Effects of dried distillers grains with solubles on growing and finishing pig performance in a commercial environment[1,2]

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ABSTRACT: Three experiments were conducted to determine the optimal level of dried distiller grains with solubles (DDGS) from a common ethanol manufacturing facility and to determine the potential interactions between dietary DDGS and added fat on performance and carcass characteristics of growing and finishing pigs. All experiments were conducted at the same commercial facility and used DDGS from the same ethanol manufacturing facility. In Exp. 1, a total of 1,050 pigs (average initial BW 47.6 kg), with 24 to 26 pigs per pen and 7 pens per treatment, were fed diets containing 0 or 15% DDGS and 0, 3, or 6% added choice white grease in a 2 × 3 factorial arrangement in a 28-d growth study. Overall, there were no DDGS × added fat interactions ($P \geq 0.14$). There was an improvement (linear, $P < 0.01$) in ADG and G:F as the percentage of added fat increased. There was no difference ($P = 0.74$) in growth performance between pigs fed 0 or 15% DDGS. In Exp. 2, a total of 1,038 pigs (average initial BW 46.3 kg), with 24 to 26 pigs per pen and 10 pens per treatment, were fed diets containing 0, 10, 20, or 30% DDGS in a 56-d growth study. Pigs fed diets containing DDGS had a tendency for decreased ADG and ADFI (both linear, $P = 0.09$ and 0.05, respectively), but the greatest reduction seemed to occur between pigs fed 10 and 20% DDGS. In Exp. 3, a total of 1,112 pigs (average initial BW 49.7 kg), with 25 to 28 pigs per pen and 9 pens per treatment, were used in a 78-d growth study to evaluate the effects of increasing DDGS (0, 5, 10, 15, or 20%) in the diet on pig growth performance and carcass characteristics. From d 0 to 78, ADG and ADFI decreased linearly ($P \leq 0.04$) with DDGS level, but the greatest reduction seemed to occur between pigs fed 15 and 20% DDGS. Efficiency of gain tended to improve ($P = 0.06$) when DDGS were included in the diet. There was no effect of DDGS ($P = 0.22$) on loin depth. Carcass weight and percentage yield decreased (linear, $P \leq 0.04$) with increasing levels of DDGS in the diet. Backfat and fat-free lean index tended to decrease (linear, $P \leq 0.09$) with increasing levels of DDGS in the diet. In conclusion, finishing pigs raised under commercial production conditions can be fed 10 to 15% DDGS from the source evaluated in this study before growth rate is compromised.

Key words: carcass, dried distillers grains with solubles, growth, swine

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INTRODUCTION

Previous research with dried distillers grains with solubles (**DDGS**) fed to swine has shown inconsistent results in growth performance, which may be due to batch-to-batch variations in drying methods, levels of residual sugars, or grain quality (Hastad, 2005; Rausch and Belyea, 2006). Research using growing and finishing pigs has shown that DDGS levels up to 10% (Whitney et al., 2006) or 30% (Senne et al., 1995; Cook et al., 2005; DeDecker et al., 2005) could be fed before growth performance was reduced; however, the research of Fu et al. (2004) and Widyaratne et al. (2004) indicated decreased performance at any level fed. Hastad (2005) theorized that DDGS palatability among sources can influence performance. Other research has focused on determining DDGS AA digestibility (Stein et al., 2006) and energy content (Nyachoti et al., 2005; Pedersen et al., 2007) to use in diet formulation and constructing DDGS nutrient databases (Spiehs et al., 2002).

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Feeding DDGS has also been shown to affect carcass characteristics in growing and finishing pigs. Specifically, feeding DDGS has been shown to reduce carcass yield (Fu et al., 2004; Cook et al., 2005; Whitney et al., 2006) and loin depth (Whitney et al., 2006).

The use of dietary fat is a common practice to improve ADG and G:F in growing and finishing pigs (Pettigrew and Moser, 1991; De la Llata et al., 2001). However, DeDecker et al. (2005) reported inconsistent responses to added fat fed with dietary DDGS. Because of the high oil content of DDGS (Spiehs et al., 2002), interactions with diets containing added fat and DDGS may be present but have not been thoroughly evaluated. Therefore, the objectives of this research under a commercial environment were to determine 1) the optimal level of DDGS from a common ethanol manufacturing facility on growing and finishing pig performance and carcass characteristics, and 2) potential interactions between dietary DDGS and added fat on growth performance.

