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Effects of Soybean Meal Level on Growth Performance of 25- to 50-lb Nursery Pigs

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Effects of Soybean Meal Level on Growth Performance of 25- to 50-lb Nursery Pigs

Abstract

Four experiments were conducted to determine the effects of increasing soybean meal (SBM) level in diets with or without 25% distillers dried grains with solubles (DDGS) on growth performance of nursery pigs raised in university or commercial facilities. Treatments were arranged in a 2 × 3 factorial with main effects of SBM (27.5, 32.5, or 37.5% of the diet) and DDGS (0 or 25% of the diet). A total of 296, 2,502, 4,118, and 711 pigs initially 23.2, 25.7, 27.5, and 27.1 lb body weight (BW) were used in Exp. 1, 2, 3, and 4, respectively. There were 10, 16, 13, and 12 replicates per treatment in Exp. 1, 2, 3, and 4, respectively. After weaning, pigs were fed common diets for approximately 21 d. Then, pens of pigs were assigned to treatments in a randomized complete block design with BW as the blocking factor and experimental diets were fed for 21 d. Pigs were weighed and feed disappearance measured to calculate average daily gain (ADG), average daily feed intake (ADFI), feed-to-gain ratio (F/G), and caloric efficiency (CE). Pigs used in all experiments did not undergo major health challenges during the experimental period and due to the low number of mortality and cull events, statistical analysis was not performed on these variables. The average cull rate was 0.7, 0.5, 0.2, and 0% and the mortality rate was 0.7, 0.3, 0.4, and 0% in Exp. 1 to 4, respectively. There were interactions ($P \leq 0.031$) between SBM and DDGS for F/G and CE in Exp. 2 and for ADG and ADFI in Exp. 3. These were mostly driven by increasing SBM negatively affecting performance in a greater magnitude when diets contained DDGS compared to diets without DDGS. The main effects of DDGS and SBM were more consistently observed across experiments. Pigs fed diets with 25% DDGS had decreased ($P \leq 0.001$) ADG and ADFI in all experiments as well as poorer ($P \leq 0.025$) F/G and CE except for Exp. 3. Feeding increasing amounts of SBM generally did not result in any major impact in ADG, but consistently improved (linear, $P \leq 0.078$) F/G and CE across experiments. The mechanism for this response is unclear but could be driven by intrinsic components of SBM, such as isoflavones, or by underestimation of SBM energy value.

Keywords

caloric efficiency, growth, protein, soybean meal, swine

Cover Page Footnote

This research was supported by the United Soybean Board. Appreciation is expressed to the United Soybean Board, New Horizon Farms (Pipestone, MN), Hord Family Farms (Bucyrus, OH), and Kalmbach Feeds, Inc. (Sycamore, OH) for animals, facilities, and expertise in conducting the experiments.

Authors

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Effects of Soybean Meal Level on Growth Performance of 25- to 50-lb Nursery Pigs[1]

Henrique S. Cemin, Mike D. Tokach, Steve S. Dritz,[2] Jason C. Woodworth, Joel M. DeRouchey, and Robert D. Goodband

Summary

Four experiments were conducted to determine the effects of increasing soybean meal (SBM) level in diets with or without 25% distillers dried grains with solubles (DDGS) on growth performance of nursery pigs raised in university or commercial facilities. Treatments were arranged in a 2 × 3 factorial with main effects of SBM (27.5, 32.5, or 37.5% of the diet) and DDGS (0 or 25% of the diet). A total of 296, 2,502, 4,118, and 711 pigs initially 23.2, 25.7, 27.5, and 27.1 lb body weight (BW) were used in Exp. 1, 2, 3, and 4, respectively. There were 10, 16, 13, and 12 replicates per treatment in Exp. 1, 2, 3, and 4, respectively. After weaning, pigs were fed common diets for approximately 21 d. Then, pens of pigs were assigned to treatments in a randomized complete block design with BW as the blocking factor and experimental diets were fed for 21 d. Pigs were weighed and feed disappearance measured to calculate average daily gain (ADG), average daily feed intake (ADFI), feed-to-gain ratio (F/G), and caloric efficiency (CE). Pigs used in all experiments did not undergo major health challenges during the experimental period and due to the low number of mortality and cull events, statistical analysis was not performed on these variables. The average cull rate was 0.7, 0.5, 0.2, and 0% and the mortality rate was 0.7, 0.3, 0.4, and 0% in Exp. 1 to 4, respectively. There were interactions ($P \leq 0.031$) between SBM and DDGS for F/G and CE in Exp. 2 and for ADG and ADFI in Exp. 3. These were mostly driven by increasing SBM negatively affecting performance in a greater magnitude when diets contained DDGS compared to diets without DDGS. The main effects of DDGS and SBM were more consistently observed across experiments. Pigs fed diets with 25% DDGS had decreased ($P \leq 0.001$) ADG and ADFI in all experiments as well as poorer ($P \leq 0.025$) F/G and CE except for Exp. 3. Feeding increasing amounts of SBM generally did not result in any major impact in ADG, but consistently improved (linear, $P \leq 0.078$) F/G and CE across experiments. The mechanism for this response is unclear but could be driven by intrinsic components of SBM, such as isoflavones, or by underestimation of SBM energy value.

[1] This research was supported by the United Soybean Board. Appreciation is expressed to the United Soybean Board, New Horizon Farms (Pipestone, MN), Hord Family Farms (Bucyrus, OH), and Kalmbach Feeds, Inc. (Sycamore, OH) for animals, facilities, and expertise in conducting the experiments.

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Introduction

Soybean meal (SBM) is the primary plant-protein source for swine diets in the United States. The amino acid (AA) profile of SBM is highly digestible and complements major dietary cereal grain AA profiles, such as those of corn and wheat. Moreover, the processing techniques to remove SBM antinutritional factors are well-described and consistent. Additionally, research suggests health benefits when feeding high SBM levels. Trials with nursery (Rocha et al.[3]; Rochell et al.[4]) and finishing pigs (Johnston et al.[5]) infected with porcine reproductive and respiratory syndrome (PRRS) suggest health-challenged pig growth performance is improved by feeding high SBM levels. Although the mechanisms are not fully understood, it is suggested that SBM bioactive compounds, namely isoflavones and saponins, may be involved in this response.

