The effects of soybean hulls level, distillers dried grains with solubles, and net energy formulation on nursery pig performance[1]

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ABSTRACT: Four experiments were conducted to investigate the effects of increasing dietary soybean hulls without or with distillers dried grains with solubles (DDGS) and net energy (NE) formulation on nursery pig performance. In experiment 1, a total of 210 nursery pigs (initially 6.6 ± 0.1 kg) were used in a 34-d study. Pigs were fed one of five diets that contained increasing soybean hulls (0%, 5%, 10%, 15%, and 20%). Diets were not balanced for NE. Increasing soybean hulls decreased (linear, $P < 0.01$) average daily gain (ADG) and gain:feed ratio(G:F), and tended to decrease average daily feed intake (ADFI; quadratic, $P < 0.10$). In experiment 2, 210 nursery pigs (initially 13.6 ± 0.1 kg) were used in a 20-d study to determine the effect of equal NE formulation in diets with soybean hulls. Pigs were fed one of five diets containing 0% (control), 10%, or 20% soybean hulls either balanced to contain equal NE to the control diet or not balanced for energy. Diets containing 10% and 20% soybean hulls with balanced NE contained 3.60% and 7.15% added soybean oil, respectively. Increasing soybean hulls decreased (linear, $P < 0.01$) ADG regardless of formulation method. Pigs fed increasing soybean hulls without added fat had decreased (linear, $P < 0.01$) G:F. Increasing soybean hulls in diets with balanced NE decreased (linear, $P < 0.02$) ADFI, but did not affect G:F. In experiment 3, 600 pigs (initially 6.8 ± 0.1 kg) were used in a 42-d study. Pigs were fed 1 of 10 diets containing 0%, 3%, 6%, 9%, or 12% soybean hulls without or with DDGS (15% from d 0 to 14, 30% from d 15 to 42). Feeding DDGS reduced ($P < 0.04$) ADG and ADFI, and tended to increase ($P < 0.06$) G:F. Increasing soybean hulls decreased G:F quadratically ($P < 0.03$) in diets without DDGS, but decreased G:F linearly ($P < 0.01$) in diets with DDGS (soybean hulls × DDGS interaction, $P < 0.05$). In experiment 4, 304 barrows (initially 11.7 ± 0.2 kg) were used in a 21-d study. Pigs were fed one of eight diets containing 0%, 5%, 10%, or 15% soybean hulls with or without 20% DDGS. No soybean hull × DDGS interactions were observed. Increasing soybean hulls tended to decrease (linear, $P < 0.08$) G:F. In conclusion, feeding low levels of soybean hulls did not affect nursery pig performance but more than 5% soybean hulls, with or without DDGS, decreased G:F. Formulating diets containing soybean hulls on an equal NE basis eliminated the negative effects on G:F, but the NE (1,003 kcal/kg) of soybean hulls used in this study was underestimated.

Key words: DDGS, growth, net energy, nursery pig, soybean hulls

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INTRODUCTION

Soybeans make up over 50% of world oilseed production with 119.5 million metric tons produced in the United States in 2017 (American Soybean Association, 2018). The majority of soybeans in the United States are processed by solvent extraction procedures to produce the main products of oil and soybean meal. During soybean preparation, the seed is cracked or dehulled and the hulls are removed from the rest of the soybean. The hulls are then marketed as a coproduct ingredient to be used in livestock diets. However, due to the soybean hull's high fiber and ash content, it has a much lower published energy value than other common ingredients (corn net energy [NE] = 2,650 kcal/kg; soybean hulls NE = 1,003 kcal/kg; INRA 2004). The majority of research evaluating the effects of soybean hulls on nursery pig performance was conducted before the year 2000 (Kornegay, 1978; Gore et al., 1986; Kornegay et al., 1995) with a consensus that increasing soybean hulls from 8% to 16% decreased G:F. To the best of our knowledge, very limited amount of data (Barbosa et al., 2008; Moreira et al., 2009; Stewart et al., 2013) were published in the last decade regarding the feeding value of soybean hulls in swine diets.

Dried distillers grains with solubles (DDGS) is a coproduct from ethanol production commonly used in swine diets. Stein and Shurson (2009) reported DDGS could be included in diets for nursery pigs beginning at 2 to 3 wk postweaning at an inclusion of up to 30% without negatively affecting growth performance. However, no data are available using DDGS and soybean hulls together in nursery diets.

Therefore, the objectives of these studies were to determine 1) the effects of increasing soybean hulls (0% to 20%) on nursery pig performance, 2) whether balancing diets on a NE basis by adding dietary fat affects pig performance, and 3) the influence of using soybean hulls and DDGS in combination on growth performance of nursery pigs in research and commercial settings.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State Institutional Animal Care and Use Committee. 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). In all experiments, caloric efficiencies of pigs were determined on NE basis. Caloric efficiencies were calculated by multiplying total feed intake by energy content of the diet (Mcal/kg) and dividing by total gain.

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

	Corn	Soybean hulls	Soybean meal	Fish meal	DDGS	Spray-dried whey
Crude protein, %	8.50	9.80	46.50	62.90	27.2	12.10
Lysine	0.26 (78)[1]	0.67 (61)	3.02 (90)	4.81 (95)	0.78 (62)	0.90 (87)
Isoleucine	0.28 (87)	0.43 (62)	2.16 (89)	2.57 (94)	1.01 (75)	0.62 (83)
Leucine	0.99 (92)	0.90 (63)	3.66 (89)	4.54 (94)	3.17 (83)	1.08 (87)
Methionine	0.17 (90)	0.11 (69)	0.67 (91)	1.77 (94)	0.55 (82)	0.17 (81)
Cysteine	0.19 (86)	0.11 (69)	0.74 (87)	0.57 (88)	0.57 (82)	0.25 (85)
Threonine	0.29 (82)	0.35 (62)	1.85 (87)	2.64 (88)	1.06 (71)	0.72 (79)
Tryptophan	0.06 (84)	0.11 (63)	0.65 (90)	0.66 (90)	0.21 (70)	0.18 (79)
Valine	0.39 (87)	0.43 (62)	2.27 (88)	3.03 (93)	1.35 (75)	0.60 (77)
NE, kcal/kg	2,650	1,003	2,020	2,335	2,650	2,215
Crude fiber, %	2.2	33.3	3.9	—		—
Calcium, %	0.03	0.54	0.34	5.21	0.03	0.75
Phosphorus, %	0.28 (14)	0.11 (30)	0.69 (23)	3.04 (94)	0.71 (77)	0.72 (97)

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

Experiment 1

A total of 210 pigs (327 × 1050; PIC, Hendersonville, TN; initially 6.6 ± 0.1 kg body weight [BW] and 28 d of age) were used in a 34-d growth experiment to evaluate the effects of increasing soybean hulls in corn–soybean meal-based nursery diets. Pigs were allotted to pens by BW, and pens were assigned to one of five treatments in a completely randomized design. There were seven pigs per pen and six replications per treatment. Five dietary treatments consisted of corn–soybean meal-based diets and were formulated with increasing soybean hulls from 0%, 5%, 10%, 15%, and 20%. Diets were in meal form and pigs were fed in two phases from d 0 to 13 and d 13 to 34 (Table 2). Treatment diets were formulated to a constant standardized ileal digestible

