The effects of medium-oil dried distillers grains with solubles on growth performance, carcass traits, and nutrient digestibility in growing–finishing pigs[1,2]

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ABSTRACT: A total of 288 mixed-sex pigs (PIC 327 × 1050; initially 68.9 kg BW) were used in a 67-d study to determine the effects of increasing medium-oil dried distillers grains with solubles (DDGS; 7.63% ether extract, 30.1% CP, 19.53% ADF, 36.47% NDF, and 4.53% ash; as-fed basis) on growth performance and carcass traits in finishing pigs. Treatments consisted of a corn–soybean meal control diet or the control diet with 15, 30, or 45% medium-oil DDGS. Diets were fed over 2 phases (69 to 100 and 100 to 126 kg) and were not balanced for energy. Diets were formulated to meet or exceed the AA, vitamin, and mineral requirements and contained constant standardized ileal digestible lysine levels within phase. Increasing medium-oil DDGS decreased (linear, $P < 0.02$) ADG and G:F. Average daily gain decreased approximately 2.3% for every 15% added medium-oil DDGS whereas G:F decreased approximately 1.3% with every 15% added DDGS. In addition, final BW, HCW, carcass yield, and loin-eye depth decreased (linear, $P < 0.03$) and jowl iodine value (IV) increased (linear, $P < 0.001$) with increasing medium-oil DDGS. Nutrient digestibility of the DDGS source was determined using pigs (initially 25.6 kg BW) that were fed either a corn-based basal diet (96.6% corn and 3.4% vitamins and minerals) or a DDGS diet, which was a 50:50 blend of the basal diet and medium-oil DDGS. There were 12 replications for each diet consisting of a 5-d adaptation period followed by 2 d of total fecal collection on a timed basis. Feces were analyzed for GE, DM, CP, crude fiber, NDF, ADF, and ether extract. On an as-fed basis, corn was analyzed to contain 3,871 and 3,515 kcal/kg GE and DE, respectively. Medium-oil DDGS was analyzed to contain 4,585 and 3,356 kcal/kg GE and DE, respectively (as-fed basis). Digestibility coefficients of the medium-oil DDGS were 70.3% DM, 82.9% CP, 61.4% ether extract, 77.4% ADF, 67.5% NDF, and 67.2% crude fiber. Caloric efficiency (ADFI × kcal energy intake/kg BW gain) was not different when expressed on a DE or a calculated ME or NE basis, which suggests that the energy values derived from the nutrient balance study were accurate. In conclusion, increasing dietary inclusion of medium-oil DDGS decreased ADG, G:F, final BW, HCW, and carcass yield and increased jowl fat IV relative to those fed a corn–soybean meal–based diet.

Key words: corn, distillers grains with solubles, digestibility, growing–finishing pigs, oil

J. Anim. Sci. 2014.92:604–611
doi:10.2527/jas2013-6798

INTRODUCTION

Dried distillers grains with solubles (**DDGS**), a byproduct of the ethanol industry, are commonly used in swine diets to lower feed costs. Dried distillers grains with solubles historically contains greater than 10% oil, maintaining a relatively high feeding value similar to corn (Stein and Shurson, 2009). Stein and Shurson (2009) summarized that growth performance will remain unchanged when DDGS constitutes up to 30% of the diet, but carcass characteristics such as carcass yield and jowl iodine value (**IV**) are adversely affected by feeding DDGS.

Most ethanol plants use an oil extraction process that removes approximately 20% of the corn oil in thin stillage via centrifugation resulting in a DDGS with

[1]Contribution no. 13-366-J from the Kansas Agric. Exp. Sta., Manhattan, KS 66506.

[2]The authors thank Rob Musser (NutriQuest, Mason City, IA) and to Jerry Lehenbauer, David Donovan, Derek Petry, Ann Smith, Brittany Kilmer, and Brad Knadler (Triumph Foods LLC, St. Joseph, MO) for technical support.

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Received June 13, 2013.
Accepted November 18, 2013.

approximately 7.5 to 8.5% oil. Some ethanol plants are beginning to add a surfactant into the whole stillage that allows for another 10 to 20% extraction of the oil bound in whole stillage resulting in a product with a range of 6.5 to 7% oil. Variation in oil extraction procedures between ethanol plants has led to DDGS products varying in oil content from 4 to 12%.