MATERIALS AND METHODS

General

The experimental protocols used in these studies were approved by the Kansas State University Institutional Animal Care and Use Committee.

All experiments were conducted at a commercial facility in southwestern Minnesota. The facility consisted of 4 barns (12.5 × 76.2 m each) with forty-eight 3.05- × 5.49-m pens. All pens contained one 4-hole, dry self-feeder and 1 cup waterer to allow for ad libitum access to feed and water. Each barn had a deep pit with completely slatted floors. The barns were curtain sided and operated on natural ventilation during the summer and mechanically assisted ventilation during the winter.

The DDGS for all experiments were obtained from a common ethanol manufacturing facility (Agri-Energy LLC, Luverne, MN). Dietary treatments in all experiments were formulated by using ingredient values from the NRC (1998), except for the value of 3,420 kcal of ME/kg (as-fed) for DDGS, which is similar to corn (NRC, 1998). Petersen et al. (2007) reported that the energy content of corn and DDGS are similar; thus, a ME value of 3,420 kcal/kg was used for both corn and DDGS in the diet formulation. For AA digestibility, values from the NRC (1998) were used for all ingredients in Exp. 1 and for all ingredients except for DDGS in Exp. 2 and 3. For DDGS in Exp. 2 and 3, AA digestibility values from Stein et al. (2006) were used. All nutrient levels in the diet were formulated at or above NRC (1998) requirements. The DDGS used in Exp. 2 and 3 were collected and analyzed in duplicate for DM, ash, ether extract, CP, AA, and crude fiber (AOAC, 1995; Table 1).

Table 1. Assumed and analytical composition of dried distillers grains with solubles (DDGS; as-fed basis)

		Analyzed[2]	
Item, %	Assumed[1]	Exp. 2	Exp. 3
DM	93.00	89.15	88.37
CP	27.7	25.0	25.8
Crude fiber	—	9.9	10.3
Ether extract	8.4	8.4	9.9
Ash	—	3.99	3.61
Lys	0.62	1.05	0.93
Ile	1.03	1.12	1.07
Leu	2.57	3.05	3.07
Met	0.50	0.49	0.51
Cys	0.52	0.49	0.52
Thr	0.94	0.97	0.97
Trp	0.25	0.18	0.17
Val	1.30	1.38	1.37

[1]Represents assumed values used in diet formulation for Exp. 1, 2, and 3 from NRC (1998).
[2]Values represent the mean of 1 sample of DDGS (Agri-Energy LLC, Luverne, MN) analyzed in duplicate.

Exp. 1

A total of 1,050 pigs (Line 1050 × 337; PIC, Franklin, KY), with an average initial BW of 47.6 kg, were used in a 28-d growth study to evaluate the effect of DDGS and increasing percentages of added fat on growth performance. Pens of pigs (24 to 26 per pen) were weighed and assigned randomly to 6 dietary treatments, with 7 pens per treatment.

Diets were fed in meal form and arranged in a 2 × 3 factorial design, with diets containing either 0 or 15% DDGS in combination with 0, 3, or 6% added choice white grease (Table 2). A constant true ileal digestible (**TID**) lysine:energy ratio of 3.21 g/Mcal of ME was maintained in all diets. Pigs and feeders were weighed on d 0, 14, and 28 to determine ADG, ADFI, and G:F. Exp. 2 A total of 1,038 pigs (Line 1050 × 337; PIC), with an average initial BW of 46.3 kg, were used in a 56-d growth study to evaluate the effect of increasing DDGS (0, 10, 20, and 30%) in the diet on pig growth performance. Pens of pigs (24 to 26 per pen) were weighed and assigned randomly to 4 dietary treatments, with 10 pens per treatment.