Distillers dried grains with solubles (DDGS) is a co-product of the ethanol industry widely used in swine diets. It is generally accepted that 30% DDGS can be included in late nursery diets without significantly compromising growth performance, although factors such as fat and fiber content and mycotoxin levels must be considered. Diets today are frequently formulated with increasing DDGS amounts and increasing feed-grade AA replacing intact protein sources such as SBM, which typically reduces diet costs. However, given the potential benefits of SBM, a minimum amount may be desirable. We hypothesize that using SBM may be especially beneficial for pigs raised under the rigors of commercial conditions with different health statuses. Therefore, the objective of the current study was to determine the effects of increasing SBM in diets with or without DDGS on growth performance of 25- to 50-lb nursery pigs across different environmental conditions.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments.

Samples of corn, SBM, and DDGS were obtained from each location and submitted to the Agricultural Experimental Station Chemical Laboratories (University of Missouri-Columbia, Columbia, MO) for total AA content analysis prior to diet formulation (Table 1). The total AA values for corn and SBM were multiplied by NRC[6] SID coefficients and used in diet formulation. Corn, SBM, and DDGS were analyzed (Ward Laboratories, Inc., Kearney, NE) for dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and ether extract. Samples of DDGS from each location were analyzed (North Dakota State University Veterinary Diagnostic Laboratory, Fargo, ND) for mycotoxin concentrations (Table 2).

[3] Rocha, G.C., R.D. Boyd, J.A.S. Almeida, Y. Liu, T.M. Che, R.N. Dilger, and J.E. Pettigrew. 2013. Soybean meal level in diets for pigs challenged with porcine reproductive and respiratory syndrome (PRRS) virus. J. Anim. Sci. 92(E-Suppl. 2):31. (Abstr.).

[4] Rochell, S.J., L.S. Alexander, G.C. Rocha, W.G. Van Alstine, R.D. Boyd, J.E. Pettigrew, and R.N. Dilger. 2015. Effects of dietary soybean meal concentration on growth and immune response of pigs infected with porcine reproductive and respiratory syndrome virus. J. Anim. Sci. 93:2987-2997. doi:10.2527/jas2014-8462.

[5] Johnston, M.E., R.D. Boyd, C. Zier-Rush, and C.E. Fralick. 2010. Soybean meal level modifies the impact of high immune stress on growth and feed efficiency in pigs. J. Anim. Sci. 88(E-Suppl. 3):57-58. (Abstr.).

[6] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

Representative diet samples were obtained from each treatment within experiment and stored at -20°C until analysis. Samples were analyzed (Ward Laboratories, Inc., Kearney, NE) for DM, CP, Ca, P, NDF, and ether extract.

A total of four experiments were conducted, one in a university facility and three in commercial research facilities. In all experiments, pigs were weaned at approximately 21 d of age, placed in pens based on initial body weight (BW), and fed common diets for approximately 21 d. On d 21, which was considered d 0 of the trials, pens of pigs were allotted to 1 of 6 dietary treatments in a randomized complete block design with BW as the blocking factor. Treatments were arranged in a 2 × 3 factorial with main effects of SBM (27.5, 32.5, or 37.5% of the diet) and DDGS (0 or 25% of the diet). The increasing levels of SBM were obtained by changing the amount of feed-grade amino acids and corn. Diets (Tables 3 to 6) were formulated to contain the same net energy (NE). The NE value for DDGS was estimated as a function of the oil content. The NE of SBM used in diet formulation was 88% of corn NE (as-fed basis) or 1,067 kcal/lb NE. There were 10, 16, 13, and 12 replicates per treatment in Exp. 1, 2, 3, and 4, respectively.

Experiment 1 was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS). A total of 296 pigs (DNA 400 × 200, Columbus, NE; initially 23.2 lb) were placed in pens of 4 or 5 mixed gender pigs each and used in a 24-d trial. Pens (5 × 5 ft) had metal slatted floors and were equipped with a four-hole stainless steel dry feeder and a nipple waterer. Experiment 2 was conducted at New Horizon Farms Nursery Research (Pipestone, MN). In Exp. 2, 2,502 pigs (PIC 337 × 1050, Hendersonville, TN; initially 25.7 lb) were placed in pens with 24 to 27 mixed gender pigs each and used in a 21-d trial. Each pen (12.1 × 7.5 ft) had plastic floors and was equipped with a six-hole stainless steel dry feeder and a pan waterer. Experiment 3 was conducted at Hord Family Farms nursery research facility (Bucyrus, OH). A total of 4,118 pigs (PIC; 337 × 1050; Hendersonville, TN; initially 27.5 lb) were used in a 21-d trial. Two pens sharing a fence line feeder were considered the experimental unit and had 48 to 54 mixed gender pigs each. Pens (8.9 × 7.5 ft) had plastic slatted floor and were equipped with a double-sided five-hole stainless steel feeder and a cup waterer. Experiment 4 was conducted at the Cooperative Research Farm's Swine Research Nursery (Kalmbach Feeds, Inc., Sycamore, OH). A total of 711 pigs (PIC; 380 ×1050; Hendersonville, TN; initially 27.1 lb) were placed in pens with 9 or 10 mixed gender pigs and used in a 21-d trial. Each pen (6 × 5 ft) had slatted metal floors and was equipped with a four-hole stainless steel dry feeder and a nipple-cup waterer.

In all experiments, pens of pigs were weighed and feed disappearance was measured weekly to calculate ADG, ADFI, and F/G. Mortality and culls were recorded daily. Caloric efficiency was calculated by multiplying ADFI by kcal of NE per lb of diet and dividing by ADG.

