Evaluating percentage of roughage in lamb finishing diets containing 40% dried distillers grains: Growth, serum urea nitrogen, nonesterified fatty acids, and insulin growth factor-1 concentrations and wool, carcass, and fatty acid characteristics[1]

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ABSTRACT: Effects of percentage of roughage on growth, serum urea N, NEFA, and IGF-1 concentrations and wool, carcass, and fatty acid (FA) characteristics were investigated in Rambouillet wether lambs (n = 33). Lambs were individually fed ad libitum pelleted diets for 98 d containing 40% dried distillers grains and other ingredients, with 10% (CSH10), 20% (CSH20), or 30% (CSH30) cottonseed hulls replacing an increasing amount of ground sorghum grain. Results indicated no interaction between diet and day for lamb BW, ADG, or G:F. Percentage of roughage did not affect lamb BW, even though ADG linearly increased ($P = 0.005$) as cottonseed hulls increased in the diet. Increasing percentage of cottonseed hulls in the diet linearly increased ($P < 0.001$) daily DMI, which resulted in a linear increase ($P = 0.001$) in degradable protein intake. All lambs had similar G:F: 0.200, 0.181, and 0.190 for lambs fed CSH10, CSH20, and CSH30 diets, respectively. Diet × day interactions were not observed ($P > 0.45$) for serum urea N, NEFA, or IGF-1 concentrations. Serum urea N linearly increased ($P = 0.005$) as percentage of cottonseed hulls increased in the diet. All lambs had similar NEFA concentrations, but serum IGF-1 linearly decreased ($P = 0.001$) as percentage of cottonseed hulls increased in the diet. Lambs had similar wool fiber characteristics except that average fiber curvature and SD of fiber curvature linearly increased ($P = 0.03$) as percentage of cottonseed hulls increased in the diet. Carcass characteristics and sensory panel traits were not affected ($P > 0.19$) by diet, except for body wall thickness (quadratic, $P = 0.03$) and a linear decrease in sustained tenderness ($P = 0.02$) as the percentage of cottonseed hulls increased in the diet. As cottonseed hulls increased in the diet, percentages of myristic and palmitoleic (linear, $P < 0.05$) and arachidic SFA (quadratic, $P = 0.03$) decreased and *cis*-9,*trans*-11 CLA increased (linear, $P = 0.007$). When sorghum grain and cottonseed hull prices are similar to those reported for this study, lamb feeders are advised to use the CSH30 diet vs. CSH10 or CSH20 diets because even though DMI was greater for lambs consuming CSH30 diet, those lambs had greater ADG and the least cost of feed·kg^{-1} of BW gain.

Key words: carcass, cottonseed hull, dried distillers grain, insulin-like growth factor-1, lamb, meat fatty acid

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INTRODUCTION

The current availability and price of dried distillers grains (**DDG**) and their ability to supply a good source of energy and protein (NRC, 2007) has increased the interest in using this product to decrease the cost of BW gain. Even though DDG with solubles have successfully been used in lamb rations at 60% of diet DM without negatively affecting growth or health (Schauer et al., 2008), concerns such as reduced DMI, growth, and feed efficiency remain among feeders because only a limited amount of research has evaluated the use of DDG in lamb diets. Roughages are used in high-concentrate diets to maintain rumen health and reduce digestive disorders (Mertens, 1997). Cottonseed hulls have reduced nutritive value compared with other ingredients (Hall and Akinyode, 2000), but their NDF and ADF is greater than most other roughage sources (NRC, 2007). Cottonseed hulls analyzed without the fiber, contained 5.63% condensed tannins (**CT**; Whitney and Muir, 2010), which can reduce degradability of protein (Yu et al., 1995) and carbohydrates (McLeod, 1974); thus,

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cottonseed hulls can potentially reduce rumen digestive disorders associated with feeds with increased protein and energy.

Increasing cottonseed hull concentration in high-concentrate diets can increase DMI (Kinser et al., 1988), but feeding an excessive amount of fiber can increase rumen fill and reduce DMI and animal growth (Mertens, 1997; Fimbres et al., 2002). In contrast, lamb ADG increased as roughage concentration increased in pelleted diets (Ross and Pavey, 1959). Considering that cottonseed hulls and DDG are currently less expensive than sorghum grain, a major feed component in lamb feedlot rations in the United States, the objective of this study was to determine if 30% cottonseed hulls can effectively be used in lamb finishing diets containing 40% DDG while concurrently reducing cost of feed·kg^{-1} of BW gain and without negatively affecting wool, carcass, or meat characteristics.

MATERIALS AND METHODS

The experimental protocol was approved by the Texas A&M University Institutional Animal Care and Use Committee.

