



Short communication

Biofuel co-products as swine feed ingredients: Combining corn distillers dried grains with solubles (DDGS) and crude glycerin

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ABSTRACT

The objective of this study was to examine the effects of combining corn DDGS with crude glycerin on growth performance and carcass traits to determine if a high level of crude glycerin supplementation could counteract the impact of corn DDGS on fatty acid profile of pork adipose. The experimental design was a 3×2 factorial arrangement of treatments with three levels of corn DDGS (0, 150, or 250 g/kg diet) and two levels of crude glycerin (0 or 100 g/kg diet). Pigs were fed one of six experimental diets over a 3-phase feeding program for 84 d with each diet within phase formulated to be equal in metabolizable energy (ME) and standardized ileal digestible lysine (SID Lys). Pigs and feeders were weighed every 14 d to determine average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (G:F). On d-84, pigs were weighed and scanned using real-time ultrasound to obtain fat depth and longissimus dorsi muscle (LM) area. Pigs were then harvested at a commercial abattoir and a sample of adipose was collected from the jowl of each pig. Because there was no interaction between level of corn DDGS and crude glycerin fed, only main effects are presented. Pig performance and carcass characteristics were not affected by dietary treatment ($P \geq 0.05$). Differences in fatty acid composition were present due to dietary treatment. Increasing the level of corn DDGS reduced concentration of both saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) and increased the concentration of polyunsaturated fatty acids (PUFA) in pork jowl adipose ($P < 0.01$). Pigs fed 100 g crude glycerin/kg diet had higher concentrations of MUFA and lower concentrations of PUFA ($P < 0.05$). Diets containing up to 250 g corn DDGS/kg and 100 g crude glycerin/kg support growth of finishing pigs. However, increasing dietary levels of corn DDGS increased the concentration of unsaturated fatty acids in pork jowl adipose and this was not ameliorated by feeding 100 g/kg crude glycerin.

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Abbreviations: ADFI, average daily feed intake; ADG, average daily gain; BW, body weight; d, day; CP, crude protein; DDGS, dried distillers grains with solubles; EE, ether extract; G:F, feed efficiency (ADG/ADFI); LM, longissimus dorsi muscle; Lys, lysine; ME, metabolizable energy; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; SBM, soybean meal; SID, standardized ileal digestibility; Thr, threonine; Trp, tryptophan.

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1. Introduction

Traditional, energy-rich feedstuffs for pigs such as corn and soybean oil are also the most common feedstocks for production of biofuels in the United States. Biofuel production from traditional pig feedstuffs results in generation of co-products that can be fed to pigs, specifically corn distillers dried grains with solubles (DDGS) from ethanol production and crude glycerin from biodiesel refining. As reviewed by [Stein and Shurson \(2009\)](#), the value of corn DDGS as a feedstuff for pigs has been examined for more than 60 years. In most cases, growing-finishing pigs fed diets containing limited amounts (≤ 250 g/kg) of corn DDGS have similar performance compared to pigs fed diets containing no corn DDGS ([Stein and Shurson, 2009](#)). Less research has been conducted examining feeding crude glycerin to pigs. However it has been demonstrated that crude glycerin from biodiesel refineries operating in the United States is a highly available energy source for growing pigs ([Lammers et al., 2008b; Kerr et al., 2009](#)). It has also been shown that pigs can be fed up to 100 g crude glycerin/kg diet with little or no effect on performance ([Kijora et al., 1995, 1997; Lammers et al., 2008a; Kerr et al., 2011](#)).

Oil is concentrated in corn DDGS and contains large amounts of unsaturated fatty acids ([Benz et al., 2010; NRC, 2012](#)). It has been shown that feeding increased amounts of corn DDGS to growing pigs increases the PUFA concentration particularly linoleic acid (C18:2), in pork adipose tissue ([Benz et al., 2010b; Xu et al., 2010a,b; Duttlinger et al., 2012](#)), resulting in softer pork fat which decreases the overall quality of the pork carcass ([NPB, 2000; Hilbrands et al., 2013](#)). Feeding 100 g crude glycerin/kg diet to growing pigs has been shown to decrease linoleic acid (C18:2) content of pork adipose ([Lammers et al., 2008a](#)). It has also been demonstrated that feeding 80 g crude glycerin/kg diet to pigs 8 wk prior to harvest improves pork belly firmness ([Schieck et al., 2010](#)). The objectives of the current study were to examine the effects of combining corn DDGS and crude glycerin on growth performance and carcass traits and to determine if a high level of crude glycerin supplementation could counteract the impact of corn DDGS on fatty acid profile of pork jowl adipose.

