Amino acid digestibility and energy content of deoiled (solvent-extracted) corn distillers dried grains with solubles for swine and effects on growth performance and carcass characteristics[1,2]

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ABSTRACT: A study with 3 experiments was conducted to determine the AA digestibility and energy concentration of deoiled (solvent-extracted) corn distillers dried grains with solubles (dDGS) and to evaluate its effect on nursery pig growth performance, finishing pig growth performance, and carcass traits. In Exp. 1, a total of 5 growing barrows (initial BW = 30.8 kg) were fitted with a T-cannula in the distal ileum and allotted to 1 of 2 treatments: 1) a diet with dDGS as the sole protein source, or 2) a N-free diet for determining basal endogenous AA losses in a crossover design at 68.0 kg of BW. Apparent and standardized (SID) ileal digestibility of AA and energy concentration of dDGS were determined. In Exp. 2, a total of 210 pigs (initial BW = 9.9 kg) were used in a 28-d experiment to evaluate the effect of dDGS on nursery pig performance. Pigs were allotted to 5 dietary treatments (0, 5, 10, 20, or 30% dDGS) formulated to contain equal ME (increased added fat with increasing dDGS) and SID Lys concentrations based on the values obtained from Exp. 1. In Exp. 3, a total of 1,215 pigs (initial BW = 29.6 kg) were used in a 99-d experiment to determine the effect of dDGS on growth and carcass characteristics of finishing pigs. Pigs were allotted to dietary treatments similar to those used in Exp. 2 and were fed in 4 phases. The analyzed chemical composition of dDGS in Exp. 1 was 35.6% CP, 5.29% ash, 4.6% fat, 18.4% ADF, and 39.5% NDF on a DM basis. Apparent ileal digestibility values of Lys, Met, and Thr in dDGS were 47.2, 79.4, and 64.1%, respectively, and SID values were 50.4, 80.4, and 68.9%, respectively. The determined GE and DE and the calculated ME and NE values of dDGS were 5,098, 3,100, 2,858, and 2,045 kcal/kg of DM, respectively. In Exp. 2, nursery pig ADG, ADFI, and G:F were similar among treatments. In Exp. 3, increasing dDGS reduced (linear; $P < 0.01$) ADG and ADFI but tended to improve (linear; $P = 0.07$) G:F. Carcass weight and yield were reduced (linear; $P < 0.01$), loin depth tended to decrease (linear; $P = 0.09$), and carcass fat iodine values increased (linear; $P < 0.01$) as dDGS increased. No difference was observed in backfat, percentage of lean, or fat-free lean index among treatments. In conclusion, dDGS had greater CP and AA but less energy content than traditional distillers dried grains with solubles. In addition, when dietary fat was added to diets to offset the reduced ME content, feeding up to 30% dDGS did not affect the growth performance of nursery pigs but did negatively affect the ADG, ADFI, and carcass fat quality of finishing pigs.

Key words: amino acid digestibility, carcass, deoiled distillers dried grains with solubles, energy, growth, pig

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INTRODUCTION

The Energy Independence and Security Act of 2007 mandates that total annual renewable fuel production in the United States must reach 136 billion L by 2022 (US Congress, 2007). This mandate has led to large-scale ethanol production and increased availability of ethanol coproducts, such as distillers dried grains with solubles (**DDGS**). This coproduct remains after ethanol is removed from fermented corn mash, and it contains greater amounts of nutrients than corn. The increased production of DDGS in recent years has triggered numerous research studies that have led to its widespread use in swine feeding (Stein and Shurson, 2009).

As the biofuel industry has evolved, additional coproducts have been developed. One such product is deoiled (solvent-extracted) corn distillers dried grains with solubles (**dDGS**; Verasun Energy Inc., Brookings, SD), which is traditional DDGS with the oil removed by solvent extraction. When most the oil is removed, CP, fiber, and mineral concentrations increase proportionately in the remaining coproduct. The extracted oil can then be used in the human food industry or for biodiesel production. Removal of oil may also improve the flowability of the coproduct and address some of the handling issues normally encountered with traditional DDGS (Ganesan et al., 2009). In pig production, the increased content of CP and other nutrients potentially increases the value of dDGS relative to traditional DDGS. However, no data are available on the actual AA digestibility and energy concentration of this coproduct. Nutrient digestibility must be determined to formulate and value dDGS accurately in swine diets, to incorporate dDGS into swine diets effectively. Thus, the objectives of this study were to 1) determine the apparent (**AID**) and standardized (**SID**) ileal digestibility of AA, 2) determine the DE and calculated ME and NE for dDGS, and 3) use these values in diet formulation to determine the effect of dDGS on growth performance, carcass characteristics, and carcass fat quality of pigs fed dDGS.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committees at Kansas State University and South Dakota State University approved the protocols used in these experiments.

This study consisted of 3 experiments. The first was a digestibility experiment conducted at the Kansas State University Swine Teaching and Research Center metabolism barn (Manhattan, KS). The second was a nursery experiment conducted at the South Dakota State University Swine Unit (Brookings, SD). The third was a growing-finishing growth performance experiment in a commercial swine research facility in southwest Minnesota. All dDGS (Verasun Energy Inc.) used in the 3 experiments was from the same production lot.

Table 1. Ingredient composition of experimental diets (as-fed basis), Exp. 1

Ingredient, %	dDGS[1]	N free
dDGS	66.70	—
Corn starch	27.05	81.15
Soybean oil	1.00	3.00
Sucrose	3.00	9.00
Solka-Floc[2]	—	3.00
Limestone	1.25	0.40
Monocalcium phosphate, 21% P	—	1.75
Vitamin premix[3]	0.25	0.25
Salt	0.35	0.45
Trace mineral premix[4]	0.15	0.15
Potassium chloride	—	0.50
Magnesium oxide	—	0.10
Chromic oxide	0.25	0.25

[1]Deoiled (solvent-extracted) distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[2]Fiber Sales and Development Corp., Urbana, OH.

[3]Provided the following per kilogram of diet: 11,023 IU of vitamin A; 1,653 IU of vitamin D_3; 44 IU of vitamin E; 4 mg of vitamin K; 8 mg of riboflavin; 28 mg of pantothenic acid; 50 mg of niacin; 0.04 mg of vitamin B_{12}.

