Crude glycerol and cottonseed oil to control DDGS-induced soft pork fat

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Abstract

Feeding corn-soybean meal diets containing > 20% DDGS result in reduced fat firmness in pork carcasses. Soft fat creates difficulties for pork processors and may ultimately influence the amount of DDGS that can be fed to finishing pigs. Supplementing diets high in DDGS (40%) with cottonseed products or crude glycerol may improve pork fat firmness. Thus, knowing the effects of these ingredients on pig performance, carcass characteristics, and pork fat firmness may allow their use as nutritional tools to improve fat firmness. The objective of this study was to assess the effect of feeding crude glycerol or minimally-refined cottonseed oil on growth performance, carcass composition, and fat firmness of growing-finishing pigs. Mixed sex pigs (n = 216, average body weight = 52 lb) were blocked by body weight and allotted to one of 3 dietary treatments. Diets were formulated to satisfy the NRC (2012) nutrient requirements, and consisted of a basal corn-soybean meal-40% DDGS (CON), CON plus 5% minimally-refined cottonseed oil (COT), and CON plus 8% crude glycerol for the last 6 week before harvest (GLY). Amino acid:energy ratios were equal among dietary treatments within all 3 phases of the experiment but COT diets had higher fat and energy concentration than CON and GLY diets. Overall average daily feed intake of pigs fed COT was lower (5.07 vs. 5.45 and 5.49 lb) but growth rate was greater (2.05 vs. 1.94 and 1.92 lb/day) compared with pigs fed CON or GLY, respectively. The improved growth performance of COT-fed pigs was likely attributable to the greater energy concentration of cottonseed oil diets. Two days before harvest, carcass composition was estimated using real-time ultrasound. No significant differences were observed for dressing percentage (75.7, 76.3, and 75.3%), fat-free lean percentage (50.5, 49.7, and 50.0%), backfat depth (0.83, 0.89, 0.87 in) and loin muscle area (6.65, 6.85, 6.59 in^2) for CON, COT and GLY, respectively.

Two gilts from each pen (16/treatment; 48 total; BW = 264 lb) were harvested at the University of Minnesota's Andrew Boss Meat Lab. Bellies, backfat and jowl fat were collected for evaluation of fat firmness. Bellies were suspended perpendicularly on a smoke stick and belly flop angle was determined. Subjective fat firmness was determined for cores of belly, jowl, and backfat. Bellies were processed into bacon, and selected bacon slices were evaluated for shatter, shrink, and cooking loss. Dietary treatment had no effect on belly flop angle (6.21, 8.57, 6.06 degrees for CON, COT and GLY, respectively). Similarly, subjective fat firmness scores were not improved by feeding COT or GLY. Feeding GLY had no effect on IV of belly fat, jowl fat or backfat compared to CON. However, COT consistently increased IV of fat in the belly, jowl, and back probably due to the elevated unsaturated fat content of the COT diets compared to CON. In conclusion, pigs fed COT had improved growth performance, which was likely due to greater energy density of diets, but carcass composition was not affected by COT or GLY diets. Supplementing corn-soybean meal-40% DDGS diets with either minimally-processed cottonseed oil or crude glycerol did not improve belly fat firmness.

Introduction

Feed ingredient prices often drive pork producers to include very high levels (30 to 50%) of DDGS in diets for growing-finishing pigs. Such high inclusion rates of DDGS create very soft fat in the resulting pork carcasses due to the elevated concentration of unsaturated fatty acids. Soft pork fat causes great concern for pork processors. These processors are placing upper limits on iodine value (IV) of pork carcasses to limit the degree of softness they will accept in pork fat. These limits could lead to direct financial penalties in the form of carcass price discounts or mandates that lower levels of DDGS be included in swine diets. Mandated lower inclusion rates of DDGS in swine diets likely will increase feed costs for producers. Realizing these competing forces are in place, it is imperative that the industry find a dietary solution that will allow continued feeding of high levels of DDGS **and** maintain carcass IV at processor-acceptable levels. Earlier research in our group indicated that crude glycerol fed in corn-soybean meal based diets during the late finishing period improved belly firmness. This work needs to be repeated in the high DDGS-containing diets being fed today. Feeding cottonseed oil is a novel approach to DDGS-induced soft pork fat that shows potential. Cottonseed oil has a relatively high content of cyclopropene fatty acids which can decrease the transformation of saturated to unsaturated fatty acids in the body. By decreasing this transformation, we may be able to improve the firmness of fat in pigs fed high levels of DDGS. Over fifty years ago, icons in the field of livestock nutrition such as F. B. Morrison recognized that cottonseed products (oil and meal) made pork fat hard. For the past 50 years, this base knowledge has been forgotten. The study reported herein revisits this knowledge and applies it to our current challenges with pork fat quality. Cottonseed oil is not a common ingredient for swine diets but neither was DDGS until we learned more about its utility.