Data were analyzed as a randomized complete block design in a 2 × 3 factorial treatment arrangement. There was significant treatment × experiment interaction, thus each experiment was analyzed separately. Single degree-of-freedom contrasts were constructed to test the linear and quadratic effects of increasing SBM and their interactions with DDGS. Block was included as a random effect and treatment as a fixed effect.

Pen was considered the experimental unit in all experiments except in Exp. 3 where two pens shared a feeder, the feeder was considered the experimental unit. Data were analyzed using the GLIMMIX procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). Results were considered significant at $P \leq 0.05$ and a tendency at $0.05 < P \leq 0.10$.

Results and Discussion

The analyzed total SBM AA concentration was similar across locations and the values were comparable to those in NRC.[6] The corn AA profile was also similar across locations and, in general, slightly less than NRC[6] values. In general, DDGS used in Exp. 1 had the highest AA content, and the DDGS used in Exp. 2, 3, and 4 had a similar AA profile. All DDGS sources had higher total AA content than the values reported in NRC,[6] especially total Lys. The DDGS sources had variation in fiber and oil content, thus the NE estimates were different for each source. The differences in ingredient composition across locations were accounted for in diet formulation and are not expected to have influenced the outcome of the study. The analyzed dietary CP, Ca, P, and NDF were consistent with formulated values (Tables 3 to 6).

There was variation in mycotoxin content in DDGS across locations (Table 2). The DDGS used in Exp. 1 had significant concentration of deoxynivalenol (DON) and total fumonisin, 1,047 and 6,347 ppb, respectively. Similarly, the DDGS used in Exp. 3 and 4 had high levels of DON (4,093 and 4,231 ppb, respectively) and contained detectable levels of zearalenone (328 and 274 ppb, respectively). The DDGS used in Exp. 2 did not contain particularly high levels of any mycotoxin.

In Exp. 1, there was no evidence ($P > 0.10$) for interactions for ADG, ADFI, F/G, or CE. Pigs fed diets with DDGS had decreased ($P < 0.01$) ADG, ADFI, and final BW, as well as poorer CE (Table 8). Pigs fed increasing SBM had a tendency ($P = 0.078$) for a linear improvement in F/G and CE.

In Exp. 2, there was an SBM × DDGS interaction ($P = 0.031$) for F/G (Table 7). Pigs fed diets without DDGS had increasing improvements in F/G as SBM concentration increased. However, for pigs fed diets with DDGS, increasing SBM from 27.5 to 32.5% resulted in similar F/G but it was improved for pigs fed diets with 37.5% SBM. A similar interaction ($P = 0.031$) was observed for CE. There was a tendency ($P = 0.063$) for an SBM × DDGS interaction for ADG, where ADG increased in pigs fed increasing SBM in diets without DDGS, whereas ADG decreased as SBM increased in diet with DDGS. There was no evidence ($P > 0.10$) for interactions for ADFI and final BW. Pigs fed diets with DDGS had decreased ($P = 0.001$) ADFI and final BW (Table 8). Increasing SBM resulted in a decrease (linear, $P = 0.015$) in ADFI.

In Exp. 3, there were SBM × DDGS interactions ($P < 0.05$) for ADG, ADFI, and final BW (Table 7). Pigs had decreased ADG, ADFI, and final BW as SBM increased; however, the magnitude of the decrease was greater for pigs fed diets with DDGS than those fed diets without DDGS. There was no evidence for interactions for F/G or CE. Pigs fed diets with DDGS had poorer ($P = 0.025$) F/G and CE and those fed increasing SBM had improved (linear, $P = 0.013$) F/G and CE (Table 8).

In Exp. 4, there was a tendency ($P = 0.076$) for an SBM × DDGS interaction for ADG (Table 7). Pigs fed diets without DDGS had decreased ADG when fed 32.5% SBM compared to 27.5 or 37.5% SBM, whereas pigs fed diets with DDGS had higher ADG when diets contained 27.5 or 37.5% SBM. There was no evidence ($P > 0.10$) for interactions for ADFI, F/G, or CE. Pigs fed diets containing DDGS had decreased ($P \leq 0.002$) ADFI, F/G, and poorer CE (Table 8). Increasing SBM resulted in an improvement (linear, $P = 0.017$) in F/G and CE.

In general, pigs used in all experiments were healthy and did not have major health challenges during the experimental period. The average cull rate was 0.7, 0.5, 0.2, and 0% and the mortality rate was 0.7, 0.3, 0.4, and 0% in Exp. 1 to 4, respectively (Table 9). Due to the low number of events, the statistical analysis for cull rate was not performed and only descriptive statistics are presented.

The reasons behind the benefits of feeding higher SBM diets to pigs are unclear. One of the modes of action could be explained by the presence of bioactive components in SBM, namely isoflavones and saponins. Isoflavones and saponins have been reported to have anti-inflammatory, antioxidant, and anti-viral properties as well as the ability to modulate intestinal permeability. However, the known available research shows uncertainty regarding the effects of isoflavones. It appears that isoflavones could be more beneficial when fed to health-challenged pigs, but results are also inconsistent. Iowa State University researchers observed improvements in performance of PRRS positive pigs driven by increasing isoflavones, but mostly during periods of peak viremia. Conversely, researchers at the University of Illinois evaluated diets with or without supplementation of isoflavones for PRRS infected nursery pigs and found no improvements in growth performance, although some immunological changes were observed.

A consistent finding in our experiments was an improvement in G:F and CE as SBM increased. Yet again, the reasons for these responses are unclear as they could be driven by the intrinsic bioactive components, but also by an underestimation of the energy value assigned for SBM. Under- or overestimating NE can be detected if pigs fed diets with increasing amounts of a test ingredient present differences in F/G or CE. Our findings suggest that the energy value assigned for SBM could have been underestimated. The NRC[6] NE estimate for SBM is 947 kcal/lb or 78% of corn NE. Our diets were formulated with 1,067 kcal/lb or 88% of corn NE and balanced for NE. Therefore, this suggests that the NRC[6] considerably underestimates the NE value of SBM and this has important ramifications in diet formulation as it increases the value of SBM.