[4]Provided the following per kilogram of complete diet: 39.7 mg of Mn from manganese oxide, 165 mg of Fe from iron sulfate, 165 mg of Zn from zinc oxide, 16.5 mg of Cu from copper sulfate, 0.298 mg of I from calcium iodate, and 0.30 mg of Se from sodium selenite.

Exp. 1

This experiment was conducted concurrently with another digestibility study on 2 other feed ingredients using the same animals. Five growing barrows (Pig Improvement Company Lines TR4 × 1050; initial BW = 30.8 ± 1.0 kg) were fitted with a T-cannula on their right flank approximately 15 cm anterior to the ileocecal valve, as described by Knabe et al. (1989). Pigs were housed individually in stainless steel metabolism crates (1.5 × 0.6 m) in an environmentally controlled building after surgery and fed a standard corn- and soybean meal-based diet for 10 d during the recovery period. After the recovery period, pigs were used in a unrelated metabolism study for 5 wk and then fed a common corn-soybean meal diet for 7 d. Pigs were then allotted randomly in a balanced crossover design, with an initial starting BW of 68.0 ± 2.0 kg. Two diets were used for this experiment: the first diet was formulated to contain the dDGS, and the second diet was formulated to be N free to determine the basal AA endogenous losses (Tables 1 and 2). Both diets contained 0.25% chromic oxide as an indigestible marker.

Each feeding period consisted of 7 d, with the first 4 d used as a period of adaptation to the diet. Feces were collected on d 5 and 6 in the morning (between 0600 and 1200 h), and ileal digesta were collected on d 6 and 7 between 0700 and 1700 h. Pigs were weighed at the beginning of each period to determine the amount of feed to be fed each day. Feed was given at a daily amount of 3 times the estimated maintenance requirement for energy. Feed was offered twice daily at 0600 and 1800 h, with the allocated daily amount divided

Table 2. Analyzed nutrient composition (%) of experimental diets (as-fed basis)

	Diet	
Item	dDGS[1]	N-free
DM	90.2	93.2
CP	20.5	0.1
Indispensable AA		
Arg	0.85	0.00
His	0.53	0.00
Ile	0.77	0.00
Leu	2.36	0.00
Lys	0.56	0.00
Met	0.38	0.00
Phe	1.05	0.00
Thr	0.75	0.00
Trp	0.12	<0.04
Val	0.99	0.00
Total indispensable AA	8.34	0.00
Dispensable AA		
Ala	1.41	0.00
Asp	1.29	0.00
Cys	0.36	0.00
Glu	3.01	0.00
Gly	0.78	0.00
Pro	1.44	0.00
Ser	0.86	0.00
Tyr	0.71	0.00
Total dispensable AA	9.85	0.00

[1]Deoiled (solvent-extracted) distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

into 2 equal meals. At the end of each period, all pigs were fasted overnight before feeding the next experimental diet the next morning. Pigs were given free access to water through a nipple waterer throughout the duration of the experiment.

Diets and dDGS samples were sent to a commercial laboratory (Ward Laboratories Inc., Kearney, NE) for proximate analysis. Ileal digesta were collected by attaching a latex balloon to the cannula. Balloons were removed periodically or when filled with digesta and emptied in a collection container that was stored in a freezer (−20°C); digesta samples were collected by individual pig for each feeding period. After the collection phase of the experiment, ileal samples from each pig by feeding period were thawed and homogenized. A subsample was taken from each homogenized sample, freeze-dried, and ground for AA analysis at the University of Missouri Agricultural Experiment Station Chemical Laboratories [Columbia, MO; method 982.30 E(a,b,c), chapter 45.3.05; AOAC International, 2006]. Grab samples of feces collected on d 5 and 6 were stored and frozen until further analysis. Fecal samples were then thawed at the conclusion of the collection phase and homogenized, by individual pig for each feeding period. A subsample was dried at 50°C in a forced-air oven and ground for analysis. Energy concentrations in diets, dDGS, and fecal samples were determined with an adiabatic bomb calorimeter (Parr Instruments, Moline, IL). Diets, ground digesta, and ground fecal samples were analyzed for chromium concentration with an atomic absorption spectrometer (model 3110, Perkin-Elmer, Waltham, MA) according to the procedures described by Williams et al. (1962) for calculation of AA and energy digestibility values. The AID and SID values for AA were calculated with analytical values obtained from these analyses. The AID for AA in the dDGS diet was calculated as

$$\text{AID } (\%) = [1 - (\text{AAd}/\text{AAf}) \times (\text{Crf}/\text{Crd})] \times 100\%$$

(Fan et al., 1995), where AAd is the concentration of that AA in the ileal digesta (g/kg of DM), AAf is the concentration of that AA in the diets (g/kg of DM), Crf is the chromium concentration in the diet (g/kg of DM), and Crd is the chromium concentration in the ileal digesta (g/kg of DM). The basal endogenous loss of each AA at the ileum was determined from the digesta samples obtained after feeding the N-free diet, with the equation

$$\text{IAAend} = [\text{AAd} \times (\text{Crf}/\text{Crd})]$$

(Moughan et al., 1992), where IAAend is the basal ileal endogenous loss of an AA (g/kg of DMI). The SID value for each AA was calculated as

$$\text{SID } (\%) = [\text{AID} + (\text{IAAend}/\text{AAf})]$$

(Jondreville et al., 1995), where IAAend and AAf are as described above.

The DE value of the dDGS diet was calculated with the equation for AID to determine the apparent total tract digestibility of energy. This value was then multiplied by the analyzed concentration of GE in the diets to determine the DE of the diet. Digestible energy of dDGS was calculated by subtracting 33% of the N-free DE from the DE of the dDGS using the difference procedure (Adeola, 2001). The DE value for dDGS was used in the following equations to calculate ME and NE:

$$\text{ME} = 1 \times \text{DE} - 0.68 \times \text{CP } (R^2 = 0.99)$$

(Noblet and Perez, 1993), and

$$\text{NE} = (0.87 \times \text{ME}) - 442 \ (R^2 = 0.94)$$

(Noblet et al., 1994).