Objectives

Objective 1 - To determine the efficacy of feeding a relatively high level of crude glycerol in late finishing diets containing high concentrations of DDGS on performance and fat quality in growing-finishing pigs.

Objective 2 - To determine the effects of minimally processed cottonseed oil on growth performance and carcass fat firmness in growing-finishing pigs fed high levels of DDGS.

Procedures

Animal care and use procedures of this experiment were approved by the Institutional Animal Care and Use Committee of the University of Minnesota.

Animals, housing and diets

This experiment was conducted at the University of Minnesota's West Central Research and Outreach Center (Morris, MN).

Mixed sex grower pigs (n = 216; Duroc x (Yorkshire x Landrace)) were housed in a grower-finisher swine unit (9 pigs/pen) with initial body weight (53 ± 9 lb) as the blocking factor. Pens were assigned randomly within block to 1 of 3 dietary treatments in a randomized complete block design, resulting in 8 pens per treatment. The facility was a totally enclosed, environmentally-controlled finishing barn containing 24 pens. Pens (5.2 × 14.8 ft) had a totally slotted, concrete floor, 1 stainless steel feeder with 4 feeding spaces and 1 nipple drinker. Throughout the 108-d growing-finishing period, a three-phase feeding program was adopted based on body weight to match dietary nutrient concentration to the pigs' stage of growth. The targeted body weight for each phase was 55 to 120 lb, 120 to 200 lb and 200 to 265 lb. Experimental diets (Table 1) consisted of: 1) a basal corn-soybean meal diet with 40% DDGS (**CON**); 2) CON diet plus 5% minimally-refined cottonseed oil added throughout the experiment (**COT**); or 3) CON plus 8% crude glycerol added for the last 6 weeks before harvest (**GLY**). Diets were formulated based on standardized ileal digestible (SID) amino acids and available phosphorus. Diets were formulated to meet or exceed NRC (2012) nutrient recommendations. Pigs had *ad libitum* access to treatment diets and water throughout the experiment. Metabolizable energy (ME) of diets was not similar across treatments, however, the ratio of SID lysine to ME was kept constant across treatments.

Growth Performance

Pigs were weighed individually when dietary treatments were applied, every 2 weeks throughout the study, and when a diet change occurred. Body weight of individual pigs was used to calculate average daily gain for each pen. Feed disappearance on a pen basis was measured on each day pigs were weighed to calculate average daily feed intake (ADFI). Gain:Feed was calculated on a pen basis.

Carcass Characteristics

Real-time ultrasound was used to estimate 10^{th} rib backfat thickness and loin muscle area 2 days before slaughter. A trained technician performed the scanning procedures using an ALOKA 500V machine (Corometrics Medical Systems, Wallingford, CT) fitted with a 12.5 cm long, 3.5 MHz linear array transducer. The transducer was placed perpendicular to the dorsal midline at the 10^{th} rib for scanning. The computer software package, Quality Evaluation and Prediction (Iowa State University, Ames, IA), was used to measure depth of backfat and longissimus muscle (LM) area on digitized images.