Diets were fed in meal form and contained 0, 10, 20, or 30% DDGS. All diets contained 6% added fat. Diets were fed in 2 phases, with phase 1 from d 0 to 28 and phase 2 from d 29 to 56 (Table 3). The phase 1 and 2 diets were formulated to contain 0.95 and 0.78% TID lysine and 0.55 and 0.54% calcium, respectively. Diets were formulated to maintain a minimum available phosphorus concentration of 0.29 and 0.26% in phase 1 and 2, respectively. The diet containing 30% DDGS exceeded the minimum requirement and thus did not contain supplemental phosphorus. Pigs and feeders were weighed on d 0, 14, 28, 42, and 56 to determine ADG, ADFI, and G:F.

Exp. 3

A total of 1,112 pigs (Line 1050 × 337; PIC), with an average initial BW of 49.8 kg, were used in a 78-d

Table 2. Diet composition (Exp. 1; as-fed basis)

	Without DDGS[1]			With DDGS		
Item	0% added fat	3% added fat	6% added fat	0% added fat	3% added fat	6% added fat
Ingredient, %						
Corn	72.40	67.65	62.81	59.62	54.80	50.00
Soybean meal, 46.5% CP	25.20	26.98	28.80	23.30	25.10	27.00
DDGS	—	—	—	15.00	15.00	15.00
Choice white grease	—	3.00	6.00	—	3.00	6.00
Monocalcium phosphate, 21% P	0.80	0.85	0.90	0.45	0.48	0.50
Limestone	0.90	0.85	0.85	0.95	0.95	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys·HCl	0.150	0.150	0.150	0.150	0.150	0.150
Vitamin premix[2]	0.075	0.075	0.075	0.075	0.075	0.75
Trace mineral premix[3]	0.100	0.100	0.100	0.100	0.100	0.100
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
True ileal digestible (TID) AA						
Lys, %	0.95	0.99	1.03	0.93	0.97	1.00
Met:Lys ratio, %	27	27	26	31	30	30
Met and Cys:Lys ratio, %	58	56	55	65	63	62
Thr:Lys ratio, %	63	63	62	70	69	68
Trp:Lys ratio, %	19	19	20	21	21	21
Total Lys, %	1.07	1.11	1.15	1.07	1.11	1.15
CP, %	17.9	18.3	18.7	20.1	20.5	20.9
TID Lys:calorie ratio, g/Mcal of ME	3.21	3.21	3.21	3.21	3.21	3.21
ME, kcal/kg	3,328	3,463	3,598	3,259	3,384	3,519
Ca, %	0.60	0.59	0.61	0.57	0.58	0.59
P, %	0.54	0.55	0.56	0.54	0.54	0.55
Available P, %	0.24	0.25	0.26	0.24	0.25	0.26

[1]Dried distillers grains with solubles.
[2]Provided (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; 0.04 mg of vitamin B_{12}; 50 mg of niacin; 28 mg of pantothenic acid; and 8 mg of riboflavin.
[3]Provided (per kilogram of diet): 16.54 mg of Cu from Cu sulfate; 0.149 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 38.6 mg of Mn from Mn oxide; 0.149 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.

growth study evaluating the effects of increasing DDGS (0, 5, 10, 15, or 20%) in the diet on pig growth performance and carcass characteristics. Pens of pigs (25 to 28 per pen) were weighed and assigned randomly to 5 dietary treatments, with 9 pens per treatment.

Diets were fed in meal form and contained 0, 5, 10, 15, or 20% DDGS with 6% added fat. Diets were fed in 4 phases, with phase 1 fed from 49.8 to 59 kg, phase 2 from 59 to 82 kg, phase 3 from 82 to 105 kg, and phase 4 from 105 to 123 kg (Tables 4 and 5). Diets were formulated to contain 0.98, 0.83, 0.73, and 0.66% TID lysine and to maintain minimum available phosphorus of 0.28, 0.25, 0.23, and 0.22% for phases 1 to 4, respectively. The diet containing 20% DDGS in phase 4 exceeded the minimum requirement and thus did not contain supplemental phosphorus. Pigs and feeders were weighed on d 0, 15, 29, 43, 57, and 78 to determine ADG, ADFI, and G:F.