Animals and Management

Rambouillet wether lambs (n = 33; approximate age = 4 mo; initial BW = 23.1 ± 2.3 kg) were weighed at the beginning of the adaptation period (i.e., 28 d before study initiation, stratified by BW, and randomly assigned to individual treatments (n = 11·treatment^{-1}). Lambs were diagnosed with coccidiosis during the adaptation period and were treated orally for 5 d with amprolium (Corid, Merial, Duluth, GA). On d 19 to 23, all lambs were again drenched daily with sulfamethazine (Sulmet, Fort Dodge, Fort Dodge, IA). Lambs received an ear tag and a subcutaneous injection of a clostridial vaccine (Vision7 with SPUR, Intervet Inc., Millsboro, DE). Lambs were randomly assigned to individual, completely covered dirt pens (2.44 × 2.97 m) with crushed limestone floors, automatic watering systems, and feed bunks. Pelleted diets (Table 1) were formulated to simulate feedlot finishing diets containing 40% DDG and 10% (**CSH10**), 20% (**CSH20**), or 30% (**CSH30**) cottonseed hulls replacing an increasing amount of ground sorghum grain. The sorghum grain was hammer-milled just before pelleting, but cottonseed hulls were not. Monensin (Rumensin 80, Elanco, Indianapolis, IN) was added to each diet at 22 g/t of feed. During the adaptation period, percentage of concentrate in the diet was gradually increased in nonamalgamated feed and pelleted diets were gradually introduced. Lambs were individually fed once daily at 0800 h with an approximate allowance of 15% refusals. Feed refusals were collected twice per week and weighed.

Lamb BW was recorded and blood serum collected on d 0, 14, 28, 56, and 84; BW was also recorded on d 98. Lambs were completely shorn 5 d before study initiation and on d 82. Lamb BW on d 84 and 98 was adjusted by adding final grease fleece weight to shorn BW; lamb BW on d 98 also included an additional 16 d of grease fleece growth weight calculated as [(final grease fleece weight/82 d) × 16 d]. Average daily gain and DMI were determined between days that BW was recorded. Daily degradable protein intake (**DPI**) was calculated for each lamb as {[(dietary CP × degradable CP/100)/100] × lamb daily DMI}. On d 100, 8 lambs per treatment were randomly selected and transported 0.5 km to Angelo State University Food Safety and Product Development Laboratory (San Angelo, TX) to evaluate sensory and carcass characteristics and meat fatty acid (**FA**) profiles.

Sample Collection and Measurements

Feeds and Laboratory Analysis. Samples of DDG were collected from random locations in the bulk DDG before feed mixing and pelletizing, which all occurred on 1 d. Cottonseed hull samples were randomly collected from a different source than that used in these diets. Samples of diets were randomly collected on d 0, 19, 41, and 69, dried at 55°C in a forced-air oven for 48 h, ground in a Wiley Mill (Arthur H. Thomas Co., Philadelphia, PA) to pass a 1-mm screen, and stored at −20°C. Samples of each diet were combined for d 0 and 19 and for d 41 and 69; thus, chemical analyses were evaluated for 2 pooled sets of samples, averaged, and presented in Tables 1 and 2. The CT in the diets were assayed for soluble, protein-bound, and fiber-bound fractions by methods described by Terrill et al. (1992). Samples were oven-dried and standards prepared as recommended by Wolfe et al. (2008). Nitrogen was analyzed by a standard method (990.03, 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 analyzed by ether extraction (2003.05, 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, NY) without correcting for residual ash and using α-amylase and Na sulfite. Ash was analyzed by a standard method (AOAC 942.05, 2006) and nonfibrous carbohydrates (**NFC**) calculated as (NFC = DM − CP − crude fat − ash − amylase-treated NDF OM; Mertens, 2002). Sulfur was evaluated by a Leco (model SC-432, St. Joseph, MI) 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, MA). The FA composition of feeds was analyzed according to procedures reported in Boles et al. (2005); details are described below.

Serum Collection and Laboratory Analysis. A 15-mL blood sample was collected 4 h after feeding from each lamb via jugular venipuncture using a non-

Table 1. Ingredients, chemical composition (%, DM basis), and cost of dried distillers grains (DDG), cottonseed hulls, and diets