2. Materials and methods

2.1. Experimental design

All procedures were approved by the Iowa State University Animal Care and Use Committee. One hundred and forty-four pigs, initial body weight (BW) 39.5 ± 0.5 kg, were allotted to 36 pens (4 pigs/pen) with sex distribution and pen weight balanced at the start of the experiment. One of six dietary treatments was randomly assigned to each pen with six replications per treatment. Diets were corn–soybean meal (SBM) based with different levels of crude glycerin and corn DDGS. The experimental design was a 3×2 factorial arrangement of treatments with three levels of corn DDGS (0, 150, 250 g/kg) and two levels of crude glycerin (0 or 100 g/kg).

2.2. Diet formulation

Laboratory analysis was used to estimate standardized ileal digestible (SID) amino acid profile of corn DDGS and to calculate the metabolizable energy (ME) content of corn DDGS and crude glycerin used in the experiment. The corn DDGS laboratory analysis was 114, 112, and 22 g/kg total Lys, Thr, and Trp, respectively on a dry matter (DM) basis. Based on [Pahm et al. \(2008\)](#) it was assumed that the SID of Lys, Thr, and Trp was 68.5%, 74.7%, and 70.8%, respectively. Thus the calculated SID Lys, Thr, and Trp content for the corn DDGS used in this experiment was 78.1, 83.7, and 15.6 g/kg DM. The ME content of corn DDGS used in this experiment was estimated as 14.24 MJ/kg ([Honeyman et al., 2007](#)). When corn DDGS was added to the corn–SBM diets the approximate substitution was: add 100 kg corn DDGS, 1.85 kg ground limestone, and 0.15 kg L-lysine–HCl; remove 76 kg corn, 23 kg SBM, and 3 kg dicalcium phosphate.

The crude glycerin used in this experiment was 834 g glycerin/kg and contained 21.1 g sodium/kg on an as fed basis. Based on [Lammers et al. \(2008b\)](#) the ME content of crude glycerin used in this experiment was estimated as 13.22 MJ/kg as fed. When crude glycerin was added to the corn–SBM diets in the current experiment the approximate substitution was: add 100 kg crude glycerin and 8 kg SBM; remove 104 kg corn and 4 kg salt.

2.3. Experimental procedures

Pigs were fed diets over a 3-phase feeding program during the 84 d trial. Diets were offered *ad libitum* and in meal form. Within each phase, diets were formulated to be similar in ME, SID Lys, Thr, and Trp, available phosphorus, and total Na and Cl. Diet formulation and calculated nutrient content by phase are presented as [Table 1](#).

Pigs were individually weighed every other week with feed disappearance recorded at the time of weighing to determine ADG, ADFI, and G:F. Dietary phase changes corresponded with the day pigs were weighed, occurring on the same day for all treatments. Pigs were housed in partially slatted finisher pens (2.7 m \times 1.8 m) within a mechanically ventilated finishing room. On d 84, all pigs were weighed (124.7 ± 1.4 kg of BW) and scanned using real-time ultrasound as described by [Sullivan](#)

Table 1Initial diet formulation and calculated analysis of diets by phase, as fed basis.^a

