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Substituting Corn Dried Distillers Grains for Cottonseed Meal in Lamb Finishing Diets: Carcass Characteristics, Meat Fatty Acid Profiles, and Sensory Panel Traits[1]

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Summary

The effects of replacing cottonseed meal (CSM) with corn dried distillers grains (DDG) on carcass characteristics, meat fatty acid profiles, and sensory panel traits were investigated in Rambouillet wether lambs. Lambs (n = 44) were individually fed ad libitum diets for 84 d containing DDG that replaced 0 percent (0DDG), 33 percent (33DDG), 66 percent (66DDG), or 100 percent (100DDG) of the CSM in a completely randomized design. Carcass characteristics, fatty acid profiles (weight percentage), and sensory panel traits from the LM were determined on 8 randomly selected wethers per diet. Carcass characteristics were not affected ($P > 0.14$) by diet. As DDG increased in the diet, extracted fat from the LM linearly increased ($P = 0.004$). The *trans*-9, 10, and 11 isomers of 18:1 and *cis*-vaccenic (18:1 *cis*-11) acid linearly increased ($P < 0.09$) in the LM, and linoleic (18:2 *cis*-9, *cis*-12) and arachidonic (20:4) acids linearly decreased ($P < 0.02$) as DDG increased in the diet. The CLA *cis*-9, *trans*-11 isomer quadratically increased ($P = 0.07$) in the LM as percentage of DDG increased in the diet. Increasing DDG in the diets quadratically affected ($P < 0.05$) cook-loss, initial and sustained juiciness, sustained tenderness, and flavor intensity. Meat from lambs fed 100DDG had less ($P = 0.01$) cook-loss and greater ($P < 0.04$) initial and sustained juiciness than meat from lambs fed 0DDG diet. Results indicated that partially or totally substituting DDG for CSM in lamb-finishing diets is acceptable and may enhance sensory traits.

Key Words: Carcass, Dried Distillers Grains, Feedlot, Lamb, Meat Fatty Acids, Sensory Panel Traits Introduction

Introduction

As quantity and availability of dried distillers grains (DDG) continues to increase (FAPRI, 2009), the livestock industry has responded by exploring more feed formulation uses for this nutrient-dense co-product. However, research to evaluate effects of feeding DDG on lamb-carcass characteristics, meat fatty acids (FA), and sensory panel traits is limited. Huls et al. (2006) reported that lamb-backfat (BF) thickness decreased, but other carcass characteristics remained similar when DDG with solubles replaced soybean meal and a portion of the corn in 90-percent concentrate diets. Schauer et al. (2008) fed lambs up to 60 percent DDG with solubles, which replaced all of the soybean meal and a portion of the barley, and reported only flank streaking and quality grade being affected.

Feeding DDG with or without solubles has resulted in variable affects on carcass characteristics, meat FA profiles, and sensory attributes in cattle (Koger et al., 2004; Gill et al., 2008; Depenbusch et al., 2009a; Depenbusch et al., 2009b). Evaluating FA profiles in ruminant-derived muscle tissue is important because some saturated FA in the human diet are directly related to elevated-blood cholesterol, which has been related coronary heart disease (Fletcher et al., 2005), and anti-carcinogenic effects of CLA have been reported (Belury, 1995). In addition, meat FA composition can affect sensory panel traits (Ponnampalam et al., 2001; Chung et al., 2006). For example, Crouse and Ferrell (1982) reported that flavor is highly correlated to 18:1 and 18:3 (r = -0.33 and 0.33, respectively) FA concentrations. Therefore, objectives were to evaluate effects of replacing cottonseed meal (CSM) with DDG on lamb-carcass characteristics, meat FA profiles, and sensory panel traits.

Materials and Methods

Animals and Management

Texas A&M University Institutional Animal Care and Use Committee approved the experimental protocol was approved (#2007-92). A detailed description of animals and management has been reported in a companion paper (McEachern et al., 2010). Briefly, Rambouillet wether lambs (n = 44; approximate age = 4 mo; initial BW = 28.8 kg ± 3.5 kg) were weighed at the beginning of the adaptation period 28 d before study initiation, stratified by BW, and randomly assigned to diets (n = 11 wethers per diet) and individual pens. Pelleted and isonitrogenous diets contained corn DDG that replaced 0 percent (0DDG), 33 percent (33DDG), 66 percent (66DDG), or 100 percent (100DDG) of the CSM (Table 1); Table 1 was previously reported in the companion paper (McEachern et al., 2010), but also included here for convenience. Lambs were individually fed *ad libitum* and once per day at 0800; daily feed offered to each lamb was the previous day's intake plus approximately 15 percent on a DM-basis.