Item[1]	DDG[2]	Cottonseed hulls[2]	Diet[3] CSH10	Diet[3] CSH20	Diet[3] CSH30
Ingredient					
Cottonseed hulls			10.00	20.00	30.00
DDG			40.00	40.00	40.00
Sorghum grain, crushed			41.44	31.60	21.75
Molasses			3.00	3.00	3.00
Limestone			2.91	2.75	2.60
Ammonium Cl			0.95	0.95	0.95
Salt			0.95	0.95	0.95
Mineral premix			0.75	0.75	0.75
Chemical composition					
Extractable condensed tannins, %	—	—	0.24	0.44	0.69
Protein-bound condensed tannins, %	—	—	0.34	0.44	0.55
Fiber-bound condensed tannins, %	—	—	0.48	0.43	0.52
Total condensed tannins, %	—	—	1.05	1.31	1.77
CP, %	22.5	6.6	16.0	16.4	16.8
Soluble protein, % of CP	35.0	32.0	38.5	34.5	35.0
Degradable protein, % of CP	49.0	34.0	51.0	46.5	46.0
Degradable protein, % of DM	11.0	2.2	8.2	7.6	7.7
Crude fat, %	4.4	0.9	4.7	5.1	5.0
NDF, %	41.8	80.0	26.1	33.4	37.6
ADF, %	14.5	69.5	11.8	14.1	18.7
ADL, %	—	—	4.3	4.8	4.8
Ash, %	3.85	2.78	5.64	6.73	6.19
NFC, %	31.3	12.6	53.2	45.2	40.6
TDN, %	71.0	33.0	85.0	83.0	81.5
ME, Mcal/kg	3.3	1.6	2.5	2.3	2.1
Ca, %	0.10	0.18	1.32	1.26	1.30
P, %	0.80	0.10	0.52	0.53	0.55
Ca:P	0.13	1.80	2.54	2.38	2.36
Mg, %	0.30	0.20	0.22	0.24	0.25
K, %	1.13	1.14	0.95	1.05	1.12
Na, %	0.48	0.02	0.62	0.64	0.63
S, %	0.40	0.09	0.32	0.35	0.35
Fe, mg/kg	171	58	286	304	246
Zn, mg/kg	90.0	14.0	69.0	73.0	70.0
Cu, mg/kg	5.0	5.0	4.0	4.0	4.0
Mn, mg/kg	53.0	17.0	49.0	57.0	52.5
Mo, mg/kg	1.0	0.4	0.9	1.1	1.0
Cost					
Cost$\cdot$t^{-1} of feed, $	180.78	115.74	213.91	201.16	188.41
Cost of feed$\cdot$kg^{-1} of BW gain, $	—	—	1.07	1.12	0.99

[1]Mineral premix ingredients: sodium chloride, potassium chloride, sulfur, manganous oxide, zinc oxide, vitamins A, D, and E, calcium carbonate, cottonseed meal, cane molasses, animal fat, and 22 g of monensin (Rumensin 80, Elanco, Indianapolis, IN)$\cdot$t^{-1} of feed. NFC: nonfibrous carbohydrates = (DM – CP – crude fat – ash – amylase-treated NDF OM). The ME of DDG and cottonseed hulls are from NRC (2007) and of diets are estimated from Small Ruminant Nutrition System, Version 1.8.7 (http://nutritionmodels.tamu.edu). Cost$\cdot$t^{-1} of feed estimated using information from local markets and current *Feedstuffs* magazines: cottonseed hulls ($116), DDG ($181), sorghum grain ($240), molasses ($265), limestone ($198), ammonium Cl ($1,086), salt ($243), mineral premix ($591). Cost of feed$\cdot$kg^{-1} of BW gain = [(cost$\cdot$t^{-1}/1,000) × (feed/BW gain)].

[2]The random sample of DDG that was used in the diets was collected just before mixing and pelleting; the random cottonseed hull sample was from a different source than that used in diets.

[3]Pelleted lamb finishing diets containing 40% DDG and 10% (CSH10), 20% (CSH20), or 30% (CSH30) cottonseed hulls replacing an increasing amount of ground sorghum grain.

heparinized Vacutainer collection tube (serum separator tube, gel, and clot activator; Becton Dickinson, Franklin Lakes, NJ). Blood samples were allowed to clot for approximately 45 min at room temperature and then centrifuged (Beckman Coulter TJ6 refrigerated centrifuge, Fullerton, CA) at 970 × g for 25 min at 4°C. Serum was decanted and frozen at −20°C for approximately 4 mo before being analyzed for serum urea N (**SUN**), NEFA, and IGF-1 concentrations. Serum urea N concentrations were analyzed using a commercial kit (Teco Diagnostics, Anaheim, CA) with intra- and interassay CV less than 3.7%. Serum NEFA concentrations were also analyzed using a commercial kit (NEFA C; Wako Chemicals, Neuss, Germany) with intra- and interassay CV less than 7.4%. Serum IGF-1 concentrations were determined by RIA using procedures of Berrie et al.

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

		Diet[2]		
Item[1]	DDG	CSH10	CSH20	CSH30
Oil, % of DM	3.3	3.8	4.7	4.8
FA, %				
C16:0	11.9	13.4	14.5	15.3
C18:0	2.3	2.1	2.1	2.3
C18:1	25.3	27.2	25.6	24.3
C18:2	53.6	50.6	51.9	52.2
C18:3	1.9	1.9	1.6	1.5
C20:0	0.5	0.4	0.4	0.4
C20:1	0.4	0.4	0.3	0.3
C22:1	0.2	0.2	0.2	0.2
C24:0	0.4	0.5	0.4	0.4
Total SFA, %	15.2	16.6	17.6	18.6

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

[2]Pelleted lamb finishing diets containing 40% DDG and 10% (CSH10), 20% (CSH20), or 30% (CSH30) cottonseed hulls replacing an increasing amount of ground sorghum grain.