Table 2. Phase 1 and phase 2 diet composition and bulk density, experiment 1 (as-fed basis)[1]

	Phase 1					Phase 2				
	Soybean hulls, %					Soybean hulls, %				
Item	0	5	10	15	20	0	5	10	15	20
Corn	54.69	50.09	45.49	40.89	36.28	63.74	59.06	54.37	49.71	45.03
Soybean meal, 46.5% crude protein	29.40	29.06	28.71	28.36	28.02	32.79	32.53	32.26	31.99	31.72
Soybean hulls	—	5.00	10.00	15.00	20.00	—	5.00	10.00	15.00	20.00
Select menhaden fish meal	3.00	3.00	3.00	3.00	3.00	—	—	—	—	—
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	—	—	—	—	—
Monocalcium P, 21% P	0.65	0.65	0.65	0.65	0.65	1.05	1.05	1.05	1.05	1.05
Limestone	0.88	0.81	0.75	0.69	0.63	0.95	0.89	0.83	0.77	0.71
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine HCl	0.25	0.24	0.24	0.23	0.23	0.33	0.32	0.32	0.31	0.30
DL-Methionine	0.12	0.13	0.14	0.15	0.16	0.13	0.14	0.15	0.15	0.16
L-Threonine	0.13	0.14	0.14	0.15	0.15	0.13	0.13	0.14	0.14	0.15
Phytase[4]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis										
SID amino acids, %										
Lysine	1.32	1.32	1.32	1.32	1.32	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	62	62	62	62	62	61	61	61	61	61
Leucine:lysine	127	125	124	122	121	129	127	126	124	123
Methionine:lysine	34	34	35	35	35	33	34	34	34	34
Methionine and cysteine:lysine	58	58	58	58	58	58	58	58	58	57
Threonine:lysine	65	65	65	65	65	63	63	63	63	63
Tryptophan:lysine	18	18	18	17	17	17	18	18	18	18
Valine:lysine	68	68	67	67	66	68	68	67	67	66
Total lysine, %	1.46	1.47	1.48	1.49	1.50	1.42	1.43	1.44	1.45	1.46
NE, Mcal/kg	2.40	2.33	2.25	2.17	2.09	2.37	2.29	2.21	2.13	2.05
SID Lys:NE, g/Mcal	5.50	5.67	5.87	6.08	6.32	5.40	5.59	5.79	6.01	6.24
Crude protein, %	21.8	21.8	21.8	21.8	21.9	21.1	21.2	21.2	21.3	21.3
Crude fiber, %	2.4	3.9	5.5	7.0	8.6	2.7	4.2	5.8	7.3	8.9
ADF, %	3.1	5.0	6.9	8.7	10.6	3.6	5.4	7.3	9.2	11.1
NDF, %	7.9	10.2	12.6	14.9	17.3	9.0	11.4	13.7	16.1	18.4
Calcium, %	0.80	0.80	0.80	0.80	0.80	0.69	0.69	0.69	0.69	0.69
Phosphorus, %	0.66	0.65	0.64	0.63	0.62	0.63	0.62	0.61	0.60	0.60
Available P, %	0.48	0.48	0.48	0.48	0.48	0.42	0.42	0.42	0.42	0.42
Bulk density, g/L	810	769	714	676	659	802	772	718	720	666

[1]Diets were fed in meal form from d 0 to 13 for phase 1 and d 13 to 34 for phase 2.

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

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

[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 phytase units (FTU)/kg, with a release of 0.10% available P.

(SID) lysine of 1.32% in phase 1 and 1.28% in phase 2. The SID lysine levels were selected based on the estimated requirement for the control diet (0% soybean hulls).

This experiment was conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. Each pen (1.22 × 1.52 m) contained a four-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pig weight and feed disappearance were measured weekly to determine average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F). All diets were manufactured at the Kansas State University Animal Sciences Feed Mill (Manhattan, KS). Samples of each diet were collected from every feeder and subsampled into a composite sample of each treatment for each phase.

Table 3. Phase 1 diet composition and bulk density, experiment 2 (as-fed basis)[1]

Soybean hulls, %	0	10	20	10	20
Dietary NE, Mcal/kg	2.37	2.21	2.05	2.37	2.37
Ingredients					
Corn	63.74	54.37	45.02	50.47	37.28
Soybean meal, 46.5% crude protein	32.79	32.26	31.72	32.55	32.30
Soybean hulls	—	10.00	20.00	10.00	20.00
Soybean oil	—	—	—	3.60	7.15
Monocalcium P, 21% P	1.05	1.05	1.05	1.05	1.05
Limestone	0.95	0.83	0.71	0.83	0.71
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15
L-Lysine HCl	0.33	0.32	0.30	0.32	0.30
DL-Methionine	0.13	0.15	0.17	0.16	0.18
L-Threonine	0.13	0.14	0.15	0.14	0.15
Phytase[4]	0.13	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0	100.0
Calculated analysis					
SID amino acids, %					
Lysine	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	61	61	61	61	60
Leucine:lysine	129	126	123	124	119
Methionine:lysine	33	34	35	34	35
Methionine and cysteine:lysine	58	58	58	58	58
Threonine:lysine	63	63	63	63	63
Tryptophan:lysine	17	18	18	17	17
Valine:lysine	68	67	66	67	65
Total lysine, %	1.42	1.44	1.46	1.44	1.46
NE, Mcal/kg	2.37	2.21	2.05	2.37	2.37
SID Lys:NE, g/Mcal	5.40	5.79	6.24	5.40	5.40
Crude protein, %	21.1	21.2	21.3	21.0	20.9
Crude fiber, %	2.7	5.8	5.7	8.9	8.7
ADF, %	3.6	7.3	7.2	11.1	10.9
NDF, %	9.0	13.7	13.4	18.4	17.7
Calcium, %	0.69	0.69	0.69	0.69	0.69
Phosphorus, %	0.63	0.61	0.60	0.60	0.58
Available P, %	0.42	0.42	0.42	0.42	0.42
Bulk density, g/L	805	698	649	743	685

[1]Dietary treatment fed in meal form from d 0 to 20.

[2]Provided per kg of premix: 4,408,000 IU vitamin A; 551,000 IU vitamin D3; 17,632 IU vitamin E; 1,763 mg vitamin K; 3,306 mg riboflavin; 11,020 mg pantothenic acid; 19,836 mg niacin; and 15.0 mg vitamin B12.

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

[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO), providing 509 phytase units (FTU)/kg, with release of 0.10% available P.