In conclusion, increasing addition of SBM from 27.5 to 37.5% of the diet did not result in major changes in ADG, but consistently improved G:F and CE. The underlying mechanism for this response is unclear but could be driven by intrinsic SBM components such as isoflavones or by underestimating SBM energy value.

Table 1. Proximate and total amino acid analysis of soybean meal, distillers dried grains with solubles (DDGS), and corn (as-fed basis)[1]

	Soybean meal				DDGS				Corn			
Item, %	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 1[2]	Exp. 2	Exp. 3	Exp. 4
Dry matter	89.7	89.5	88.84	88.4	90.0	90.8	89.1	89.5	88.3	87.8	89.2	85.9
Crude protein	47.5	47.5	48.5	47.6	31.2	28.7	27.5	27.2	8.2	6.3	7.3	7.0
Neutral detergent fiber	8.1	8.0	6.7	9.7	25.5	27.9	30.6	30.5	9.1	7.0	5.2	6.8
Ether extract	1.4	1.5	1.7	1.6	6.6	8.8	6.9	7.1	3.5	3.6	3.7	2.8
Calcium	0.61	0.54	0.54	0.62	0.10	0.08	0.06	0.06	0.02	0.07	0.07	0.04
Phosphorus	0.71	0.69	0.63	0.60	1.01	0.88	0.91	0.84	0.26	0.23	0.23	0.20
Amino acids												
Alanine	2.02	2.07	2.08	2.01	2.75	1.86	1.85	1.85	0.60	0.45	0.52	0.48
Arginine	3.40	3.46	3.39	3.34	1.58	1.27	1.25	1.22	0.37	0.30	0.34	0.28
Aspartic acid	5.24	5.43	5.39	5.25	2.46	1.79	1.79	1.81	0.54	0.44	0.48	0.43
Cystine	0.73	0.73	0.69	0.69	0.80	0.60	0.60	0.65	0.19	0.16	0.18	0.16
Glutamic acid	8.34	8.69	8.64	8.29	6.05	3.64	4.18	4.20	1.48	1.11	1.27	1.15
Glycine	1.97	2.00	2.04	1.96	1.49	1.11	1.13	1.16	0.31	0.26	0.29	0.28
Histidine	1.23	1.26	1.22	1.22	1.06	0.78	0.79	0.79	0.24	0.19	0.21	0.19
Isoleucine	2.28	2.30	2.31	2.26	1.60	1.09	1.04	1.07	0.28	0.24	0.26	0.24
Leucine	3.59	3.70	3.66	3.58	4.90	3.19	3.02	3.10	0.96	0.71	0.83	0.75
Lysine	3.05	3.14	3.03	3.01	1.22	1.08	1.04	1.04	0.25	0.25	0.26	0.24
Methionine	0.67	0.67	0.65	0.63	0.80	0.50	0.53	0.53	0.18	0.13	0.14	0.14
Phenylalanine	2.44	2.52	2.46	2.39	2.21	1.69	1.33	1.27	0.39	0.31	0.35	0.31
Proline	2.36	2.48	2.42	2.26	3.04	2.07	2.20	2.25	0.71	0.56	0.59	0.56
Serine	2.03	2.19	2.12	1.94	1.66	1.26	1.14	1.11	0.38	0.29	0.33	0.28
Threonine	1.80	1.88	1.83	1.79	1.46	1.10	1.02	1.05	0.28	0.23	0.27	0.24
Tryptophan	0.72	0.69	0.62	0.67	0.38	0.22	0.18	0.21	0.06	0.06	0.05	0.06
Tyrosine	1.74	1.77	1.51	1.61	1.51	1.03	1.06	0.90	0.26	0.18	0.18	0.13
Valine	2.32	2.38	2.40	2.34	2.08	1.45	1.38	1.37	0.38	0.31	0.34	0.32

[1]A representative sample of each ingredient was obtained, homogenized, and submitted to the Agricultural Experimental Station Chemical Laboratories (University of Missouri-Columbia, Columbia, MO) for amino acid analysis and Ward Laboratories (Kearney, NE) for proximate analysis prior to diet formulation.
[2]NRC amino acid values were used for corn in Exp. 1. National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

Table 2. Mycotoxin analysis of distillers dried grains with solubles[1]

Mycotoxins	Practical quantitation limit, ppb	Exp. 1	Exp. 2	Exp. 3	Exp. 4
Aflatoxin B1	20	< 20	< 20	< 20	< 20
Aflatoxin B2	20	< 20	< 20	< 20	< 20
Aflatoxin G1	20	< 20	< 20	< 20	< 20
Aflatoxin G2	20	< 20	< 20	< 20	< 20
Deoxynivalenol	200	1,047	825	4,093	4,231
Fumonisin B1	200	5,031	214	961	895
Fumonisin B2	200	1,316	< 200	244	244
HT-2 toxin	200	< 200	< 200	< 200	< 200
Ochratoxin A	20	< 20	< 20	< 20	< 20
T-2 toxin	20	< 20	< 20	< 20	< 20
Sterigmatocystin	20	< 20	< 20	< 20	< 20
Zearalenone	100	111	< 100	328	274

[1]A representative sample of each source was collected, homogenized, and submitted to North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND).

