Effects of increasing crude glycerol and dried distillers grains with solubles on growth performance, carcass characteristics, and carcass fat quality of finishing pigs[1,2]

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ABSTRACT: This study was conducted to determine the effects of dietary crude glycerol and dried distillers grains with solubles (DDGS) on growing-finishing pig performance, carcass characteristics, and carcass fat quality. We hypothesized that because dietary crude glycerol has been observed to increase carcass SFA, it might ameliorate the negative effects of DDGS on fat quality. The 97-d study was conducted at a commercial swine research facility in southwestern Minnesota with 1,160 barrows (initial BW = 31.0 ± 1.1 kg). Pigs were blocked by initial BW, and pens were randomly allotted to 1 of 6 dietary treatments with 7 replications per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of crude glycerol (0, 2.5, or 5%) and DDGS (0 or 20%). All corn-soybean meal-based diets contained 3% added fat (choice white grease). There were no glycerol × DDGS interactions for any response criteria evaluated. Increasing dietary glycerol did not affect finishing pig growth performance. Adding 20% DDGS to the diet did not affect ADG; however, finishing pigs fed diets with added DDGS had greater (2.47 vs. 2.41 kg/d; $P = 0.02$) ADFI and poorer (0.39 vs. 0.40; $P = 0.01$) G:F than pigs not fed DDGS. Feeding increasing dietary glycerol or 20% DDGS did not affect carcass characteristics. For carcass fat quality, feeding 20% DDGS resulted in decreased ($P < 0.01$) palmitic and oleic acids, total SFA and total MUFA, and increased ($P < 0.01$) linoleic, total PUFA, total unsaturated fatty acids, and iodine value in jowl fat, belly fat, and backfat. Increasing dietary crude glycerol increased myristic acid (linear, $P < 0.05$) and MUFA (quadratic, $P < 0.05$) in jowl fat and increased (quadratic, $P < 0.05$) oleic acid and MUFA in backfat. In conclusion, feeding 20% DDGS to finishing pigs increased ADFI, reduced G:F, and increased carcass fat iodine value, whereas feeding crude glycerol did not influence growth performance, carcass characteristics, and had a minor influence on fatty acids of carcass fat. Both of these biofuel coproducts can be used in combination without affecting finishing pig performance or carcass traits; however, feeding crude glycerol did not fully mitigate the increased unsaturation of carcass fat observed when feeding DDGS.

Key words: dried distillers grains with solubles, glycerol, growth, iodine value, swine

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INTRODUCTION

The Energy Independence and Security Act of 2007 spurred the rapid expansion of biofuel production in the United States (Renewable Fuels Association, 2009). This growth in production and the demand for alternative fuels led to increased availability of coproducts such as dried distiller grains with solubles (**DDGS**) from ethanol production (Belyea et al., 2004) and crude glycerol from biodiesel production (Thompson and He, 2006). These coproducts provide alternative ingredients for livestock feed, but a better understanding of their feeding value is needed.

Stein and Shurson (2009) reviewed research on the use of DDGS in swine diets and reported that up to 20% DDGS can be fed to growing-finishing pigs without negatively affecting growth performance. Past research demonstrated that feeding glycerol in swine di-

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ets had no impact on performance (Lammers et al., 2008; Schieck et al., 2010a), whereas other data have shown benefits for both nursery (Groesbeck et al., 2008; Shields et al., 2011) and finishing pigs (Schieck et al., 2010b). Feeding biofuel coproducts to pigs may also affect carcass quality. For carcass fat quality, research has consistently documented carcass quality changes when pigs are fed DDGS such as reduced percentage carcass yield, increased carcass fat softness, and reduced belly firmness (Stein and Shurson, 2009). In contrast, Mourot et al. (1994) showed that carcass fat was more saturated when pigs were fed dietary glycerol, whereas Schieck et al. (2010b) reported improved carcass firmness when fed the last 8 wk before slaughter. However, the mechanism for this effect is not fully understood. Thus, the use of glycerol in diets containing greater amounts of unsaturated fats, such as from DDGS, may provide a dietary means to ameliorate some of the negative carcass quality characteristics associated with feeding DDGS. Therefore, the objective of this study was to evaluate the effects of dietary crude glycerol and DDGS on growing-finishing pig performance, carcass characteristics, and carcass fat quality.

MATERIALS AND METHODS

All animal procedures were reviewed and approved by the Kansas State University Institutional Animal Care and Use Committee.

General

The trial was conducted at a commercial research facility in southwestern Minnesota. The facility has 4 individual barns (12.5 × 76.2 m), each with 48 pens (3.05 × 5.49 m) that provide approximately 0.69 m^2 per pig. All pens contain one 4-hole dry self-feeder and a cup waterer to allow for ad libitum access to feed and water. Each barn has a deep pit for manure storage and completely slatted floors. The barns operate on natural ventilation during the summer and mechanically assisted ventilation during the winter. All barns are curtain sided.

Multiple lots of crude glycerol from the same soybean biodiesel production facility (Minnesota Soybean Processors, Brewster, MN) and multiple lots of DDGS from 2 ethanol production facilities [Agri-Energy LLC, Luverne, MN (d 0 to 70); VeraSun Energy, Aurora, SD (d 70 to 97)] were used in the trial (Tables 1 and 2).

Animals and Diets

A total of 1,160 barrows (Line 337 × 1050, PIC, Hendersonville, TN) with an initial BW of 31.0 ± 1.1 kg were used in a 97-d growth assay. Pigs were randomly allotted to pens, and pens of pigs were allotted to 1 of 6 dietary treatments with 7 pens per treatment. Pens were blocked on the basis of average initial pen weight. Each pen contained 27 or 28 barrows.