Experiment 2

A total of 210 pigs (327 × 1050; PIC; initially 13.6 ± 0.1 kg BW and 35 d of age) were used in a 20-d growth experiment to determine the effects of increasing dietary soybean hulls with or without a constant NE level on nursery pig performance. Pigs were allotted to pens by initial BW, and pens were assigned to one of five dietary treatments in a completely randomized design. There were seven pigs per pen with six replications per treatment. All pigs were initially fed a common commercial diet for the first 14 d after weaning. Starting on d 14 postweaning (d 0 of the experiment), pigs were fed the experimental diets. Diets were fed in meal form from d 0 to 20 (Table 3). The five treatments consisted of a corn–soybean meal-based diet and diets with 10% or 20% soybean hulls either balanced on a NE basis equal to the corn–soybean meal diet or not balanced for energy. Diets were formulated to a constant SID lysine of 1.28%. The diets balanced for NE contained 3.6% and 7.15% added soybean oil in the 10% and 20% soybean hull diets, respectively, to achieve the same NE as the control diet.

This experiment was conducted, feed manufactured, and samples collected as described for experiment 1. Pig weight and feed disappearance were measured on d 0, 7, 13, and 20 of the trial to determine ADG, ADFI, and G:F.

Experiment 3

A total of 600 pigs (C-29 × 359; PIC; initially 6.6 ± 0.1 kg BW and 28 d of age) were used in a 42-d growth study to evaluate the effects of soybean hulls in corn–soybean meal-based diets with and without DDGS on nursery pig growth performance. Pigs were allotted to pens by initial BW, and pens of pigs were blocked by initial pen weight and room location and assigned to 1 of 10 treatments. There were 10 pigs per pen (five barrows and five gilts) and 10 replications per dietary treatment. All pigs were fed a common pelleted starter diet for 10 d after weaning. Starting on d 10 postweaning (d 0 of the experiment), pigs were fed the experimental diets. Diets were fed in meal form in two phases from d 0 to 14 and d 15 to 42 (Tables 4 and 5). The 10 treatments included diets containing 0%, 3%, 6%, 9%, or 12% ground soybean hulls (408 µm) with or without DDGS (15% and 30% for phases 1 and 2, respectively).

A single batch of soybean hulls was ground at the Kansas State University Grain Science Feed Mill through a hammer mill (P-250D Pulverator; Jacobson Machine Works, Minneapolis, MN) equipped with a 1.59-mm screen and shipped to Kalmbach Feeds, Inc. (Upper Sandusky, OH) for diet manufacturing. All diets within each phase were formulated on a common SID lysine concentration of 1.32% in phase 1 and 1.28% in phase 2. The SID lysine levels fed were selected based on the required level for the diets without soybean hulls and DDGS. All phase 1 diets contained 4% fish meal and 10% spray-dried whey.

This experiment was conducted at the Cooperative Research Farm's Swine Research Nursery (Sycamore, OH), which is owned and managed by Kalmbach Feeds, Inc. 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 ADG, ADFI, and G:F. Samples of each dietary treatment were collected from every feeder for each phase and sent to Kansas State University where they were subsampled into composite samples.

Experiment 4

A total of 304 barrows (337 × 1050; PIC; initially 11.7 ± 0.2 kg BW and 35 d of age) were used in a 21-d growth trial to determine the effects of soybean hulls in corn–soybean meal-based diets with and without DDGS on nursery pig growth performance. Pigs were allotted to pens by BW, and pens were assigned to one of eight treatments. There were nine replicate pens per treatment with four to five pigs per pen. All pigs were initially fed common commercial diets for the first 14 d. On d 14 postweaning (d 0 of the experiment), experimental diets were fed to the nursery pigs. Treatments were arranged in a 2 × 4 factorial with main effects of DDGS (0% or 20%) and soybean hulls (0%, 5%, 10%, and 15%). Diets were fed in meal form from d 0 to 21 (Table 6). Treatment diets were formulated to a constant SID lysine level of 1.28%. The SID lysine levels fed were selected based on the required level for the diets without soybean hulls and DDGS.

This experiment was conducted at the Kansas State University Segregated Early Weaning Research Facility in Manhattan, KS. Each pen (1.22 × 1.22 m) contained a four-hole dry self-feeder and one cup waterer to provide ad libitum access to feed and water. Pig weight and feed disappearance were measured weekly to determine ADG, ADFI, and G:F. All diets were manufactured at the Kansas State University

Table 4. Composition of phase 1 diets, experiment 3 (as-fed basis)[1]

	Phase 1									
DDGS, %	0	0	0	0	0	15	15	15	15	15
Item Soybean hulls, %	0	3	6	9	12	0	3	6	9	12
Corn	55.23	52.52	49.75	47.05	44.27	43.14	40.34	37.65	34.94	32.24
Soybean meal, 46.5% crude protein	28.19	27.92	27.73	27.46	27.27	25.54	25.35	25.08	24.81	24.54
Soybean hulls	—	3.00	6.00	9.00	12.00	—	3.00	6.00	9.00	12.00
DDGS	—	—	—	—	—	15.00	15.00	15.00	15.00	15.00
Select menhaden fish meal	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Monocalcium P, 21% P	0.50	0.50	0.50	0.50	0.50	0.15	0.15	0.15	0.15	0.15
Limestone	0.83	0.80	0.76	0.72	0.69	1.00	0.98	0.95	0.91	0.88
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine HCl	0.23	0.23	0.22	0.22	0.22	0.26	0.26	0.25	0.25	0.25
DL-Methionine	0.12	0.13	0.13	0.14	0.14	0.05	0.06	0.06	0.07	0.07
L-Threonine	0.13	0.13	0.14	0.14	0.14	0.09	0.09	0.09	0.10	0.10
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis										
SID amino acids, %										
Lysine	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
Isoleucine:lysine	63	62	62	62	62	65	65	65	65	65
Leucine:lysine	128	127	126	125	124	143	142	141	140	139
Methionine:lysine	35	35	35	35	36	32	32	32	32	33
Methionine and cysteine:lysine	58	58	58	58	58	58	58	58	58	58
Threonine:lysine	65	65	66	66	65	65	65	65	65	65
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	69	69	69	68	68	73	73	73	72	72
Total lysine, %	1.46	1.47	1.47	1.48	1.49	1.49	1.49	1.50	1.51	1.52
NE, Mcal/kg	2.40	2.35	2.30	2.26	2.21	2.42	2.37	2.33	2.28	2.23
SID Lys:NE, g/Mcal	5.50	5.62	5.74	5.84	5.97	5.45	5.57	5.67	5.79	5.92
Crude protein, %	21.9	21.9	22.0	22.0	22.0	23.7	23.7	23.7	23.8	23.8
Crude fiber, %	2.3	3.2	4.2	5.1	6.0	1.9	2.9	3.8	4.7	5.7
ADF, %	3.1	4.2	5.3	6.4	7.6	5.0	6.2	7.3	8.4	9.5
NDF, %	7.8	9.2	10.6	12.0	13.5	11.6	13.0	14.4	15.8	17.2
Calcium, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Phosphorus, %	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Available P, %	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46

[1]Dietary treatment fed in meal form from d 0 to 14 for phase 1.