A concern is that the new, medium-oil DDGS (>6 and <9% oil; NRC, 2012) may negatively affect ADG and G:F because of its low energy content. Anderson et al. (2012) suggested that GE and total dietary fiber are the significant criteria in estimating energy values of corn coproducts. On the other hand, Pedersen et al. (2007) observed that ash, oil, ADF, and GE were significant variables when predicting energy content of DDGS ranging in oil content from 8.6 to 12.4%. Few data are available on nutrient digestibility or feeding value of medium-oil DDGS.

Therefore, the objective of this study was to evaluate effects of medium-oil DDGS on finishing pig growth performance and carcass characteristics and to determine its DE and nutrient digestibility.

Table 1. Analyzed nutrient composition of medium-oil corn dried distillers grains with solubles (DDGS; as-fed basis)

Item	Medium-oil DDGS[1]
DM, %	93.70
CP, %	30.10
Ether extract, %	7.63
Crude fiber, %	10.58
Ash, %	4.53
ADF, %	19.53
NDF, %	36.47
Starch, %	7.6
P, %	0.92
Essential AA, %	
Arg	1.12
His	0.75
Ile	1.11 (1.01)
Leu	3.38 (3.17)
Lys	0.92 (0.78)
Met	0.53 (0.58)
Thr	1.03 (1.06)
Trp	0.23 (0.21)
Val	1.46 (1.35)

[1]Values represent the mean of 3 samples analyzed in duplicate. Diets were prepared using values in parentheses (AA) and standardized ileal digestibility values from Stein (2007).

MATERIALS AND METHODS

General

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

Experiment 1 was conducted in a totally enclosed, environmentally controlled, mechanically ventilated facility containing 36 pens. The pens (2.4 by 3.1 m) had adjustable gates, which allowed for 0.93 m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder with 2 eating spaces (Farmweld, Teutopolis, IL) located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility use a computerized feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) that both recorded and delivered diets to pens as specified. The equipment provided pigs with ad libitum access to feed and water.

In Exp. 2, pigs were housed in a totally enclosed, environmentally controlled, mechanically ventilated facility containing 12 stainless steel metabolism cages (1.5 by 0.6 m). Each cage was equipped with a feeder and a nipple waterer to allow ad libitum access to water and had metal mesh flooring that allowed for total collection of feces.

Animals and Diets

Experiment 1. A total of 288 mixed-sex finishing pigs (327 × 1050; PIC, Hendersonville, TN; initially 68.9 kg BW) were used in a 67-d growth study. Pens of pigs were allotted to 1 of 4 dietary treatments with 8 pigs per pen and 9 replications per treatment. A single batch of corn and medium-oil DDGS was used in this study and analyzed for chemical composition (Table 1). The DDGS contained 7.63% ether extract, 30.1% CP, 19.53% ADF, and 36.47% NDF (as-fed basis; AOAC International, 2006; Ward Laboratories, Kearney, NE). Amino acid profile was analyzed at the University of Missouri – Columbia Agricultural Experiment Station Chemical Laboratory (Columbia, MO; AOAC International, 2006). Fatty acid analysis (Sukhija and Palmquist, 1988) was conducted on the medium-oil DDGS at the Kansas State Analytical Laboratory (Manhattan, KS) using gas chromatography with a flame ionization detector with external reference standards (Table 2). At the time of diet formulation, the 2012 NRC publication was not available; therefore, total AA and standardized ileal digestibility (**SID**) coefficients in DDGS from Stein (2007) were used in diet formulation.

Pigs were fed corn–soybean meal–based diets containing 0, 15, 30, or 45% medium-oil DDGS. Diets were fed in 2 phases from approximately 69 to 100 and 100 to 126 kg (Tables 3 and 4). Complete diets were analyzed for DM (method 934.01; AOAC International, 2006), CP (method 990.03; AOAC International, 2006), crude fiber (method 978.10; AOAC International, 2006), NDF and ADF, and ether extract (method 920.39 A; AOAC International, 2006) at a commercial laboratory (Ward Laboratories, Kearney, NE). All pigs and feeders were weighed on d 0, 33, and 67 to determine ADG, ADFI, and G:F.