Table 1. Analyzed composition of crude glycerol (as-fed basis)

Item	Analyzed[1]
Total glycerol,[2] %	82.2
Methanol,[3] mg/kg	136
Moisture,[4] %	9.7 (9.1 to 10.5)
CP,[4] %	1.9 (0.2 to 2.8)
Ether extract,[4] %	2.7 (1.1 to 7.1)
Ash,[4] %	5.4 (5.1 to 5.6)

[1]Values represent the mean of 4 samples of glycerol (Minnesota Soybean Processors, Brewster, MN) with the value range in parentheses.

[2]Determined by the Minnesota Soybean Processors as 100 − % total fatty acid − % moisture − % methanol − % ash.

[3]Values reported by Minnesota Soybean Processors.

[4]Analysis by Ward Laboratories Inc., Kearney, NE.

Pigs were fed corn-soybean meal-based diets in 4 phases (Tables 3, 4, 5, and 6) in meal form. The treatments were arranged in a 2 × 3 factorial with main effects of crude glycerol (0, 2.5, or 5%) and DDGS (0 or 20%). All experimental diets were balanced to maintain a constant standardized ileal digestible (**SID**) Lys:ME within each phase. For both DDGS and crude glycerol, the NRC (1998) ME value of corn (3,420 kcal/kg) was used in diet formulation. Previously, Pedersen et al. (2007) reported that DDGS has the same energy value as corn and the DDGS; thus, corn ME was used for DDGS. Also, DDGS nutrient composition and digestibility values used in diet formulation were from Stein et al. (2006) and Pedersen et al. (2007). Pigs and feeders were weighed approximately every 14 d to determine the response criteria of ADG, ADFI, and G:F. Pigs were marketed on d 97 of the study.

At the end of the 97-d experiment, pigs from each pen were individually tattooed with pen number and

Table 2. Assumed and analyzed composition of dried distillers grains with solubles (DDGS; as-fed basis)

		Analyzed	
Item, %	Assumed[1]	Sample 1[2]	Sample 2[3]
DM	93.0	91.7	91.6
CP	27.2	26.1	28.0
Crude fiber	—	9.0	9.3
Ether extract	10.7	11.9	11.1
Ash	—	3.7	4.1
Total AA			
Lys	0.78	0.76	0.89
Ile	1.01	0.97	1.03
Leu	3.17	2.93	3.05
Met	0.55	0.49	0.53
Cys	0.55	0.47	0.47
Thr	1.06	0.97	1.00
Trp	0.21	0.19	0.22
Val	1.35	1.30	1.38

[1]Represents assumed values used in diet formulation.

[2]Values represent the mean of 2 samples of DDGS (Agri-Energy LLC, Luverne, MN) fed from d 0 to 70.

[3]Values represent the mean of 3 samples of DDGS (VeraSun Energy, Aurora, SD) fed from d 70 to 97.

Table 3. Phase 1 diet composition (as-fed basis)[1]

Item	0% DDGS[2]			20% DDGS		
	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol
Ingredient, %						
Corn	68.17	65.46	62.76	55.14	52.44	49.74
Soybean meal, 46.5% CP	26.63	26.83	27.03	19.69	19.89	20.09
Crude glycerol	—	2.50	5.00	—	2.50	5.00
Dried distillers grains with solubles	—	—	—	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.63	0.63	0.63	0.18	0.18	0.18
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Phytase[5]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys·HCl	0.15	0.15	0.15	0.30	0.30	0.30
DL-Met	0.01	0.02	0.02	—	—	—
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible AA, %						
Lys	0.98	0.98	0.98	0.98	0.98	0.98
Met:Lys	28	28	29	30	30	29
Met+Cys:Lys	57	57	57	61	61	60
Thr:Lys	60	60	60	61	61	60
Trp:Lys	19	19	19	18	18	18
CP, %	18.33	18.20	18.06	19.57	19.44	19.30
Total Lys, %	1.10	1.10	1.10	1.13	1.13	1.13
ME, kcal/kg	3,479	3,479	3,479	3,488	3,488	3,488
Lys:ME, g/Mcal	2.82	2.82	2.82	2.81	2.81	2.81
Ca, %	0.55	0.55	0.55	0.55	0.55	0.55
P, %	0.51	0.50	0.49	0.47	0.46	0.46
Available P,[6] %	0.28	0.28	0.28	0.28	0.28	0.28

[1]Fed from 31.0 to 54.4 kg of BW.

[2]DDGS = dried distillers grains with solubles.

[3]Provided per kilogram of diet: 6,614 IU of vitamin A; 827 IU of vitamin D; 26 IU of vitamin E; 2.6 mg of vitamin K; 0.02 mg of vitamin B_{12}; 30 mg of niacin; 17 mg of pantothenic acid; and 5 mg of riboflavin.

[4]Provided per kilogram of diet: 16.53 mg of Cu from Cu sulfate; 0.298 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 39.7 mg of Mn from Mn oxide, 0.298 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.

[5]OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[6]Includes expected P release of 0.10% from added phytase.

shipped approximately 96 km to the processing plant (JBS Swift & Company, Worthington, MN). Pigs were slaughtered under commercial conditions with carbon dioxide stunning. Standard carcass traits of loin and backfat depth, HCW, fat-free lean index, and yield were collected. Yield was calculated as HCW divided by BW obtained at the plant immediately before slaughter. Fat depth and loin depth were measured with an optical probe (Fat-O-Meater, SFK Technology A/S, Herlev, Denmark) inserted between the third and fourth rib from the last rib (counting from the posterior of the carcass) and 7 cm from the dorsal midline of the hot carcass. Fat-free lean index was calculated according to the NPPC (2000b) procedures.