(1995). Intra- and interassay CV for IGF-1 were 9.4 and 19.2%, respectively, with a 95% recovery rate.

Wool. Fleece and fiber measurements were made at the Texas AgriLife Research Center in the Wool and Mohair Research Laboratory, San Angelo. After grease fleece weights were obtained for each individual fleece, staples (n = 10) were removed from random positions in each fleece for staple strength (Agritest Pty. Ltd., 1988) and length measurements (ASTM, 2007b). The remainder of the fleece was then pressure-cored (32 × 13 mm cores, Johnson and Larsen, 1978) to obtain a 50-g random sample. Two 25-g subsamples were used to determine lab-scoured yield (ASTM, 2007a). One of the washed and dried duplicates was mini-cored (ASTM, 2008) to obtain a few milligrams of 2-mm snippets that represented the whole fleece. These snippets were washed in a Buchner funnel with 1,1,1-trichloroethane (10 mL) and acetone (10 mL), dried at 105°C for 1 h, and cooled and conditioned for 12 h in a standard atmosphere of 21 ± 1°C and 65 ± 2% relative humidity (ASTM, 2007c). Conditioned snippets were then spread onto microscope slides (7 × 7 cm) and measured for fiber diameter distribution (mean, SD, and CV), comfort factor (% fibers ≤ 30 μm), and average fiber curvature, SD, and CV, using an OFDA 100 (BSC Electronics, Ardross, Western Australia; Baxter et al., 1992; ASTM, 2008).

Carcass Characteristics and Feed and Meat FA Profiles. After slaughter, HCW was recorded and carcasses were chilled at 2 ± 1°C. At 48 h postmortem, each carcass was ribbed between the 12th and 13th ribs for carcass evaluation. Carcasses were analyzed by a trained evaluator to determine LM area, backfat thickness at the 12th rib (**BF**), body wall thickness, and circumference of both legs across the stifle joint (USDA, 1997). At 48 h postmortem, the loin (NAMP #232a) was removed from the left side of each carcass by deboning the LM from the thoracic vertebrae according to procedures of NAMP (1997). Five chops were cut from starting at the loin (posterior) end; the first chop was designated for FA methyl ester analysis, cut to straighten the LM face, vacuum-packaged separately, and stored at −80°C until analyzed. Consequently, four 2.54-cm-thick chops were then serially cut for sensory analysis, labeled, vacuum packaged separately, and stored at −10°C until analyzed.

Fatty acid profiles of feed and meat samples were analyzed according to procedures reported by Boles et al. (2005). 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). For each loin chop, 2 subsamples were collected from cross-sections of the LM, including any residual intermuscular fat, freeze-dried, and ground in an electric coffee grinder. From each of these samples, 2 subsamples were again collected and analyzed; thus, there were 4 analyses for each loin chop. The resulting FA methyl esters were then analyzed by GLC as described by Boles et al. (2005). The various FA were identified using standard samples from Nu-Chek-Prep (Elysian, MN), and concentrations were determined using the methods of Murrieta et al. (2003), with tridecanoic acid ($C_{13:0}$) methyl ester added before extraction as an internal standard. The 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 a fresh-tissue basis. Known FA averaged 93.6% (CV = 1.8%); data for unknown FA is not reported.

Sensory Panel Evaluation

A trained sensory panel (6 to 7 members; Cross et al., 1978) evaluated chops cut from the loin section (AMSA, 1995). Frozen chops were randomly selected, removed from the freezer, and allowed to thaw for 24 h at 2°C ± 1. Chops were removed from the vacuum package and cooked on a clam-shell-style grill (Kerth et al., 2003) for 7 min resulting in an internal temperature of 71°C. Samples were trimmed to less than 0.64 cm of outside fat and connective tissue, cut into 1.27-cm × 1.27-cm steak portions using a plastic grid, and placed in warming pans until served to the panelist. 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 that were secluded in partitioned booths with controlled levels 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