Table 3. Diet composition of Experiment 1 (as-fed basis)

DDGS[1]:	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Ingredient, %						
Corn	66.67	61.76	56.86	40.66	35.69	30.71
Soybean meal	27.52	32.51	37.48	27.50	32.52	37.50
DDGS	---	---	---	25.00	25.00	25.00
Choice white grease	1.60	2.00	2.40	3.80	4.15	4.50
Calcium carbonate	0.80	0.78	0.75	1.18	1.15	1.13
Monocalcium phosphate, 21.5% P	1.03	0.95	0.90	0.30	0.23	0.15
Sodium chloride	0.68	0.68	0.68	0.50	0.50	0.50
L-Lysine HCl	0.545	0.385	0.225	0.400	0.240	0.080
DL-Methionine	0.225	0.180	0.130	0.070	0.025	---
L-Threonine	0.280	0.215	0.150	0.140	0.075	0.010
L-Tryptophan	0.065	0.035	0.005	0.030	---	---
L-Valine	0.175	0.090	---	---	---	---
Vitamin premix[2]	0.250	0.250	0.250	0.250	0.250	0.250
Trace-mineral premix[3]	0.150	0.150	0.150	0.150	0.150	0.150
Phytase[4]	0.025	0.025	0.025	0.025	0.025	0.025
Total	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 3. Diet composition of Experiment 1 (as-fed basis)

DDGS[1]:	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Calculated analysis						
SID[5] amino acids, %						
Lysine	1.30	1.30	1.30	1.30	1.30	1.30
Isoleucine:lysine	55	62	69	67	74	81
Leucine:lysine	110	119	128	149	158	167
Methionine:lysine	38	36	34	32	30	30
Methionine and cystine:lysine	58	58	58	58	58	60
Threonine:lysine	65	65	65	65	65	65
Tryptophan:lysine	21.3	21.3	21.4	21.2	21.2	23.6
Valine:lysine	72	72	72	75	81	88
Histidine:lysine	34	37	41	42	45	49
Net energy, kcal/lb	1,175	1,175	1,175	1,175	1,175	1,175
Crude protein, %	19.5	21.2	22.8	24.7	26.4	28.2
Neutral detergent fiber, %	8.3	8.3	8.2	12.3	12.3	12.2
Calcium, %	0.74	0.74	0.75	0.78	0.78	0.79
STTD P,[6] %	0.45	0.45	0.45	0.45	0.45	0.45
Analyzed values, %						
Dry matter	90.2	90.0	90.3	90.8	90.9	90.5
Crude protein	19.9	21.7	21.9	23.9	25.9	28.4
Neutral detergent fiber	5.2	5.5	5.5	13.4	12.8	13.5
Ether extract	4.3	4.7	5.0	7.8	8.0	7.9
Calcium	0.79	0.73	0.87	1.02	0.90	1.01
Phosphorus	0.53	0.56	0.60	0.61	0.60	0.62

[1]DDGS = distillers dried grains with solubles.
[2]Provided per lb of premix: 750,000 IU vitamin A; 300,000 IU vitamin D; 8,000 IU vitamin E; 600 mg vitamin K; 6 mg vitamin B12; 9,000 mg niacin; 5,000 mg pantothenic acid; and 1,500 mg riboflavin.
[3]Provided per lb of premix: 33 g Zn from zinc sulfate; 33 g Fe from ferrous sulfate; 10 g Mn from manganese oxide; 5 g Cu from copper sulfate; 0.09 g I from calcium iodate; and 0.09 g Se from sodium selenite.
[4]Ronozyme HiPhos 2700 (DSM Nutritional Products, Inc., Parsipanny, NJ).
[5]SID = standardized ileal digestible.
[6]STTD P = standardized total tract digestible phosphorus.

Table 4. Diet composition of Experiment 2 (as-fed basis)

DDGS[1]:	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Ingredient, %						
Corn	66.81	61.91	56.91	42.07	37.08	32.05
Soybean meal	27.49	32.48	37.49	27.50	32.50	37.50
DDGS	---	---	---	25.00	25.00	25.00
Beef tallow	1.60	2.00	2.45	2.45	2.85	3.25
Calcium carbonate	0.80	0.78	0.75	1.18	1.15	1.13
Monocalcium phosphate, 21.5% P	1.03	0.95	0.90	0.30	0.23	0.15
Sodium chloride	0.68	0.68	0.68	0.50	0.50	0.50
L-Lysine HCl	0.513	0.352	0.190	0.365	0.204	0.043
DL-Methionine	0.260	0.210	0.165	0.115	0.065	0.020
L-Threonine	0.285	0.215	0.145	0.135	0.065	---
L-Tryptophan	0.073	0.045	0.015	0.045	0.018	---
L-Valine	0.205	0.125	0.025	---	---	---
Vitamin trace-mineral premix[2]	0.150	0.150	0.150	0.150	0.150	0.150
Phytase[3]	0.015	0.015	0.015	0.015	0.015	0.015
Total	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 4. Diet composition of Experiment 2 (as-fed basis)

DDGS[1] :	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Calculated analysis						
SID[4] amino acids, %						
Lysine	1.30	1.30	1.30	1.30	1.30	1.30
Isoleucine:lysine	54	61	68	66	73	79
Leucine:lysine	101	111	121	141	150	160
Methionine:lysine	38	36	35	33	31	29
Methionine and cystine:lysine	58	58	58	58	58	58
Threonine:lysine	65	65	65	65	65	65
Tryptophan:lysine	21.3	21.4	21.3	21.3	21.4	22.2
Valine:lysine	73	73	73	73	80	87
Histidine:lysine	32	36	40	41	44	48
Net energy, kcal/kg	1,175	1,175	1,175	1,175	1,175	1,175
Crude protein, %	18.2	20.0	21.7	23.3	25.1	26.9
Neutral detergent fiber, %	8.8	8.6	8.4	13.2	12.9	12.7
Calcium, %	0.71	0.72	0.74	0.74	0.75	0.76
STTD P,[5] %	0.45	0.45	0.45	0.45	0.45	0.45
Analyzed values, %						
Dry matter	88.6	89.0	89.0	90.6	90.4	91.1
Crude protein	19.0	19.7	21.8	22.0	25.2	28.2
Neutral detergent fiber	7.4	6.4	5.7	10.9	12.3	13.2
Ether extract	4.2	3.9	4.3	5.7	6.5	6.6
Calcium	0.62	0.61	0.67	0.72	0.67	0.56
Phosphorus	0.55	0.52	0.56	0.53	0.59	0.59

[1]DDGS = distillers dried grains with solubles.
[2]Provided per lb of premix: 2,424,242 IU vitamin A; 606,061 IU vitamin D; 45,455 IU vitamin E; 758 mg vitamin K; 9.7 mg vitamin B12; 13,182 mg niacin; 6,970 mg pantothenic acid; 1,818 mg riboflavin; 30.3 mg biotin; 303 mg folic acid; 545 mg vitamin B6; 33 g Zn from zinc sulfate; 30 g Fe from ferrous sulfate; 12 g Mn from manganese oxide; 4.5 g Cu from copper sulfate; 0.23 g I from calcium iodate; and 0.09 g Se from sodium selenite.
[3]Optiphos 2000 (Huvepharma, Inc., Peachtree City, GA).
[4]SID = standardized ileal digestible.
[5]STTD P = standardized total tract digestible phosphorus.