Table 2. Fatty acid analysis of corn medium-oil dried distillers grains with solubles (DDGS)

Item	Medium-oil DDGS
Myristic acid (C14:0), %	0.08
Palmitic acid (C16:0), %	13.69
Palmitoleic acid (C16:1), %	0.15
Margaric acid (C17:0), %	0.11
Stearic acid (C18:0), %	1.86
Oleic acid (C18:1 *cis*-9), %	22.50
Vaccenic acid (C18:1n-7), %	1.25
Linoleic acid (C18:2n-6), %	56.75
α-Linoleic acid (C18:3n-3), %	1.80
Arachidic acid (C20:0), %	0.41
Gadoleic acid (C20:1), %	0.24
Eicosadienoic acid (C20:2), %	0.08
Arachidonic acid (C20:4n-6), %	0.05
Other fatty acids, %	1.00
Total SFA,[1] %	16.15
Total MUFA,[2] %	24.19
Total PUFA,[3] %	58.70
Total *trans* fatty acids,[4] %	0.15
UFA:SFA ratio[5]	5.13
PUFA:SFA ratio[6]	3.63
Iodine value,[7] g/100g	122.7

[1]Total saturated fatty acids = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] +[C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[2]Total monounsaturated fatty acids = ([C14:1] + [C16:1] + [C18:1 cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[3]Total polyunsaturated fatty acids = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[4]Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]); brackets indicate concentration.

[5]UFA = unsaturated fatty acids. UFA:SFA = (total MUFA + total PUFA)/ total SFA.

[6]PUFA:SFA = total PUFA/total SFA.

[7]Calculated as 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; brackets indicate concentration.

On d 67, all pigs were weighed and transported approximately 2.5 h to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for harvest under USDA inspection. Before slaughter, pigs were individually tattooed to allow for carcass data collection at the packing plant. Hot carcass weight was measured immediately after evisceration, and each carcass was evaluated for carcass yield, backfat depth, loin depth, and percentage lean. Carcass yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the plant. Fat depth and loin depth were measured with an optical probe inserted between the third and fourth last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. In addition, jowl fat samples were collected and analyzed by near infrared spectroscopy (Bruker MPA, Bremen, Germany) at the plant for IV using the equation of Cocciardi et al. (2009).

Experiment 2. A total of 12 barrows (initially 25.6 kg BW) were used in a 6-wk study to determine nutrient digestibility of corn, the medium-oil DDGS used in the growth study, and 4 other sources of DDGS. The other 4 sources of DDGS were used in a different growth study outlined by Graham (2013). Pigs were randomly allotted to 1 of 2 Latin square designs with 6 pigs each to achieve 12 replications per diet. The medium-oil DDGS used in the digestibility study were from the same batch as the growth study and nutrient digestibility of the DDGS source was determined by feeding either a corn-based basal diet (96.6% corn and 3.4% vitamins and minerals) or a 50:50 blend of basal diet and DDGS (Table 5). Ingredients, complete diets, and feces were analyzed for DM (method 934.01; AOAC International, 2006), CP (method 990.03; AOAC International, 2006), crude fiber (method 978.10; AOAC International, 2006), NDF, ADF, and ether extract (method 920.39 A; AOAC International, 2006) at a commercial laboratory (Ward Laboratories, Kearney, NE).

Pigs were fed the same amount of each diet (2.5x maintenance, determined by their BW on d 1 of each period) for the duration of each 7-d period. Each day's ration was equally divided between 2 meals (fed at 0600 and 1800 h, respectively). Each period consisted of a 5-d diet adaptation period (Adeola, 2001), which consisted of 10 meals, followed by 2 consecutive days of total fecal collection (Stein et al., 2006). On the morning of d 6 (meal 11), just before the morning meal, pigs were allowed approximately 5 min to stand, drink, and defecate. After that time, feces were removed and the morning meal was fed. This meal on the morning of d 6 marked the beginning of the timed fecal collection period. On d 8 of period 1 (d 1 of period 2 or meal 15), the same amount of time was given to pigs, allowing them to stand up, drink, and defecate. Before feeding, all feces were collected, marking the end of the timed collection period. On the same morning that collection ended, pigs were weighed and fed a new treatment diet in a random order. Feces were stored in a freezer (–20°C) until further processing and analysis. At the conclusion of a collection period, all feces for each pig were combined, homogenized, and dried in a forced-air oven at 50°C. Samples were finely ground using a coffee grinder and then subsampled for further analysis. Gross energy concentrations of the ingredients, diets, and fecal samples were measured via adiabatic bomb calorimetry (Model 13031; Parr Instruments, Moline, IL). Calculations outlined by Adeola (2001) were used to determine digestible energy values. The ME and NE values were calculated based on Eq. [1–6] and [1–7] from NRC (2012).