Ingredient	Phase 1	Phase 2	Phase 3
Corn	73.30	78.50	83.50
Soybean meal	23.80	19.00	14.20
Corn DDGS ^b	0	0	0
Crude glycerin	0	0	0
L-Lysine–HCl	0.11	0.07	0.06
Dicalcium phosphate	1.20	0.92	0.73
Ground limestone	0.79	0.71	0.71
Sodium chloride	0.40	0.40	0.40
Vitamin and mineral mix ^c	0.40	0.40	0.40
ME, MJ/kg	13.8	13.9	13.9
Crude protein, g/kg ^d	17.5	15.6	13.7
Ether extract, g/kg ^e	29.1	30.2	31.2
SID Lys, g/kg	8.2	7.0	5.8
SID Thr, g/kg	5.7	5.0	4.3
SID Trp, g/kg	1.8	1.5	1.3
Available Phosphorus, g/kg	2.9	2.1	1.9
Sodium, g/kg	2.0	2.0	2.0
Chloride, g/kg	3.3	3.3	3.3

^a Experimental design was 2 × 3 factorial arrangement with two levels of crude glycerin (0 or 100 g/kg) and three levels of DDGS (0, 150, or 250 g/kg). When crude glycerin was added to basal diets in the current experiment the approximate substitution rate was: add 100 kg crude glycerin and 8 kg soybean meal; remove 104 kg corn and 4 kg salt. When DDGS was added to corn–soybean meal diets the approximate substitution was: add 100 kg DDGS, 1.85 kg ground limestone, and 0.15 kg L-lysine–HCl; remove 76 kg corn, 23 kg soybean meal, and 3 kg dicalcium phosphate.

^b DDGS, dried distillers grains with solubles.

^c Vitamin and mineral mix which provided the following per kilogram of diet: 5513 IU vitamin A; 29 IU vitamin E; 42 mg niacin; 22 mg D-pantothenic acid; 8 mg riboflavin; 17 mg Zn as ZnO; 210 mg Fe as Fe₂SO₄; 1 mg Cu as CuO; 54 mg Mn as MnO₂; 2.4 mg I as Cal; and 0.18 mg Se as Na₂SeO₃.

^d Crude protein (CP) content of experimental diets ranged from 17.0 to 20.5; 15.1 to 18.6; and 13.2 to 16.8 g/kg of diet for phase 1, 2, and 3, respectively. In all cases, the lowest CP content was found in diets containing 0 g/kg DDGS × 100 g/kg crude glycerin and the highest CP content was found in diets containing 250 g/kg DDGS × 0 g/kg crude glycerin.

^e Ether extract (EE) content of experimental diets ranged from 25.6 to 49.4; 26.7 to 50.5; and 27.7 to 51.4 g/kg of diet for phase 1, 2, and 3, respectively. In all cases the lowest EE content was found in diets containing 0 g/kg DDGS × 100 g/kg crude glycerin and the highest EE content was found in diets containing 250 g/kg DDGS × 0 g/kg crude glycerin.

et al. (2007). Pigs were harvested at a commercial abattoir and a sample of adipose was collected from the jowl of each pig. Fatty-acid profile analysis was performed as described by Lammers et al. (2008a).

2.4. Statistical analysis

Treatments were arranged as a 3 × 2 factorial and data were subjected to ANOVA using JMP 11.0 (SAS Inst. Inc., Cary, NC). For all parameters (growth performance, scanned carcass attributes, and fatty acid profile of jowl adipose) a pen of four pigs was considered the experimental unit. Results were considered significant at $P \leq 0.05$. When differences were observed, means were compared using Tukey's HSD.

3. Results and discussion

Pig performance, carcass trait, and fatty acid composition of pork jowl adipose are summarized in Table 2. There was no interaction between level of corn DDGS and crude glycerin fed. This agrees with work by Duttlinger et al. (2012) who reported no interaction between corn DDGS fed at 0 or 200 g/kg and crude glycerin fed at 0, 25, or 50 g/kg. Similarly Lee et al. (2013) reported that combining 300 g corn DDGS/kg diet with 50 g crude glycerin/kg diet did not impact ADG, ADFI, or G:F as compared to feeding diets containing either 300 or 0 g/kg corn DDGS.