Lambs were shorn 5 d before study initiation and on d 82. Lamb BW was recorded, and serum was collected from centrifuged blood on d 0, d 14, d 28, d 56, and d 84. Lamb growth, wool characteristics, and serum NEFA, urea N, and IGF-1 concentrations are presented in a companion paper (McEachern et al., 2010). On d 85, 8 lambs per diet were randomly selected, transported 0.5 km to the Angelo State University Food Safety and Product Development Laboratory (San Angelo, Texas), and slaughtered to evaluate carcass and sensory characteristics and meat FA profiles.

Sample Collection and Measurements

Feeds: Samples of diets were randomly collected on d 0, d 19, d 41, and d 69, dried at 55°C, ground to pass a 1-mm screen, and stored at -20°C. Samples of each diet were combined for d 0 and d 19 and for d 41 and d 69, thus chemical analyses were evaluated for two pooled sets of samples, averaged, and presented in Table 1. Nitrogen was analyzed by a standard method (AOAC, 2006) and CP calculated as 6.25 × N. Sodium borate-Na phosphate buffer and enzymatic digestion procedures were used to analyze soluble and degradable feed protein, respectively (Roe et al., 1990). Crude fat was measured by ether extraction (AOAC, 2006). The NDF and ADF were analyzed using Van Soest et al. (1991) procedures modified for an Ankom 2000 Fiber Analyzer (Ankom Technol. Corp., Fairport, N.Y.) without correcting for residual ash and using α-amylase. Sulfur was evaluated using a Leco (model SC-432, St. Joseph, Mich.) analyzer, and all other minerals were analyzed by a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma Radial Spectrometer (Thermo Instrument Systems, Inc., Waltham, Mass.). Corn DDG and diets were also evaluated for individual fatty acids as described in the following section.

Carcass Characteristics and Feed and Meat Fatty Acid Profiles: Detailed descriptions of carcass characteristics, feed and meat FA profiles, and sensory panel trait analyses have been previously reported (Whitney and Lupton, 2010). Following harvest, HCW was recorded and carcasses were chilled at 2°C ± 1°C. At 48 h postmortem, each carcass was ribbed between the 12th and 13th ribs for carcass evaluation. Carcasses were analyzed to determine BF thickness at the 12th rib, LM area, and circumference of both legs across the stifle joints on the intact carcass, maturity, and flank streaking (USDA, 1997). At 48-h postmortem, the loin (NAMP #232a) was removed according to procedures of NAMP (1997). Five chops, 2.54-cm thick, were cut from starting at the posterior end and stored 4 months at -80°C until analyzed; the first chop was designated for FA methyl ester analysis, and the other four chops were designated for sensory analysis.

Fatty acid methyl esters were prepared by direct esterification with methanolic KOH of muscle tissue and feed samples according to procedures of Murrieta et al. (2003). Fatty acid profiles of feed and meat samples were analyzed according to procedures reported by Boles et al. (2005). For each loin chop, 2 sub-samples were collected from cross-sections of the LM, including any residual intermuscular fat, freeze-dried, and ground in an electric coffee grinder. Meat moisture was determined before and after freeze-drying. From each of these samples, 2 sub-samples were again collected, analyzed, and averaged. The resulting FA methyl esters were then analyzed by GLC as described by Boles et al. (2005); FA concentrations were determined using the methods of Murri-

Table 1. Ingredient, chemical composition (% DM basis), and cost of corn dried distillers grains (DDG), cottonseed meal (CSM) and diets.