[2]Provided by 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; and 0.40 mg vitamin B_{12}.

[3]Provided per kg of the diet: 25 mg Mn from manganese oxide, 88 mg Fe from iron sulfate, 2000 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.

[4]Ronozyme CT (10,000) (International Nutrition, Omaha, NE), providing 1,852 phytase units (FTU)/kg, with a release of 0.10% available P.

Animal Sciences Feed Mill. Complete diet samples were collected from every feeder and subsampled into composite samples of each treatment for each phase.

Chemical Analyses

In all four experiments, soybean hulls were collected at the time of feed manufacturing and a single composite sample for each experiment was analyzed for moisture (method 934.01; AOAC International, 2006), crude protein (990.03; AOAC International, 2006), acid detergent fiber (ADF; ANKOM Technology, 1998a), neutral detergent fiber (NDF; ANKOM Technology, 1998b), crude fiber (method 978.10; AOAC International, 2006), Ca (method 965.14/985.01; AOAC International, 2006), and P

Table 5. Composition of phase 2 diets, experiment 3 (as-fed basis)[1]

	Phase 2									
DDGS, %	0	0	0	0	0	30	30	30	30	30
Item Soybean hulls, %	0	3	6	9	12	0	3	6	9	12
Corn	63.93	61.03	58.34	55.59	52.92	39.73	36.98	34.19	31.43	28.72
Soybean meal, 46.5% crude protein	32.71	32.67	32.40	32.21	31.94	27.34	27.15	26.96	26.77	26.50
Soybean hulls	—	3.00	6.00	9.00	12.00	—	3.00	6.00	9.00	12.00
DDGS	—	—	—	—	—	30.00	30.00	30.00	30.00	30.00
Monocalcium P, 21% P	1.05	1.05	1.05	1.05	1.05	0.35	0.35	0.35	0.35	0.35
Limestone	0.95	0.89	0.83	0.77	0.71	1.35	1.30	1.28	1.23	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine HCl	0.33	0.32	0.32	0.32	0.31	0.40	0.39	0.39	0.38	0.38
DL-Methionine	0.13	0.14	0.15	0.15	0.16	0.01	0.01	0.01	0.01	0.02
L-Threonine	0.13	0.13	0.14	0.14	0.14	0.05	0.05	0.05	0.06	0.06
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis										
SID amino acids,%										
Lysine	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Isoleucine:lysine	61	62	61	61	61	66	66	66	66	66
Leucine:lysine	129	128	127	126	125	160	159	158	157	156
Methionine:lysine	33	33	34	34	35	29	29	29	29	29
Methionine and cysteine:lysine	58	58	58	58	59	59	58	58	58	58
Threonine:lysine	63	63	63	63	63	63	63	63	63	63
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	68	68	68	67	67	77	77	76	76	76
Total lysine, %	1.42	1.42	1.43	1.44	1.44	1.47	1.48	1.49	1.50	1.50
NE, Mcal/kg	2.36	2.31	2.26	2.22	2.17	2.40	2.35	2.31	2.26	2.21
SID Lys:NE, g/Mcal	5.42	5.54	5.66	5.77	5.90	5.33	5.45	5.54	5.66	5.79
Crude protein, %	21.13	21.23	21.25	21.29	21.31	24.67	24.71	24.75	24.79	24.80
Crude fiber, %	2.7	3.6	4.5	5.5	6.4	1.9	2.9	3.8	4.7	5.7
ADF, %	3.6	4.7	5.8	6.9	8.1	7.5	8.6	9.7	10.9	12.0
NDF, %	9.1	10.5	11.9	13.3	14.7	16.6	18.0	19.5	20.9	22.3
Calcium, %	0.69	0.68	0.67	0.66	0.65	0.69	0.69	0.69	0.69	0.69
Phosphorus, %	0.63	0.62	0.62	0.61	0.61	0.59	0.58	0.58	0.57	0.57
Available P, %	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

[1]Dietary treatment fed in meal form from d 14 to 42 for phase 2.

[2]Provided by 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; and 0.40 mg vitamin B_{12}.

[3]Provided per kg of the diet: 25 mg Mn from manganese oxide, 88 mg Fe from iron sulfate, 2000 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.

[4]Ronozyme CT (10,000) (International Nutrition, Omaha, NE), providing 1,852 phytase units (FTU)/kg, with a release of 0.10% available P.

(method 965.17/985.01; AOAC International, 2006) at Ward Laboratories (Kearney, NE). 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).

For experiment 3 and 4, DDGS were collected at the time of feed manufacturing and a single composite sample for each experiment was analyzed for the same analyses as described for the soybean hulls with the addition of crude fat (method 920.39 A; AOAC International, 2006).

Table 6. Composition of diets, experiment 4 (as-fed basis)[1]

DDGS, %	0	0	0	0	20	20	20	20
Item Soybean hulls, %	0	5	10	15	0	5	10	15
Corn	64.42	59.84	55.15	50.72	48.25	43.81	39.21	34.47
Soybean meal, 46.5% crude protein	32.08	31.73	31.47	30.97	28.55	28.05	27.71	27.52
Soybean hulls	—	5.00	10.00	15.00	—	5.00	10.00	15.00
DDGS	—	—	—	—	20.00	20.00	20.00	20.00
Monocalcium P, 21% P	1.05	1.05	1.05	1.05	0.6	0.6	0.6	0.6
Limestone	1.00	0.93	0.88	0.80	1.25	1.18	1.13	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lysine HCl	0.33	0.32	0.31	0.31	0.37	0.37	0.36	0.35
DL-Methionine	0.125	0.130	0.140	0.150	0.043	0.045	0.053	0.060
L-Threonine	0.125	0.123	0.125	0.130	0.065	0.070	0.073	0.075
Phytase[4]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
SID amino acids,%								
Lysine	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Isoleucine:lysine	61	61	61	61	65	65	65	65
Leucine:lysine	129	128	127	125	151	149	147	146
Methionine:lysine	33	33	34	34	30	30	30	31
Methionine and cysteine:lysine	58	58	58	58	58	58	58	58
Threonine:lysine	63	63	63	63	63	63	63	63
Tryptophan:lysine	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Valine:lysine	68	68	67	67	74	74	73	73
Total lysine, %	1.39	1.41	1.42	1.43	1.43	1.44	1.46	1.47
NE, Mcal/kg	2.37	2.29	2.21	2.13	2.40	2.32	2.24	2.16
SID Lys:NE, g/Mcal	5.32	5.50	5.70	5.92	5.25	5.43	5.63	5.83
Crude protein, %	20.9	20.9	21.0	21.0	23.2	23.2	23.3	23.4
Crude fiber, %	2.7	4.2	5.8	7.3	2.2	3.7	5.3	6.8
ADF, %	3.5	5.4	7.3	9.2	6.2	8.0	9.9	11.8
NDF, %	9.0	11.4	13.7	16.1	14.1	16.4	18.8	21.1
Calcium, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Phosphorus, %	0.62	0.61	0.61	0.60	0.60	0.59	0.58	0.58
Available P, %	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Bulk density, g/L	749	730	696	640	702	666	633	648

[1]Dietary treatment fed in meal form d 0 to 21.