Exp. 2

A total of 210 pigs (Whiteshire Hamroc Duroc × Yorkshire; initially, 9.9 ± 1.8 kg of BW) were assigned to pens in blocks based on initial BW within sex. Pens within block were then randomly allotted to 1 of the 5 dietary treatments in a 28-d experiment. There were 7 pens (4 barrow and 3 gilt pens) per treatment and 6

Table 3. Diet composition (as-fed basis), Exp. 2[1]

	dDGS,[2] %				
Item	0	5	10	20	30
Ingredient, %					
Corn	63.56	58.87	54.25	44.97	35.67
Soybean meal, 46.5% CP	32.57	31.39	30.21	27.84	25.48
dDGS	—	5.00	10.00	20.00	30.00
Soybean oil	—	0.90	1.75	3.50	5.25
Monocalcium P, 21% P	1.65	1.50	1.40	1.15	0.90
Limestone	0.95	1.05	1.10	1.23	1.38
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15
L-Lys·HCl	0.30	0.33	0.35	0.40	0.45
DL-Met	0.12	0.11	0.10	0.08	0.06
L-Thr	0.10	0.10	0.09	0.08	0.06
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Standardized ileal digestible AA,[5] %					
Lys	1.25	1.25	1.25	1.25	1.25
Met:Lys	33	33	33	33	33
Met and Cys:Lys	58	58	58	58	58
Thr:Lys	62	62	62	62	62
Trp:Lys	18	18	18	17	17
Total Lys, %	1.38	1.40	1.42	1.45	1.48
CP, %	21.0	21.6	22.2	23.5	24.7
SID Lys:ME, g/Mcal	3.79	3.79	3.79	3.79	3.79
ME, kcal/kg	3,298	3,299	3,298	3,299	3,299
Ca, %	0.80	0.80	0.80	0.80	0.80
P, %	0.75	0.73	0.73	0.71	0.69
Available P, %	0.42	0.42	0.42	0.42	0.42

[1]Diets fed in meal form from approximately 10 to 23 kg of BW.

[2]Deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[3]Provided the following per kilogram of diet: 11,023 IU of vitamin A; 1,653 IU of vitamin D_3; 44 IU of vitamin E; 4 mg of vitamin K; 8 mg of riboflavin; 28 mg of pantothenic acid; 50 mg of niacin; and 0.04 mg of vitamin B_{12}.

[4]Provided the following per kilogram of complete diet: 39.7 mg of Mn from manganese oxide, 165 mg of Fe from iron sulfate, 165 mg of Zn from zinc oxide, 16.5 mg of Cu from copper sulfate, 0.298 mg of I from calcium iodate, and 0.298 mg of Se from sodium selenite.

[5]Based on standardized ileal digestible (SID) AA values determined in Exp. 1.

pigs per pen. Barrows and gilts were housed in separate mechanically ventilated barns. Both barns had completely slatted flooring. Barrows were housed in 1.2 × 1.2 m pens, and gilts were housed in 1.2 × 1.5 m pens. Each pen was equipped with nipple waterers and 3-hole feeders. All pigs were fed similar pelleted starter diets until the start of the experiment. The ME and SID AA values obtained in Exp. 1 were used in diet formulation. The 5 dietary treatments contained dDGS at 0, 5, 10, 20, or 30% (Table 3) and were fed in meal form. All diets were formulated to contain equal ME and SID Lys concentrations. Soybean oil was added to the dDGS diets as an energy source to equalize the dietary ME of the 5 treatments. Pigs were weighed, and feed disappearance was determined on d 0, 14, and 28 to determine ADG, ADFI, and G:F.

Exp. 3

A total of 1,215 pigs (Pig Improvement Company Lines 337 × 1050; initial BW = 29.6 ± 1.1 kg) were used and were stocked initially with 27 pigs (12 to 14 barrows and 12 to 14 gilts) in each pen (5.5 × 3.0 m). All pens of pigs were randomly allotted to 1 of 5 dietary treatments in a completely randomized design in a 99-d experiment. Diets were fed in meal form. The barns were double curtain sided with completely slatted flooring and deep pits for manure storage. Each pen contained 1 self-feeder and 1 cup waterer. A robotic feeding system (FeedPro, Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts on an individual pen basis was used. The 5 treatments consisted of diets containing 0, 5, 10, 20, or 30% dDGS. Pigs were fed in 4 phases from approximately 29 to 54, 54 to 77, 77 to 100, and 100 to 120 kg of BW for phases 1 to 4, respectively (Tables 4 and 5). Diets were formulated to contain 0.94, 0.80, 0.69, and 0.95% SID Lys and to maintain available P concentrations of at least 0.27, 0.24, 0.22, and 0.21% for phases 1 to 4, respectively. All dietary treatments were formulated to contain similar dietary ME and SID Lys concentrations within each phase. Choice white grease was added in increasing amounts as dDGS increased in the diet to maintain uniform dietary ME. Ractopamine hydrochlo-

Table 4. Phase 1 and 2 diet composition (as-fed basis), Exp. 3[1]

	Phase 1: dDGS,[2] %					Phase 2: dDGS, %				
Item	0	5	10	20	30	0	5	10	20	30
Ingredient, %										
Corn	73.10	68.34	63.60	54.12	44.49	78.77	74.04	69.26	59.80	50.08
Soybean meal, 46.5% CP	24.79	23.61	22.43	20.09	17.75	19.22	18.04	16.87	14.51	12.18
dDGS	—	5.00	10.00	20.00	30.00	—	5.00	10.00	20.00	30.00
Choice white grease	—	0.95	1.93	3.80	5.75	—	0.95	1.93	3.80	5.80
Monocalcium phosphate, 21% P	0.60	0.48	0.35	0.13	0.00	0.50	0.35	0.25	0.00	0.00
Limestone	0.85	0.93	0.98	1.10	1.20	0.85	0.93	0.98	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase[3]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[4]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
L-Lys·HCl	0.15	0.18	0.20	0.25	0.30	0.15	0.18	0.20	0.25	0.30
Total	100	100	100	100	100	100	100	100	100	100
Calculated analysis										
Standardized ileal digestible AA,[5] %										
Lys	0.94	0.94	0.94	0.94	0.94	0.80	0.80	0.80	0.80	0.80
Met:Lys	28	29	30	32	34	30	31	32	34	36
Met and Cys:Lys	58	59	60	62	64	61	62	64	66	68
Thr:Lys	61	62	62	64	65	62	63	64	65	67
Trp:Lys	19	19	19	19	18	19	19	19	18	18
Total Lys, %	1.06	1.07	1.09	1.12	1.15	0.90	0.92	0.93	0.96	0.99
CP, %	17.89	18.52	19.15	20.42	21.68	15.78	16.41	17.04	18.31	19.57
SID Lys:ME, g/Mcal	2.81	2.81	2.81	2.81	2.81	2.39	2.39	2.39	2.39	2.39
ME, kcal/kg	3,344	3,344	3,344	3,344	3,344	3,351	3,351	3,351	3,351	3,351
Ca, %	0.54	0.54	0.54	0.54	0.54	0.50	0.50	0.50	0.50	0.50
P, %	0.50	0.49	0.48	0.47	0.48	0.46	0.44	0.44	0.42	0.45
Available P,[6] %	0.27	0.27	0.27	0.27	0.30	0.24	0.24	0.24	0.24	0.29
Dietary fat iodine value,[7] g/100 g	121.4	108.4	97.8	98.1	88.4	117.2	108.0	100.9	94.2	88.7
Iodine value product[8]	25.5	36.8	42.1	55.9	69.8	16.4	30.2	39.3	57.5	70.9