Pigs were tattooed individually and final body weight was measured 2 days before harvest. Pigs were harvested at Natural Foods Holding, Sioux City, IA (n = 165) and at the Andrew Boss Laboratory of Meat Science (ABLMS), University of Minnesota, St. Paul, MN (n = 47), where hot carcass weight (HCW) was determined. Fat free lean percent was calculated according to National Pork Producers Council (NPPC; 2000): Fat-free lean % = {[5.7769 + (0.401 × HCW, lb) - (18.838 × ultrasound 10th rib backfat depth, inch) + (4.357 × ultrasound 10th rib LM area, $inch^2$) + (1.006 × sex) (barrow = 1, gilt = 2)] / HCW, lb} × 100. Dressing percentage was calculated as: dressing, % = (HCW, lb / final BW, lb) × 100.

Pork fat firmness and color

Two gilts (n = 47) closest to the mean body weight of each pen were selected for in-depth evaluation. Bellies from the right side of the carcasses were retrieved and belly width, weight and length were determined. Bellies were delimited into 2 rows (dorsal and ventral) and 4 columns (head to tail), and belly thickness, without skin, was determined by inserting a probe. Bellies were subjected to a belly flop angle firmness test. Bellies were placed perpendicularly on a smoke stick with the skin side down. Distance between the two drooping ends of the belly was determined. Belly length and distance between the drooping ends were used to calculate the firmness score. The firmness score was determined by the upper angle of the isosceles triangle formed by placing the belly on the smoke stick. The belly flop angle firmness score was calculated as: $\cos^{-1} \{[0.5 \times (\text{length}^2) – (\text{distance}^2)] / [0.5 \times (\text{length}^2)]\}$.

From each of the 47 carcasses, jowl, backfat and belly fat samples were retrieved, frozen, and stored at – 20 ºC until further analyses. As needed for each analysis, fat samples were allowed to thaw at room temperature. To assess subjective fat firmness of jowl, backfat and belly, a trained panelist ranked (1 = extremely soft to 5 = extremely firm) each fresh fat sample by compressing the sample between the thumb and the index finger. The belly fat samples were also ranked by 8 trained panelists for visual color according to the NPPC (2000) Japanese fat color scale (1 = white to 4 = yellow).

To assess objective fat firmness, cores of jowl, backfat and belly fat samples were compressed (skin side down) to 80% of the core thickness between upper and lower flat plates of the Shimadzu texture analyzer (model EZ-SX, Shimadzu, Corp., Jiangsu, China). Belly fat samples were selected to determine melting point temperature. Fat samples were melted in an oven and capillary tubes were filled with fat by placing the tube in contact with the melted fats. Filled capillary tubes were frozen in ice, and subsequently placed in a hot water bath to determine melting temperature.

Pork fat quality

Belly fat was used to determine thiobarbituric acid reactive substances (TBARS). Collected fresh belly fat samples were frozen in dry ice and shipped to the Agricultural Utilization Research Institute, Marshall, MN. The TBARS assay was performed according to the methods described by Tarladgis et al. (1960). Samples of jowl, backfat, and belly fat were frozen and shipped in dry ice to the University of Arkansas, Fayetteville, AR. Fatty acid analysis was performed according to Browne et al. (2013), using gas chromatography to separate fatty acid methyl esters. Iodine value (IV) was calculated according to the AOCS (1998) equation: $(0.95 \times [\Sigma 16{:}1]) + (0.86 \times [\Sigma 18{:}1]) + (1.732 \times [\Sigma 18{:}2]) + (2.616 \times [\Sigma 18{:}3]) + (0.785 \times [20{:}1]) + (0.723 \times [C22{:}1])$, where brackets indicate the weight percentage.

Bacon quality

Bellies were processed commercially into bacon. Briefly, bellies were injected with standard cure solution to target 110% of the green weight and cooked in a smokehouse. After cooking, bellies were transported back to ABLMS and weighed to determine cooked weight. Cook yield was calculated as: (cooked weight/green weight) x 100. Bellies were trimmed, peeled and sliced. From 5 equal longitudinal sections of the belly were selected 2 slices for bacon quality evaluation. Bacon slices had length and weight measured. Raw bacon slices received shatter scores (1 = no visual cracks to 6 = severe cracks) from 4 longitudinal locations by rolling the slices over the index finger as described by Rentfrow et al. (2003). Subsequently, bacon slices from each section were cooked on a flat griddle at 280 °F. Cooked bacon slices were weighed and length was measured to determine cooking shrink and cooking loss. Cooked bacon slices received distortion scores (1 = flat to 5 = completely curled) as described by Rentfrow et al. (2003).