Table 3. Diet composition, d 0 to 33 (Exp. 1; as-fed basis)[1]

Item	Medium-oil dried distillers grains with solubles (DDGS), %			
	0	15	30	45
Ingredient, %				
Corn	79.00	66.83	54.80	42.45
Soybean meal (46.5% CP)	18.48	15.84	13.04	10.41
Medium-oil DDGS	–	15.00	30.00	45.00
Monocalcium P (21% P)	0.90	0.55	0.20	–
Limestone	0.89	1.03	1.17	1.32
Salt	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.10	0.10	0.10	0.10
Trace mineral premix[3]	0.10	0.10	0.10	0.10
L-Lysine HCl	0.18	0.21	0.24	0.27
L-Threonine	0.01	–	–	–
Total	100	100	100	100
Calculated composition				
Standardized ileal digestible (SID) amino acids,[4] %				
Lys	0.80	0.80	0.80	0.80
Ile:Lys	68	73	77	81
Leu:Lys	165	190	215	239
Met:Lys	29	34	38	43
Met and Cys:Lys	60	65	70	76
Thr:Lys	61	66	71	76
Trp:Lys	19	19	19	19
Valine:Lys	80	87	93	101
Total Lys, %	0.90	0.93	0.96	0.99
ME, kcal/kg	3,334	3,343	3,352	3,356
SID Lys:ME, g/Mcal	2.40	2.39	2.39	2.38
CP, %	15.48	17.32	19.11	20.95
Ca, %	0.59	0.57	0.55	0.56
P, %	0.54	0.52	0.50	0.51
Available P, %	0.25	0.25	0.25	0.28
Analyzed composition (as fed), %				
DM	89.4	89.8	90.4	90.9
CP	15.0	17.2	19.7	22.4
Ether extract	3.5	3.6	4.6	5.8
Crude fiber	2.0	2.5	3.3	4.6
ADF	3.2	5.1	6.2	7.1
NDF	7.4	9.1	11.4	15.2

[1]Diets were fed in meal form from d 0 to 33 of the experiment.

[2]Provided per kilogram of premix: 4,409,249 IU vitamin A, 551,156 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 kilogram 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]Amino acid and ME values used in diet formulation for the medium-oil DDGS were derived from Stein (2007).

Table 4. Diet composition, d 33 to 67 (Exp. 1; as-fed basis)[1]

Item	Medium-oil dried distillers grains with solubles (DDGS), %			
	0	15	30	45
Ingredient, %				
Corn	82.71	70.55	58.52	45.99
Soybean meal (46.5% CP)	14.96	12.31	9.52	6.90
Medium-oil DDGS	–	15.00	30.00	45.00
Monocalcium P (21% P)	0.75	0.40	0.05	–
Limestone	0.87	1.00	1.14	1.30
Salt	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.10	0.10	0.10	0.10
Trace mineral premix[3]	0.10	0.10	0.10	0.10
L-Lysine HCl	0.16	0.19	0.23	0.26
L-Threonine	0.01	–	–	–
Total	100	100	100	100
Calculated composition				
Standardized ileal digestible (SID) amino acids,[4] %				
Lys	0.70	0.70	0.70	0.70
Ile:Lys	70	75	79	84
Leu:Lys	177	206	234	262
Met:Lys	31	36	41	47
Met and Cys:Lys	64	70	76	82
Thr:Lys	64	68	74	80
Trp:Lys	19	19	19	19
Valine:Lys	83	91	99	107
Total Lys, %	0.79	0.82	0.85	0.88
ME, kcal/kg	3,343	3,352	3,360	3,356
SID Lys:ME, g/Mcal	2.09	2.09	2.09	2.09
CP, %	14.15	15.98	17.77	19.60
Ca, %	0.54	0.52	0.50	0.54
P, %	0.49	0.47	0.45	0.50
Available P, %	0.21	0.21	0.21	0.27
Analyzed composition (as fed), %				
DM	89.5	89.6	89.7	90.3
CP	15.4	14.2	16.1	15.5
Ether extract	3.2	3.4	4.4	4.2
Crude fiber	2.0	2.1	2.7	2.5
ADF	3.5	6.0	5.4	5.6
NDF	6.9	7.8	10.3	10.0

[1]Diets were fed in meal form from d 33 to 67 of the experiment.

[2]Provided per kilogram of premix: 4,409,249 IU vitamin A, 551,156 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 kilogram 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]Amino acid and ME values used in diet formulation for the medium-oil DDGS were derived from Stein (2007).