On d 57, the 3 heaviest pigs from all pens were visually selected, removed, and marketed. At the end of the experiment, pigs from each pen were individually tattooed and shipped approximately 96 km to a commercial processing plant (Swift, Worthington, MN), where BW was recorded and standard carcass measurements of loin and backfat depths, HCW, lean percentage, yield, and fat-free lean index were obtained. Yield was calculated as HCW divided by BW. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th 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.

Statistical Analysis

Data from all experiments were analyzed with ANOVA by using the MIXED procedure (SAS Inst. Inc., Cary, NC). Pigs for all experiments were blocked by initial BW. Orthogonal polynomials were used to determine the effects of increasing DDGS in Exp. 2 and 3. In Exp. 1, 2, and 3, the pen was the experimental unit. In Exp. 1, data were analyzed as a 2×3 factorial arrangement of treatments in 7 randomized blocks. In Exp. 2 and 3, all data were analyzed as a randomized complete block design. For Exp. 3, carcass weight was used as a covariate for the backfat, fat-free lean index, and loin depth data.

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

	Phase 1, d 0 to 28				Phase 2, d 29 to 56			
Item	0% DDGS[1]	10% DDGS	20% DDGS	30% DDGS	0% DDGS	10% DDGS	20% DDGS	30% DDGS
Ingredient, %								
Corn	64.60	55.45	46.30	37.10	70.70	61.50	52.35	43.10
Soybean meal, 46.5% CP	27.25	26.60	25.90	25.25	21.25	20.60	19.95	19.25
DDGS	—	10.00	20.00	30.00	—	10.00	20.00	30.00
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Monocalcium phosphate, 21% P	0.70	0.40	0.15	—	0.60	0.35	0.10	—
Limestone	0.83	0.93	1.00	1.03	0.88	0.98	1.05	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys·HCl	0.100	0.100	0.100	0.100	0.075	0.075	0.075	0.075
Vitamin premix with phytase[2]	0.075	0.075	0.075	0.075	0.063	0.063	0.063	0.063
Trace mineral premix[3]	0.100	0.100	0.100	0.100	0.075	0.057	0.075	0.075
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition								
True ileal digestible (TID) AA								
Lys, %	0.95	0.95	0.95	0.95	0.78	0.78	0.78	0.78
Met:Lys ratio, %	28	30	32	34	30	33	35	38
Met and Cys:Lys ratio, %	57	61	64	67	63	67	71	75
Thr:Lys ratio, %	62	65	68	71	65	69	73	76
Trp:Lys ratio, %	20	19	18	18	21	19	18	17
Total Lys, %	1.07	1.09	1.11	1.12	0.88	0.90	0.92	0.94
CP, %	18.3	19.9	21.6	23.3	16.0	17.7	19.3	21.0
TID Lys:calorie ratio, g/Mcal of ME	2.50	2.50	2.50	2.50	2.08	2.08	2.08	2.08
ME, kcal/kg	3,611	3,558	3,505	3,450	3,618	3,563	3,510	3,452
Ca, %	0.55	0.55	0.55	0.55	0.54	0.54	0.54	0.54
P, %	0.52	0.50	0.49	0.51	0.47	0.46	0.46	0.48
Available P,[4] %	0.29	0.29	0.29	0.31	0.26	0.26	0.26	0.29

[1]Dried distillers grains with solubles.
[2]Provided (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; 0.04 mg of vitamin B_{12}; 50 mg of niacin; 28 mg of pantothenic acid; 8 mg of riboflavin; and 300 phytase units (FTU) of phytase in phase 1 and 250 FTU of phytase in phase 2.
[3]Provided (per kilogram of diet): 16.54 mg Cu from Cu sulfate; 0.149 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 38.6 mg of Mn from Mn oxide; 0.149 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.
[4]Includes expected phytate P release of 0.08% in phase 1 and 0.07% for phase 2, respectively, from added phytase.