Table 5. Diet composition of Experiment 3 (as-fed basis)

DDGS[1]:	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Ingredient, %						
Corn	66.34	61.51	56.56	40.64	35.66	30.68
Soybean meal	27.50	32.50	37.50	27.50	32.50	37.50
DDGS	---	---	---	25.00	25.00	25.00
Corn oil	1.60	1.95	2.35	3.45	3.80	4.15
Calcium carbonate	0.85	0.83	0.80	1.23	1.20	1.20
Monocalcium phosphate, 21.5% P	1.15	1.05	1.00	0.45	0.40	0.33
Sodium chloride	0.50	0.50	0.50	0.33	0.33	0.33
L-Lysine HCl	0.547	0.387	0.228	0.408	0.249	0.090
DL-Methionine	0.255	0.210	0.165	0.090	0.045	0.000
L-Threonine	0.280	0.215	0.150	0.150	0.080	0.015
L-Tryptophan	0.095	0.065	0.040	0.065	0.040	0.010
L-Valine	0.185	0.090	0.000	0.000	0.000	0.000
Vitamin trace-mineral premix[2]	0.175	0.175	0.175	0.175	0.175	0.175
Phytase[3]	0.025	0.025	0.025	0.025	0.025	0.025
Sodium metabisulfite	0.500	0.500	0.500	0.500	0.500	0.500
Total	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 5. Diet composition of Experiment 3 (as-fed basis)

DDGS[1]:	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Calculated analysis						
SID[4] amino acids, %						
Lysine	1.30	1.30	1.30	1.30	1.30	1.30
Isoleucine:lysine	54	61	69	65	72	80
Leucine:lysine	105	115	124	139	149	159
Methionine:lysine	38	36	34	31	30	28
Methionine and cystine:lysine	57	57	57	56	56	57
Threonine:lysine	65	65	65	65	65	65
Tryptophan:lysine	21.2	20.9	21.1	20.6	20.7	20.4
Valine:lysine	72	72	72	73	80	87
Histidine:lysine	32	36	39	41	44	48
Net energy, kcal/kg	1,175	1,175	1,175	1,175	1,175	1,175
Crude protein, %	19.2	21.0	22.7	23.8	25.6	27.4
Neutral detergent fiber, %	5.3	5.4	5.4	11.6	11.7	11.7
Calcium, %	0.72	0.72	0.72	0.74	0.75	0.76
STTD P,[5] %	0.45	0.45	0.45	0.45	0.45	0.45
Analyzed values, %						
Dry matter	87.8	88.0	88.3	88.4	88.2	88.4
Crude protein	19.2	19.2	21.3	20.8	24.2	26.7
Neutral detergent fiber	7.1	6.8	6.8	11.3	13.1	13.2
Ether extract	4.4	4.7	4.8	7.3	7.4	7.3
Calcium	0.74	0.78	0.79	0.97	0.83	0.97
Phosphorus	0.52	0.56	0.53	0.57	0.58	0.56

[1]DDGS = distillers dried grains with solubles.
[2]Provided per lb of premix: 750,000 IU vitamin A; 250,000 IU vitamin D; 8,000 IU vitamin E; 600 mg vitamin K; 6 mg vitamin B12; 10,000 mg niacin; 5,000 mg pantothenic acid; 1,400 mg riboflavin; 40 g Zn from zinc sulfate; 35 g Fe from ferrous sulfate; 3 g Mn from manganese oxide; 4.5 g Cu from copper sulfate; 0.09 g I from calcium iodate; and 0.09 g Se from sodium selenite.
[3]Quantum Blue 2500 (AB Vista, Marlborough, UK).
[4]SID = standardized ileal digestible.
[5]STTD P = standardized total tract digestible phosphorus.

Table 6. Diet composition of Experiment 4 (as-fed basis)

DDGS[1]:	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Ingredient, %						
Corn	66.15	61.17	56.33	40.26	35.23	30.21
Soybean meal	27.51	32.52	37.51	27.52	32.52	37.52
DDGS	---	---	---	25.00	25.00	25.00
Corn oil	1.80	2.25	2.60	3.80	4.20	4.60
Calcium carbonate	0.75	0.73	0.70	1.10	1.08	1.05
Monocalcium phosphate, 21.5% P	1.20	1.15	1.05	0.55	0.50	0.45
Sodium chloride	0.50	0.50	0.50	0.35	0.35	0.35
L-Lysine HCl	0.565	0.406	0.247	0.422	0.264	0.105
DL-Methionine	0.280	0.235	0.190	0.110	0.070	0.025
L-Threonine	0.305	0.235	0.165	0.165	0.100	0.030
L-Tryptophan	0.085	0.055	0.025	0.060	0.030	0.000
L-Valine	0.185	0.095	0.015	0.000	0.000	0.000
Vitamin premix[2]	0.050	0.050	0.050	0.050	0.050	0.050
Trace-mineral premix[3]	0.090	0.090	0.090	0.090	0.090	0.090
Phytase[4]	0.025	0.025	0.025	0.025	0.025	0.025
Sodium metabisulfite	0.500	0.500	0.500	0.500	0.500	0.500
Total	100.0	100.0	100.0	100.0	100.0	100.0

continued

Table 6. Diet composition of Experiment 4 (as-fed basis)