Statistical Analysis

Analysis of variance was used with the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Data for the growth trial were analyzed as a completely randomized design with pen as the experimental unit. Because HCW differed, it was used as a covariate for backfat, loin depth, and percentage lean. Linear and quadratic contrasts were used to determine the effects of increasing medium-oil DDGS. Differences were considered significant at $P < 0.05$ and a trend at $P < 0.10$. Single degree of freedom contrasts were used to separate means of pigs fed either the corn- or DDGS-based diets in the nutrient balance study. Data for Exp. 2 was analyzed as a replicated Latin square design. The

Table 5. Diet composition, Exp. 2, as-fed basis

Ingredient, %	Corn basal diet
Corn	96.90
Limestone	2.30
Salt	0.40
Vitamin premix[1]	0.25
Trace mineral premix[2]	0.15

[1]Provided per kilogram of premix: 4,409,249 IU vitamin A, 551,156 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}.

[2]Provided per kilogram 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. Vitamins and minerals are diluted by 50% in the test diets.

statistical model included DDGS source as a fixed effect and Latin square, pig within Latin square, and period as random effects. Single degree of freedom contrasts were used to separate means of pigs fed either the corn- or DDGS-based diet in the nutrient balance study.

RESULTS AND DISCUSSION

Chemical Analysis

Dried distillers grains with solubles have historically contained approximately 10.5% or greater oil (Stein and Shurson, 2009). Today, many ethanol plants use an extraction procedure to remove corn oil via centrifugation during processing resulting in DDGS with approximately 7% oil, similar to that of the medium-oil DDGS used in this study (Table 1).

Dried distillers grains with solubles, which are reviewed by Stein and Shurson (2009), are lower in ADF, NDF, and CP than the medium-oil DDGS used in this study. According to NRC (2012), the Lys concentration in medium-oil DDGS is greater (0.90 vs. 0.77%) than in traditional DDGS. The analyzed value of Lys from the medium-oil DDGS was 0.92%, confirming it was similar to the reported Lys value for medium-oil DDGS in the NRC (2012). The analyzed Lys concentration of the medium-oil DDGS as a percentage of CP was 3.06%, suggesting that the medium-oil DDGS was not subject to heat damage and would likely have relatively high standardized ileal AA digestibility (Kim et al., 2012).

Growth Performance and Carcass Traits

Experiment 1. Pigs fed increasing medium-oil DDGS had decreased (linear, $P < 0.02$) ADG and G:F (Table 6). There was a trend (linear, $P < 0.10$) for decreased ADFI with increasing medium-oil DDGS. Average daily gain and G:F decreased approximately 2.2 and 1.3%, respectively, with every 15% of added medium-oil DDGS. Unlike observations in our study, in a review of over 20 papers, Stein and Shurson (2009) concluded that up to 30% DDGS could be added to the diet without negatively affecting growth performance; however, in the majority of the studies examined by Stein and Shurson (2009), the DDGS sources contained at least 10% oil. This is because at that time, the centrifugation process of removing a portion of the oil in DDGS had not been widely implemented.

Table 6. Effect of medium-oil dried distillers grains with solubles on finishing pig growth performance and carcass characteristics (Exp. 1)[1]

	Medium-oil dried distillers grains with solubles, %					Probability, $P <$	
	0%	15%	30%	45%	SEM	Linear	Quadratic
Initial BW, kg	68.9	68.9	68.9	68.9	0.9	0.99	0.99
d 0 to 67							
ADG, kg	0.875	0.848	0.838	0.817	0.010	0.01	0.77
ADFI, kg	2.739	2.709	2.681	2.664	0.034	0.10	0.84
G:F	0.320	0.313	0.313	0.307	0.004	0.02	0.99
Final BW, kg	127.3	125.8	125.2	124.0	1.1	0.03	0.87
Carcass data							
HCW, kg	93.39	91.43	90.11	88.52	0.83	0.001	0.82
Carcass yield,[2] %	73.98	73.16	72.36	71.84	0.16	0.001	0.35
Backfat depth,[3] mm	19.4	19.8	19.4	18.7	0.40	0.17	0.15
Loin depth,[3] mm	61.0	60.0	59.7	57.9	0.81	0.01	0.58
Lean,[3] %	53.1	52.8	52.8	52.7	0.23	0.32	0.65
Jowl IV,[4] mg/g	70.2	71.1	73.7	76.3	0.27	0.001	0.01

[1]A total of 288 mixed-sex pigs (PIC 327 × 1050; initially 68.9 kg BW) were used in the 67-d trial with 8 pigs per pen and 9 replications (pens) per treatment.