[1]Diets fed in meal form from 29 to 54 kg of BW for phase 1 and from 54 to 77 kg of BW for phase 2.

[2]Deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[3]Provided the following per kilogram of diet: 3,527 IU of vitamin A; 529 IU of vitamin D_3; 14 IU of vitamin E; 1.4 mg of vitamin K; 2.6 mg of riboflavin; 8.8 mg of pantothenic acid; 15.9 mg of niacin; 0.01 mg of vitamin B_{12}; and 450 phytase units/kg of phytase.

[4]Provided the following per kilogram of complete diet: 21.2 mg of Mn from manganese oxide, 88.2 mg of Fe from iron sulfate, 88.2 mg of Zn from zinc oxide, 8.8 mg of Cu from copper sulfate, 0.159 mg of I from calcium iodate, and 0.159 mg of Se from sodium selenite.

[5]Based on standardized ileal digestible (SID) AA values determined from Exp. 1.

[6]Includes an expected phytate P release of 0.08% from phytase (Phyzyme, Danisco Animal Nutrition, St. Louis, MO).

[7]Dietary fat iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723 (AOCS, 1998), where the brackets are percentage of fatty acid.

[8]Iodine value of diet oil × diet oil (%) × 0.10 (Christensen, 1962).

Table 5. Phase 3 and 4 diet composition (as-fed basis), Exp. 3[1]

	Phase 3: dDGS,[2] %					Phase 4: dDGS, %				
Item	0	5	10	20	30	0	5	10	20	30
Ingredient, %										
Corn	83.21	78.47	73.71	64.21	54.49	73.06	68.27	63.56	53.96	44.10
Soybean meal, 46.5% CP	14.84	13.66	12.49	10.14	7.81	25.17	23.99	22.82	20.47	18.15
dDGS	—	5.00	10.00	20.00	30.00	—	5.00	10.00	20.00	30.00
Choice white grease	—	0.95	1.90	3.80	5.80	—	0.98	1.90	3.85	5.90
Monocalcium phosphate, 21% P	0.45	0.34	0.23	0.00	0.00	0.35	0.23	0.10	0.00	0.00
Limestone	0.88	0.93	1.00	1.13	1.13	0.80	0.88	0.95	1.00	1.08
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix with phytase[3]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix[4]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
L-Lys·HCl	0.15	0.18	0.20	0.25	0.30	0.15	0.18	0.20	0.25	0.30
Ractopamine·HCl,[5] 20 g/kg	—	—	—	—	—	0.025	0.025	0.025	0.025	0.025
Total	100	100	100	100	100	100	100	100	100	100
Calculated analysis										
Standardized ileal digestible AA,[6] %										
Lys	0.69	0.69	0.69	0.69	0.69	0.95	0.95	0.95	0.95	0.95
Met:Lys	32	33	34	37	39	28	29	30	32	33
Met and Cys	65	66	68	70	73	58	58	59	61	63
Thr:Lys	63	64	65	67	69	61	62	62	64	65
Trp:Lys	19	18	18	18	17	19	19	19	19	18
Total Lys, %	0.78	0.80	0.81	0.84	0.87	1.07	1.08	1.10	1.13	1.16
CP, %	14.12	14.75	15.38	16.65	17.91	18.05	18.69	19.32	20.58	21.83
SID Lys:ME, g/Mcal	2.06	2.06	2.06	2.06	2.06	2.83	2.83	2.83	2.83	2.83
ME, kcal/kg	3,353	3,353	3,353	3,353	3,353	3,355	3,355	3,355	3,355	3,355
Ca, %	0.49	0.49	0.49	0.49	0.49	0.48	0.48	0.48	0.48	0.50
P, %	0.43	0.42	0.42	0.40	0.43	0.45	0.44	0.43	0.44	0.48
Available P,[7] %	0.22	0.22	0.22	0.23	0.28	0.21	0.21	0.21	0.24	0.29
Dietary fat iodine value,[8] g/100 g	116.1	107.5	100.8	94.2	89.4	121.6	107.8	100.2	94.7	88.2
Iodine value product[9]	19.7	33.3	41.3	59.3	69.8	26.8	31.3	40.1	54.9	67.9

[1]Diets fed in meal form from 77 to 100 kg of BW for phase 3 and from 100 to 120 kg of BW for phase 4.

[2]Deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[3]Provided the following per kilogram of diet: 2,646 IU of vitamin A; 397 IU of vitamin D_3; 11 IU of vitamin E; 1.1 mg of vitamin K; 2.0 mg of riboflavin; 6.6 mg of pantothenic acid; 11.9 mg of niacin; 0.01 mg of vitamin B_{12}; and 375 phytase units/kg of phytase.

[4]Provided the following per kilogram of complete diet: 15.9 mg of Mn from manganese oxide, 66.1 mg of Fe from iron sulfate, 66.1 mg of Zn from zinc oxide, 6.6 mg of Cu from copper sulfate, 0.119 mg of I from calcium iodate, and 0.119 mg of Se from sodium selenite.

[5]Elanco Animal Health, Greenfield, IN.

[6]Based on standardized ileal digestible AA values determined in Exp. 1.

[7]Includes an expected phytate P release of 0.07% from phytase (Phyzyme, Danisco Animal Nutrition, St. Louis, MO).

[8]Dietary fat iodine value = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723 (AOCS, 1998), where the brackets are percentage of fatty acid.

[9]Iodine value of diet oil × diet oil (%) × 0.10 (Christensen, 1962).

ride (Elanco Animal Health, Greenfield, IN) was added in all phase 4 diets. Hence, SID Lys was increased in the last dietary phase.