[2]Provided per kg of premix: 4,408,000 IU vitamin A; 551,000 IU vitamin D3; 17,632 IU vitamin E; 1,763 mg vitamin K; 3,306 mg riboflavin; 11,020 mg pantothenic acid; 19,836 mg niacin; and 15.0 mg vitamin B12.

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

[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO), providing 509 phytase units (FTU)/kg, with release of 0.10% available P.

Statistical Analyses

In all four experiments, data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Experiments 1, 2, and 4 were analyzed as a completely randomized design in contrast to the randomized complete block design for experiment 3. In experiment 1, polynomial contrasts were used to determine the linear and quadratic effects of increasing soybean hulls. In experiment 2, preplanned polynomial contrasts were used to determine the effects of diet formulation method, linear and quadratic effects of increasing soybean hulls, along with their interactions. For experiment 3 and 4, preplanned contrasts were the following: 1) the two-way interactions between soybean hull and DDGS inclusions, 2) main effects of DDGS, and 3) linear and quadratic effects of increasing soybean hulls within non-DDGS and DDGS diets. In all experiments, results were considered significant at $P \leq 0.05$ and a trend at $0.05 < P \leq 0.10$.

RESULTS

Chemical Analysis

In all four experiments, ingredient samples of soybean hulls were verified to be similar to those used in diet formulation (Table 7), with the exception of a lower Ca and ADF value in the soybean hulls for experiment 4. The minor differences among other nutrients would not be expected to influence the results of the study. Analyzed chemical composition of DDGS in experiment 3 was similar to those used in diet formulation; however, the DDGS in experiment 4 contained less fat than expected. The NRC (2012) classified DDGS as high oil if oil is greater than 10%, which was the case in experiment 3, whereas the DDGS in experiment 4 would be classified as medium oil DDGS with oil content less than 9% and greater than 6%. As soybean hulls and DDGS were added to the diets in increasing amounts, dietary bulk density decreased, whereas crude fiber and NDF increased as expected (Tables 2 to 6).

Experiment 1

In phase 1 (d 0 to 13), increasing soybean hulls decreased (linear, $P < 0.01$) ADG and G:F, but did not affect ADFI (Table 8). Similarly, for phase 2 (d 13 to 34), pigs fed increasing soybean hulls had decreased (linear, $P < 0.01$) ADG and G:F, with a tendency for increased (quadratic, $P < 0.10$)

Table 7. Chemical analysis and bulk density of soybean hulls and DDGS (as-fed basis)

	Experiment 1	Experiment 2	Experiment 3		Experiment 4	
Item	Soybean hulls	Soybean hulls	Soybean hulls	DDGS	Soybean hulls	DDGS
Dry matter, %	91.9	90.6	91.40	91.01	91.71	90.77
Crude protein, %	11.2	10.2	10.1	26.3	13.4	29.5
ADF, %	44.0	42.0	42	13.3	25.2	16.1
NDF, %	59.0	56.2	58.3	25.5	51.2	27.5
Crude fiber, %	34.2	33.3	34.3	9.3	31.8	8.1
Crude fat, %	—	—	—	11.8	—	8.7
Calcium, %	0.64	0.65	0.66	0.07	0.11	0.04
Phosphorus, %	0.11	0.11	0.10	0.85	0.17	0.87
Bulk density, g/L	359	444	486	—	518	—

Table 8. Effects of soybean hulls on nursery pig performance (experiment 1)[1]

							Probability, $P <$	
Soybean hulls, %	0	5	10	15	20	SEM	Linear	Quadratic
d 0 to 13								
ADG, g	218	210	201	186	175	12.0	0.01	0.79
ADFI, g	329	322	343	324	300	14.0	0.21	0.16
G:F	0.673	0.663	0.591	0.583	0.594	0.023	0.01	0.23
d 13 to 34								
ADG, g	579	582	571	558	510	14.0	0.01	0.07
ADFI, g	897	889	918	911	847	23.0	0.30	0.10
G:F	0.646	0.654	0.622	0.612	0.603	0.009	0.01	0.62
d 0 to 34								
ADG, g	441	440	429	415	382	11.0	0.01	0.11
ADFI, g	680	673	698	685	638	18.0	0.23	0.10
G:F	0.651	0.656	0.616	0.607	0.602	0.009	0.01	0.88
Caloric efficiency[2]	3.66	3.51	3.60	3.53	3.44	0.05	0.02	0.84
BW, kg								
d 0	6.64	6.64	6.75	6.64	6.64	0.06	1.00	0.38
d 13	9.48	9.37	9.36	9.17	8.91	0.17	0.02	0.47
d 34	21.67	21.61	21.37	20.92	19.64	0.40	0.01	0.09

[1]A total of 210 nursery pigs (PIC 337 × 1050, initially 6.6 ± 0.1 kg) were used in a 34-d study with seven pigs per pen and six replications per treatment.

[2]Caloric efficiencies, Mcal/kg gain = (total feed intake, kg × dietary NE, Mcal/kg) ÷ total weight gain, kg.

ADFI. Overall (d 0 to 34), pigs fed increasing soybean hulls had decreased (linear, $P < 0.01$) ADG and G:F, with a tendency for decreased (quadratic, $P < 0.10$) ADFI. ADFI was maintained when soybean hulls increased from 0% to 15% but decreased when diet contained 20% soybean hulls. Increasing soybean hulls in the diet improved (linear, $P < 0.02$) NE caloric efficiency. Pig BW decreased (linear, $P < 0.05$) with increasing soybean hulls throughout the experiment.

Experiment 2

Soybean hull level × NE formulation interactions were tested based on the four treatments containing soybean hulls (10% or 20% soybean hulls with or without balancing for dietary NE) and were not significant for ADG, ADFI, or G:F ($P > 0.10$; Table 9). Pigs fed increasing soybean hulls had decreased (linear, $P < 0.05$) ADG and final BW, whether or not diets were formulated to a constant NE. When diets were not balanced for NE (no added soybean oil), increasing soybean hulls did not affect ADFI but decreased (linear, $P < 0.01$) G:F. In contrast, when adding fat to diets containing soybean hulls to achieve similar dietary NE to the control diets, increasing soybean hulls decreased ($P < 0.01$) ADFI but did not affect G:F. There was a tendency ($P = 0.09$) for a soybean hulls level × NE interaction for caloric efficiency, where increasing soybean hulls improved caloric efficiency when diets were not balanced for NE, but not for diets with added fat.