Lamb BW, ADG, daily DMI, G:F, SUN, NEFA, and IGF-1 were initially analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) and a model that included diet, day, and diet × day interaction as fixed effects with day as the repeated measure and lamb-within-diet as the subject. Only daily DMI and DPI had diet × day interactions ($P = 0.003$) and thus were analyzed by day. However, interactions were not a result of changes in treatment ranks; thus, only main effects are reported. Wool characteristics were analyzed using a model that included diet with lamb as the experimental unit. Average fiber diameter evaluated on a mid-side sample at the start of the study was initially used as a covariate for average fleece fiber diameter, and initial BW was used as a covariate for clean fleece weight, but covariates were removed because they did not significantly affect results. Wool production per unit of BW ($g \cdot kg^{-1}$) was calculated as clean wool production divided by final shorn BW. Nonnormal data were transformed using natural log (for BW) or arcsin square root (for G:F) functions. Covariance structures (compound symmetry, heterogeneous compound symmetry, and heterogeneous autoregressive order-1) were used to determine the most appropriate structure for each model. Fatty acid data were analyzed using the MIXED procedure and a model that included diet with meat subsample as the random effect and lamb as the experimental unit. Carcass and sensory panel data were analyzed using the GLIMMIX procedure of SAS with a model that included diet as the fixed effect and lamb as the experimental unit. Data are reported as least squares means with greatest SE. Single degree of freedom linear and quadratic orthogonal polynomial contrasts were used to compare treatment means; only the highest order contrast that was significant ($P < 0.05$) was discussed.

RESULTS AND DISCUSSION

Chemical Composition of DDG, Cottonseed Hulls, and Treatment Diets

As cottonseed hulls increased and sorghum grain decreased in the diets, soluble and degradable protein, NFC, and TDN declined and NDF and ADF increased. Dried distillers grains contained greater CP, degradable protein, ADF, NDF, crude fat, and TDN than previously reported for sorghum grain (NRC, 2007). Sorghum grain has been reported to contain 0.14% of total CT (Terrill et al., 1992); thus, increasing cottonseed hulls in the diet at the expense of sorghum grain was the primary factor that increased total, extractable, and protein-bound CT (Table 1). Extractable CT, which was almost 3 times greater in CSH30 than CSH10 diets, is more reactive in binding protein and carbohydrates than bound CT (McLeod, 1974; Barry and Manley, 1986). The greatest CT concentration in the current study was 1.77% of DM, which did not negatively affect DMI. Condensed tannin concentrations of 5 to 10% of DM can be detrimental to ruminants, but concentrations of 1 to 3% can be beneficial (Barry, 1989). Greater percentage of cottonseed hulls in the diet also increased percentage of oil, increased percentages of palmitic and linoleic acids and total saturates, and decreased percentage of oleic acid in the oil (Table 2).

Lamb DMI and Growth

Even though CSH10 diet had the greatest degradable protein (% of CP and % of DM), a linear increase in DMI ($P < 0.001$) resulted in a linear increase ($P = 0.001$) in DPI. Considering that calculated ME declined as percentage of cottonseed hulls increased in the diet (Table 1), DMI results agree with the principle that dietary energy density regulates intake (Perry et al., 1959). Others have reported that DMI increased as dietary fiber increased in high-concentrate lamb rations (Kinser et al., 1988; Fimbres et al., 2002).

The physically effective NDF (**peNDF**) of a feed is defined as the effectiveness of NDF to stimulate chewing activity in relation to feed particle size (Mertens, 1997). Even though peNDF has not been explicitly defined for sheep, its principles may be useful for lambs (Smith, 2008). As DMI and percentage of cottonseed hulls increased in CSH10, CSH20, and CSH30 diets, NDF and peNDF intakes increased, which potentially reduced subclinical rumen digestive disorders that have been associated with feeding high protein and energy feeds (Huntington, 1988).

To further complicate the DMI discussion, cottonseed hulls have been reported to contain 5.64% CT (% of DM, no cotton fiber included in analysis; Whitney and Muir, 2010), and CT concentrations in the current study increased as cottonseed hulls increased in the diet.

Table 3. Effects of percentage of roughage in lamb finishing diets containing dried distillers grains (DDG) on growth and serum urea N (SUN), NEFA, and IGF-1 concentrations

	Diet[2]				P-value[3]	
Item[1]	CSH10	CSH20	CSH30	SEM	Linear	Quadratic
n	11	11	11			
Final BW, kg	50.5	53.7	54.7	1.5	0.52	0.33
ADG, kg	0.29	0.31	0.35	0.01	0.005	0.50
DMI, kg	1.49	1.74	1.96	0.07	<0.001	0.90
DPI, kg	0.12	0.13	0.15	0.01	0.001	0.51
G:F, kg/kg	0.20	0.18	0.19	0.01	0.33	0.13
SUN, mg/dL	12.1	11.9	14.4	0.5	0.005	0.05
NEFA, μEq/L	83.5	89.6	81.1	5.2	0.76	0.32
IGF-1, ng/mL	188	168	154	6.7	0.001	0.69

[1]DPI = degradable protein intake; G:F = kg of ADG/kg of DMI.

[2]Pelleted diets were lamb finishing diets containing 40% DDG and 10% (CSH10), 20% (CSH20), or 30% (CSH30) cottonseed hulls replacing an increasing amount of ground sorghum grain.