Statistical analysis

Data were analyzed using PROC MIXED (SAS Inst. Inc., Cary, NC) in a randomized complete block design. The statistical model included dietary treatment as the fixed effect, and block and pens as random effects. Repeated measures in time were used to analyze growth performance and TBARS data. When repeated measures was used, the statistical model included dietary treatments and time as fixed effects, and block and pens as the random effects. Belly firmness was analyzed with belly thickness as a covariate. Pen was considered the experimental unit. Means were separated using the PDIFF option of SAS with the Tukey-Kramer adjustment for multiple comparisons. The standard errors calculated by PROC MIXED were averaged to calculate a pooled standard error for each trait.

Results

Overall, ADFI of pigs fed COT was less ($P < 0.01$) than pigs fed CON and GLY (Table 2). Pigs fed COT grew faster and had greater G:F than pigs fed CON and GLY diets. Final BW of pigs fed COT was greater ($P < 0.01$) than pigs fed CON or GLY. Consequently, pigs fed COT had greater ($P < 0.01$; Table 3) HCW compared with CON or GLY fed pigs. No differences were observed among dietary treatments for dressing percentage, fat-free lean percentage, backfat depth and loin muscle area. Neither COT nor GLY diets improved belly firmness as measured by the belly flop angle.

Subjective firmness scores of belly, jowl, and backfat were not different when comparing COT or GLY with CON (Table 4). The force required to compress belly fat cores to 80% of their original height tended to be less ($P = 0.07$) for GLY than for CON indicating somewhat softer fat. No differences were observed in compression of jowl fat and backfat for pigs fed CON, COT and GLY. Pigs assigned to COT had greater ($P < 0.01$) melting point of belly fat compared with pigs fed CON and GLY indicating that there may have been a slightly higher degree of saturation in these fat samples.

Belly fat of pigs assigned to COT had greater ($P < 0.05$) concentration of saturated fatty acids (SFA) and poly-unsaturated fatty acids (PUFA) and lower concentration of mono-unsaturated fatty acids (MUFA) compared with pigs fed CON or GLY (Table 5). In addition, COT-fed pigs displayed elevated concentrations of linoleic acid (C18:2) in belly fat compared with pigs fed CON or GLY. These shifts in fatty acid concentration of belly fat yielded increased (P < 0.05) IV of belly fat for pigs fed COT. Similar changes in fatty acid composition of jowl and back fat were observed. On d 7 post-mortem, TBARS concentration of belly fat was greater ($P < 0.05$; Table 6) for pigs fed COT compared with pigs fed GLY, but both were similar to CON.

No significant differences were observed for bacon shrinkage, bacon cooking loss, bacon shatter scores or bacon distortion scores across dietary treatments (Table 7).

Discussion

Growth performance

We are not aware of any previous studies that investigated the effects of feeding cottonseed oil on pig performance and carcass quality. Consequently, our results provide new information to the swine industry. Pigs fed COT grew faster and more efficiently than did pigs fed CON or GLY diets. We suspect this improved performance can be explained by the greater energy density of the COT diets compared with CON or GLY. Diets with elevated energy density decrease feed intake and improve rate and efficiency of growth in pigs (Smith et al., 1999; Apple et al., 2004; Cho and Kim, 2012). In our study, glycerol feeding had no effect on growth performance. However, the response of swine growth performance to glycerol feeding is conflicting among studies. Adding 10% crude glycerol to finishing pig diets can reduce ADG and efficiency of gain (Della Casa et al., 2009). However, in a study conducted by Schieck et al. (2010), glycerol inclusion of 8% throughout the growing-finishing period increased ADG and ADFI, but there was no effect when pigs were fed glycerol-containing diets only for 8 week before harvest. Other authors have reported no effect of glycerol feeding on growth performance of growing finishing pigs (Lammers et al., 2008; Duttlinger et al., 2012; Lee et al., 2013). The variable response of pigs to dietary crude glycerol may be explained by the variable concentration of glycerol in the crude glycerol used in these experiments (Kerr et al., 2009).