Pig performance and carcass characteristics were not affected by inclusion of corn DDGS ($P \geq 0.05$). Duttlinger et al. (2012) reported pigs fed 200 g corn DDGS/kg diet had larger ADFI compared to pigs fed 0 g/kg, but this was not observed in the current study. Lee et al. (2013) reported that pigs fed 300 g corn DDGS/kg diet had smaller longissimus dorsi muscle (LM) than pigs fed 0 g corn DDGS/kg diet. In the current study there was a trend ($P = 0.06$) for pigs fed 150 or 250 g/kg corn DDGS to have smaller LM as compared to those fed 0 g/kg corn DDGS.

Pig performance and carcass characteristics were not affected by inclusion of crude glycerin ($P \geq 0.05$). This contrasts with other work showing improved ADG, ADFI, and G:F when feeding 80 g crude glycerin/kg diet for the final 8 wk of finishing (Schieck et al., 2010). Other studies have shown no change in pig performance or carcass characteristics when feeding crude glycerin (Lammers et al., 2008a; Duttlinger et al., 2012).

Differences in fatty acid composition of pork jowl adipose were present based on dietary treatment. Feeding 150 or 250 g corn DDGS/kg diet reduced concentration of palmitic acid, C16:0 and palmitoleic acid, C16:1 ($P \leq 0.01$). Pigs fed 250 g corn DDGS/kg diet had lower concentration of stearic acid, C18:0 and higher concentrations of oleic C18:1, linoleic C18:2, and linolenic C18:3 acids as compared to pigs fed 0 g/kg corn DDGS ($P < 0.01$). Total SFA concentration decreased with increasing

Table 2Performance, scanned carcass attributes and fatty acid profile of jowl adipose of pigs fed corn DDGS^a and crude glycerin.^b

	Corn DDGS, g/kg diet			Crude glycerin, g/kg diet		SEM	P-value ^c	
	0	150	250	0	100		DDGS	Glycerin
ADG, kg/d	1.03	0.99	1.01	1.03	1.01	0.02	0.27	0.34
ADFI, kg/d	2.89	2.80	2.87	2.89	2.94	0.09	0.72	0.71
G:F, g/g	0.36	0.35	0.35	0.36	0.34	0.01	0.86	0.17
10th rib back fat, mm	23.25	21.13	20.63	23.25	23.91	0.91	0.12	0.61
LM area, cm ²	49.86	46.48	47.01	49.86	48.12	1.06	0.06	0.25
Fatty acid, % of total fat								
C14:0	2.14 ^x	2.01 ^y	2.03 ^{xy}	2.14	2.12	0.04	0.03	0.63
C16:0	30.34 ^x	28.59 ^y	27.91 ^y	30.44	30.05	0.20	<0.01	0.31
C16:1	30.40 ^x	2.78 ^y	2.77 ^y	3.40	3.64	0.12	<0.01	0.15
C17:0	0.34	0.33	0.34	0.34	0.31	0.02	0.99	0.27
C17:1	0.31 ^x	0.28 ^{xy}	0.26 ^y	0.31	0.32	0.01	0.02	0.58
C18:0	14.36 ^x	13.61 ^x	12.53 ^y	14.36	13.68	0.28	<0.01	0.09
C18:1	38.91 ^x	37.23 ^y	35.35 ^z	38.91	40.81	0.45	<0.01	<0.01
C18:2	9.59 ^x	14.45 ^y	18.03 ^z	9.58	8.52	0.34	<0.01	0.03
C18:3	0.43 ^x	0.49 ^{xy}	0.55 ^y	0.43	0.37	0.02	<0.01	0.09
C20:4	0.18	0.21	0.22	0.18	0.18	0.01	0.07	0.91
SFA	47.19 ^x	44.55 ^y	42.81 ^z	47.19	46.15	0.38	<0.01	0.06
MUFA	42.62 ^x	40.29 ^y	38.39 ^z	42.62	44.78	0.47	<0.01	<0.01
PUFA	10.20 ^x	15.16 ^y	18.80 ^z	10.20	9.07	0.34	<0.01	0.03

^{xy} For main effects of corn DDGS inclusion, least square means within a row with different superscript are different (P-value <0.05).^a DDGS, dried distillers grains with solubles.^b 84-d feeding period with 10th rib backfat and LM areas based on ultrasound scan.^c There was no interaction between level of corn DDGS and crude glycerin (P-value >0.05).

corn DDGS inclusion (P<0.01) while both MUFA and PUFA concentration of pork jowl adipose increased with increasing corn DDGS inclusion (P<0.01). In an earlier study feeding increasing levels of corn DDGS also resulted in linolenic C18:2, total PUFA, and PUFA:SFA of pork jowl adipose to increase linearly (Benz et al., 2010).