Table 9. Effects of soybean hulls and NE formulation on nursery pig performance, experiment 2[1]

							Probability, $P <$				
							Soybean hulls, unbalanced NE[2]		Soybean hulls, balanced NE[3]		
Soybean hulls, %	0	10	20	10	20						NE
Diet NE, Mcal/kg	2.37	2.21	2.05	2.37	2.37	SEM	Linear	Quadratic	Linear	Quadratic	formulation
d 0 to 20											
ADG, g	680	663	625	671	636	10.0	0.01	0.39	0.01	0.28	0.32
ADFI, g	1,070	1,109	1,094	1,046	1,006	17.0	0.33	0.21	0.02	0.68	0.01
G:F	0.637	0.597	0.571	0.641	0.631	0.008	0.01	0.61	0.62	0.49	0.01
Caloric efficiency[4,5]	3.72	3.69	3.59	3.69	3.74	0.04	0.05	0.48	0.70	0.43	0.11
BW, kg											
d 0	13.6	13.6	13.6	13.6	13.5	0.26	0.99	0.96	0.93	0.96	0.93
d 20	27.2	26.9	26.0	27.0	26.3	0.31	0.02	0.56	0.04	0.47	0.58

[1]A total of 210 nursery pigs (PIC 337 × 1050, initially 13.6 ± 0.10 kg) were used in a 20-d study with seven pigs per pen and six replications per treatment.

[2]Contrasts among diets with 0%, 10%, and 20% soybean hulls without equal NE formulation.

[3]Contrasts among diets with 0%, 10%, and 20% soybean hulls with equal NE formulation.

[4]Caloric efficiencies, Mcal/kg gain = (total feed intake, kg × dietary NE, Mcal/kg) ÷ total weight gain, kg.

[5]Soybean hulls × NE interaction, $P = 0.09$.

Table 10. Main effects of soybean hulls and DDGS on nursery pig performance, experiment 3[1]

										Probability, $P <$		
	Soybean hulls, %						DDGS[2]			Soybean hulls		
Item	0	3	6	9	12	SEM	−	+	SEM	Linear	Quadratic	DDGS
d 0 to 42												
ADG, g	553	544	551	544	529	12	555	533	7.0	0.23	0.55	0.04
ADFI, g	826	820	854	853	807	23	857	807	14.0	0.95	0.20	0.02
G:F	0.670	0.665	0.647	0.638	0.658	0.007	0.648	0.662	0.005	0.03	0.04	0.06
Caloric efficiency[3]	3.58	3.54	3.56	3.54	3.37	0.04	3.52	3.51	0.03	0.01	0.05	0.73
BW, kg												
d 0	6.7	6.6	6.6	6.6	6.6	0.3	6.6	6.6	0.2	0.98	0.92	0.92
d 42	29.9	29.5	29.8	29.7	28.9	0.8	30.0	29.1	0.5	0.47	0.65	0.16

[1]A total of 600 nursery pigs (PIC C-29 × 359, initially 6.6 ± 0.10 kg) were used in a 42-d growth trial with 10 replications per pen.

[2]Phase 1 = 15% DDGS, Phase 2 = 30% DDGS.

[3]Caloric efficiencies, Mcal/kg gain = (total feed intake, kg × dietary NE, Mcal/kg) ÷ total weight gain, kg.

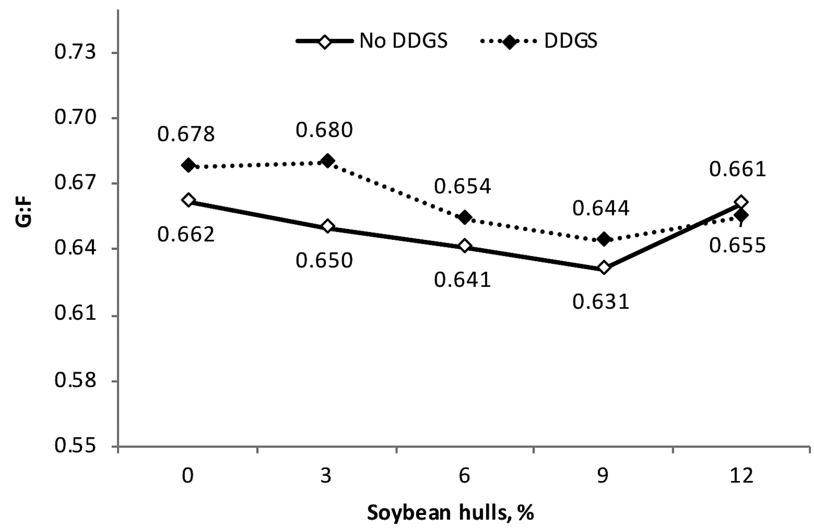

Figure 1. Effects of soybean hulls × DDGS interaction ($P < 0.05$) on (G:F), experiment 3.

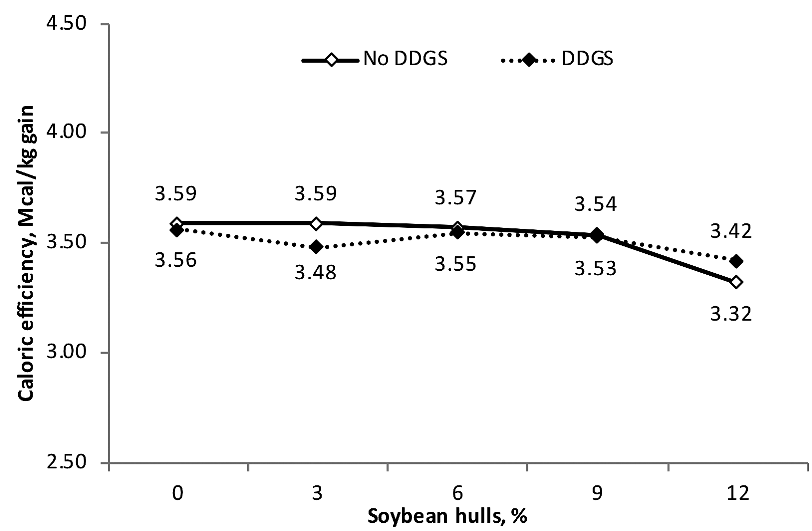

Figure 2. Effects of soybean hulls × DDGS interaction ($P < 0.05$) on caloric efficiency on NE basis, experiment 3.

Experiment 3

For the overall period (d 0 to 42), soybean hulls × DDGS interactions were not observed for ADG or ADFI, but were significant G:F and NE caloric efficiency ($P < 0.05$; Table 10). There was no evidence for any dose effects of increasing soybean hulls on ADG or ADFI ($P >$ 0.20). Increasing soybean hulls decreased G:F quadratically ($P < 0.03$) when added to diets without DDGS but linearly ($P < 0.01$) when added to diets with DDGS (Fig. 1). NE caloric efficiency improved (quadratic, $P < 0.04$) with increasing soybean hulls in diets without DDGS but were not influenced when soybean hulls were added to diets containing DDGS (Fig. 2). Including DDGS in diets decreased (P < 0.04) ADG and ADFI but tended to improve ($P < 0.10$) G:F.