Carcass characteristics

Across treatments, all pigs were harvested on the same day at either Natural Foods or St. Paul. Since COT-fed pigs displayed faster ADG, they had greater final BW and consequently greater HCW than pigs assigned to the other treatments. However, no other carcass traits were affected by dietary treatment. Others (Le Dividich et al., 1987; Apple et al., 2004) have reported that pigs fed diets with different energy density can have similar carcass characteristics. The lack of response of carcass traits to glycerol feeding is in agreement with studies reported by others (Schieck et al., 2010; Duttlinger et al., 2012; Lee et al., 2013).

Belly firmness

Including more than 20% DDGS in growing-finishing pig diets decreases belly firmness (Whitney et al., 2006; Cromwell et al., 2011). Soft bellies are more difficult to process into bacon than firm bellies. Previous reports suggested that cottonseed oil (Ellis and Isbell, 1926) or crude glycerol (Mourot et al., 1994; Schieck et al., 2010) could improve belly firmness. Ellis and Isbell (1926) found much greater subjective fat firmness for pigs fed cottonseed oil compared with those fed corn oil. Belly firmness improved when feeding corn-soy diets containing 8% crude glycerol for 8 weeks before harvest (Schieck et al., 2010). However in these reports, the experimental diets did not include DDGS. Inclusion of high levels of DDGS in diets exacerbates problems with soft bellies so our intent was to study cottonseed oil and crude glycerol in diets that are known to create soft bellies. In this study, neither COT nor GLY diets improved belly firmness. In agreement with our results, other researchers reported that dietary glycerol had no effect on belly firmness (Lee et al., 2013) or fat quality (Duttlinger et al., 2012) when DDGS was included in the diet.

Carcass fat quality

Corn oil, which is abundant in DDGS, has high amounts of PUFA and linoleic acid that are deposited in pork fat. Increasing unsaturation of pork fat decreases pork fat firmness and consequently belly firmness (Xu et al., 2010). Pork processors use IV as a measure to describe the unsaturated to saturated fatty acid content of pork fat. Increasing concentration of DDGS in diets will increase pork fat PUFA and consequently the IV (Cromwell et al., 2011). High pork fat unsaturation is associated with soft pork fat, low melting point, and increased potential for lipid oxidation over time.

Cottonseed oil contains cyclopropene fatty acids (CPFA) which are known to inhibit the desaturase enzyme responsible for creating unsaturated fatty acids in the body (Nixon et al., 1977). Feeding CPFA supplied by cottonseed oil may decrease pork fat unsaturation, resulting in firmer pork fat and bellies. Ellis and Isbell (1926) found much lower IV and firmer fat when supplementing diets with cottonseed oil instead of corn oil. In our study, pork fat of pigs fed cottonseed oil had greater concentration of PUFA and linoleic acid and higher IV than pigs fed

CON. Although cottonseed oil has elevated levels of CPFA's which decrease manufacture of unsaturated fatty acids in the body, cottonseed also contains high levels of unsaturated fatty acids similar to the corn oil supplied by DDGS. The increased concentration of unsaturated fatty acids supplied by cottonseed oil likely masked the potentially positive effects of CPFA on fat firmness. The dietary concentration of CPFA in COT diets was not enough to compensate for the higher intake of PUFA. Pigs fed cottonseed oil did have a greater proportion of SFA and less MUFA which suggests that CPFA's may have reduced body synthesis of unsaturated fatty acids. We realize that dietary fat level and cottonseed oil inclusion in the diet were confounded in this experiment. Our intent was to study the efficacy of cottonseed oil in practical diets containing high concentrations of DDGS. Diets high in DDGS are commonplace in the swine industry so we wanted to evaluate if the simple addition of cottonseed oil to these diets would be effective in mitigating the soft fat problems associated with these diets.