			Diet (% of CSM replaced by DDG)			
Item	DDG[2]	CSM[2]	0DDG	33DDG	66DDG	100DDG
Cottonseed hulls			25.0	25.0	25.0	25.0
DDG			–	6.6	13.2	20.0
CSM			20.0	13.4	6.8	–
Grain sorghum, crushed			47.40	46.95	46.51	46.04
Molasses			3.0	3.0	3.0	3.0
Limestone			2.0	1.85	1.69	1.54
Ammonium chloride			0.75	0.75	0.75	0.75
Salt			0.85	0.85	0.85	0.85
Urea			–	0.6	1.2	1.82
Mineral premix[1]			1.0	1.0	1.0	1.0
CP, %	22.5	50.8	18.8	17.9	18.7	19.0
Soluble protein, %	35.0	21.0	29.5	30.5	44.5	47.0
Degradable protein, %	49.0	49.0	57.5	45.5	60.5	68.0
Crude fat, %	4.4	5.3	4.6	5.0	4.6	5.2
NDF, %	41.8	17.0	25.4	26.6	25.2	27.1
ADF, %	14.5	14.0	14.9	17.5	14.3	15.0
TDN, %	71.0	76.0	85.0	85.0	85.5	85.0
Ca, %	0.10	0.34	0.83	1.02	0.86	1.00
P, %	0.80	1.66	0.44	0.48	0.41	0.44
Ca:P	0.13	0.21	1.89	2.13	2.10	2.27
Mg, %	0.30	0.86	0.25	0.26	0.22	0.22
K, %	1.13	1.76	0.89	0.91	0.84	0.88
Na, %	0.48	0.27	0.51	0.44	0.52	0.52
S, %	0.40	0.58	0.28	0.29	0.28	0.30
Fe, mg/kg	171	145	424	504	325	284
Zn, mg/kg	90.0	72.0	59.5	59.0	57.5	59.5
Cu, mg/kg	5.0	15.0	4.0	5.0	3.5	4.0
Mn, mg/kg	53.0	22.0	48.0	55.5	50.0	54.5
Mo, mg/kg	1.0	2.4	0.60	0.85	0.70	0.80
Cost $/metric ton	180.78	254.63	221.46	219.07	216.68	214.22
Cost $/kg of gain			1.14	1.23	1.21	1.13

[1] Mineral premix ingredients: sodium chloride, potassium chloride, sulfur, manganous oxide, zinc oxide, vitamins A, D, and E, calcium carbonate, CSM, cane molasses, and animal fat. Soluble and degradable protein fractions = % of CP. Cost/metric ton of feed estimated using information from local markets and current Feedstuffs magazines: cottonseed hulls ($116), DDG ($181), CSM ($255), milo ($240), molasses ($265), limestone ($198), ammonium Cl ($1086), salt ($243), urea ($695), mineral premix ($591). Cost of feed kg-1 gain = ([Cost/metric ton of feed/1000] × [feed/gain]).
[2] The random sample of DDG that was used in the diets was collected when feed was pelleted; the random CSM samples were from a different source than that used in the diets.

eta et. al. (2003) with tridecanoic acid (C13:0) methyl ester added before extraction as an internal standard. The FA percent was calculated on dry-weight basis by using the recovery of an internal standard as follows: [(1 mg of internal standard × total area under curve for all peaks)/(area under standard peak/sample weight)] × 100, and then converted to fresh-tissue basis. Known FA averaged 94.6 percent of total extracted fat (CV = 1.5 percent).

Sensory Panel Evaluation: A trained sensory panel (6 to 7 members; Cross et al., 1978) evaluated chops cut from the loin section (AMSA, 1995). Randomly selected chops were allowed to thaw for 24 h at 2°C ± 1°C and cooked on a clam-shell-style grill (Kerth et al., 2003) for 7 min. Samples were trimmed to less than 0.64 cm of outside fat and connective tissue, cut into 1.27-cm × 1.27-cm portions, and placed in warming pans until served to panelists. Chop samples were evaluated for initial and sustained juiciness, initial and sustained tenderness, and flavor intensity on a scale of 1 to 8, where 1 = extremely dry, tough, and bland, and 8 = extremely juicy, tender, and intense, respectively. Additionally, chops were evaluated for off-flavor, where 1 = extreme off-flavor and 4 = no off-flavor. Samples from each chop were evaluated by panelists who were secluded in partitioned booths with a controlled level of red incandescent light. A "warm-up" sample chop was served at initiation of each sensory session, followed by 6 to 8 chop samples per session. Panelists were instructed to cleanse their palate with a salt-free saltine cracker and water before each sample.