DDGS[1]:	0%			25%		
Soybean meal:	27.5%	32.5%	37.5%	27.5%	32.5%	37.5%
Calculated analysis						
SID[5] amino acids, %						
Lysine	1.30	1.30	1.30	1.30	1.30	1.30
Isoleucine:lysine	53	60	67	64	71	78
Leucine:lysine	100	110	119	137	147	156
Methionine:lysine	39	38	36	32	31	29
Methionine and cystine:lysine	58	58	58	58	58	58
Threonine:lysine	65	65	64	65	65	65
Tryptophan:lysine	21.8	21.7	21.6	21.8	21.7	21.6
Valine:lysine	71	71	71	71	78	85
Histidine:lysine	31	35	39	40	44	47
Net energy, kcal/kg	1,175	1,175	1,175	1,175	1,175	1,175
Crude protein, %	18.8	20.5	22.3	23.3	25.1	26.9
Neutral detergent fiber, %	7.9	8.0	8.1	13.5	13.6	13.7
Calcium, %	0.69	0.70	0.70	0.72	0.73	0.74
STTD P,[6] %	0.45	0.45	0.45	0.45	0.45	0.45
Analyzed values, %						
Dry matter	87.8	88.0	88.1	88.5	88.7	88.8
Crude protein	17.2	18.8	22.2	23.4	25.3	25.8
Neutral detergent fiber	6.5	6.1	5.9	12.6	12.9	12.4
Ether extract	4.2	4.1	4.7	6.8	7.3	7.6
Calcium	0.53	0.61	0.72	0.67	0.89	0.79
Phosphorus	0.49	0.52	0.61	0.62	0.61	0.62

[1]DDGS = distillers dried grains with solubles.
[2]Provided per lb of premix: 13,000,000 IU vitamin A; 2,000,000 IU vitamin D; 48,000 IU vitamin E; 3,633 mg vitamin K; 36 mg vitamin B12; 140,000 mg niacin; 30,000 mg pantothenic acid; and 7,000 mg riboflavin.
[3]Provided per lb of premix: 51 g Zn from zinc sulfate; 47 g Fe from ferrous sulfate; 14 g Mn from manganese sulfate; 7 g Cu from copper sulfate; 0.7 g I from ethylenediamine dihydriodide; and 0.09 g Se from sodium selenite.
[4]Quantum Blue 2500 (AB Vista, Marlborough, UK).
[5]SID = standardized ileal digestible.
[6]STTD P = standardized total tract digestible phosphorus.

Table 7. Interactive effects of distillers dried grains with solubles (DDGS) and soybean meal (SBM) on growth performance of nursery pigs

	0% DDGS			25% DDGS				Probability, *P* <	
Item[1]	27.5% SBM	32.5% SBM	37.5% SBM	27.5% SBM	32.5% SBM	37.5% SBM	SEM	DDGS × SBM linear	DDGS × SBM quadratic
Initial BW, lb									
Exp. 1[2]	23.3	23.3	23.2	23.2	23.3	23.1	0.436	0.758	0.926
Exp. 2[3]	25.7	25.7	25.7	25.8	25.7	25.8	0.395	0.999	0.736
Exp. 3[4]	27.6	27.5	27.5	27.6	27.5	27.5	0.551	0.845	0.875
Exp. 4[5]	27.1	27.1	27.1	27.1	27.1	27.1	1.266	0.992	0.984
Final BW, lb									
Exp. 1	51.3	53.6	52.0	56.0	56.8	55.0	1.179	0.251	0.595
Exp. 2	50.0	50.8	50.4	49.4	49.2	48.9	0.560	0.220	0.459
Exp. 3	57.9	57.6	57.1	56.3	54.7	54.0	0.828	0.013	0.271
Exp. 4	54.5	53.5	54.8	50.7	51.7	51.6	2.191	0.668	0.205
ADG, lb									
Exp. 1	1.14	1.23	1.18	1.37	1.37	1.33	0.045	0.263	0.389
Exp. 2	1.15	1.19	1.17	1.12	1.12	1.09	0.015	0.063	0.568
Exp. 3	1.43	1.43	1.40	1.36	1.29	1.26	0.017	0.003	0.198
Exp. 4	1.31	1.26	1.32	1.12	1.17	1.17	0.047	0.553	0.076
ADFI, lb									
Exp. 1	1.85	1.88	1.79	2.03	1.99	1.96	0.058	0.895	0.421
Exp. 2	1.75	1.76	1.73	1.69	1.70	1.61	0.025	0.190	0.476
Exp. 3	2.13	2.11	2.05	2.04	1.92	1.87	0.025	0.001	0.016
Exp. 4	1.92	1.84	1.89	1.73	1.77	1.72	0.073	0.813	0.111
F/G									
Exp. 1	1.63	1.53	1.54	1.48	1.46	1.47	0.031	0.102	0.454
Exp. 2	1.52	1.48	1.47	1.50	1.52	1.47	0.011	0.470	0.031
Exp. 3	1.49	1.48	1.46	1.50	1.49	1.48	0.011	0.615	0.477
Exp. 4	1.47	1.46	1.43	1.54	1.51	1.48	0.025	0.601	0.642
CE, kcal/lb gain									
Exp. 1	1,737	1,715	1,733	1,920	1,799	1,805	36.70	0.102	0.454
Exp. 2	1,781	1,740	1,728	1,768	1,782	1,733	13.39	0.470	0.031
Exp. 3	1,748	1,733	1,714	1,767	1,745	1,745	13.05	0.615	0.477
Exp. 4	1,731	1,721	1,685	1,814	1,773	1,744	28.79	0.601	0.642

[1]BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. CE = caloric efficiency.
[2]A total of 296 pigs (initially 23.2 lb) were used in a 24-d study with 4 or 5 pigs per pen and 10 replicates per treatment.
[3]A total of 2,502 pigs (initially 25.7 lb) were used in a 21-d trial with 24 to 27 pigs per pen and 16 replicates per treatment.
[4]A total of 4,118 pigs (initially 27.5 lb) were used in a 21-d trial with 48 to 54 pigs per feeder (experimental unit) and 13 replicates per treatment.
[5]A total of 711 pigs (initially 27.1 lb) were used in a 21-d trial with 9 or 10 pigs per pen and 12 replicates per treatment.