RESULTS

Analytical Analysis

Analyses of DDGS used in Exp. 2 and 3 indicated that, in general, analyzed AA values were similar to those used in diet formulation (Table 1). The main differences were observed in CP and lysine values, in which the CP was decreased and the lysine was greater in the DDGS than those used in diet formulations for both experiments. Although the lysine contents for DDGS were greater for the analyzed vs. assumed values used to formulate diets, this did not seem to affect growth performance in these experiments. Stein (2007) proposed DDGS with a lysine:CP ratio of 2.80% or greater to be of high quality for swine diets. In fact, ratios were 4.2 and 4.1% for Exp. 1 and 2, respectively, which would indicate that a high-quality source of DDGS was used in the 3 experiments.

Exp. 1

Overall (d 0 to 28), there were no DDGS × added fat interactions ($P \geq 0.14$; Table 6) in ADG, ADFI, or G:F. There was no difference in ADFI ($P = 0.60$), but ADG and G:F improved (linear, $P < 0.01$) as the percentage of added fat increased. There was no difference ($P \geq 0.74$) in pig growth performance between pigs fed 0 and 15% DDGS.

Exp. 2

Overall (d 0 to 56), pigs fed diets with increasing DDGS up to 30% had a tendency for decreased ADG (linear, $P = 0.09$; Table 7) and decreased ADFI (linear, $P < 0.05$). This seemed to be due to reductions in ADFI for pigs fed diets containing greater than 10% DDGS. There was no difference ($P = 0.38$) in G:F.

Exp. 3

Overall (d 0 to 78), ADG and ADFI decreased (linear; $P \leq 0.04$) with increasing level of DDGS up to 20% in the diet (Table 8). Efficiency of gain tended to improve ($P = 0.06$) when DDGS were included in the diet. There were no differences ($P \leq 0.17$) in slaughter weight or loin depth. However, carcass weight and percentage yield decreased linearly ($P \leq 0.04$) with increasing level

Table 4. Diet composition (Exp. 3, as-fed basis)[1]

	Phase 1					Phase 2				
Item	0% DDGS[2]	5% DDGS	10% DDGS	15% DDGS	20% DDGS	0% DDGS	5% DDGS	10% DDGS	15% DDGS	20% DDGS
Ingredient, %										
Corn	65.00	60.65	56.30	51.95	47.60	71.05	66.70	62.35	58.00	53.65
Soybean meal, 46.5% CP	26.85	26.30	25.75	25.15	24.60	20.90	20.35	19.75	19.20	18.65
DDGS	—	5.00	10.00	15.00	20.00	—	5.00	10.00	15.00	20.00
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Monocalcium phosphate, 21% P	0.63	0.50	0.38	0.25	0.13	0.58	0.45	0.33	0.20	0.08
Limestone	0.85	0.90	0.94	0.99	1.03	0.85	0.89	0.92	0.98	1.03
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys·HCl	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
Vitamin premix with phytase[3]	0.075	0.075	0.075	0.075	0.075	0.063	0.063	0.063	0.063	0.063
Trace mineral premix[4]	0.075	0.075	0.075	0.075	0.075	0.063	0.063	0.063	0.063	0.063
Total	100	100	100	100	100	100	100	100	100	100
Calculated composition										
True ileal digestible (TID) AA										
Lys, %	0.98	0.98	0.98	0.98	0.98	0.83	0.83	0.83	0.83	0.83
Met:Lys ratio, %	27	28	29	31	32	28	30	31	33	34
Met and Cys:Lys ratio, %	55	58	60	63	65	59	62	64	67	70
Thr:Lys ratio, %	60	62	64	66	68	61	63	65	68	70
Trp:Lys ratio, %	19	20	20	21	21	19	20	20	21	22
Total Lys, %	1.10	1.10	1.10	1.11	1.11	0.93	0.94	0.94	0.94	0.94
CP, %	18.2	18.9	19.7	20.4	21.2	15.9	16.7	17.4	18.2	18.9
TID Lys:calorie ratio, g/Mcal of ME	2.71	2.71	2.71	2.70	2.70	2.29	2.29	2.29	2.29	2.29
ME, kcal/kg	3,616	3,618	3,622	3,624	3,627	3,620	3,622	3,627	3,629	3,633
Ca, %	0.55	0.55	0.55	0.55	0.55	0.52	0.52	0.52	0.52	0.52
P, %	0.50	0.49	0.49	0.49	0.48	0.46	0.46	0.46	0.45	0.45
Available P,[5] %	0.28	0.28	0.28	0.28	0.28	0.25	0.25	0.25	0.25	0.25