Some studies have reported decreased unsaturation of carcass fat from pigs fed diets containing glycerol (Mourot et al., 1994; Lammers et al., 2008). However, in our study, glycerol feeding did not reduce unsaturation of pork fat. Our results are in agreement with other authors who showed that feeding glycerol to pigs had no effect on fatty acid composition of pork fat (Duttlinger et al., 2012; Lee et al., 2013). Pork fat firmness and fat oxidation are directly related to the fatty acid composition. Our study showed that feeding COT and GLY diets to pigs were not able to decrease pork fat unsaturation, and consequently, we observed no improvements in fat firmness and oxidative potential of pork fat.

In conclusion, neither minimally refined cottonseed oil nor crude glycerol additions to diets containing 40% DDGS increased belly firmness or reduced IV. Feeding crude glycerol diets had no impact on fatty acid composition of bellies. Including COT actually increased IV of carcass fat probably due to the added unsaturated fatty acids contributed by cottonseed oil which could not be overcome by the cyclopropene fatty acid content of the cottonseed oil. Neither cottonseed oil nor crude glycerol reduced pork fat oxidation based on the TBARS measurements.

Future Research Needs

The future of this line of research is currently uncertain. Back in 2011 when this project was proposed to the MN Corn Research & Promotion Council and AURI, there was much angst about the problem of soft pork fat caused by high-level DDGS feeding to finishing pigs. The corn and ethanol industries wanted DDGS to be used heavily in swine feeding. Pork producers wanted to be able to feed the cost-effective DDGS to finishing pigs to capture the economic benefits. But, pork processors were getting very wary of the quality of carcasses being produced by such feeding programs. Hence, there was a need for research to seek a solution. At that same time, a relatively small proportion of the ethanol producers were producing reduced oil DDGS by extracting corn oil prior to producing DDGS. Over the time period required to complete this project, the proportion of ethanol producers that are producing these lower-oil DDGS products have shifted from the minority to the majority of plants. Economic benefits to ethanol producers for extracting oil have transformed the market place such that most DDGS produced now is reduced oil DDGS (4 to 12% crude fat). With significant portions of the corn oil removed from DDGS, there is less of a concern with soft fat caused by feeding high dietary levels of DDGS.

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Table 1. Composition and calculated nutrient content of experimental diets (as-fed)[1]

	Phase I (55 to 120 lb)			Phase II (120 to 200 lb)			Phase III (200 lb to mkt)		
Item	CON	COT	GLY	CON	COT	GLY	CON	COT	GLY
Ingredient, %									
Corn, yellow dent	37.02	28.41	37.02	46.03	37.83	37.78	51.56	44.81	43.24
Corn DDGS	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Soybean meal, 46.5% CP	20.12	23.76	20.12	11.52	14.75	12.10	6.06	7.81	6.76
Cottonseed oil	-	5.00	-	-	5.00	-	-	5.00	-
Crude glycerol	-	-	-	-	-	8.00	-	-	8.00
Limestone	1.55	1.52	1.55	1.44	1.42	1.43	1.43	1.41	1.40
Salt	0.35	0.35	0.35	0.35	0.35	-	0.35	0.35	-
Monocalcium phosphate	0.28	0.28	0.28	0.04	0.03	0.07	-	-	-
VTM premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys hydrochloride	0.30	0.30	0.30	0.30	0.30	0.30	0.28	0.30	0.28
Tylan 40	0.125	0.125	0.125	0.05	0.05	0.05	0.05	0.05	0.05
Agrado Plus	-	-	-	0.02	0.02	0.02	0.02	0.02	0.02
Calculated composition									
Dry matter, %	87.58	88.22	87.58	87.45	88.09	87.64	87.35	87.97	87.54
ME, kcal/lb	1,480	1,594	1,480	1,488	1,603	1,478	1,490	1,605	1,480
CP, %	23.73	24.72	23.73	20.48	21.3	20.07	18.37	18.65	18.01
Crude Fat %	5.20	10.01	5.20	5.26	10.07	4.99	5.28	10.10	5.02
Total Ca, %	0.73	0.73	0.73	0.62	0.62	0.62	0.59	0.59	0.58
Total P, %	0.63	0.63	0.63	0.55	0.54	0.53	0.51	0.51	0.50
SID Lys, %	1.09	1.17	1.09	0.88	0.95	0.88	0.73	0.78	0.73
Linoleic acid (C18:2), %	2.57	5.03	2.57	2.66	5.12	2.53	2.71	5.19	2.59
Gossypol, %	-	<0.01	-	-	0.001	-	-	0.001	-
SID Lys:ME, g/Mcal	3.34	3.33	3.34	2.68	2.69	2.70	2.22	2.21	2.24