Statistical Analyses

Data were analyzed using the PROC MIXED procedure (SAS Inst. Inc., Cary, N.C.). Lamb carcass characteristics, meat moisture, and sensory panel traits were analyzed using a model that included diet with lamb as the experimental unit. Fatty acid data were analyzed using a model that included diet with meat subsample (n = 2; using lamb within diet as the subject) as the random effect and lamb as the experimental unit. Data are reported as least-square means with greatest standard errors. Diet effects were tested using the following single degree of freedom non-orthogonal contrasts: 1) linear and 2) quadratic effects of replacing CSM with DDG, and 3) 0DDG vs. 100DDG. PROC IML was used to generate coefficients for contrasts with unequal spacing (DDG replacing 0 percent, 33 percent, 66 percent, 100 percent of the CSM). Only the highest order contrast that was significant ($P < 0.10$) was discussed. Correlations were evaluated using the Spearman correlation procedure.

Results and Discussion

Chemical and Fatty Acid Composition of Diets

Chemical composition of DDG, CSM, and diets are presented in Table 1 and have previously been reported (McEachern et al., 2010); FA profiles of DDG and diets are presented in Table 2. Diets contained relatively similar CP, but soluble and degradable CP increased with increasing concentration of DDG in the diet. All diets were formulated to be isonitrogenous and for this purpose, feed urea was added to the diets. In addition, crude fat was 0.6 percentage units greater in 100DDG vs. 0DDG. Percentage of oil increased (except for 66DDG) and percentages of 16:0 and total saturates decreased as percentage of DDG increased in the diet. The DDG contained a high concentration of 18:2, which agrees with values reported for DDG with solubles (Harfoot, 1981); however, this did not result in 18:2 greatly increasing in the diets as percentage of DDG increased.

Table 2. Fatty acid (FA) profile of corn dried distillers grains (DDG) and diets.

		Diet (% of CSM replaced by DDG)[2]			
Item[1]	DDG	0DDG	33DDG	66DDG	100DDG
Oil, % of DM	3.3	4.2	4.6	4.2	4.7
FA, % of oil					
C16:0	11.9	16.5	15.9	15.7	14.8
C18:0	2.3	2.1	2.2	2.1	2.3
C18:1	25.3	26.2	26.1	26.7	26.2
C18:2	53.6	48.7	49.5	49.3	49.3
C18:3	1.9	1.5	2.0	1.5	2.1
C20:0	0.5	0.3	0.4	0.3	0.4
C20:1	0.4	0.3	0.3	0.3	0.3
C22:1	0.2	0.2	0.4	0.2	0.3
C24:0	0.4	0.2	0.2	0.2	0.2
Total SFA, %	15.2	19.4	19.1	18.5	17.9

[1] The FA expressed as a percentage of total FA.

Carcass Characteristics

The use of DDG as an alternative for CSM in Rambouillet wether diets had no affect ($P > 0.13$) on carcass characteristics (Table 3). Lambs could have been harvested earlier because slaughter live weight (SLW) and BF thickness of all lambs were greater than what has been suggested for the sheep industry (Snowder et al., 1994). Huls et al. (2006) reported that BF thickness declined, but all other carcass characteristics were similar for lambs fed diets containing 23 percent DDGS vs. no DDGS. Schauer et al. (2008) showed that increasing DDGS in diets up to 60 percent did not affect lamb carcass characteristics, except for increased flank streaking and USDA quality grade. Similar results have been reported in cattle (Uwituze, 2008; Depenbusch et al. 2009b), but Depenbusch et al. (2009a) and Gordon et al. (2002a) reported that BF thickness declined as distillers grains increased in the diet. Research investigating the inclusion of DDG in lamb-finishing diets has shown no negative effect on carcass characteristics, thus it could serve as a plausible substitute for CSM in lamb-finishing diets.