[3]Linear and quadratic orthogonal polynomial contrasts.

Condensed tannins have been associated with reducing DMI (Burns and Cope, 1974), ruminal fluid and particulate matter passage rates (Silanikove et al., 2001), and digestibility (Reed et al., 1990). Dietary CT concentration, and thus CT intake, increased as percentage of cottonseed hulls increased in the diet, but did not result in less DMI. A lack of CT effect on DMI is probably due to the concentrations of energy and protein being great in all the diets and nutrient-toxin interactions that are known to occur (Freeland and Janzen, 1974). Greater CT may have actually contributed, along with the greater feed fiber, to reducing digestive problems because CT have been reported to reduce solubility and degradability of protein (Pritchard et al., 1988; Yu et al., 1995) and bind carbohydrates (McLeod, 1974) and other nutrients (Yu et al., 1993, 1996). Determining if CT in cottonseed hulls act as complementary compounds as described by others (Rogosic et al., 2003), especially when feeding increased amounts of DDG, warrants further investigation.

Diet × day interactions were not observed ($P > 0.12$) for lamb BW, ADG, or G:F (Table 3). Initial (data not shown) and final lamb BW were similar ($P = 0.19$) among diets and BW remained similar ($P > 0.32$) throughout the study, even though ADG linearly increased ($P = 0.005$) as percentage of cottonseed hulls increased in the diet. As percentage of cottonseed hulls increased in the diet, G:F remained similar ($P = 0.13$) among lambs because ADG and DMI increased at similar rates. Others reported similar results that lamb ADG increased as percentage of roughage increased in pelleted diets (Perry et al., 1959). In contrast, greater concentrations of roughage in the diet reduced ADG and G:F (Fimbres et al., 2002).

SUN, NEFA, and IGF-1

Diet × day interactions were not observed ($P > 0.45$) for SUN, NEFA, or IGF-1 concentrations (Table 3). A linear response ($P = 0.005$) for SUN as percentage of cottonseed hulls were increased in the diet was observed. Others have reported that an increase in circulating urea N in sheep is associated with greater N intake (Sultan and Loerch, 1992) and apparent N digestibility (Egan and Kellaway, 1971). Serum urea N concentrations approximately 5 to 9 mg·dL in steers indicated excessive N intake and excretion (Cole et al., 2003). Considering that circulating urea N is closely related to urinary N excretion in sheep (Cocimano and Leng, 1967), lambs fed CSH30 diet were probably excreting the greatest amount of N. Condensed tannins can reduce protein degradation (Barry and Manley, 1986); thus, CT may have kept SUN concentrations from being even greater than reported by increasing N excretion as discussed by Nuñez-Hernandez et al. (1991).

All lambs had similar ($P = 0.32$) NEFA concentrations throughout the study and the reduced concentrations suggested that very little fat was being mobilized (Chilliard et al., 2000). Circulating NEFA concentrations have remained similar among cattle fed different levels of degradable protein (Blauwiekel and Kincaid, 1986). Secondary compounds can induce physiological stress (Pritz et al., 1997), and circulating NEFA can increase during stress (Bell, 1995); similar NEFA concentrations suggest that CT were not negatively affecting tissues.

Serum IGF-1 concentrations linearly decreased ($P = 0.001$) as percentage of cottonseed hulls increased in the diet. This result is not consistent with linear increases in ADG, DMI, and DPI associated with increasing dietary cottonseed hulls. Circulating IGF-1 is commonly associated with DMI (Smith et al., 2002), CP intake (Wester et al., 1995), and growth rate (Breier, 1999). Reasons for the discrepancy are not readily apparent because no literature was discovered reporting a negative relationship between circulating IGF-1 and ADG for growing livestock. One plausible explanation is that CT can decrease in vitro (Vasta et al., 2009a) and in vivo (Vasta et al., 2009b) rumen biohydrogenation, and thus increase the concentration of CLA escaping the

Table 4. Effects of percentage of roughage in lamb finishing diets containing dried distillers grains on wool characteristics

Item	Diet[1] CSH10	CSH20	CSH30	SEM	P-value[2] Linear	Quadratic
n	11	11	11			
Grease fleece weight, kg	1.26	1.18	1.26	0.06	0.96	0.30
Clean wool fiber present, %	40.36	43.77	42.19	1.54	0.41	0.20
Clean fleece weight, kg	0.50	0.51	0.53	0.03	0.48	0.90
Clean wool production/unit of BW, g/kg	10.78	10.40	10.64	0.51	0.85	0.63
Average fiber diameter, μm	19.76	19.78	20.19	0.38	0.42	0.68
SD fiber diameter, μm	4.43	4.37	4.68	0.12	0.17	0.22
Average staple length, mm	31.45	32.37	33.21	1.19	0.30	0.98
SD staple length, mm	3.33	3.56	3.81	0.30	0.29	0.85
Average fiber curvature, deg/mm	102.7	105.4	110.5	2.5	0.03	0.69
SD fiber curvature, deg/mm	62.55	65.55	67.09	1.37	0.03	0.67

[1]Pelleted diets were lamb finishing diets containing 40% dried distillers grains and 10% (CSH10), 20% (CSH20), or 30% (CSH30) cottonseed hulls replacing an increasing amount of ground sorghum grain.