[1]Dietary treatments fed in meal form from 49 to 59 kg for phase 1, and 59 to 82 kg for phase 2.
[2]Dried distillers grains with solubles.
[3]Provided (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; 0.04 mg of vitamin B_{12}; 50 mg of niacin; 28 mg of pantothenic acid; 8 mg of riboflavin; and 300 phytase units (FTU) of phytase for phase 1, and 250 FTU phytase for phase 2.
[4]Provided (per kilogram of diet): 16.54 mg of Cu from Cu sulfate; 0.149 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 38.6 mg of Mn from Mn oxide; 0.149 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.
[5]Includes expected phytate P release of 0.08% for phase 1, and 0.07% for phase 2, respectively, from added phytase.

Table 5. Diet composition (Exp. 3, as-fed basis)[1]

	Phase 3					Phase 4				
Item	0% DDGS[2]	5% DDGS	10% DDGS	15% DDGS	20% DDGS	0% DDGS	5% DDGS	10% DDGS	15% DDGS	20% DDGS
Ingredient, %										
Corn	75.15	70.80	66.45	62.10	57.75	77.90	73.55	69.20	64.90	60.55
Soybean meal, 46.5% CP	16.90	16.35	15.80	15.20	14.65	14.15	13.55	13.00	12.45	11.85
DDGS	—	5.00	10.00	15.00	20.00	—	5.00	10.00	15.00	20.00
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Monocalcium phosphate, 21% P	0.53	0.40	0.27	0.14	0.01	0.53	0.39	0.26	0.13	—
Limestone	0.80	0.84	0.89	0.93	0.97	0.83	0.87	0.91	0.96	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys·HCl	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
Vitamin premix with phytase[3]	0.063	0.063	0.063	0.063	0.063	0.050	0.050	0.050	0.050	0.050
Trace mineral premix[4]	0.063	0.063	0.063	0.063	0.063	0.050	0.050	0.050	0.050	0.050
Total	100	100	100	100	100	100	100	100	100	100
Calculated composition										
True ileal digestible (TID) AA										
Lys, %	0.73	0.73	0.73	0.73	0.73	0.66	0.66	0.66	0.66	0.66
Met:Lys ratio, %	30	32	33	35	37	31	33	35	37	39
Met and Cys:Lys ratio, %	62	65	68	71	75	64	68	71	75	79
Thr:Lys ratio, %	62	64	67	70	72	63	65	68	71	74
Trp:Lys ratio, %	19	19	20	21	22	18	19	20	21	22
Total Lys, %	0.82	0.83	0.83	0.83	0.83	0.75	0.75	0.75	0.76	0.76
CP, %	14.4	15.1	15.9	16.7	17.4	13.3	14.1	14.8	15.6	16.4
TID Lys:calorie ratio, g/Mcal of ME	2.01	2.01	2.01	2.01	2.01	1.82	1.82	1.82	1.82	1.81
ME, kcal/kg	3,628	3,629	3,631	3,635	3,638	3,626	3,629	3,633	3,636	3,639
Ca, %	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
P, %	0.44	0.43	0.43	0.42	0.42	0.43	0.42	0.42	0.41	0.41
Available P,[5] %	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22

[1]Dietary treatments fed in meal form from 82 to 105 kg for phase 3 and 105 to 123 kg for phase 4.
[2]Dried distillers grains with solubles.
[3]Provided (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; 0.04 mg of vitamin B_{12}; 50 mg of niacin; 28 mg of pantothenic acid; 8 mg of riboflavin; and 250 phytase units (FTU) of phytase for phase 3 and 200 FTU phytase for phase 4.
[4]Provided (per kilogram of diet): 16.54 mg of Cu from Cu sulfate; 0.149 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 38.6 mg of Mn from Mn oxide; 0.149 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.
[5]Includes expected phytate P release of 0.07% for phase 3, and 0.06% for phase 4, respectively, from added phytase.