Meat Fatty Acid Profiles

Concentrations of the weight percentages of FA methyl esters are presented in Table 3. Weight percentages of 14:0, 16:1, 18:0, and 20:0 acids were not affected by diet ($P > 0.19$), but 16:0 was greater ($P = 0.07$) in meat from lambs fed 0DDG vs. 100DDG. Feeding DDG to cattle has resulted in variable meat stearic FA responses (Gill et al., 2008; Depenbusch et al., 2009a). Total percentage of fat in LM tissue linearly increased ($P = 0.004$) as DDG increased in the diet, and LM from lambs fed 100DDG had 1.4 times greater fat than LM from lambs fed 0DDG.

Total-saturated FA concentrations were not different ($P > 0.22$) among diets, which agrees with others who reported similar meat saturated FA concentrations in cattle fed DDG with solubles. For humans, dietary intake of some saturated FA are directly linked to elevated concentrations of blood cholesterol, which can increase the risk for coronary heart disease (Fletcher et al., 2005), but 18:0 has been reported to be neutral in relation to human health (Grundy, 1989; Grundy, 1994; Pariza, 2004). Cobb (1992) suggested that stearic acid should be considered separately from other saturated FA when discussing dietary control of cholesterol. Therefore, saturated FA concentration was also evaluated in the current study without including 18:0. When 18:0 was excluded, saturated FA was less ($P = 0.09$) in meat from lambs fed 100DDG vs. 0DDG.

The 18:1 FA were the most abun-

Table 3. Effects of substituting corn dried distillers grains (DDG) for cottonseed meal (CSM) on carcass characteristics and meat fatty acid profile (FA; %, weight basis).

Item[2]	Diet (% of CSM replaced by DDG)				SEM	*P*-value[1]		
	0 DDG	33 DDG	66 DDG	100 DDG		Linear	Quad	0DDG vs. 100DDG
n	8	8	8	8				
Carcass characteristics								
Slaughter live wt., kg	49.0	50.3	50.7	49.4	1.4	0.83	0.37	0.87
HCW, kg	29.3	29.7	29.9	29.2	0.9	0.97	0.54	0.95
LM area, cm^2	15.8	15.4	14.8	16.4	0.7	0.69	0.14	0.54
Backfat, cm	0.76	0.6	0.6	0.5	0.1	0.23	0.90	0.22
Body wall, cm	2.16	2.31	2.18	1.93	0.15	0.21	0.19	0.27
Leg circumference, cm	67.19	67.75	67.88	67.63	0.86	0.71	0.64	0.72
Meat moisture, %	67.59	66.43	66.42	67.20	1.27	0.84	0.45	0.83
Meat fatty acids, %								
Myristic acid (14:0)	5.99	5.51	5.63	5.55	0.28	0.34	0.49	0.27
Palmitic acid (16:0)	26.87	25.76	26.34	25.90	0.39	0.17	0.38	0.07
Palmitoleic acid (16:1)	3.20	3.18	3.05	3.45	0.16	0.42	0.15	0.36
Stearic acid (18:0)	7.27	7.94	7.87	7.61	0.35	0.65	0.20	0.58
Oleic acid (18:1, *cis*-9)	33.24	35.26	33.61	34.89	0.72	0.30	0.62	0.10
trans-9,10,11 isomers of 18:1	2.55	2.94	4.20	4.24	0.27	<0.001	0.23	<0.001
cis-Vaccenic acid (18:1, *cis*-11)	1.41	1.45	1.45	1.51	0.04	0.09	0.81	0.07
CLA (18:2 *cis*-9 *trans*-11)	0.29	0.31	0.34	0.30	0.02	0.50	0.06	0.86
Linoleic (18:2, *cis*-9 *cis*-12)	11.47	10.10	9.89	8.67	0.64	0.006	0.94	0.005
Arachidic acid (20:0)	0.35	0.32	0.34	0.34	0.01	0.89	0.20	0.67
Arachidonic acid (20:4)	2.40	2.01	1.77	1.53	0.21	0.001	0.66	0.01
Fat, %	4.70	5.77	6.76	6.65	0.67	0.004	0.42	0.007
Saturated FA, %[3]	40.49	39.54	40.19	39.40	0.65	0.36	0.91	0.23
Saturated FA, %; no 18:0[4]	33.22	31.60	32.32	31.79	0.58	0.17	0.36	0.09