[1]CON = corn-soybean meal with 40% DDGS basal diet; COT = CON + 5% minimally refined cottonseed oil fed throughout the experiment; GLY = CON fed during the first 8 weeks, CON + 8% crude glycerol fed during the last 6 weeks of the experiment.

Table 2. Effect of dietary treatments on growth performance

Item	Dietary treatments[1]			Pooled SE	P Value
	CON	COT	GLY		
ADFI, lb	5.45[a]	5.07[b]	5.49[a]	0.13	<0.01
ADG, lb	1.94[a]	2.05[b]	1.92[a]	0.02	<0.01
G:F	0.36[a]	0.41[b]	0.35[a]	0.01	<0.01
Final BW, lb	262.2[a]	274.1[b]	261.5[a]	5.18	<0.01

[1]CON = corn-soybean meal with 40% DDGS basal diet; COT = CON + 5% minimally refined cottonseed oil fed throughout the experiment; GLY = CON fed during the first 8 weeks, CON + 8% crude glycerol fed during the last 6 weeks of the experiment.

[a,b]Means within a row with different superscripts differ (*P* < 0.05).

Table 3. Effect of dietary treatments on carcass characteristics and belly firmness

Item	Dietary treatments[1]			Pooled SE	P Value
	CON	COT	GLY		
Hot carcass wt., lb	198.2[a]	209.3[b]	196.7[a]	3.99	<0.01
Dressing percent	75.70	76.30	75.30	0.43	0.28
Fat-free lean, %	50.50	49.70	50.00	0.44	0.47
10th-rib backfat, in	0.83	0.89	0.87	0.04	0.28
LM area, sq. in.	6.65	6.85	6.59	0.16	0.29
Belly firmness, degrees[2]	6.21	8.57	6.06	0.95	0.16

[1]CON = corn-soybean meal with 40% DDGS basal diet; COT = CON + 5% minimally refined cottonseed oil fed throughout the experiment; GLY = CON fed during the first 8 weeks, CON + 8% crude glycerol fed during the last 6 weeks of the experiment.

[2]Belly firmness angle adjusted for belly thickness.

[a,b]Means within a row with different superscripts differ (*P* < 0.05).

Table 4. Effect of dietary treatments on fat firmness, subjective color scores and melting point

Item	Dietary treatments[1]			Pooled SE	P Value
	CON	COT	GLY		
Belly fat					
Subjective firmness scores[2]	4.67	4.22	4.45	0.17	0.22
Subjective color scores[3]	2.48	2.48	2.42	0.13	0.92
Compression, N[4]	0.0110[x]	0.0108[xy]	0.0106[y]	0.00	0.08
Melting point, °C	26.3[a]	30.4[b]	25.3[a]	0.86	<0.01
Jowl fat					
Subjective firmness scores	3.93	4.15	4.12	0.21	0.74
Compression, N	0.0107	0.0110	0.0107	0.00	0.31
Backfat					
Subjective firmness scores	3.25[ab]	2.64[a]	3.38[b]	0.19	0.05
Compression, N	0.0109	0.0109	0.0109	0.00	0.99

[1]CON = corn-soybean meal with 40% DDGS basal diet; COT = CON + 5% minimally refined cottonseed oil fed throughout the experiment; GLY = CON fed during the first 8 weeks, CON + 8% crude glycerol fed during the last 6 weeks of the experiment.