Fatty Acid Analysis

After exiting the kill floor, carcasses were sent through deep-chill chambers (approximately −40°C) for approximately 90 min. After deep chill, carcasses were segregated on an outside rail in a holding cooler. Approximately 2 h after exiting deep chill, the right side jowl was removed with a perpendicular cut flush with the carcass shoulder from 2 randomly selected barrows from each pen. Backfat and belly fat samples were collected from the same barrows. A sample (approximately 200 g total) of backfat was removed from the 10th rib area off the carcass midline. An attempt was made to remove all layers of backfat. The jowl fat and backfat samples were placed in a vacuum bag, vacuum sealed, and stored at approximately 4°C. Then carcasses were allowed to chill overnight. At approximately 18 h after slaughter, the bellies were removed and collected from the right side of the carcass (IMPS 408; IMPS, 1996). A belly strip (approximately 5 cm wide and 70 cm long) was removed from the dorsal edge of each belly. Belly strips were vacuum packaged, stored at 4°C, and then transported to Kansas State University under refrigerated conditions. Samples were frozen at −18°C until sample preparation and fatty acid analysis.

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

Item	0% DDGS[2]			20% DDGS		
	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol
Ingredient, %						
Corn	74.27	71.57	68.87	61.20	58.50	55.80
Soybean meal, 46.5% CP	20.66	20.86	21.06	13.72	13.92	14.12
Crude glycerol	—	2.50	5.00	—	2.50	5.00
Dried distillers grains with solubles	—	—	—	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.55	0.55	0.55	0.13	0.13	0.13
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix[4]	0.08	0.08	0.08	0.08	0.08	0.08
Phytase[5]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys·HCl	0.15	0.15	0.15	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible AA, %						
Lys	0.83	0.83	0.83	0.83	0.83	0.83
Met:Lys	29	29	28	32	32	32
Met+Cys:Lys	60	59	58	66	65	64
Thr:Lys	61	61	61	62	62	61
Trp:Lys	19	19	19	17	17	17
CP, %	16.06	15.93	15.79	17.31	17.17	17.04
Total Lys, %	0.93	0.93	0.93	0.97	0.96	0.96
ME, kcal/kg	3,483	3,483	3,483	3,494	3,494	3,494
Lys:ME, g/Mcal	2.38	2.38	2.38	2.38	2.38	2.38
Ca, %	0.52	0.52	0.52	0.52	0.52	0.52
P, %	0.47	0.46	0.45	0.43	0.43	0.42
Available P,[6] %	0.25	0.24	0.24	0.25	0.25	0.25

[1]Fed from 54.4 to 77.1 kg of BW.

[2]DDGS = dried distillers grains with solubles.

[3]Provided per kilogram of diet: 5,511 IU of vitamin A; 689 IU of vitamin D; 22 IU of vitamin E; 2.2 mg of vitamin K; 0.02 mg of vitamin B_{12}; 25 mg of niacin; 14 mg of pantothenic acid; and 4 mg of riboflavin.

[4]Provided per kilogram of diet: 13.64 mg of Cu from Cu sulfate; 0.246 mg of I from Ca iodate; 136 mg of Fe from Fe sulfate; 32.7 mg of Mn from Mn oxide, 0.246 mg of Se from Na selenite; and 136 mg of Zn from Zn oxide.

[5]OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[6]Includes expected P release of 0.10% from added phytase.

Samples were thawed and dissected to separate adipose tissue from skin and lean tissue. Adipose tissue was subsampled and ground. Grinding was performed by cutting fat samples into approximately 1-cm^3 pieces, freezing the pieces in liquid N, and grinding them in a stainless-steel grinding tub powered by a blender (Waring Commercial Blender, Dynamics Corporation of America, New Hartford, CT). Ground fat (50 μg) was then weighed into screw-cap tubes with Teflon-lined caps. Fat was combined with 3 mL of methanolic-HCl and 2 mL of internal standard [2 mg/mL of methyl tridecanoic acid (C13:0) in benzene] and subsequently heated in a water bath for 135 min at 70°C for transmethylation. Tubes were vortexed at 45 and 90 min during this heating period. After cooling, addition of 2 mL of benzene and 3 mL of K_2CO_3 allowed the methyl esters to be extracted and transferred to a vial for subsequent quantification of methylated fatty acids by gas chromatography for fatty acid analysis. Injection port and detector temperatures were 250°C with a flow rate of 1 mL/min helium and a split ratio of 100 to 1. Oven temperature began at 140°C, increased at 2°C/min to 200°C, increased at 4°C/min to 245°C, and was held for 17 min. From the fatty acid analysis, iodine value (**IV**) was calculated from the following equation (AOCS, 1998): IV = [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 indicate concentration (percentage) of the fatty acid.

Statistical Analysis

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure (SAS Inst. Inc., Cary, NC) with the pen as the experimental unit. Main effects of crude glycerol level and DDGS and their interactions were tested. Linear and quadratic polynomial contrasts were used to determine the effects of increasing dietary glycerol. Statistical significance and tendencies were set at $P \leq 0.05$ and $P \leq 0.10$, respectively, for all statistical tests. Least squares means were calculated for each independent variable.

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

Item	0% DDGS[2]			20% DDGS		
	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol
Ingredient, %						
Corn	78.67	75.97	73.27	64.12	61.42	58.72
Soybean meal, 46.5% CP	16.28	16.48	16.68	10.90	11.10	11.30
Crude glycerol	—	2.50	5.00	—	2.50	5.00
Dried distillers grains with solubles	—	—	—	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.55	0.55	0.55	0.10	0.10	0.10
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix[4]	0.07	0.07	0.07	0.07	0.07	0.07
Phytase[5]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys·HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible AA, %						
Lys	0.72	0.72	0.72	0.72	0.72	0.72
Met:Lys	31	30	30	35	35	35
Met+Cys:Lys	63	62	61	72	71	71
Thr:Lys	62	62	62	66	66	65
Trp:Lys	19	19	19	17	17	17
CP, %	14.40	14.27	14.13	16.20	16.06	15.93
Total Lys, %	0.81	0.81	0.81	0.85	0.85	0.85
ME, kcal/kg	3,488	3,488	3,488	3,496	3,496	3,496
Lys:ME, g/Mcal	2.06	2.06	2.06	2.06	2.06	2.06
Ca, %	0.50	0.50	0.50	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P,[6] %	0.23	0.23	0.23	0.23	0.23	0.23

[1]Fed from 77.1 to 99.8 kg of BW.