[1] Linear and quadratic (Quad) orthogonal polynomial contrasts.
[2] FA % was calculated on dry-weight basis by using the recovery of an internal standard as follows: [(1 mg of internal standard × total area under curve for all peaks)/(area under standard peak/sample weight)] × 100, and then converted to fresh-tissue basis.
[3] Saturated FA = all saturated FA (C14:0 to C20:0)
[4] Saturated FA, no 18:0 = all saturated FA excluding stearic acid (18:0).

dant of all FA, which agrees with previous reports (Kott et al., 2003; Boles et al., 2005; Juarez et al., 2008). Weight percentage of 18:1, *cis*-9 was greater ($P = 0.09$) in meat from lambs fed 100DDG vs. 0DDG. Or-Rashid et al. (2008) suggested that greater 18:1 *cis*-9 in ruminal fluid may indicate partial protection of 18:1 *cis*-9 from ruminal biohydrogenation. Even though ruminal fluid was not evaluated in the current study, FA composition of intramuscular fat can reflect ruminal FA profile (Vasta et al., 2009).

Weight percentage of 18:1 *cis*-11 isomer linearly increased ($P < 0.08$) as percentage of DDG increased in the diet and was greater ($P < 0.07$) in meat from lambs fed 100DDG vs. 0DDG. Total 18:1 *trans* isomers linearly increased ($P < 0.001$) as percentage of DDG increased in the diet and were greater ($P < 0.001$) in meat from lambs fed 100DDG vs. 0DDG. Greater dietary fat has resulted in greater total 18:1 *trans*-10 isomer in LM of sheep (Wynn et al., 2006). Crouse and Ferrell (1982) reported a negative relationship between muscle 18:1 and carcass fat, but no correlation ($P > 0.35$) was observed in the current study.

Increasing percentage of DDG in the diet quadratically increased ($P = 0.07$) *cis*-9, *trans*-11 CLA isomer and linearly decreased ($P = 0.007$) *cis*-9, *cis*-12 isomer of 18:2. Meat from lambs fed 0DDG had greater ($P = 0.005$) weight percentage of *cis*-9, *cis*-12 isomer of 18:2 than lambs fed 100DDG. Viapond et al. (1995) reported that feeding lambs malt distillers grains increased meat *cis*-9, *cis*-12 isomer of 18:2, but did not affect 16:0, 16:1, 18:0, or 18:1 FA. Feeding distillers grains to cattle increased meat n-6 FA concentrations (Gill et al., 2008), which is opposite of what was observed in the current study for *cis*-9, *cis*-12 isomer of 18:2 and 20:4.

The *cis*-9, *trans*-11 CLA isomer originates exclusively through the biohydrogenation pathway (BH) (Griinari et al., 2000), and BH can be reduced by increasing ruminal acidity (Harfoot and Hazelwood, 1997). Kim et al. (2007) suggested that greater *cis*-9, *cis*-12 isomer of 18:2 in lamb muscle tissue resulted from greater *cis*-9, *cis*-12 isomer of 18:2 escaping a more acidic ruminal environment. In addition, ruminal BH proceeds to a greater extent as NDF concentration increases (Sackman et al., 2003), which is related to cellulolytic microbes being the primary microbes involved in BH (Kelper and Tove, 1967). Depenbush et al. (2009a) reported that feeding DDG with solubles may favor cellulolytic bacteria in the rumen. Even though NDF did not linearly increase as percentage of DDG increased in the diet, ruminal pH may have increased, resulting in BH proceeding to a greater extent. However, DDG small particle size may reduce its effective fiber (Schingoethe, 2006) and feeding DDG with solubles has reduced ruminal pH (May, 2007; Uwituze, 2008). Furthermore, greater *cis*-9, *cis*-12 isomer of 18:2 escaping ruminal BH would result in less 18:0 in muscle tissue and lead to less 18:1 *cis*-9 (Kim et al., 2007), and greater 18:0 would be expected if more complete BH did occur (Vasta et al., 2009), which is in direct contrast to the current study. Additional research evaluating effects of feeding DDG on BH and other factors, i.e. ruminal-particle-passage rate, on muscle-tissue FA profile is warranted.