[2]Linear and quadratic orthogonal polynomial contrasts.

rumen (Dhiman et al., 2000). Dietary CLA has been reported to reduce IGF-1 receptor transcript and protein content in humans (Kim et al., 2003) and circulating IGF-1 in rats (Buison et al., 2000). Effects of CT on rumen biohydrogenation of FA and serum IGF-1 without reducing animal growth warrants further investigation.

Wool Production and Characteristics

Wool production and characteristics are summarized in Table 4. The differences among treatments in diet constituents did not produce differences in the amount of wool grown or in any of the characteristics measured except average and SD of fiber curvature. In yearling Rambouillet rams fed a feedlot ration, fiber curvature was not correlated (r = 0.04) with average fiber diameter (Lupton et al., 2003). In the current study, inspection of the average fiber diameter and curvature data in Table 4 suggested a positive correlation, but in fact the correlation is not significant (r = 0.08; $P = 0.66$). However, increasing the percentage of cottonseed hulls in the diets linearly increased average and SD of fiber curvature ($P = 0.03$). We have no rational explanation for this observation. Increasing cottonseed hulls from 10 to 30% in the diets containing 40% DDG produced no effect on wool production, fiber diameter, or staple length.

Carcass Characteristics and Feed and Meat FA Profiles

Body wall thickness ($P = 0.03$) quadratically increased as cottonseed hulls increased in the diet. All other carcass characteristics were similar ($P > 0.19$) among lambs. Fimbres et al. (2002) reported that HCW of lambs linearly declined as percentage of hay (roughage concentration) was increased from 0 to 30% in finishing diets, but fat thickness and LM area were similar. Results are also similar to Beauchemin et al. (1995) who reported that CP intake had little effect on carcass characteristics. Even though no differences ($P = 0.19$) were observed for BF thickness, the BF thickness of lambs fed CSH10 and CSH20 diets is considered unacceptable to US markets according to Snowder et al. (1994). Slaughter weights in the current study averaged 53 kg, which is greater than the optimal slaughter weight of Rambouillet wethers suggested by Snowder et al. (1994).

Percentage of fat was similar ($P = 0.29$) in lamb LM, but increasing percentage of cottonseed hulls in the diet decreased weight percentages of myristic, palmitoleic (linear; $P < 0.05$), and arachidic (quadratic; $P = 0.03$) acids and linearly increased weight percentages of stearic acid ($P = 0.04$) and CLA *cis*-9,*trans*-11 isomer ($P = 0.007$; Table 5). Greater CLA concentration may have been a result of dietary linoleic concentrations increasing (Griinari and Bauman, 1999) as cottonseed hulls increased in the diet. In addition, Vasta et al. (2009b) reported greater concentrations of the *cis*-9,*trans*-11 CLA isomer in LM of sheep fed diets containing tannins, which was attributed to tannins reducing the last step in rumen biohydrogenation and leading to an accumulation of the *trans* C18:1 isomer; the *cis*-9,*trans*-11 CLA isomer can be endogenously produced from *trans* C18:1 (Griinari et al., 2000). A quadratic response ($P = 0.03$) was also observed for the *trans*-9,10,11 isomers of C18:1, which was mainly due to LM of lambs fed the CSH20 diet having the greatest concentration.

Increasing most SFA in meat is undesirable because of negative effects on human health (i.e., increased blood cholesterol and incidence of coronary heart disease; Fletcher et al., 2005). Even though stearic acid is a SFA, it has been reported to have no effect on circulating cholesterol (Grundy, 1989, 1994) or have a hypocholesterolemic effect in humans (Hegsted et al., 1965; Bonanome and Grundy, 1988). Stearic acid has also been reported to reduce plasma cholesterol in hamsters (Hassel et al., 1997; Schneider et al., 2000). The

Table 5. Effects of percentage of roughage in lamb finishing diets containing dried distillers grains (DDG) on carcass characteristics and meat fatty acid profile (%, dry-weight basis)