[2]Subjective firmness scores from 1 = very soft to 5 = very firm.

[3]Color scores from 1 = Pinkish white to 4 = dark red.

[4]Newtons of force

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[x,y]Means within a row with different superscripts differ ($P < 0.10$).

Table 5. Effect of dietary treatments on fatty acid composition of pork fat

	Dietary treatments[1]				
Item	CON	COT	GLY	Pooled SE	P Value
Belly fat					
SFA	37.49[a]	40.71[b]	37.77[a]	0.41	<0.01
MUFA	38.81[a]	23.65[b]	39.08[a]	0.54	<0.01
PUFA	22.68[a]	34.89[b]	22.14[a]	0.66	<0.01
18:2, wt %[2]	20.62[a]	32.58[b]	20.16[a]	0.63	<0.01
IV[3]	71.15[a]	78.57[b]	70.57[a]	0.72	<0.01
Jowl fat					
SFA	32.98[a]	36.60[b]	31.97[a]	0.48	<0.01
MUFA	41.00[a]	25.99[b]	43.54[a]	0.82	<0.01
PUFA	24.74[a]	36.50[b]	23.28[a]	0.79	<0.01
18:2, wt %	22.23[a]	30.04[b]	20.81[a]	2.19	0.02
IV	76.09[a]	82.75[b]	75.80[a]	0.85	<0.01
Backfat					
SFA	35.49	36.08	34.41	0.63	0.21
MUFA	36.62[a]	22.90[b]	38.40[a]	0.76	<0.01
PUFA	26.78[a]	40.21[b]	26.07[a]	0.87	<0.01
18:2, wt %	24.39[a]	33.27[b]	23.68[a]	2.87	0.03
IV	75.92[a]	86.60[b]	76.33[a]	1.08	<0.01

[1]CON = corn-soybean meal with 40% DDGS basal diet; COT = CON + 5% minimally refined cottonseed oil fed throughout the experiment; GLY = CON fed during the first 8 weeks, CON + 8% crude glycerol fed during the last 6 weeks of the experiment.

[2]C18:2 = Linoleic acid.

[3]IV = iodine value.

[a,b]Means within a row with different superscripts differ (*P* < 0.05).

Table 6. Effect of dietary treatments on thiobarbituric acid-reactive substance (TBARS) concentration in belly fat

	Dietary treatments[1]									
	Day 0[2]			Day 7						
	CON	COT	GLY	CON	COT	GLY	Pooled SE	Diet	Day	Diet*Day
TBARS, ng MDA eq/mg fat	0.09	0.09	0.10	1.25[ab]	1.44[a]	1.04[b]	0.06	0.01	<0.01	0.01

[1]CON = corn-soybean meal with 40% DDGS basal diet; COT = CON + 5% minimally refined cottonseed oil fed throughout the experiment; GLY = CON fed during the first 8 weeks , CON + 8% crude glycerol fed during the last 6 weeks of the experiment.
[2]Belly fat was analyzed in samples collected at harvest (day 0) and after 7 days of storage at 4ºC.
[a,b]Means within a row with different superscripts differ (*P* < 0.05).

Table 7. Effect of dietary treatments on bacon characteristics

	Dietary treatments[1]				
Item	CON	COT	GLY	Pooled SE	P Value
Cook shrink, %	13.48[xy]	11.01[x]	14.89[y]	1.22	0.07
Cook loss, %	37.83[xy]	36.09[x]	39.72[y]	1.45	0.08
Shatter scores[2]	2.22	2.22	2.22	0.11	0.99
Distortion scores[3]	1.43	1.59	1.49	0.11	0.57

[1]CON = corn-soybean meal with 40% DDGS basal diet; COT = CON + 5% minimally refined cottonseed oil fed throughout the experiment; GLY = CON fed during the first 8 weeks, CON + 8% crude glycerol fed during the last 6 weeks of the experiment.
[2]Shatter scores from 1 = no visual cracks to 6 = severe cracks.
[3]Distortion scores from 1 = flat slice to 5 = completely curled slice.
[x,y]Means within a row with different superscripts differ (*P* < 0.10).