[2]DDGS = dried distillers grains with solubles.

[3]Provided per kilogram of diet: 4,409 IU of vitamin A; 551 IU of vitamin D; 18 IU of vitamin E; 1.8 mg of vitamin K; 0.02 mg of vitamin B_{12}; 20 mg of niacin; 11 mg of pantothenic acid; and 3 mg of riboflavin.

[4]Provided per kilogram of diet: 10.75 mg of Cu from Cu sulfate; 0.193 mg of I from Ca iodate; 107 mg of Fe from Fe sulfate; 25.8 mg of Mn from Mn oxide, 0.193 mg of Se from Na selenite; and 107 mg of Zn from Zn oxide.

[5]OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[6]Includes expected P release of 0.10% from added phytase.

RESULTS

In general, analyzed composition values for crude glycerol (Table 1) were greater than those reported by Lammers et al. (2008). Analyzed composition values for the 2 DDGS sources used in this study were similar to those used in diet formulation (Table 2).

Overall (d 0 to 97), there were no glycerol × DDGS interactions for growth performance, carcass characteristics, or carcass fat quality; therefore, only main effects are discussed. Increasing dietary glycerol did not affect growth performance (Table 7). Adding 20% DDGS to the diet did not affect ADG; however, finishing pigs fed diets with added DDGS had greater ($P < 0.05$) ADFI and poorer ($P < 0.01$) G:F than pigs fed diets without DDGS. Increasing dietary glycerol did not affect HCW, HCW variation, carcass yield, backfat depth, loin depth, or fat-free lean index (Table 8). Likewise, adding 20% DDGS to the diet did not affect any carcass characteristics measured.

For carcass fat quality, as expected, feeding 20% DDGS to finishing pigs resulted in decreased ($P < 0.01$) palmitic and oleic acids, and total SFA and total MUFA, and increased ($P < 0.01$) linoleic, total PUFA, total unsaturated fatty acids (**UFA**; MUFA + PUFA):SFA, PUFA:SFA, and IV in jowl fat, belly fat, and backfat compared with feeding no DDGS (Tables 9, 10, and 11). Feeding DDGS did not affect total *trans* fatty acids concentration in any of the 3 fat depots.

Increasing dietary crude glycerol increased myristic acid (linear, $P < 0.05$) and MUFA (quadratic, $P < 0.05$), and tended to increase (quadratic, $P < 0.10$) the vaccenic acid content in jowl fat (Table 9). Also, margaric acid tended to decrease ($P < 0.10$) quadratically in jowl fat. Also, pigs fed increasing glycerol tended to have decreased (quadratic, $P < 0.10$) linoleic acid and PUFA in jowl fat. For belly fat, pigs fed increasing glycerol tended to have increased myristic (linear, $P < 0.10$), whereas margaric acid tended to decrease ($P < 0.10$) quadratically (Table 10). Finally for backfat, pigs

Table 6. Phase 4 diet composition (as-fed basis)[1]

Item	0% DDGS[2]			20% DDGS		
	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol
Ingredient, %						
Corn	80.64	77.93	75.23	66.09	63.39	60.69
Soybean meal, 46.5% CP	14.29	14.50	14.70	8.91	9.11	9.31
Crude glycerol	—	2.50	5.00	—	2.50	5.00
Dried distillers grains with solubles	—	—	—	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.60	0.60	0.60	0.15	0.15	0.15
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix[4]	0.05	0.05	0.05	0.05	0.05	0.05
Phytase[5]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys·HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible AA, %						
Lys	0.64	0.64	0.64	0.64	0.64	0.64
Met:Lys	31	31	31	37	36	36
Met+Cys:Lys	65	64	63	75	74	73
Thr:Lys	63	62	62	67	67	66
Trp:Lys	19	19	18	17	17	17
CP, %	13.65	13.51	13.37	15.44	15.31	15.17
Total Lys, %	0.76	0.76	0.76	0.79	0.79	0.79
ME, kcal/kg	3,488	3,488	3,488	3,496	3,496	3,496
Lys:ME, g/Mcal	1.92	1.92	1.92	1.92	1.92	1.92
Ca, %	0.51	0.51	0.51	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P,[6] %	0.22	0.22	0.22	0.22	0.22	0.22

[1]Fed from 99.8 to 123.8 kg.

[2]DDGS = dried distillers grains with solubles.

[3]Provided per kilogram of diet: 4,409 IU of vitamin A; 551 IU of vitamin D; 18 IU of vitamin E; 1.8 mg of vitamin K; 0.02 mg of vitamin B_{12}; 20 mg of niacin; 11 mg of pantothenic acid; and 3 mg of riboflavin.

[4]Provided per kilogram of diet: 10.75 mg of Cu from Cu sulfate; 0.193 mg of I from Ca iodate; 107 mg of Fe from Fe sulfate; 25.8 mg of Mn from Mn oxide, 0.193 mg of Se from Na selenite; and 107 mg of Zn from Zn oxide.

[5]OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[6]Includes expected P release of 0.10% from added phytase.

fed increasing dietary glycerol had increased (quadratic, $P < 0.05$) oleic acid and MUFA, and had a tendency for increased (linear, $P < 0.09$) myristic and palmitic acids (Table 11). However, there was a tendency for increased (linear, $P < 0.10$) linoliec acid and a tendency for decreased (linear, $P < 0.10$) PUFA:SFA. Although differences were found in all depots for dietary glycerol altering fatty acid composition to be more saturated, no differences were found for carcass fat IV in any of the 3 fat depot locations tested.

DISCUSSION

Growth Performance

For pork producers, the importance of identifying alternatives to traditional ingredients in swine diets has dramatically increased in recent years because of considerable increases in grain and supplement costs. In the past decade, much research has been devoted to determining the feeding value of DDGS, and this led to a rapid increase in DDGS usage in commercial pig production. Optimal inclusion DDGS in swine diets have been determined on the basis of growth performance and economics (Fu et al., 2004; Hastad, 2005; Whitney et al., 2006); however, the main issue with using greater dietary DDGS is the negative effect on carcass fat quality (Whitney et al., 2006; Benz et al., 2010; Xu et al., 2010).