[2]Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[3]Adjusted by using HCW as a covariate.

[4]IV = iodine value.

Pigs fed increasing medium-oil DDGS had decreased (linear, $P < 0.03$) final BW, carcass yield, HCW, backfat, and loin-eye depth (Table 6). These findings are consistent with previous research that observed similar changes in carcass characteristics with increasing DDGS (Cook et al., 2005; Whitney et al., 2006; Linneen et al., 2008). The decrease in carcass yield agrees with other reports and relates to increases in intestinal and organ weights that vary based on the solubility of fiber used, the inclusion rate in the diet, and the duration of feeding (Agyekum et al., 2012; Asmus, 2012). Carcass yield decreased 0.48% for each 10% increase in DDGS in this experiment as compared with 0.28 (Linneen et al., 2008), 0.51 (Whitney et al., 2006), and 0.55% (Cook et al., 2005) for each 10% DDGS from previous experiments.

The decreased backfat and loin depth may have been caused by the decreased energy intake available above maintenance for pigs fed increasing levels of medium-oil DDGS. Energy intake decreased approximately 2% for each 15% increase in DDGS. Maintenance energy requirements may also have been increased as a result of increasing fiber content in the diet increasing organ weights (Agyekum et al., 2012). Crude protein intake also increased approximately 10% for each 15% increase in dietary DDGS. The energetic cost to deaminate and excrete the excess crude protein may also have increase maintenance energy requirements and reduced energy available for growth.

Increasing medium-oil DDGS also increased jowl IV (linear, $P < 0.001$; quadratic, $P < 0.01$). This result is similar to previous observations (Benz et al., 2010; Asmus, 2012), where increasing DDGS increased jowl IV. Bee et al. (2002) observed that fatty acid composition in the fat depots directly correlates to fatty acid composition of the diet. Farnworth and Kramer (1987) observed that dietary fat inhibits natural de novo synthesis, allowing for direct deposition of fatty acids from the diet. De novo fat deposition typically is relatively saturated fat and includes the C16 and C18 saturated and monounsaturated fatty acids (Wood et al., 2008). Concentration of C18:2n-6 (linoleic acid) is considerably greater in diets with DDGS and has been shown to linearly increase in concentration in tissues when dietary intake increases (Wood, 1984). Similarly, Benz et al. (2010) observed that concentrations of C18:2n-6, PUFA, and IV increased linearly in jowl, backfat, and belly fat as DDGS increased. Their conclusion was that feeding DDGS at 20% of the diet may result in unacceptable IV and fat quality. Some packing plants have listed a maximum jowl IV of 73 (Benz et al., 2010).

Our original hypothesis was that carcass fat quality traits such as C18:2n-6 concentrations and IV may not be as negatively affected by medium-oil DDGS with less corn oil than feeding traditional DDGS. When feeding traditional DDGS (>10.5% oil), jowl IV increases approximately 2 mg/g for every 10% traditional DDGS added to the diet (Benz et al., 2010). In the present study, however, adding medium-oil DDGS to the diet increased jowl IV by only 1.4 mg/g for every 10% addition. Thus, the IV increase for medium-oil DDGS is approximately 70% of the increase with high-oil DDGS. This difference is consistent with the oil content in the medium-oil DDGS value (7.63%), which is approximately 70% of the oil content in high-oil DDGS (>10% oil). In addition, jowl fat IV was increased in a quadratic manner in the current experiment indicating that the medium-oil DDGS had less impact on jowl IV at the 15% inclusion rate, with a greater impact when included at 30 or 45% of the diet.

Experiment 2. The GE and DE values observed for the corn used in this study, 3,871 and 3,515 kcal/kg, respectively (Table 7), were similar to the respective published values of 3,933 and 3,451 kcal/kg (NRC, 2012). The GE in medium-oil DDGS in our study (4,585 kcal/kg) was 97% of the listed value of medium-oil DDGS (4,710 kcal/kg; NRC, 2012), which was expected because the medium-oil DDGS used in this study contained approximately 1.5% units less oil than that listed in the NRC (2012). The DE for the medium-oil DDGS used in this study was determined to be 3,356 kcal/kg (as-fed basis), which is 73.2% of GE and similar to GE digestibility values observed by Pedersen et al. (2007).