Feeding diets containing 100 g crude glycerin/kg reduced (P<0.05) linoleic and linolenic acid concentrations as well as total MUFA and PUFA (P<0.05) in pork jowl adipose. In contrast, Duttlinger et al. (2012) did not find any changes in fatty acid composition of jowl adipose when feeding 25 or 50 g crude glycerin/kg. Although Schieck et al. (2010) did not measure individual fatty acid composition, belly firmness increased when pigs were fed diets containing 80 g/kg crude glycerin for the last 8 wk prior to harvest.

After processing of corn grain to ethanol, the fat content of the remaining corn DDGS is more than twice that of corn grain (NRC, 2012). Corn oil contains a large amount of unsaturated fatty acids, particularly linoleic acid (C18:2) and oleic acid (C18:1) (NRC, 2012). It has been shown that feeding increased amounts of corn DDGS to growing pigs increases the concentration of PUFA, particularly linoleic acid (C18:2) in pork adipose tissue (Benz et al., 2010; Xu et al., 2010a,b; Hilbrands et al., 2013). Increasing the percentage of unsaturated fatty acids in pork adipose results in softer pork fat which decreases the overall quality of the pork carcass (NPB, 2000).

Conceptually, substituting crude glycerin for corn grain in diets containing 250 g/kg corn DDGS, should reduce the total concentration of corn oil in the diet. Thus there may be potential for lessening some of the negative impacts to pork quality of higher levels of corn DDGS in finishing pig diets by adding high levels of crude glycerin. However no interaction between corn DDGS and crude glycerin (included at 100 g/kg) was detected in the current study or in two previous examinations of combining corn DDGS and lower levels of crude glycerin (Benz et al., 2010; Lee et al., 2013). It is unclear whether feeding higher levels of crude glycerin (>100 g/kg of diet) would be a suitable strategy for offsetting the increase of unsaturated fatty acids in pork jowl adipose resulting from feeding 250 g/kg corn DDGS.

4. Conclusions

Diets containing up to 250 g/kg corn DDGS and 100 g/kg crude glycerin support growth and performance of finishing pigs and can reduce consumption of corn grain in pork production. Increasing dietary levels of corn DDGS increased the concentration of unsaturated fatty acids in pork jowl adipose. Feeding diets containing 100 g/kg crude glycerin was insufficient to offset this impact. It is unclear whether increasing the inclusion of crude glycerin would ameliorate the negative impacts on pork adipose associated with feeding 250 g corn DDGS/kg diet or if this strategy is economical or practical for commercial production units.

Conflict of interest

The authors declare that there are no conflict of interests.