Biodiesel is produced through transesterification of triglycerides in oils or fats with an alcohol, usually methanol (Van Gerpen, 2005). Through this reaction, fatty acids are methylated to form methyl alkyl esters (i.e., biodiesel) and the principal coproduct, crude glycerol (Ma and Hanna, 1999; Thompson and He, 2006). Early studies assessing the effects of feeding pure or crude glycerol to broiler chickens (Simon et al., 1996) and pigs (Kijora et al., 1997) provided initial evidence that glycerol can be used as a source of dietary energy for livestock. This was expected because glycerol plays an important role in energy metabolism. Glycerol is an important structural component of triglycerides and

Table 7. Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) on growing-finishing pig performance (d 0 to 97)[1]

	0% DDGS			20% DDGS				*P*-value				
											Glycerol	
Item	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	SEM	DDGS × glycerol	DDGS	Glycerol	Linear	Quadratic
Initial BW, kg	30.8	30.9	31.3	31.0	31.2	30.9	1.12	0.95	0.98	0.98	0.84	0.94
ADG, kg	0.97	0.96	0.96	0.97	0.96	0.96	0.01	0.99	0.73	0.44	0.38	0.35
ADFI, kg	2.43	2.39	2.40	2.45	2.46	2.51	0.03	0.29	0.02	0.59	0.63	0.37
G:F	0.40	0.40	0.40	0.40	0.39	0.38	0.003	0.13	0.01	0.33	0.15	0.75
Final BW, kg	124.1	123.4	123.3	124.2	124.2	123.4	1.45	0.96	0.76	0.87	0.60	0.98
Removals[2]	6	7	6	6	10	6	—	—	—	—	—	—

[1]A total of 1,160 barrows with an initial BW of 31.0 ± 1.1 kg were used in a 97-d experiment with 27 or 28 pigs per pen and 7 replications per treatment.

[2]Removal from the study for lameness, death, tail biting, ulcers, light weight cull, or hemorrhagic bowel.

Table 8. Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on carcass characteristics[1,2]

	0% DDGS			20% DDGS				*P*-value				
											Glycerol	
Item	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	SEM	DDGS × glycerol	DDGS	Glycerol	Linear	Quadratic
Carcass wt, kg	93.1	92.9	92.1	91.4	91.9	92.7	1.08	0.63	0.45	0.99	0.92	0.98
Carcass wt CV, %	9.0	9.4	9.2	8.8	8.1	8.9	0.67	0.67	0.35	0.94	0.82	0.76
Yield, %	75.1	75.5	75.7	74.5	75.9	75.7	0.47	0.56	0.93	0.17	0.11	0.37
Backfat, mm	19.9	19.7	19.8	19.3	19.0	19.6	0.48	0.87	0.18	0.81	0.86	0.54
Loin depth, mm	62.9	62.8	60.7	60.9	61.2	62.0	0.79	0.12	0.27	0.77	0.57	0.62
FFLI,[3] %	49.2	49.1	49.1	49.3	49.4	49.3	0.24	0.93	0.32	0.96	0.81	0.89

[1]A total of 1,160 barrows with an initial BW of 31.0 ± 1.1 kg were used in a 97-d experiment with 27 or 28 pigs per pen and 7 replications per treatment.

[2]A total of 1,119 barrows were marketed with 23 to 26 pigs per pen.

[3]Fat-free lean index.

Table 9. Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on jowl fat quality[1,2]

	0% DDGS			20% DDGS				*P*-value				
											Glycerol	
Item	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	SEM	DDGS × glycerol	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.32	1.48	1.46	1.31	1.30	1.35	0.04	0.10	<0.01	0.06	0.03	0.35
Palmitic acid (16:0), %	21.40	22.10	22.14	20.78	20.91	20.89	0.29	0.51	<0.01	0.27	0.16	0.43
Palmitoleic acid (16:1), %	2.75	3.02	2.97	2.48	2.44	2.46	0.12	0.40	<0.01	0.61	0.43	0.55
Margaric acid (17:0), %	0.53	0.49	0.56	0.53	0.50	0.53	0.03	0.73	0.63	0.14	0.52	0.07
Stearic acid (18:0), %	9.30	8.95	9.22	8.93	9.09	8.75	0.26	0.47	0.29	0.88	0.63	0.89
Oleic acid (18:1 *cis*-9), %	41.28	42.17	41.21	39.50	40.19	39.99	0.45	0.63	<0.01	0.29	0.89	0.12
Vaccenic acid (18:1n-7), %	3.29	3.60	3.45	2.99	3.03	3.02	0.08	0.28	<0.01	0.13	0.25	0.10
Linoleic acid (18:2n-6), %	14.48	13.04	13.61	18.63	17.04	17.70	0.68	0.99	<0.01	0.11	0.20	0.09
α-Linolenic acid (18:3n-3), %	0.71	0.65	0.69	0.73	0.73	0.72	0.73	0.48	0.11	0.64	0.64	0.42
γ-Linolenic acid (18:3n-6), %	0.47	0.30	0.36	0.23	0.40	0.33	0.47	0.57	0.68	0.99	0.99	0.99
Arachidic acid (20:0), %	0.35	0.31	0.36	0.26	0.33	0.29	0.06	0.60	0.35	0.92	0.69	0.89
Eicosadienoic acid (20:2), %	0.85	0.76	0.79	0.95	0.97	0.97	0.03	0.23	<0.01	0.57	0.51	0.41
Arachidonic acid (20:4n-6), %	0.12	0.12	0.10	0.12	0.12	0.12	0.01	0.22	0.42	0.55	0.33	0.64
Other fatty acids, %	1.57	1.48	1.52	1.20	1.46	1.37	0.20	0.66	0.28	0.92	0.79	0.76
Total SFA,[3] %	33.39	33.79	34.22	32.22	32.58	32.25	0.47	0.64	<0.01	0.61	0.37	0.69
Total MUFA,[4] %	49.15	50.69	49.46	46.55	47.40	47.24	0.50	0.56	<0.01	0.08	0.36	0.04
Total PUFA,[5] %	17.46	15.52	16.32	21.23	20.02	20.51	0.72	0.88	<0.01	0.11	0.21	0.09
Total *trans* fatty acids,[6] %	0.61	0.55	0.60	0.41	0.58	0.52	0.13	0.69	0.45	0.90	0.70	0.79
UFA:SFA ratio[7]	2.00	1.96	1.93	2.11	2.08	2.11	0.04	0.70	<0.01	0.66	0.41	0.71
PUFA:SFA ratio[8]	0.53	0.46	0.48	0.66	0.62	0.64	0.03	0.91	<0.01	0.19	0.23	0.17
Iodine value,[9] g/100 g	70.5	68.6	68.9	74.1	73.3	74.0	0.88	0.69	0.01	0.33	0.36	0.24