Pigs were weighed by pen, and feed disappearance was measured on d 0, on every 14 d until d 70, and on d 78, 93, and 99 to determine ADG, ADFI, and G:F. Feed intake and G:F were determined from feed delivery data generated through the automated feeding system and the amount of feed remaining in the feeder in each pen on each weigh date. Two pigs (1 barrow and 1 gilt), representative of the average BW from each pen, were selected, tattooed to identify pig and pen of origin, and then transported to a commercial processing plant (JBS Swift & Company, Worthington, MN) on d 93 to collect jowl fat, belly fat, and backfat samples for fatty acid analysis and iodine value (**IV**) determination. Briefly, pigs were processed and carcasses were sent through deep-chill chambers (approximately −40°C) for approximately 90 min. Approximately 2 h after taken out of the deep-chill chambers, the right-side jowl was removed with a perpendicular cut flush with the carcass shoulder. A small (approximately 20-g) sample of backfat was removed from the 10th-rib area off the carcass midline. Jowl and backfat samples were placed in a vacuum bag, vacuum sealed, and stored at approximately 4°C. Carcasses were allowed to chill overnight. At approximately 18 h after slaughter, a belly strip (approximately 5 cm wide and 70 cm long) was removed from the scribe side of each belly. Belly strips were vacuum-packaged and stored at 4°C. All fat samples were frozen at −18°C and transferred to Kansas State University, where the fat samples were stored in a freezer (−20°C) until further analysis. At the end of the experiment (d 99), the remaining pigs were individually tattooed with pen numbers to allow carcass data collection by pen and transported to the processing plant (JBS Swift & Company). Standard carcass criteria traits of loin and backfat depth, HCW, percentage of lean, and yield were collected. Yield was calculated as HCW divided by BW. Fat depth and loin depth were measured with an optical probe inserted between the third and fourth rib from the last rib (counting from the ham end of the carcass) and 7 cm from the dorsal midline of the hot carcass. Lean percentage was provided from the packing plant by using a proprietary equation, and the fat-free lean index was calculated according to National Pork Producers Council (2000) procedures.

Fat samples collected on d 93 were processed at the Kansas State University Swine Laboratory and analyzed for fatty acids according to procedures described by Sukhija and Palmquist (1988). Briefly, 50 mg of adipose tissue was prepared in screw-cap tubes with polytetrafluoroethylene-lined caps. Two milliliters of an internal standard [2 mg/mL of methyl heptadecanoic acid (C17:0) in benzene] and 3 mL of methanolic-HCl were then added to the tube containing the fat sample. The tubes were placed in a water bath for 120 min at 70°C for transmethylation. After the tubes were cooled to room temperature, 5 mL of 6% K_2CO_3 and 2 mL of benzene were added to allow the methyl esters to be extracted and then transferred to a vial for subsequent quantification of the methylated fatty acids by gas chromatography (method 996.06; AOAC International, 2006). Fatty acids from each fat sample were expressed as a percentage of the total fatty acids. Iodine value, expressed as grams per 100 g of fat, was then calculated on the basis of the fatty acid profile of each sample according to the following equation (AOCS, 1998):

$$\begin{aligned}\text{IV} = {} & [\text{C16:1}] \times 0.95 + [\text{C18:1}] \times 0.86 + [\text{C18:2}] \\ & \times 1.732 + [\text{C18:3}] \times 2.616 + [\text{C20:1}] \\ & \times 0.785 + [\text{C22:1}] \times 0.723,\end{aligned}$$

where the brackets are percentages of fatty acid.

Statistical Analysis

Data were analyzed as a randomized complete block design in Exp. 2 and a completely randomized design in Exp. 3. Analysis of variance was performed using the MIXED procedure (SAS Inst. Inc., Cary, NC). For Exp. 2, the effect of diet was included in the model as a fixed effect and block was included as a random effect. Note that the effects of initial pig BW, sex, and barn were confounded within block, with the effects of sex confounded with barn. Pen was the experimental unit in Exp. 2 and 3, with the exception that in Exp. 3, the individual pig data were used for the carcass fat measurements. In addition to treatment, sex was included as a fixed effect in the model. Pen nested within treatment was included in the statistical model as a random error term when data involved individual pigs so that the error term used for hypothesis testing was based on pen-to-pen variation within treatment and accounted for the clustering within pen. Including the error term in the model ensured that the denominator degrees of freedom corresponding to pen were not inflated by the replication within pen. Polynomial contrasts were used to determine the effects of increasing dDGS. Contrast coefficients were determined for unequally spaced treatments by using the IML procedure of SAS. In Exp. 3, backfat, loin depth, and percentage of lean were adjusted to a common carcass weight by using carcass weight as a continuous covariate in the statistical model. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

RESULTS AND DISCUSSION

Exp. 1

Nutrient composition of the dDGS used in Exp. 1 is reported in Table 6. The CP of dDGS was 35.58% (DM basis), which was greater than the CP content reported in traditional DDGS [30.9, 26.5, and 31.1% (DM basis) by Stein et al. (2006), Pahm et al. (2008), and

Table 6. Analyzed composition of dDGS[1] (%)

Item	DM basis	As-fed basis
DM	100.00	87.69
CP	35.58	31.20
Crude fat	4.56	4.00
NDF	39.46	34.60
ADF	18.36	16.1
Ash	5.29	4.64
Ca	0.06	0.05
P	0.87	0.76
Indispensable AA		
Arg	1.50	1.31
His	0.93	0.82
Ile	1.38	1.21
Leu	4.15	3.64
Lys	0.99	0.87
Met	0.67	0.58
Phe	1.92	1.69
Thr	1.26	1.10
Trp	0.22	0.19
Val	1.75	1.54
Dispensable AA		
Ala	2.43	2.13
Asp	2.10	1.84
Cys	0.62	0.54
Glu	4.85	4.26
Gly	1.35	1.18
Pro	2.41	2.11
Ser	1.48	1.30
Tyr	1.29	1.13

[1]Deoiled (solvent-extracted) distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

Urriola et al. (2009), respectively], as expected, and it was slightly greater than the 34.0% CP (DM basis) content of a dDGS reported by Saunders and Rosentrater (2009). However, the difference in CP content between the product evaluated in this study and that of Saunders and Rosentrater (2009) may be considered normal, even though both were dDGS products. Variation in nutrient values has been reported to exist in samples of traditional DDGS between plants that use similar manufacturing technologies (Spiehs et al., 2002; Pedersen et al., 2007). This variability in nutrient content may also apply to dDGS products. As expected, the ADF and NDF fractions as well as the P content in dDGS were greater relative to those of traditional DDGS (Stein, 2007). Because the P in DDGS is highly available, including DDGS in swine diets minimizes the need for inorganic P supplementation (Pedersen et al., 2007).