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References

- Benz, J.M., Linneen, S.K., Tokach, M.D., Dritz, S.S., Nelssen, J.L., DeRouche, J.M., Goodband, R.D., Sulabo, R.C., Prusa, K.J., 2010. Effects of dried distillers grains with solubles on carcass fat quality of finishing pigs. *J. Anim. Sci.* 88, 3666–3682.
- Duttlinger, A.J., DeRouche, J.M., Tokach, M.D., Dritz, S.S., Goodband, R.D., Nelssen, J.L., Houser, T.A., Sulabo, R.C., 2012. Effects of increasing crude glycerol and dried distillers grains with solubles on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. *J. Anim. Sci.* 90, 840–852.
- Hilbrands, A.M., Johnston, L.J., McClelland, K.M., Cox, R.B., Baidoo, S.K., Souza, L.W.O., Shurson, G.C., 2013. Effects of abrupt introduction and removal of high and low digestibility corn distillers dried grains with solubles from the diet on growth performance and carcass characteristics of growing-finishing pigs. *J. Anim. Sci.* 91, 248–258.
- Honeyman, M.S., Lammers, P.J., Hoyer, S., 2007. Distillers Dried Grains with Solubles. IPIC 11a. Iowa State Univ., Ames, Iowa, USA.
- Kerr, B.J., Weber, T.E., Dozier III, W.A., Kidd, 2009. Digestible and metabolizable energy content of crude glycerin originating from different sources in nursery pigs. *J. Anim. Sci.* 87, 4042–4049.
- Kerr, B.J., Shurson, G.C., Johnston, L.J., Dozier III, G., 2011. Utilization of crude glycerin in nonruminants. In: Montero, G., Stoytcheva, M. (Eds.), *Biodiesel—Quality, Emissions, and By-Products*. InTech, Croatia, pp. 365–380.
- Kijora, C., Bergner, H., Kupsch, R.-D., Hageman, L., 1995. Glycerol as a feed component in diets of fattening pigs. *Arch. Anim. Nutr.* 47, 345–360.
- Kijora, C., Kupsch, R.-D., Bergner, H., Wenk, C., Prabucki, A.L., 1997. Comparative investigations on the utilization of glycerol, free fatty acids, free fatty acids in combination with glycerol and vegetable oil in fattening pigs. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 77, 127–138.
- Lammers, P.J., Kerr, B.J., Weber, T.E., Bregendahl, K., Lonergan, S.M., Prusa, K.J., Ahn, D.U., Stoffregen, W.C., Dozier III, W.A., Honeyman, 2008a. Growth performance, carcass characteristics, meat quality, and tissue histology of growing pigs fed crude glycerin-supplemented diets. *J. Anim. Sci.* 82, 2962–2970.
- Lammers, P.J., Kerr, B.J., Weber, T.E., Dozier III, W.A., Kidd, Bregendahl, M.T., Honeyman, K., 2008b. Digestible and metabolizable energy of crude glycerol fed to pigs. *J. Anim. Sci.* 86, 602–608.
- Lee, J.W., Kil, D.Y., Keever, B.D., Killefer, J., McKeith, F.K., Sulabo, R.C., Stein, H.H., 2013. Carcass fat quality of pigs is not improved by adding corn germ, beef tallow, palm kernel oil, or glycerol to finishing diets containing distillers dried grains with solubles. *J. Anim. Sci.* 91, 2426–2437.
- NPB, 2000. Pork Composition and Quality Assessment Procedure. National Pork Board, Des Moines, IA, USA.
- NRC, 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, DC, USA.
- Pahm, A.A., Pedersen, C., Hoehler, D., Stein, H.H., 2008. Factors affecting the variability in ileal amino acid digestibility in corn distillers dried grains with solubles fed to growing pigs. *J. Anim. Sci.* 86, 2180–2189.
- Schieck, S.J., Shurson, G.C., Kerr, B.J., Johnston, L.J., 2010. Evaluation of glycerol, a biodiesel coproduct, in grow-finish pig diets to support growth and pork quality. *J. Anim. Sci.* 88, 3927–3935.
- Stein, H.H., Shurson, G.C., 2009. The use and application of distillers dried grains with solubles in swine diets. *J. Anim. Sci.* 87, 1292–1303.
- Sullivan, Z.M., Honeyman, M.S., Gibson, L.R., Prusa, K.J., 2007. Effects of triticale-based diets on finishing pig performance and pork quality in deep-bedded hoop barns. *Meat Sci.* 76, 428–437.
- Xu, G., Baidoo, S.K., Johnston, L.J., Bibus, D., Cannon, J.E., Shurson, G.C., 2010a. Effects of feeding diets containing increasing content of corn distillers dried grains with solubles to grower-finisher pigs on growth performance, carcass composition, and pork fat quality. *J. Anim. Sci.* 88, 1398–1410.
- Xu, G., Baidoo, S.K., Johnston, L.J., Bibus, D., Cannon, J.E., Shurson, G.C., 2010b. The effects of feeding diets containing corn distillers dried grains with solubles, and withdrawal period of distillers dried grains with solubles, on growth performance and pork quality in grower-finisher pigs. *J. Anim. Sci.* 88, 1388–1397.