[1]A total of 1,160 barrows with an initial BW of 31.0 ± 1.1 kg were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

[2]A total of 84 barrows were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.

[3]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 indicate concentration.

[4]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where the brackets indicate concentration.

[5]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where the brackets indicate concentration.

[6]Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]), where the brackets indicate concentration.

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

[8]PUFA:SFA ratio = total PUFA/total SFA.

[9]Calculated as IV = [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 indicate concentration (AOCS, 1998).

Table 10. Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on belly fat quality[1,2]

	0% DDGS			20% DDGS				*P*-value				
											Glycerol	
Item	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	SEM	DDGS × glycerol	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.32	1.39	1.43	1.26	1.24	1.27	0.04	0.26	<0.01	0.22	0.09	0.82
Palmitic acid (16:0), %	23.20	23.12	23.62	21.60	21.95	21.57	0.33	0.42	<0.01	0.84	0.56	0.89
Palmitoleic acid (16:1), %	2.16	2.26	2.37	2.01	1.95	1.93	0.08	0.19	<0.01	0.75	0.47	0.85
Margaric acid (17:0), %	0.54	0.53	0.57	0.54	0.49	0.55	0.02	0.76	0.30	0.11	0.35	0.06
Stearic acid (18:0), %	11.81	11.30	11.55	10.32	10.90	10.49	0.35	0.31	<0.01	0.98	0.90	0.85
Oleic acid (18:1 *cis*-9), %	39.09	39.49	39.21	37.16	38.41	37.84	0.36	0.35	<0.01	0.40	0.79	0.18
Vaccenic acid (18:1n-7), %	2.72	2.83	2.85	2.53	2.51	2.51	0.04	0.32	<0.01	0.59	0.33	0.76
Linoleic acid (18:2n-6), %	14.51	14.08	13.52	19.88	17.86	18.82	0.66	0.42	<0.01	0.16	0.14	0.23
α-Linolenic acid (18:3n-3), %	0.65	0.66	0.65	0.72	0.68	0.71	0.03	0.53	0.04	0.90	0.83	0.68
γ-Linolenic acid (18:3n-6), %	0.25	0.33	0.29	0.22	0.25	0.29	0.12	0.94	0.67	0.87	0.64	0.79
Arachidic acid (20:0), %	0.34	0.35	0.36	0.29	0.33	0.32	0.04	0.91	0.25	0.75	0.55	0.66
Eicosadienoic acid (20:2), %	0.78	0.77	0.75	0.94	0.90	0.98	0.03	0.15	<0.01	0.54	0.96	0.28
Arachidonic acid (20:4n-6), %	0.10	0.12	0.11	0.11	0.10	0.11	0.01	0.20	0.51	0.99	0.86	0.97
Other fatty acids, %	1.12	1.32	1.28	1.11	1.13	1.21	0.12	0.76	0.37	0.56	0.32	0.69
Total SFA,[3] %	37.61	37.12	38.00	34.42	35.30	34.59	0.60	0.38	<0.01	0.90	0.65	0.93
Total MUFA,[4] %	45.60	46.32	46.12	43.18	44.43	43.91	0.39	0.55	<0.01	0.35	0.41	0.20
Total PUFA,[5] %	16.79	16.56	15.87	22.40	20.27	21.50	0.72	0.33	<0.01	0.25	0.22	0.26
Total *trans* fatty acids,[6] %	0.43	0.55	0.52	0.42	0.48	0.51	0.10	0.96	0.72	0.57	0.38	0.57
UFA:SFA ratio[7]	1.67	1.70	1.63	1.91	1.84	1.90	0.05	0.41	<0.01	0.89	0.66	0.86
PUFA:SFA ratio[8]	0.45	0.45	0.42	0.65	0.58	0.63	0.03	0.35	<0.01	0.37	0.30	0.35
Iodine value,[9] g/100 g	66.7	66.8	65.5	73.6	71.5	72.9	1.07	0.40	0.01	0.60	0.40	0.58

[1]A total of 1,160 barrows with an initial BW of 31.0 ± 1.1 kg were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

[2]A total of 84 barrows were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.

[3]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 indicate concentration.

[4]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where the brackets indicate concentration.

[5]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where the brackets indicate concentration.

[6]Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]), where the brackets indicate concentration.

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

[8]PUFA:SFA ratio = total PUFA/total SFA.

[9]Calculated as IV = [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 indicate concentration (AOCS, 1998).