Table 8. Main effects of distillers dried grains with solubles (DDGS) and soybean meal (SBM) on growth performance of nursery pigs

	DDGS			Probability,	SBM				Probability, P <	
Item[1]	0%	25%	SEM	P <	27.5%	32.5%	37.5%	SEM	Linear	Quadratic
Initial BW, lb										
Exp. 1[2]	23.2	23.3	0.405	0.602	23.2	23.3	23.2	0.413	0.727	0.514
Exp. 2[3]	25.7	25.7	0.395	0.980	25.8	25.7	25.7	0.395	0.951	0.763
Exp. 3[4]	27.6	27.5	0.551	0.779	27.6	27.5	27.5	0.551	0.462	0.559
Exp. 4[5]	27.1	27.1	1.238	0.947	27.1	27.1	27.1	1.245	0.988	0.991
Final BW, lb										
Exp. 1	55.9	52.3	1.016	0.001	53.7	55.2	53.5	1.059	0.838	0.014
Exp. 2	50.4	49.2	0.560	0.001	49.7	50.0	49.7	0.560	0.927	0.356
Exp. 3	57.5	55.0	0.828	0.001	57.1	56.1	55.6	0.828	0.001	0.459
Exp. 4	54.3	51.4	2.105	0.001	52.6	52.6	53.2	2.127	0.426	0.626
ADG, lb										
Exp. 1	1.36	1.18	0.036	0.001	1.26	1.30	1.25	0.038	0.915	0.137
Exp. 2	1.17	1.11	0.015	0.001	1.14	1.15	1.13	0.015	0.726	0.127
Exp. 3	1.42	1.30	0.017	0.001	1.40	1.36	1.33	0.017	0.001	0.612
Exp. 4	1.29	1.15	0.043	0.001	1.21	1.21	1.24	0.044	0.271	0.500
ADFI, lb										
Exp. 1	1.99	1.84	0.048	0.001	1.94	1.94	1.88	0.051	0.123	0.397
Exp. 2	1.74	1.67	0.025	0.001	1.72	1.73	1.67	0.025	0.015	0.057
Exp. 3	2.10	1.94	0.025	0.001	2.09	2.01	1.96	0.025	0.001	0.289
Exp. 4	1.88	1.74	0.066	0.001	1.82	1.81	1.81	0.068	0.666	0.727
F/G										
Exp. 1	1.47	1.57	0.022	0.001	1.56	1.50	1.51	0.024	0.078	0.152
Exp. 2	1.49	1.50	0.011	0.258	1.51	1.50	1.47	0.011	0.001	0.403
Exp. 3	1.47	1.49	0.011	0.025	1.50	1.48	1.47	0.011	0.013	0.657
Exp. 4	1.46	1.51	0.018	0.002	1.51	1.49	1.46	0.020	0.017	0.858
CE, kcal/lb gain										
Exp. 1	1,728	1,842	25.10	0.001	1,828	1,757	1,769	28.56	0.078	0.152
Exp. 2	1,750	1,761	9.14	0.258	1,774	1,761	1,730	10.43	0.001	0.403
Exp. 3	1,732	1,752	9.51	0.025	1,757	1,739	1,729	10.48	0.013	0.657
Exp. 4	1,712	1,777	21.25	0.002	1,773	1,747	1,714	23.30	0.017	0.858

[1]BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. CE = caloric efficiency.
[2]A total of 296 pigs (initially 23.2 lb) were used in a 24-d study with 4 or 5 pigs per pen and 10 replicates per treatment.
[3]A total of 2,502 pigs (initially 25.7 lb) were used in a 21-d trial with 24 to 27 pigs per pen and 16 replicates per treatment.
[4]A total of 4,118 pigs (initially 27.5 lb) were used in a 21-d trial with 48 to 54 pigs per feeder (experimental unit) and 13 replicates per treatment.
[5]A total of 711 pigs (initially 27.1 lb) were used in a 21-d trial with 9 or 10 pigs per pen and 12 replicates per treatment.

Table 9. Effects of distillers dried grains with solubles (DDGS) and soybean meal (SBM) on cull and mortality rate of nursery pigs[1,2]

	0% DDGS			25% DDGS		
Item	27.5% SBM	32.5% SBM	37.5% SBM	27.5% SBM	32.5% SBM	37.5% SBM
Culls, %						
Exp. 1	0.0	2.0	2.0	0.0	0.0	0.0
Exp. 2	0.5	0.7	0.7	0.0	0.5	0.5
Exp. 3	0.1	0.4	0.1	0.3	0.4	0.1
Exp. 4	0.0	0.0	0.0	0.0	0.0	0.0
Mortality, %						
Exp. 1	2.0	0.0	0.0	0.0	2.0	0.0
Exp. 2	0.2	0.0	0.2	0.0	0.2	1.0
Exp. 3	0.4	0.3	0.3	0.3	0.3	0.6
Exp. 4	0.0	0.0	0.0	0.0	0.0	0.0
Total, %						
Exp. 1	2.0	2.0	2.0	0.0	2.0	0.0
Exp. 2	0.7	0.7	1.0	0.0	0.7	1.5
Exp. 3	0.5	0.7	0.4	0.6	0.7	0.7
Exp. 4	0.0	0.0	0.0	0.0	0.0	0.0

[1]A total of 296, 2,502, 4,118, and 711 pigs were used in Exp. 1, 2, 3, and 4, respectively, in 21-d duration nursery trials.

[2]Descriptive data are presented. Due to the low number of events, statistical analysis was not performed.