Experiment 4

Overall (d 0 to 21), there were no soybean hulls × DDGS interactions observed ($P > 0.25$) and, therefore, main effects were present in Table 11. Adding soybean hulls or DDGS to the diet did not influence ADG or ADFI. Increasing soybean hulls tended to decrease (linear, $P = 0.08$) G:F, but NE caloric efficiency improved (linear, $P < 0.01$). There were no differences ($P > 0.40$) in pig BW for the duration of this study.

DISCUSSION

Soybean hulls are a low-energy ingredient that will increase the fiber content in nursery pig diets. Pigs are able to digest some forms of dietary fiber better than others. Chabeauti et al. (1991) reported high-fiber ingredients containing more lignin are

Table 11. Main effects of soybean hulls and DDGS on nursery pig performance, experiment 4[1]

	Soybean hulls, %					DDGS, %			Probability, $P <$		
									Soybean hulls		
Item	0	5	10	15	SEM	0	20	SEM	Linear	Quadratic	DDGS
d 0 to 21											
ADG, g	523	528	521	506	9.94	526	513	7	0.18	0.28	0.17
ADFI, g	813	822	821	809	16.4	825	807	11	0.85	0.52	0.26
G:F	0.644	0.644	0.636	0.623	0.008	0.639	0.636	0.005	0.08	0.51	0.72
Caloric efficiency[2]	3.71	3.59	3.51	3.44	0.04	3.53	3.59	0.03	0.01	0.53	0.15
BW, kg											
d 0	11.7	11.6	11.6	11.6	0.18	11.7	11.7	0.1	0.77	0.82	0.94
d 21	22.7	22.7	22.9	22.2	0.33	22.8	22.5	0.2	0.41	0.32	0.40

[1]A total of 304 pigs (PIC 337 × 1050, initially 11.7 ± 0.2 kg) were used in a 21-d growth trial with nine replications per treatment.

[2]Caloric efficiencies, Mcal/kg gain = (total feed intake, kg × dietary NE, Mcal/kg) ÷ total weight gain, kg.

less digestible than a fibrous ingredient that contains more pectin and less non-starch polysaccharides. Noblet and Le Goff (2001) illustrated that type of dietary fiber sources will have an impact on NE value due to their chemical properties. For instance, dietary fiber in the form of pectin is highly digestible whereas lignin and cellulose are mostly indigestible.

Just et al. (1983), Noblet and Perez (1993), and Zhang et al. (2013) illustrated that energy digestibility is reduced as dietary fiber increased in the diet. In all of the current experiments, increasing soybean hulls increased dietary fiber and decreased the calculated NE of the diets as expected. Consequently, pigs fed increasing soybean hulls had poorer G:F, but this effect was not apparent at low inclusion rates. Feeding soybean hulls up to 5% in experiments 1 and 4, and 3% in experiment 3, did not affect G:F nor ADG of nursery pigs. These results are generally similar to those of Kornegay (1978), Gore et al. (1986), and Kornegay et al. (1995) who all reported reduced G:F when 8% to 16% of soybean hulls were included in nursery diets. These findings suggest that low amounts of soybean hulls can be added to nursery diets without affecting G:F, even when diets are not balanced to the same energy level.

Interestingly, in all the current studies, adding 5% or more soybean hulls to corn–soybean meal or corn–soybean meal-DDGS diets improved caloric efficiency on a NE basis. The improved caloric efficiency potentially indicates that the INRA (2004) published energy value for soybean hulls that were used in diet formulation (1,003 kcal/kg) may slightly underestimate the energy content of soybean hulls. Conversely, Stewart et al. (2013) determined NE (603 kcal/kg) of a soybean hulls source that was lower than the value suggested by INRA (2004). However, a higher inclusion of soybean hulls (30%) was used in the diets of that study and consequently dietary energy density is significantly lower than the diets used in current trials. In addition, Stewart et al. (2013) used growing-finishing pigs instead of nursery pigs. Increased pig weight may influence the energy level of test ingredients with different estimates for nursery and finishing pigs (Noblet and Le Goff, 2001; Le Gall et al. 2009).

A common practice in swine diet formulation has been to add fat to increase dietary energy in diets that contain lower energy ingredients, such as soybean hulls. Gore et al. (1986) indicated that adding soybean oil to diets containing soybean hulls tended to reduce ADFI and improve G:F, but added oil did not affect ADG. In experiment 2, when soybean oil was added to the diets containing 10% or 20% soybean hulls to balance dietary NE, the added oil decreased ADFI but maintained similar G:F as that of pigs fed corn–soybean meal based control diet. While nursery pigs are in an energy-dependent state of growth, the effects of adding fat to nursery diets on ADG are variable. Cera et al. (1990) and Tokach et al. (1995) reported added fat from corn oil, soybean oil, medium-chain triglycerides, or animal–vegetable blend did not affect nursery pig's ADG for the first 14 d after weaning, but improved performance when fed after 35 d of age. An improvement in ADG was expected in experiment 2 as pigs were approximately 35 d of age at the initiation of the experiment; however, pigs responded by decreasing ADFI, instead of increased ADG.

Baird et al. (1975) evaluated effects of different levels of crude fiber, crude protein, and bulk density in diets for finishing pigs and reported that the pig can tolerate a variety of crude fiber levels in diets and that diet energy density determined ADFI. It has been hypothesized that low diet bulk density with increased NDF and reduced palatability can prevent pigs from consuming enough feed to reach their energy requirement for optimal growth. Kornegay (1978) observed that high levels of added soybean hulls (24%) increased ADFI, but pigs were unable to maintain the growth rate of pigs fed low-fiber diets. This suggested that the low energy, low bulk density diet containing soybean hulls restricted intake to the point of reducing growth rate. Corn DDGS also have higher crude fiber (6% to 8%) and NDF contents (30% to 33%) than corn (1.98% crude fiber and 9.11% NDF; NRC, 2012). High levels of soybean hulls or combining DDGS with soybean hulls substantially increases the fiber content and lowers the bulk density of the diet (Tables 2, 3 and 6), which might have prevented pigs from achieving the same energy intake as those fed a corn–soybean meal diet. This effect was observed in experiments 1, 3, and 4 where decreased ADFI and ADG were observed for pigs fed the diets with the highest crude fiber and NDF.