Table 11. Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on backfat quality[1,2]

								P-value				
	0% DDGS			20% DDGS							Glycerol	
Item	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	0% crude glycerol	2.5% crude glycerol	5% crude glycerol	SEM	DDGS × glycerol	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.36	1.44	1.46	1.31	1.27	1.34	0.04	0.30	<0.01	0.19	0.08	0.70
Palmitic acid (16:0), %	23.62	23.78	24.54	22.12	22.38	22.40	0.34	0.51	<0.01	0.22	0.09	0.78
Palmitoleic acid (16:1), %	2.24	2.28	2.36	1.92	1.95	1.95	0.09	0.81	<0.01	0.69	0.40	0.98
Margaric acid (17:0), %	0.54	0.54	0.57	0.54	0.50	0.54	0.03	0.76	0.34	0.44	0.65	0.23
Stearic acid (18:0), %	11.97	11.70	12.25	10.86	11.11	10.93	0.38	0.63	<0.01	0.87	0.66	0.78
Oleic acid (18:1 *cis*-9), %	38.55	39.01	38.89	36.62	37.99	37.23	0.35	0.43	<0.01	0.07	0.26	0.04
Vaccenic acid (18:1n-7), %	2.69	2.78	2.76	2.41	2.46	2.46	0.05	0.95	<0.01	0.41	0.30	0.41
Linoleic acid (18:2n-6), %	14.59	14.10	12.98	19.99	18.03	18.80	0.76	0.44	<0.01	0.16	0.08	0.44
α-Linolenic acid (18:3n-3), %	0.65	0.64	0.59	0.70	0.66	0.68	0.03	0.45	0.02	0.37	0.16	0.91
γ-Linolenic acid (18:3n-6), %	0.19	0.16	0.17	0.13	0.14	0.16	0.03	0.64	0.29	0.90	0.97	0.64
Arachidic acid (20:0), %	0.33	0.29	0.31	0.24	0.25	0.25	0.02	0.64	<0.01	0.76	0.80	0.49
Eicosadienoic acid (20:2), %	0.74	0.73	0.68	0.88	0.86	0.89	0.02	0.18	<0.01	0.51	0.25	0.98
Arachidonic acid (20:4n-6), %	0.10	0.09	0.09	0.11	0.11	0.09	0.008	0.40	0.21	0.32	0.15	0.70
Other fatty acids, %	1.13	1.18	1.03	0.96	1.06	1.01	0.06	0.45	0.05	0.25	0.70	0.11
Total SFA,[3] %	38.24	38.17	39.55	35.44	35.89	35.84	0.66	0.56	<0.01	0.42	0.21	0.69
Total MUFA,[4] %	44.98	45.60	45.52	42.33	43.85	43.10	0.41	0.53	<0.01	0.05	0.12	0.05
Total PUFA,[5] %	16.78	16.22	14.93	22.23	20.26	21.06	0.82	0.44	<0.01	0.16	0.08	0.48
Total *trans* fatty acids,[6] %	0.38	0.40	0.33	0.30	0.37	0.34	0.04	0.52	0.31	0.42	0.99	0.20
UFA:SFA ratio[7]	1.62	1.62	1.53	1.83	1.80	1.80	0.05	0.63	<0.01	0.46	0.24	0.74
PUFA:SFA ratio[8]	0.44	0.43	0.38	0.63	0.57	0.59	0.03	0.52	<0.01	0.23	0.10	0.64
Iodine value,[9] g/100 g	66.1	65.7	63.5	73.1	71.0	71.8	1.22	0.48	0.01	0.27	0.11	0.79

[1]A total of 1,160 barrows with an initial BW of 31.0 ± 1.1 kg were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.

[2]A total of 84 barrows were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.

[3]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 indicate concentration.

[4]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where the brackets indicate concentration.

[5]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where the brackets indicate concentration.

[6]Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 trans]}, where the brackets indicate concentration.

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

[8]PUFA:SFA ratio = total PUFA/total SFA.

[9]Calculated as IV = [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 indicate concentration (AOCS, 1998).

phospholipids (Min et al., 2010). Glycerol is a precursor to glyceraldehyde 3-phosphate, an intermediate in the lipogenesis and gluconeogenesis pathways, and yields energy through glycolysis and the citric acid cycle (Lin, 1977; Brisson et al., 2001). As an energy source, glycerol can be oxidized, which yields 22 mol of ATP/mol (Min et al., 2010). In a study with growing pigs, Lammers et al. (2008) demonstrated that dietary crude glycerol provides 3.21 Mcal of ME/kg and is well digested, with apparent total tract energy digestibility ranging from 89 to 92%. Thus, the ability to feed pigs both crude glycerol and DDGS may provide a means to reduce feed costs by replacing corn and soybean meal.

Stein and Shurson (2009) reported that feeding 20% DDGS to finishing pigs does not negatively affect growth performance. However, in the present study, we observed increased ADFI and reduced G:F. Gaines et al. (2007a,b) also observed poorer G:F, whereas Xu et al. (2010) reported improved G:F in finishing pigs fed diets containing DDGS. These differences in G:F may be due to the innate variability in energy concentration among the DDGS sources used in those experiments (Stein and Shurson, 2009). In the present study, the NRC (1998) ME value of corn (3,420 kcal/kg) was assigned to DDGS in formulation of diets containing DDGS. Unfortunately, the ME value used by Gaines et al. (2007a,b) and Xu et al. (2010) was not reported. The reduction in G:F in the present study may indicate that the energy concentration of DDGS was less than the value used in diet formulation.

Compared with the analyzed values of crude glycerol reported by Lammers et al. (2008), our values were slightly greater for CP and ether extract and slightly less for total glycerol. However, these differences did not result in any substantial effects on growth performance compared with pigs fed diets without glycerol. Our results agree with most previous research, in which including crude glycerol at 2.5 to 5% of the diet did not affect growth performance of growing and finishing pigs fed corn-soybean meal diets (Lammers et al., 2008; Huang et al., 2010), barley-soybean meal diets (Kijora et al., 1997; Kijora and Kupsch, 2006), corn-barley-soybean meal diets (Della Casa et al., 2009), or wheat-soybean meal diets (Mourot et al., 1994).