Table 6. Effects of dried distillers grains with solubles (DDGS) with added fat on the performance of growing and finishing pigs (Exp. 1)[1]

	Without DDGS			With DDGS				*P*-value			
										Added fat	
Item	0% added fat	3% added fat	6% added fat	0% added fat	3% added fat	6% added fat	SE	DDGS × fat	DDGS	Level	Linear
d 0 to 28											
ADG, g	900	962	965	916	923	988	14.5	0.14	0.99	0.01	0.01
ADFI, g	2,127	2,164	2,129	2,179	2,120	2,145	36.9	0.26	0.74	0.87	0.60
G:F, g/g	0.423	0.445	0.453	0.421	0.435	0.461	0.007	0.41	0.82	0.01	0.01
Removals[2]	1	1	0	1	0	0					

[1]A total of 1,050 pigs (initial BW, 47.6 kg), with 24 to 26 pigs per pen and 7 pens per treatment.
[2]Removal from the study for lameness, death, tail biting, fighting, ulcers, or jumping to another pen.

of DDGS in the diet. In addition, backfat and fat-free lean index tended to decrease ($P \leq 0.09$) with increasing level of DDGS in the diet.

DISCUSSION

Feeding pigs DDGS from a single source and in a common commercial environment provided a means to determine the optimal level of DDGS for the commercial production system. Similar to our results, Whitney et al. (2006) showed a linear decrease in ADG by feeding diets containing 0, 10, 20, or 30% DDGS, and the decrease was primarily due to a large decrease in ADG for pigs fed diets containing greater than 10% DDGS. Linear reductions in ADG and ADFI were also reported by others when up to 30% DDGS was fed (Cromwell et al., 1993; Fu et al., 2004). Studies that used DDGS concentrations of 40% resulted in decreased ADG (Senne et al., 1996; Widyaratne et al., 2004) and decreased ADFI and BW (Widyaratne et al., 2004). However, Senne et al. (1995) showed no differences in growth performance of pigs fed diets containing up to 30% DDGS.

Carcass weight and yield have been shown to be decrease (Fu et al., 2004; Cook et al., 2005; Whitney et al., 2006) as the concentration of DDGS in the diet increases. In Exp. 3, the carcass weight was linearly decreased with increasing levels of DDGS in the diet because of the low slaughter weight and low percentage yield for those pigs fed any level of DDGS. The linear decrease in carcass weight for pigs fed DDGS in Exp. 3 equated to a 1.82-kg reduction in carcass weight for pigs fed 20% DDGS in the diet compared with those not fed DDGS. Whitney et al. (2006) reported a 5.1-kg reduction in carcass weight for pigs fed 30% DDGS compared with pigs fed no DDGS.

Our results showed that percentage yield was reduced as DDGS increased in the diet. Percentage yield decreases as the weight of the visceral organs increases, which would explain the decrease in percentage yield for pigs fed increasing levels of DDGS (Stahley et al., 1979; Noblet et al., 1987; Chen et al., 1999). The visceral organ weight increase could be attributed to an increase in dietary CP in diets containing DDGS, which caused increased metabolic activity to break down and excrete the excess AA (Ssu et al., 2004). The increase in dietary fiber in pigs fed DDGS may have also contributed to the reduction in percentage yield. Research has shown that feeding fiber increases the rate of passage, causing increased intestinal growth and gut cell proliferation (Gill et al., 2000). It has also been reported that the weight of digesta can be increased, resulting in a reduced percentage yield (Pluske et al., 2003). It is well documented that feeding pigs diets high in fiber reduces percentage yield (Pond et al., 1988; Zhu et al., 1990; Pluske et al., 1998), which may apply to pigs consuming diets with DDGS.