Sensory Panel Traits

Sensorial attributes for lamb chops are presented in Table 4. Incorporating DDG in the diet resulted in less cooking loss ($P < 0.004$). Initial- and sustained-juiciness scores quadratically increased ($P < 0.05$) in unison with greater DDG in the diet, and meat from lambs fed 100DDG had greater ($P < 0.04$) initial and sustained juiciness than meat from lambs fed 0DDG. Greater juiciness was also reported by Leupp et al. (2009), but not by Roeber et al. (2005) when analyzing sensory attributes of steaks from steers fed DDG. In addition, initial- and sustained-juiciness scores were not correlated ($P > 0.11$) to lamb BF or percentage of fat in LM, but was negatively correlated (r = -0.34, -0.56; $P = 0.06$, <0.001, respectively) to cook-loss. Cook-loss was also correlated (r = -0.35, $P = 0.04$) to sustained tenderness. Interestingly, initial-tenderness scores showed no effect due to DDG replacement ($P > 0.15$), but sustained-tenderness scores exhibited a quadratic response ($P = 0.04$) to DDG replacement.

Considering the linear increase in initial and sustained juiciness scores, tenderness would also be expected to linearly increase due to a halo effect as described by Roeber et al. (2000); increased sustained juiciness creating a generalized notion of increased tenderness by the panelists. Roeber et al. (2000) documented that consumers generalized displeasure in tenderness based on decreased juiciness of the sample. Initial (r = 0.74, 0.70, $P < 0.001$) and sustained (r = 0.68, 0.66; $P < 0.001$) juiciness was correlated to initial and sustained tenderness, respectively.

Flavor intensity of chops quadratically increased ($P = 0.003$), but off-flavor ratings were not affected by diet ($P = 0.14$). This mirrors results reported by Leupp et al. (2009) and Gordon et al. (2002b) who also observed increased flavor intensity with no effect on off-flavors. Perception of flavor intensity may also be a function of increased percentage of fat in the meat and greater initial and sustained juiciness. Flavor intensity was correlated to cook loss, initial and sustained juiciness, tenderness scores, off-flavor, and 18:1 *cis*-9 isomer (r = -0.43, 0.52, 0.60, 0.58, 0.56, -0.45, 0.43, respectively; $P < 0.02$). In contrast to the current study, a positive correlation between beef flavor and off-flavor intensity has been reported (Calkins and Hodgen, 2007).

Conclusions

Substituting DDG for CSM in lamb-finishing diets did not affect carcass characteristics. However, as DDG increased in the diet, percentage of total fat and fatty acid profile in muscle were affected; most notably an increase in the *trans* isomers of 18:1 and a decrease in *cis*-9, *cis*-12 isomer of 18:2. Results indicate that partially or totally substituting DDG for CSM in lamb finishing diets is acceptable and enhances juiciness, tenderness, and flavor intensity without affecting off-flavor of lamb meat.

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Table 4. Effects of substituting dried distillers grains (DDG) for cottonseed meal (CSM) on sensory panel traits of lambs chops.

	Diet (% of CSM replaced by DDG)					*P*-value[1]		
Item[2]	**0DDG**	**33DDG**	**66DDG**	**100DDG**	**SEM**	**Linear**	**Quadratic**	**0DDG vs. 100DDG**
cook-loss	23.3	18.3	19.6	20.0	0.9	0.03	0.004	0.01
initial juiciness	4.7	5.5	5.4	5.4	0.2	0.04	0.04	0.02
sustained juiciness	4.8	5.8	5.5	5.2	0.2	0.11	<0.001	0.03
initial tenderness	5.5	6.1	5.8	5.6	0.3	0.93	0.15	0.87
sustained tenderness	5.4	6.2	5.9	5.6	0.3	0.70	0.04	0.53
flavor intensity	4.9	5.6	5.3	5.0	0.1	0.98	0.003	0.60
off-flavor	3.9	3.8	3.9	3.9	0.1	0.59	0.14	0.86

[1] Linear and quadratic orthogonal polynomial contrasts.
[2] Cook-loss expressed as the % of weight loss from raw weight; initial and sustained juiciness and tenderness and flavor intensity scored on an 8-point scale (1 = extremely dry, tough, and bland, and 8 = extremely juicy, tender, and intense, respectively); off-flavor scored on a 4-point scale (4 = no off-flavor, 1 = extreme off-flavor).

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