As expected, the fat content of dDGS was less than that of traditional DDGS as a result of the oil separation used to produce the dDGS. However, it was almost double the 2.7% fat content (DM basis) reported by Saunders and Rosentrater (2009) for a similar oil-extracted DDGS product. These differences may be a reflection of differences in efficiency of the fat extraction procedures used to make each coproduct.

Analyzed concentrations of almost all AA, with the exception of Trp, increased in dDGS relative to traditional DDGS. For AA digestibility, Lys, Met, and Thr in dDGS had AID values of 47.2, 79.4, and 64.1%, respectively (Table 7). The AID value of Lys was less than published values for traditional DDGS, but most other AA AID values were greater than published values for DDGS (Stein and Shurson, 2009). Standardized ileal digestibility values were 50.4% for Lys, 80.4% for Met, and 68.9% for Thr. Although Trp was present at a reduced concentration, it had a greater digestibility value in dDGS than in traditional DDGS (78 vs. 70%; Stein and Shurson, 2009). Like AID, the SID value of Lys was less than most published values for traditional DDGS (Stein and Shurson, 2009). The smaller SID value for Lys for dDGS indicates the product may have been subjected to excessive heat during drying. Lysine has consistently been found to have a smaller SID value in traditional DDGS than in corn (Fastinger and Mahan, 2006; Stein et al., 2006; Pahm et al., 2008). This can be attributed to the Maillard reaction that occurs when DDGS is subjected to excessive heat, wherein reducing sugars bind to Lys and render it unavailable to the animal (Adrian, 1974). It has been suggested that the ratio of Lys to CP can serve as a guideline for identifying DDGS with a greater degree of heat damage and that DDGS with a Lys-to-CP ratio of greater than 2.8 is ideal (Stein, 2007). The ratio for the dDGS tested in this study was 2.8 even though the SID value was at least 10 percentage points less than the summarized

Table 7. Apparent (AID) and standardized (SID) ileal digestibility of AA in dDGS[1] by growing pigs[2,3]

Item	SID, %	AID, %
Indispensable AA		
Arg	82.7 ± 1.7	79.7 ± 1.4
His	74.6 ± 2.8	72.8 ± 2.8
Ile	74.5 ± 2.0	72.5 ± 2.0
Leu	83.8 ± 1.8	82.7 ± 1.7
Lys	50.4 ± 1.9	47.2 ± 2.0
Met	80.4 ± 1.6	79.4 ± 1.5
Phe	80.8 ± 1.6	79.4 ± 1.6
Thr	68.9 ± 2.3	64.1 ± 2.2
Trp	78.0 ± 1.6	73.7 ± 1.5
Val	73.8 ± 2.1	71.8 ± 2.1
Dispensable AA		
Ala	79.1 ± 2.1	77.2 ± 2.0
Asp	64.6 ± 2.5	61.3 ± 2.5
Cys	66.9 ± 4.0	64.1 ± 3.8
Glu	79.0 ± 2.5	77.5 ± 2.4
Gly	64.6 ± 3.0	52.7 ± 3.7
Pro	87.8 ± 6.6	73.4 ± 4.2
Ser	76.9 ± 2.1	73.2 ± 1.9
Tyr	82.4 ± 1.6	80.6 ± 1.6

[1]Deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[2]Values are means of 5 observations per treatment. The SD for each digestibility value is also shown.

[3]The SID represents the corrected AID accounting for basal endogenous loss of an AA. Calculated basal endogenous losses after feeding the N-free diet were as follows (g/kg of DMI): Arg, 0.29; His, 0.11; Ile, 0.17; Leu, 0.29; Lys, 0.19; Met, 0.04; Phe, 0.16; Thr, 0.40; Trp, 0.06; Val, 0.22; Ala, 0.29; Asp, 0.46; Cys, 0.11; Glu, 0.52; Gly, 1.02; Pro, 2.28; Ser, 0.35; and Tyr, 0.14.

Table 8. Energy values of dDGS[1] for growing pigs[2]

Item	Amount, kcal/kg of DM
GE	5,098
DE	3,100
ME[3]	2,858
NE[4]	2,045

[1]dDGS = deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[2]Values are means of 5 observations per treatment.

[3]The ME value of dDGS was calculated as ME = 1 × DE – 0.68 × CP (R^2 = 0.99; Noblet and Perez, 1993).

[4]The NE value of dDGS was calculated as NE = (0.87 × ME) − 442 (R^2 = 0.99; Noblet et al., 1994).

values for SID Lys for traditional corn DDGS reported by Stein and Shurson (2009). However, the ratio proposed by Stein (2007) was based on traditional DDGS and not further processed DDGS; thus, the proposed ratio may not be a valid indicator for this product.

The determined GE and DE values and calculated ME and NE values of dDGS were 5,098, 3,100, 2,858, and 2,045 kcal/kg of DM, respectively (Table 8). These values are less than traditional DDGS energy values, which was expected because of the removal of the majority of the oil. The determined DE for dDGS represented only 61% of its GE. In a review of studies on traditional DDGS, Stein and Shurson (2009) reported averages of 5,434 and 4,140 kcal/kg of DM for the GE and DE values, respectively, of DDGS. Thus, the DE in DDGS represented 76% of the GE value. The decreased digestibility of energy in dDGS can be attributed to its smaller crude fat content and the energy dilution effect of its greater fiber content.