Table 7. Apparent total tract digestibility of corn and medium-oil dried distillers grains with solubles (DDGS; as-fed basis)[1]

Item	Corn	Medium-oil DDGS	SEM
Digestibility, %			
DM	93.3^a	70.5^b	1.94
GE	91.1^a	73.2^b	1.80
CP	85.5^a	83.1^a	1.35
Ether extract (oil)	21.8^a	61.7^b	3.53
ADF	59.4^a	77.5^b	2.20
NDF	59.9^a	67.8^b	3.23
Crude fiber	47.4^a	67.4^b	2.29

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]A total of 12 pigs (PIC 327 × 1050; initially 25.6 kg BW) were used in two 6-wk Latin square design studies to provide 12 observations per treatment.

The measured DE and calculated ME and NE values in this study were assigned for the medium-oil DDGS to calculate caloric efficiency for the growth trial (Exp. 1). Caloric efficiency was calculated based on ADFI × dietary energy (Mcal/kg) and divided by total BW gain (Table 8).

Caloric efficiency for DE, ME, and NE did not change as medium-oil DDGS increased, indicating that the values were accurate for the growth portion of this study. If the published NRC (2012) energy values are used, caloric efficiency on both a DE and an ME basis increases (worsens) as medium-oil DDGS increases in the diet, suggesting that the NRC (2012) overestimates the energy value of this particular medium-oil DDGS (Table 8). This result would be logical because the oil content in the NRC (2012) medium-oil DDGS is slightly greater than the oil content in the medium-oil DDGS used in the present study; however, when calculated on a NE basis, there was no difference in caloric efficiency, suggesting that the NRC (2012) NE value (2,343 kcal/kg; 88% of the value of corn; as-fed basis) was a better estimate of the energy content of medium-oil DDGS. This conclusion is supported by the ME and NE calculations derived in our study (3,153 and 2,069 kcal/kg, respectively; as-fed basis), where ME was 93% of the NRC (2012) estimate and NE was 88% of the NRC (2012) NE value.

Other prediction equations have been developed from studies comparing DDGS with varying nutrient composition to see if chemical analysis could predict energy content. Using NRC (2012) equations (Eq. [1–6] for ME and Eq. [1–7] for NE; Table 9), ME and NE of medium-oil DDGS used in our study is calculated to be 3,153 and 2,069 kcal/kg, respectively, or approximately 93 and 88% of the ME and NE values listed for medium-oil DDGS in the NRC (2012) on an as-fed basis.

Table 8. Caloric efficiencies using published and observed energy values for medium-oil dried distillers grains with solubles (DDGS)

	Medium-oil DDGS, %					Probability, $P <$	
	0%	15%	30%	45%	SEM	Linear	Quadratic
Observed values[1]							
Caloric efficiency, Mcal/kg							
DE	10.9	11.0	11.0	11.1	0.1	0.31	0.91
ME	10.5	10.6	10.5	10.6	0.1	0.66	0.90
NE	7.8	7.8	7.7	7.8	0.1	0.88	0.90
Published values[2]							
Caloric efficiency, Mcal/kg							
DE	10.9	11.1	11.2	11.4	0.1	0.01	0.93
ME	10.5	10.7	10.7	10.9	0.1	0.02	0.93
NE	7.8	7.9	7.8	7.9	0.1	0.62	0.90

[1]Observed DE was determined in the digestibility portion of this study (Exp. 2); ME and NE were calculated based on Eq. [1–6] and [1–7] from NRC, 2012.

[2] Calculations used the published DE, ME, and NE values for medium-oil DDGS (>6 and <9% oil) in NRC, 2012.

Anderson et al. (2012) used 18 corn coproducts to generate prediction equations for DE and ME. Sources included DDGS, high-protein distillers dried grains, corn bran, corn germ, corn germ meal, oil-extracted DDGS, corn gluten meal, corn gluten feed, and corn dried solubles. Using the equations of Anderson et al. (2012; Table 9) with GE and nutrient analysis, predicted values for DE and ME of medium-oil DDGS were 3,291 and 3,124 kcal/kg (as-fed basis), respectively. The DE and ME values are similar to the 3,356 and 3,153 kcal/kg (as-fed basis), respectively, that was either calculated in this study (DE) or calculated from DE using NRC (2012) equations (ME). Surprisingly, ether extract was not included in the prediction equation for ME in Anderson et al. (2012) although it was included for DE.