The tendency for reduced backfat with increasing dietary levels of DDGS was not consistent with other research (Fu et al., 2004; Cook et al., 2005; Whitney et

Table 7. Effects of increasing levels of dried distillers grains with solubles (DDGS) on the performance of growing and finishing pigs (Exp. 2)[1]

	DDGS, %				*P*-value			
Item	0	10	20	30	Treatment	Linear	Quadratic	SE
d 0 to 56								
ADG, g	849	858	834	835	0.16	0.09	0.67	10.5
ADFI, g	1,946	1,975	1,913	1,900	0.09	0.05	0.35	35.7
G:F, g/g	0.437	0.435	0.437	0.440	0.66	0.38	0.38	0.005
Total removals[2]	3	10	9	8				

[1]A total of 1,038 (initial BW, 46.3 kg), with 24 to 26 pigs per pen and 10 pens per treatment.
[2]Removal from the study for lameness, death, tail biting, fighting, ulcers, or jumping to another pen.

Table 8. Effects of increasing levels of dried distillers grains with solubles (DDGS) on the performance and carcass characteristics of growing and finishing pigs (Exp. 3)[1]

	DDGS, %					*P*-value			
Item	0	5	10	15	20	Treatment	Linear	Quadratic	SE
d 0 to 78									
ADG, g	921	915	915	896	883	0.14	0.02	0.43	11.9
ADFI, g	2,392	2,317	2,368	2,310	2,288	0.13	0.04	0.98	31.4
G:F, g/g	0.385	0.395	0.387	0.388	0.386	0.06	0.46	0.14	0.003
Total removals[2]	9	10	5	10	14				
Slaughter wt,[3] kg	117.89	117.76	117.75	116.42	116.42	0.68	0.17	0.85	1.03
Carcass wt, kg	89.21	88.85	88.63	87.57	87.39	0.34	0.04	0.86	0.83
Yield, %	75.67	75.46	75.39	75.22	75.06	0.24	0.02	1.00	0.002
Backfat,[4] mm	18.6	18.8	18.2	18.1	17.9	0.40	0.07	0.97	0.35
Loin depth,[4] mm	58.52	58.45	58.13	57.26	57.50	0.75	0.22	0.98	0.81
FFLI[4,5]	49.34	49.45	49.53	49.70	49.65	0.48	0.09	0.67	0.15

[1]A total of 1,112 pigs (initially BW, 49.7 kg), with 25 to 28 pigs per pen and 9 pens per treatment.
[2]Removal from test for lameness, death, tail biting, fighting, ulcers, or jumping to another pen.
[3]Weight determined at the slaughter plant.
[4]Data analyzed by using carcass weight as a covariate.
[5]FFLI = fat-free lean index.

al., 2006), which showed no differences in backfat when pigs were fed increasing levels of DDGS in the diet. Pigs fed diets containing DDGS were leaner, perhaps because of being fed higher dietary CP, which has been shown to decrease fat accretion (Chen et al., 1999).

Our results also indicated no differences in loin depth for pigs fed DDGS. This is in contrast to research by Whitney et al. (2006), which showed the loin depth to be linearly reduced with increasing levels of DDGS. However, Fu et al. (2004) also showed no differences in loin depths for pigs fed DDGS.

Research has shown that added dietary fat improves ADG and G:F in growing and finishing pigs in both research and commercial environments (Pettigrew and Moser, 1991; De la Llata et al., 2001). Results from Exp. 1 indicated that increasing the energy density of the diet by adding fat improved pig ADG and G:F regardless of dietary DDGS. DeDecker et al. (2005) also evaluated added dietary choice white grease at 3 or 6%, with dietary DDGS ranging from 0 to 30%. They reported no improvement in ADG when pigs were fed 3% added choice white grease, but did have higher ADG when fed 6% choice white grease concurrently with DDGS. Therefore, using added dietary fat up to 6% in diets that contained DDGS would provide similar growth performance improvements compared with diets without DDGS; however, carcass fat quality effects of these combinations were not investigated.

In summary, DDGS from the source evaluated can be included at a level of 10 to 15% in growing and finishing diets before growth performance would be reduced in the commercial environment. In addition, the reduced carcass percentage yield and weight observed with increasing levels of dietary DDGS agreed with previous research. Including added dietary fat did not interact with the use of DDGS in the diet; thus, supplemental fat can be used in diets containing DDGS.

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