Some studies have shown improved ADG (Stevens et al., 2008; Schieck et al., 2010b), increased ADFI, and reduced G:F (Stevens et al., 2008) in finishing pigs fed glycerol. The difference in responses between Stevens et al. (2008) and the current study may be due to glycerol quality. Stevens et al. (2008) fed crude glycerol (84% glycerol and <100 mg of methanol/kg) in the first 3 phases (d 0 to 84) and then used food-grade glycerol (99.7% glycerol) in the fourth and final phase (d 84 to 105). In contrast, crude glycerol (82.2% glycerol and 136 mg of methanol/kg) was fed in all 4 phases of our study. Additional research is needed to determine the effect of purity of glycerol source on pig growth performance.

Carcass Characteristics

Whitney et al. (2006) reported a linear increase in the CV for final BW as DDGS was added to the diet. However, Drescher et al. (2009) observed no differences in the CV for final BW and HCW, which was similar to our results. The majority of the studies included in the review article of Stein and Shurson (2009) showed no effects of feeding DDGS on carcass characteristics of growing-finishing pigs. Results of the current study are consistent with those findings for pigs fed DDGS.

Kijora and Kupsch (2006) observed that pigs fed 10% crude glycerol had leaner carcasses than control pigs, but the authors attributed this to differences in growth rates during the finishing phase rather than to glycerol intake. In contrast, Stevens et al. (2008) reported a linear increase in 10th-rib backfat and a linear decrease in percentage fat free lean when dietary crude glycerol was fed. However, the present study data are consistent with other research (Kijora et al., 1997; Lammers et al., 2008; Schieck et al., 2010b), which showed that feeding dietary glycerol to finishing pigs did not alter carcass characteristics. A reason for the inconstancy among research reports is unknown. However, Stevens et al. (2008) used food-grade glycerol, which contains a greater percentage of glycerol than the glycerol used in other research; therefore, their glycerol-supplemented diets might have had greater energy concentrations that may have resulted in the fatter carcasses.

Carcass Fat Quality

It is widely accepted that fatty acid composition of the fat depots closely mimics fatty acid composition of the diet (Wiseman and Agunbiade, 1998; Averette Gatlin et al., 2002). This is mainly the result of dietary fats inhibiting de novo fatty acid synthesis in favor of direct deposition of dietary fatty acids in adipose tissue (Farnworth and Kramer, 1987; Chilliard, 1993). Thus, carcass fat composition can be manipulated by selecting dietary fat sources and feed ingredients on the basis of certain quality criteria. Carcass fat quality is important for meat processors mainly because of its effects on several processing and quality issues, especially for bacon production, retail packaging, product shelf life, and susceptibility to oxidative damage (Wood and Enser, 1997; NPPC, 2000a). Therefore, standards for pork carcasses based on different measures such as fat IV, PUFA:SFA, and belly firmness have been established to determine acceptable levels of fat quality.

One of the major issues in using greater amounts of DDGS in finishing diets is the effect on carcass fat quality. Soft carcass fat is indicative of greater dietary C18:2n-6 and PUFA concentrations, but this effect is mainly a result of a proportional decrease in SFA and changes in the distribution of fatty acids in fat tissues (Enser et al., 1984). This was observed in the current study, in which adding 20% DDGS to the diet increased

linoleic acid (C18:2n-6), PUFA, and PUFA:SFA and reduced oleic acid (C18:1c9), palmitic acid (C16:0), and SFA concentrations in all fat depots. These results also conform to those of Benz et al. (2010) and Xu et al. (2010). Thus, feeding ingredients greater in unsaturated fats, such as DDGS, changes the proportion of fatty acids in adipose tissues.

Carcass fat IV provides an overall estimate of fatty acid unsaturation, which can serve as an indicator of the percentage of UFA, softness of fat, or potential rancidity (Hugo and Roodt, 2007). As expected, pigs fed DDGS had greater carcass fat IV than those fed diets without DDGS, which is consistent with numerous studies (White et al., 2007; Hill et al., 2008; Stender and Honeyman, 2008). The current study showed an increase of approximately 4.5, 6.3, and 6.9 g/100 g in jowl fat, belly fat, and backfat IV, respectively, when 20% DDGS was included in the diet. Benz et al. (2010) showed an increase of approximately 1.6, 2.2, and 2.3 g/100 g in jowl fat, belly fat, and backfat IV, respectively, for every 10% increase in DDGS in the diet. Both studies indicate that jowl fat IV increased at a slower rate relative to belly fat and backfat IV as DDGS increased in the diet. In the present study, all diets contained 3% choice white grease. It has been shown that feeding 5.0% choice white grease for 83 d before slaughter increased IV values by 3.0 and 4.4 g/100 g in jowl and backfat, respectively (Benz et al., 2011). However, no previous data are available to indicate the response to carcass fat quality would be altered depending on whether added fat was included or not in diets containing glycerol.

In the present study, we observed limited differences for fat to be more saturated in pigs fed crude glycerol in jowl fat, backfat, or belly fat. Mourot et al. (1994) observed that finishing pigs fed glycerol had increased oleic acid and decreased linoleic and linolenic acid in backfat, which resulted in a greater degree of saturation. Schieck et al. (2010b) also reported that pigs fed 8% glycerol tended to have a greater degree of belly firmness compared with pigs that were not fed glycerol. We hypothesized that adding crude glycerol to finishing diets with DDGS may ameliorate the negative effects of DDGS on carcass fat IV. However, we observed only numerical reductions (0.7 to 2.1 percentage units) in belly fat and backfat IV. One reason for the lack of a larger change could be the inclusion level of crude glycerol used (2.5 to 5%) in the present study compared with previous research in which differences were found.

In conclusion, feeding 20% DDGS to finishing pigs increased ADFI, reduced G:F, and increased carcass fat IV, whereas feeding crude glycerol did not influence growth performance or carcass characteristics. Also, we observed minor differences for carcass fat to be more saturated in pigs fed crude glycerol. Both of these biofuel coproducts can be used in combination without affecting finishing pig performance or carcass characteristics, but feeding crude glycerol did not mitigate the increased unsaturation of carcass fat observed when feeding DDGS.

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