	Treatment diet[2]				*P*-value[3]	
Item[1]	CSH10	CSH20	CSH30	SEM	Linear	Quadratic
n	8	8	8			
Carcass characteristic						
HCW, kg	27.7	29.3	27.4	0.7	0.74	0.07
LM area, cm^2	15.2	15.9	15.6	0.73	0.76	0.59
Backfat, cm	0.79	0.84	0.59	0.11	0.19	0.26
Body wall, cm	1.49	1.78	1.43	0.11	0.68	0.03
Leg circumference, cm	65.19	65.00	64.38	0.63	0.37	0.78
Meat moisture, %	62.74	64.08	63.99	1.16	0.45	0.62
Meat fatty acid						
Fat, %	5.17	6.04	5.53	0.80	0.80	0.29
Myristic acid (14:0)	6.16	4.78	5.14	0.34	0.04	0.05
Palmitic acid (16:0)	25.71	25.40	25.66	0.33	0.92	0.49
Palmitoleic acid (16:1)	3.59	2.91	2.94	0.14	0.004	0.06
Stearic acid (18:0)	5.61	7.02	6.99	0.49	0.04	0.18
Oleic acid (18:1, *cis*-9)	30.81	31.77	31.40	0.75	0.59	0.48
Trans-9,10,11 isomers of 18:1	5.26	6.20	4.68	0.43	0.30	0.03
Cis-vaccenic acid (18:1, *cis*-11)	1.43	1.44	1.34	0.04	0.15	0.35
CLA (18:2, *cis*-9 *trans*-11)	0.19	0.26	0.27	0.01	0.007	0.12
Linoleic (18:2, *cis*-9 *cis*-12)	11.97	10.52	11.97	0.72	0.99	0.12
Arachidic acid (20:0)	0.46	0.37	0.37	0.02	0.002	0.03
Arachidonic acid (20:4)	2.10	1.67	2.01	0.15	0.78	0.15

[1]Fatty acid % 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.

[2]Pelleted lamb finishing diets containing 40% DDG and 10% (CSH10), 20% (CSH20), or 30% (CSH30) cottonseed hulls replacing an increasing amount of ground sorghum grain.

[3]Linear and quadratic orthogonal polynomial contrasts.

cis-9,*trans*-11 isomer of CLA has been reported to be anticarcinogenic (Belury, 1995; Ip, 1997).

Sensory Panel Evaluation

Increasing cottonseed hulls in the diet linearly decreased sustained tenderness ($P = 0.02$), but all other sensory panel traits were similar ($P > 0.05$; Table 6). Type of FA in the diet can affect FA composition in meat lipids (Ponnampalam et al., 2001); thus, initial juiciness may have been influenced by differences in myristic, palmitoleic, and stearic acid concentrations in the LM (Table 5). Positive correlations between myristic acid and juiciness have been reported by some (Waldman et al., 1965), but not by others (Terrill et al., 1968). Palmitoleic acid has been related to juiciness in beef (Dryden and Marchello, 1970) and stearic acid has been related to fat hardness due to its greater melting point compared with other FA (Chung et al., 2006). In the current study, feeding greater energy diets (fewer

Table 6. Effects of percentage of roughage in lamb finishing diets containing dried distillers grains (DDG) on sensory panel traits of lamb LM chops

	Treatment diet[2]				*P*-value[3]	
Item[1]	CSH10	CSH20	CSH30	SEM	Linear	Quadratic
n	8	8	8			
Cook loss	19.36	19.87	20.89	1.05	0.32	0.84
Initial juiciness	5.60	5.52	5.06	0.19	0.05	0.42
Sustained juiciness	5.71	5.56	5.40	0.18	0.23	0.96
Initial tenderness	5.94	5.63	5.29	0.29	0.13	0.98
Sustained tenderness	6.25	5.92	5.25	0.27	0.02	0.63
Flavor intensity	5.56	5.33	5.29	0.15	0.22	0.62
Off-flavor	3.75	3.81	3.77	0.09	0.87	0.65

[1]Cook loss expressed as % 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).

[2]Pelleted lamb finishing diets containing 40% DDG and 10% (CSH10), 20% (CSH20), or 30% (CSH30) cottonseed hulls replacing an increasing amount of ground sorghum grain.

[3]Linear and quadratic orthogonal polynomial contrasts.

cottonseed hulls) did not result in greater flavor intensity as reported for cattle meat (Melton, 1990).

Conclusions

Results were interpreted to indicate that cottonseed hulls are a good roughage source for lamb finishing diets containing 40% DDG. Lamb feeders are advised to use the CSH30 diet vs. CSH10 or CSH20 diets because even though DMI was greater for lambs consuming the CSH30 diet, those lambs had greater ADG, the least cost of feed·kg^{-1} of BW gain, and potentially greater-valued meat. As ADG and DMI increased, serum IGF-1 decreased, which was exactly opposite of what was expected. One explanation was related to CT concentrations increasing as percentage of cottonseed hulls increased in the diet. Condensed tannins can increase postruminal CLA, which has been shown to reduce circulating IGF-1 in rats; therefore, indirect effects of CT reducing serum IGF-1 without an associated reduction in animal growth need to be further investigated. Research is also needed to further evaluate the CSH30 diet, but substituting all of the sorghum grain with DDG.

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