Exp. 2

Overall (d 0 to 28), nursery pigs fed increasing dDGS had similar ADG, ADFI, and G:F (Table 9). These data indicate that increasing dietary dDGS up to 30% did not affect growth performance for nursery pigs weighing 10 to 23 kg when the diets were balanced for both SID AA and ME. Early research by Combs and Wallace (1969) on feeding traditional DDGS in nursery pigs showed that adding 20% DDGS in the diets did not affect growth performance. However, they also reported that digestibility of DM, CP, and ether extract was reduced when pigs were fed 20% DDGS diets compared with diets containing 0 or 10% DDGS. Using traditional DDGS from new-generation ethanol plants, Whitney and Shurson (2004) reported that DDGS can be fed at up to 25% without negatively affecting growth performance. Recent studies have further supported this conclusion. Other researchers have not reported differences in ADG between DDGS-fed and non-DDGS-fed nursery pigs (Linneen et al., 2006; Spencer et al., 2007; Barbosa et al., 2008), and some researchers have also reported improvement in G:F (Gaines et al., 2006; Spencer et al., 2007; Barbosa et al., 2008). In the present study, dDGS was added at up to 30%, and the resulting growth performance in nursery pigs was similar to that of pigs fed diets without dDGS when the diets were balanced for digestible AA and ME content.

Exp. 3

Overall (d 0 to 99), ADG and ADFI decreased (linear, $P < 0.01$; Table 10) and G:F tended to increase (linear, $P = 0.07$) with increasing dDGS in the diet. Results from this trial are similar to previous research on traditional DDGS in which feed intake was reduced when DDGS was fed at more than 20% of the diet (Fu et al., 2004; Xu et al., 2007; Linneen et al., 2008), although in some other studies feeding up to 30% traditional DDGS did not affect the growth performance of finishing pigs (Cook et al., 2005; DeDecker et al., 2005; Xu et al., 2007). The addition of dDGS to growing-finishing diets appears to affect palatability negatively, but the reasons for the decrease in feed intake are not clear.

Carcass weight and percentage yield decreased (linear, $P < 0.01$) and loin depth tended to decrease (linear, $P = 0.09$) as dDGS increased. However, no differences were observed among treatments in backfat depth, percentage of lean, or fat-free lean index. The reduction in carcass weight can be attributed to the decreased ADG and yield as pigs were fed increasing dDGS. The decrease in carcass weight in pigs fed 30% dDGS compared with pigs not fed dDGS observed in

Table 9. Effects of dDGS[1] on nursery growth performance, Exp. 2[2]

	dDGS, %						*P*-value	
Item	0	5	10	20	30	SEM	Linear	Quadratic
BW, kg								
d 0	10.0	10.0	9.6	9.9	9.9	0.5	0.15	0.78
d 28	22.7	22.8	22.2	22.4	22.3	0.6	0.23	0.94
d 0 to 28								
ADG, kg	0.455	0.459	0.452	0.445	0.442	0.019	0.25	0.98
ADFI, kg	0.749	0.771	0.760	0.751	0.761	0.009	0.95	0.86
G:F	0.609	0.595	0.594	0.593	0.582	0.027	0.23	0.80

[1]dDGS = deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[2]A total of 210 pigs (initial BW = 9.9 kg) were used, with 6 pigs per pen and 7 replicate pens (4 barrows and 3 gilts) per treatment.

Table 10. Effects of dDGS[1] on growth performance and carcass characteristics of growing-finishing pigs, Exp. 3[2]

	dDGS, %						*P*-value	
Item	0	5	10	20	30	SE	Linear	Quadratic
BW, kg								
d 0	29.6	29.6	29.6	29.6	29.6	0.5	0.94	0.99
d 99	121.4	119.3	118.8	118.2	116.2	0.9	0.001	0.68
d 0 to 99								
ADG, kg	0.909	0.893	0.887	0.887	0.873	0.008	0.01	0.61
ADFI, kg	2.16	2.17	2.11	2.11	2.04	0.03	0.003	0.72
G:F	0.420	0.413	0.422	0.421	0.431	0.006	0.07	0.42
Carcass wt, kg	91.1	89.0	89.1	87.7	86.3	0.8	<0.001	0.66
Yield, %	75.5	75.0	75.0	74.7	74.3	0.0	0.01	0.73
Backfat,[3] mm	16.46	16.53	16.53	16.38	16.96	0.25	0.26	0.25
Loin depth,[3] mm	63.5	62.2	62.5	63.0	60.7	0.8	0.09	0.55
Lean,[3] %	56.48	55.91	56.30	56.43	55.78	0.20	0.16	0.28
FFLI,[3,4]	50.4	50.4	50.4	50.5	50.2	0.1	0.20	0.19

[1]dDGS = deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[2]A total of 1,215 pigs (initially, 29.6 kg of BW) were used, with 27 pigs per pen and 9 pens per treatment. On d 93, 2 pigs (1 barrow and 1 gilt) were removed from each pen and were not included in carcass data.

[3]Values are adjusted to a common carcass weight.

[4]Fat-free lean index.

this study (4.8 kg) is similar to the 5.1 kg decrease in carcass weight reported in an earlier study in pigs fed traditional DDGS (Whitney et al., 2006). The reduction in carcass yield was not unexpected because this effect has been reported consistently in finishing pigs fed traditional DDGS (Fu et al., 2004; Linneen et al., 2008; Weimer et al., 2008). We hypothesize that the reduction in percentage yield is related to the high fiber content of the dDGS diets. Diets containing high fiber content have been suggested to increase the basal metabolic rate (Pond et al., 1988), which could account for the decreased percentage yield in pigs fed diets containing dDGS. Previous studies also have shown that diets high in fiber increase the rate of passage in the gastrointestinal tract, resulting in increased gut cell proliferation and intestinal growth (Jin et al., 1994; Gill et al., 2000). The increased fiber content in dDGS could have led to a greater volume of intestinal fluid and volume of digesta (Pluske et al., 2003) and, along with the increased protein content of dDGS, an increased weight of intestines and other visceral organs (Kass et al., 1980; Stanogias and Pearce, 1985; Pond et al., 1989). Because visceral organs are excluded from the carcass, percentage yield is negatively affected in pigs fed dDGS diets because of the greater volume and weight of entrails removed during slaughter. In addition, the majority of the energy required for maintenance is used by visceral organs, such as the liver and the gastrointestinal tract (Johnson et al., 1990; Mahr-un-nisa and Feroz, 1999). Thus, the resulting increase in weight of the visceral organs could have resulted in a further increase in the maintenance requirement and diverted nutrient utilization away from the production of carcass lean and adipose tissue.

As with other nutrients, fat content in traditional DDGS is increased approximately 3-fold compared with corn and is rich in unsaturated fatty acids. Thus, feeding DDGS to pigs results in increased IV (a measure of the degree of unsaturation) in carcass fat (Feoli et al., 2007; Benz, 2008; White et al., 2009). The reduced fat content of dDGS would reduce the total amount of unsaturated fatty acids in the diet containing dDGS compared with traditional DDGS. Furthermore, the reduced oil content of dDGS may improve some of the handling issues commonly encountered with traditional DDGS through increased flowability. Ganesan et al. (2009) reported that a low-oil DDGS product had a slight improvement in flowability compared with regular DDGS.