Using DE and ME equations from Pedersen et al. (2007; Table 9), predicted values for DE and ME were 4,242 and 3,583 kcal/kg (as-fed basis), respectively. The predicted DE value was considerably greater than the value observed in the nutrient balance portion of this study. Predicted values of DE and ME using a simpler set of equations by Pedersen et al. (2007) were 5,341 and 4,783 kcal/kg (as-fed basis), respectively. These values are both considerably greater than all other calculated values, which suggest that some degree of accuracy is lost as prediction equations use fewer components of the proximate analyses or the ingredient they are predicting contain nutrient values outside the range used to derive the prediction equations. This is especially true in the case of Pedersen et al. (2007), where ether extract, ADF, and NDF varied considerably compared with the values of the medium-oil DDGS used in the present study.

The digestibility of ether extract in this particular medium-oil DDGS source was lower than values of approximately 70% ether extract digestibility reported by Stein et al. (2009), but the 4 DDGS sources used in the analysis by Stein et al. (2009) were high-oil DDGS that ranged from 10 to 12.5% oil. Measurements in Stein et al. (2009) and our study were taken on an apparent total tract digestibility basis; however, data from Kim et al. (2012) indicate that true ileal digestibility may provide a more accurate measurement of lipid digestion. This is largely due to the fact that microbes can synthesize fat from carbohydrates in the hindgut (Kil et al., 2011). Endogenous losses of fat would lead to fat digestibility to be underestimated to a greater extent as fat level is reduced in an ingredient, which may explain the lower apparent digestibility in our study compared with Stein et al. (2009).

The CP digestibility of the corn and medium-oil DDGS used in this study was 85.5 and 83.1%, respectively, similar to the 82 and 83% for corn and DDGS observed by Pedersen et al. (2007). The fact that the Lys concentration, as a percentage of CP, was greater than 3% suggests little heat damage in the medium-oil DDGS, which explains the high CP digestibility (Kim et al., 2012). The medium-oil DDGS had similar crude fiber and ADF as the mean

Table 9. Energy prediction equations

Item	Equation	7.63% oil DDGS[1]
NRC (2012)		
ME[2]	(1.00 × DE) – (0.68 × CP)	3,153
NE[3]	(0.726 × ME) + (1.33 × EE) + (0.39 × Starch) – (0.62 × CP) – (0.83 × ADF)	2,069
Anderson et al. (2012)		
DE	–2,161 + (1.39 × GE) – (20.70 × NDF) – (40.30 × EE)	3,291
ME	(0.94 × GE) – (23.45 × NDF) – (70.23 × ash)	3,124
Pedersen et al. (2007)		
DE (1)	–12,637 – (128.27 × ash) + (25.38 × CP) – (115.72 × EE) – (138.02 × ADF) + (3.569 × GE)	4,242
DE (2)	–9,929 – (180.38 × ash) – (106.82 × EE) – (120.44 × ADF) + (3.202 × GE)	5,341
ME (1)	–11,128 – (124.99 × ash) + (35.76 × CP) – (63.40 × EE) – (150.92 × ADF) + (14.85 × NDF) + (3.023 × GE)	3,583
ME (2)	–4,212 – (266.38 × ash) – (108.35 × ADF) + (1.911 × GE)	4,783

[1]DDGS = dried distillers grains with solubles.

[2]Refers to Eq. [1–6] from NRC (2012) to calculate ME.

[3]Refers to Eq. [1–7] from NRC (2012) to calculate NE.

of 10 DDGS samples determined by Urriola et al. (2010). In addition, the medium-oil DDGS used in the present experiment was similar in NDF concentrations when compared to published values (36.5 vs. 36 to 38%; Urriola et al., 2010; NRC, 2012). Urriola et al. (2010) estimated apparent total tract digestibility of ADF, NDF, and crude fiber at 58.5, 59.3, and 44.3%, respectively, compared to 77.5, 67.8, and 67.4% for ADF, NDF, and crude fiber of the medium-oil DDGS used in the present study.

Because energy content of DDGS appears to be one of the most important factors determining its value relative to corn, a reduction in energy content of the DDGS significantly reduces its feeding value. The DE of the medium-oil DDGS used in this study was 3,356 kcal/kg, which is lower than the NRC (2012) value of 3,582 kcal/kg. Results of this study indicate that increasing medium-oil DDGS in finishing pig diets reduces ADG, G:F, final BW, HCW, and carcass yield and increased jowl fat IV relative to pigs fed a corn–soybean meal–based diet.

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