When feeding both soybean hulls and DDGS to nursery pigs, we observed a DDGS × soybean hulls interaction for G:F in experiment 3. Increasing soybean hulls decreased G:F linearly when diets also contained DDGS, whereas diets without DDGS were affected quadratically. This was driven by an unexpected increase of G:F when increasing soybean hulls from 9% to 12% in diets without DDGS, whereas this response was not observed when diets contained DDGS (Fig. 1). Further research is needed to verify this response. Barbosa et al. (2008) evaluated the effects of 15% DDGS and 4% soybean hulls in nursery pig diets. They observed DDGS × soybean hulls interactions for ADFI and a trend for G:F. Soybean hulls increased ADFI to a greater extent when added to the control diet, but when added to the diet containing DDGS, intake did not increase as much. For G:F, adding DDGS to the control diet tended to improve G:F, but adding DDGS to diets containing soybean hulls did not affect G:F. Diets containing DDGS and soybean hulls have a lower bulk density and increased fiber concentration. It is plausible that the lower bulk density or higher dietary fiber could increase gut fill. The increased gut fill could prevent the pig from increasing intake enough to reach its energy requirement.

Feeding DDGS decreased ADG and ADFI but the magnitude of this effect was greater in experiment 3 than experiment 4. This may be explained by the difference between trial designs. In experiment 4, pigs started on diets at a heavier weight and the amount of dietary fiber was lower, because less DDGS (20%) were used compared with experiment 3 (15% DDGS in phase 1 and 30% in phase 2). Also, analysis of DDGS differed between trials with the DDGS in experiment 4 having lower oil content (8.7 vs. 11.8%, respectively) than that of DDGS used in experiment 3.

In conclusion, these data indicate that soybean hulls do not affect nursery pig performance when added at 5% or less, but 6% to 20% decreased G:F. However, formulating diets on equal NE basis helps to eliminate the negative effects of high level soybean hulls on G:F. NE caloric efficiency was improved when increasing soybean hulls, indicating that the published energy value for soybean hulls may have been underestimated. Further research is needed to understand potential interaction among high levels of high-fiber ingredients on growth performance of nursery pigs.

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LITERATURE CITED

American Soybean Association. 2018. U.S. yield and production: production history. [accessed October 3, 2018]. Available from http://soystats.com/u-s-yield-production-production-history.

ANKOM Technology. 1998a. Method for determining acid detergent fiber, Ankom 200/220 Fiber Analyzer. Ankom Technology, Fairport, NY.

ANKOM Technology. 1998b. Method for determining neutral detergent fiber, Ankom 200/220 Fiber Analyzer. Ankom Technology, Fairport, NY.

AOAC International. 2006. Official methods of analysis of AOAC International, 18th ed. Assoc. Off. Anal. Chem, Arlington, VA.

Baird, D. M., H. C. McCampbell, and J. R. Allison. 1975. Effect of levels of crude fiber, protein and bulk in diets for finishing hogs. J. Anim. Sci. 41:1039–1047. doi:10.2527/jas1975.4141039x

Barbosa, F. F., S. S. Dritz, M. D. Tokach, J. M. DeRouchey, R. D. Goodband, and J. L. Nelssen. 2008. Use of dried distillers grains with solubles and soybean hulls in nursery pig diets. J. Anim. Sci. 86 (Suppl. 2): 446. (Abstr.).

Cera, K. R., D. C. Mahan, and G. A. Reinhart. 1990. Evaluation of various extracted vegetable oils, roasted soybeans, medium-chain triglyceride and an animal-vegetable fat blend for postweaning swine. J. Anim. Sci. 68:2756–2765. doi:10.2527/1990.6892756x

Chabeauti, E., J. Noblet, and B. Carré. 1991. Digestion of plant cell walls from four different sources in growing pigs. Anim. Feed Sci. Technol. 32:207–213. doi:10.1016/0377-8401(91)90024-M

Gore, A. M., E. T. Kornegay, and H. P. Veit. 1986. The effects of soybean oil on nursery air quality and performance of weanling pigs. J. Anim. Sci. 63:1–7. doi:10.2527/jas1986.6311

INRA (Institut National de la Recherche Agronomique). 2004. Tables of composition and nutritional value of feed material. In: Sauvant, D., J-M. Perez, and G. Tran, editor. Wageningen Academic Publishers, The Netherlands and INRA, Paris, France.

Just, A., J. A. Fernandez, and H. Jorgensen. 1983. The net energy value of diets for growth in pigs in relation to the fermentative processes in the digestive tract and the site of absorption of the nutrients. Livest. Prod. Sci. 10:171–186. doi:10.1016/0301-6226(83)90033-7

Kornegay, E. T. 1978. Feeding value and digestibility of soybean hulls for swine. J. Anim. Sci. 47:1272–1280. doi:10.2527/jas1978.4761272x

Kornegay, E. T., D. Rhein-Welker, M. D. Lindemann, and C. M. Wood. 1995. Performance and nutrient digestibility in weanling pigs as influenced by yeast culture additions to starter diets containing dried whey or one of two fiber sources. J. Anim. Sci. 73:1381–1389. doi:10.2527/1995.7351381x

Le Gall, M., M. Warpechowski, Y. Jaguelin-Peyraud, and J. Noblet. 2009. Influence of dietary fibre level and pelleting on the digestibility of energy and nutrients in growing pigs and adult sows. Animal. 3:352–359. doi:10.1017/S1751731108003728

Moreira, I., M. Kutschenko, D. Paiano, C. Scapinelo, A. E. Murakami, and A. R. Bonet de Quadros. 2009. Effects of different grinding levels (particle size) of soybean hull on starting pigs performance and digestibility. Braz. Arch. Biol. Technol. 52(5):1243–1252. doi:10.1590/S1516-89132009000500023

Noblet, J., and G. Le Goff. 2001. Effect of dietary fibre on the energy value of feeds for pigs. J. Anim. Feed Sci. and Technol. 90:35–52. doi:10.1016/S0377-8401(01)00195-X

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389–3398. doi:10.2527/1993.71123389x

NRC. 1998. Nutrient requirements of swine, 10th rev. ed. Natl. Acad. Press, Washington, DC.

NRC. 2012. Nutrient requirements of swine, 11th rev. ed. Natl. Acad. Press, Washington, DC.

Stein, H. H., and G. C. Shurson. 2009. The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292–1303. doi:10.2527/jas.2008-1290

Stewart, L. L., D. Y. Kil, F. Ji, R. B. Hinson, A. D. Beaulieu, G. L. Allee, J. F. Patience, J. E. Pettigrew, and H. H. Stein. 2013. Effects of dietary soybean hulls and wheat middlings on body composition, nutrient and energy retention, and the net energy of diets and ingredients fed to growing and finishing pigs. J. Anim. Sci. 91:2756–2765. doi:10.2527/jas.2012-5147

Tokach, M. D., J. E. Pettigrew, L. J. Johnston, M. Overland, J. W. Rust, and S. G. Cornelius. 1995. Effect of adding fat and(or) milk products to the weanling pig diet on performance in the nursery and subsequent grow-finish stages. J. Anim. Sci. 73:3358–3368. doi:10.2527/1995.73113358x

Zhang, W., D. Li, L. Liu, J. Zang, Q. Duan, W. Yang, and L. Zhang. 2013. The effects of dietary fiber level on nutrient digestibility in growing pigs. J. Anim. Sci. and Biotech. 4:17. doi:10.1186/2049-1891-4-17