As dDGS increased in the diets, total SFA decreased (linear; $P < 0.01$) and linoleic acid (C18:2), MUFA and PUFA, and IV increased (linear; $P < 0.01$) in all fat depots (Table 11). Because dDGS was not completely devoid of corn oil, the diets still provided an increasing source of unsaturated fatty acids. Among the fatty acids, linoleic acid is considered to have the greatest effect on fat firmness (Berschauer, 1984). Linoleic acid is unsaturated; therefore, the greater the percentage of linoleic acid, the greater the degree of unsaturation in the resulting fat. A high concentration of unsaturated fatty acids has been shown to affect bacon quality negatively and cause processing difficulties (Person et al., 2005). It can also result in rapid oxidation, which decreases the shelf life of pork (Wood et al., 2003).

Although dDGS contains less oil than traditional DDGS, the increase in IV of fat was expected because of the increasing choice white grease in diets with dDGS. Iodine values from the 3 fat stores increased between 5.0 and 6.6 g/100 g in pigs fed 30% dDGS in the diet compared with control pigs. This translates into an increase in IV of fat of approximately 1.7 to 2.2 g/100 g reported for every 10% inclusion of dDGS in the diet when fed in combination with choice white grease. This was similar to the rate of increase in fat IV reported by

Table 11. Effects of dDGS[1] on carcass fat quality

	dDGS,[2] %						Sex[3]			*P*-value		
Item	0	5	10	20	30	SEM	Barrow	Gilt	SEM	Linear	Quadratic	Sex
C18:2 fatty acids, %												
Jowl fat	13.6	13.7	14.7	15.9	17.1	0.3	14.5	15.4	0.2	<0.001	0.75	0.002
Backfat	16.5	16.3	17.0	18.9	18.4	0.4	16.5	18.3	0.3	<0.001	0.40	<0.001
Belly fat	15.3	15.4	16.3	17.8	18.2	0.4	15.7	17.5	0.3	<0.001	0.50	<0.001
Total SFA,[4] %												
Jowl fat	35.7	35.1	35.0	33.8	32.3	0.3	34.9	33.9	0.2	<0.001	0.34	0.001
Backfat	37.6	37.5	37.2	34.8	33.6	0.4	36.7	35.5	0.3	<0.001	0.34	0.001
Belly fat	37.9	36.9	36.5	34.3	33.0	0.4	36.4	35.0	0.3	<0.001	0.85	0.0003
Total MUFA,[5] %												
Jowl fat	48.9	49.3	48.4	48.2	48.3	0.4	48.6	48.7	0.3	0.09	0.55	0.80
Backfat	43.9	44.4	43.8	44.1	45.8	0.4	44.8	44.0	0.3	0.01	0.07	0.07
Belly fat	44.8	45.7	45.2	45.6	46.6	0.4	45.9	45.3	0.3	0.01	0.54	0.152
Total PUFA,[6] %												
Jowl fat	15.4	15.6	16.6	18.0	19.4	0.3	16.5	17.5	0.2	<0.001	0.79	0.002
Backfat	18.5	18.2	19.0	21.1	20.6	0.5	18.5	20.4	0.3	<0.001	0.38	<0.001
Belly fat	17.2	17.4	18.4	20.1	20.4	0.4	17.7	19.7	0.3	<0.001	0.44	<0.001
Iodine value,[7] g/100 g												
Jowl fat	67.5	68.1	69.0	71.1	73.3	0.5	68.9	70.7	0.3	<0.001	0.41	<0.001
Backfat	68.5	68.4	69.2	73.0	73.5	0.6	69.2	71.9	0.4	<0.001	0.99	<0.001
Belly fat	67.1	68.0	69.1	72.4	73.7	0.6	68.7	71.5	0.4	<0.001	0.64	<0.001

[1]dDGS = deoiled (solvent-extracted) corn distillers dried grains with solubles (Verasun Energy Inc., Brookings, SD).

[2]Values are means of 18 observations per treatment.

[3]Values are means of 45 observations per treatment.

[4]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), where the brackets are percentage of fatty acid.

[5]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where the brackets are percentage of fatty acid.

[6]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where the brackets are percentage of fatty acid.

[7]Calculated as [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785+ [C22:1] × 0.723, where the brackets are percentage of fatty acid (AOCS, 1998).

Whitney et al. (2006) for pigs fed 0, 10, 20, and 30% DDGS and by Benz (2008) in pigs fed 0, 5, 10, 15, and 20% DDGS. The increase in IV in this study, however, would not be expected to be as large without the increase in added choice white grease needed to maintain isocaloric diets within each phase. Adding supplemental fat to diets containing coproducts that have had the majority of the fat removed would be practical when formulating to a constant dietary energy or when the combination of a low-oil coproduct and available fat source is lower cost than the coproduct containing its original concentration of fat. In addition, the decreased IV ($P < 0.01$) for barrows compared with gilts was in agreement with reports of Averette-Gatlin et al. (2002) and Benz (2008).

In summary, AA and energy digestibility values were established for dDGS in this study and were validated through growth performance experiments in nursery and growing-finishing pigs. This coproduct of the ethanol and fat extraction industries has increased CP and AA but has less energy and slightly less Lys digestibility compared with traditional DDGS. Results of the growth experiments showed that up to 30% dDGS can be added to nursery diets for pigs weighing 10 to 23 kg without negatively affecting growth performance, provided fat is added to the diets to offset the decreased ME content of dDGS. These data validate the accuracy of the previously determined ME (2,858 kcal/kg of DM) and SID AA values for dDGS because no changes in G:F were observed when dDGS was fed at increasing amounts in the diet. However, increasing dDGS in growing-finishing diets resulted in reduced growth performance and had negative effects on carcass traits, especially at amounts greater than 20%. In addition, fat quality, as measured by IV, decreased when adding increasing dietary dDGS, which can be attributed to more dietary oil from dDGS and the use of increased choice white grease to maintain equal dietary energy. Thus, factors that may affect economics, such as feed ingredient prices, finishing space, and packer specifications, must be considered when using dDGS at greater amounts in growing-finishing pig diets.

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