated by INRA (2004) for both growing and finishing pigs.

Feed-processing techniques such as fine grinding to reduce cereal grain particle size have been shown to improve pig performance and nutrient digestibility (Healy et al., 1994; Wondra et al., 1995a, 1995b). However, little data are available on reducing particle size of non-cereal grains, such as soybean hulls, in diets for swine. It was hypothesized that by reducing the particle size of soybean hulls the digestibility would improve. A study from South America by Moreira et al. (2009) observed an improvement in digestible energy and ME when soybean hulls were ground through a 2.5-mm screen. However, soybeans are process differently in South America than in the United States. In South America, the soybean hulls are separated before roasting and, therefore, trypsin inhibitors may still be present in the hulls. It is possible that the digestibility improvement observed by Moreira et al. (2009) was the result of reducing trypsin inhibitors by the heat generated during grinding instead of decreasing particle size of soybean hulls. In experiment 1, grinding soybean hulls resulted in reduced nursery ADG, ADFI, and tended to reduce final

BW. Feed efficiency and caloric efficiency were also worsened by grinding soybean hulls. These results imply that grinding soybean hulls did not improve pig performance by means of improved digestibility and in fact, the opposite may have occurred. It could be possible that increased passage rate caused by fine particles of fiber decreased diet digestibility. Future research is needed to verify and understand the mechanism of this effect.

Pelleting swine diet has consistently shown improvements in growth performance (Stark et al., 1994; Wondra et al., 1995b; Nemechek et al., 2015). In the current nursery study, pelleting increased ADG and final BW as expected, whereas the increase in ADFI resulted in no impact on G:F. In experiment 1, soybean hull grind type × diet form interactions were observed for ADFI, G:F, and caloric efficiency as improvements by grinding soybean hulls were observed when diets were fed in meal form but not for pigs fed pelleted diets. This observation suggests that the growth-promoting effects of grinding soybean hulls and pelleting diets were not additive. Tendencies for diet form × soybean hull level interactions were also observed for nursery performance. Improved ADFI with decreased G:F by increasing soybean hulls from 10% to 20% was observed in meal diets but not for diets in pellet form. Pigs fed increased amount of soybean hulls were expected to increase ADFI to compensate for the decreased dietary energy density. Pelleting has been reported to improve nutrient digestibility over meal diets (Wondra et al., 1995a; Rojas et al., 2016). It is possible that pelleting improved energy digestibility of fibrous diets and thus ADFI and G:F were not as affected as it was in meal diets.

It was not surprising that increasing soybean hulls from 0% to 15% decreased carcass yield in finishing pigs. This data agree with previous research (Asmus et al., 2012; Salyer et al., 2012; Coble et al., 2018) that showed a reduction in carcass yield as fiber increased in the diet. As dietary fiber increased, gut fill and visceral organ weight increase, consequently decreasing carcass yield (Coble et al., 2018). The increased organ weight caused by fiber has been speculated to increase the animals' maintenance requirement by redirecting nutrients from carcass to the visceral organs (Ferrell, 1988). However, in this study there was no effect of soybean hulls on ADG or ADFI. If the maintenance requirement increased due to organ weight, it was not increased enough to significantly increase intake to meet the higher maintenance requirement caused by increased organ weight. In this study, increasing soybean hull inclusion caused dietary energy to decrease and consequently, less energy was partitioned toward fat deposition. Therefore, backfat decreased with increasing soybean hull inclusion. Due to the decreased backfat, there were increases in percent lean and FFLI in pigs fed more soybean hulls.

In summary, increasing soybean hulls reduced G:F in both nursery and finishing pigs. However, caloric efficiency improved as soybean hull level increased, suggesting that the published energy values used in diet formulation (1,003 kcal NE/kg; INRA, 2004) for soybean hulls may be underestimated. Pelleting nursery diets provided the expected improvement in ADG and eliminated the negative effect of increasing soybean hulls on G:F. The hypothesis that reducing the particle size of soybean hulls may improve its energy value was proven false. Grinding soybean hulls reduced ADFI and ADG in nursery pigs and G:F in finishing pigs.

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