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Substituting distillers dried grains for cottonseed meal in lamb-finishing diets: growth, wool characteristics, and serum NEFA, urea N, and IGF-1 concentrations[1]

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Summary

Effects of replacing cottonseed meal (CSM) with corn distillers dried grains (DDG) on growth, wool, and serum NEFA, urea N (SUN), and IGF-1 concentrations 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. Diet × day interactions were not observed ($P > 0.12$) for BW, ADG, DMI, degradable protein intake, or G:F. As DDG increased in the diet, ADG and G:F decreased quadratically ($P = 0.08$), but no difference ($P = 0.13$) in daily DMI was observed. Lambs fed 100DDG diet had similar ($P > 0.23$) ADG, average DMI, and G:F compared to lambs fed 0DDG diet. A diet × day interaction ($P < 0.001$) was observed for SUN, but not for serum NEFA or IGF-1 concentrations ($P > 0.16$). At times, SUN increased ($P < 0.10$) as DDG increasingly replaced CSM, which was attributed to an increase (quadratic, $P < 0.001$) in degradable protein intake. Serum NEFA decreased linearly ($P < 0.08$) and serum IGF-1 decreased quadratically ($P < 0.05$) as DDG increasingly replaced CSM in the diets. Wool characteristics were not affected ($P > 0.10$) by diet. Results indicated that DDG can replace all the CSM in lamb-finishing diets without negatively affecting growth, efficiency of gain, or wool characteristics, and can potentially reduce cost of feed•kg^{-1} gain.

Key Words: Cottonseed Meal, Distillers Dried Grains, IGF-1, Lambs, Wool

Introduction

Up to 80 million tons of distillers dried grains (DDG) are expected to be produced by 2014 (FAPRI, 2009; Neeley, 2009), which should continue making DDG an economical feed due to market saturation. Research evaluating the use of distillers byproducts in beef- and dairy-cattle diets is extensive, and performance has been variable (Firkins et al., 1985; Ham et al., 1994; Depenbusch et al., 2009). A limited amount of research has evaluated effects of using DDG in lamb-finishing diets (NASS, 2007); however, the sheep industry has demonstrated an interest to use this feed resource to lower the cost of gain.

Cottonseed meal is a common protein source for lamb-finishing diets, especially in Texas. Even though CSM contains a greater concentration of CP and degradable protein than DDG (NRC, 2007), potential exists for DDG to completely replace CSM as the protein source in finishing diets. For example, Huls et al. (2006) reported that DDG with solubles (DDGS) could be effectively fed to lambs at 23 percent of diet DM by replacing soybean meal and a portion of corn in diets where soy hulls were the only fiber source. Others have reported that DDGS could be fed to lambs with alfalfa hay and replace 20 percent of the barley (Schauer et al., 2005) or fed at 60 percent of diet DM without affecting final BW, G:F, or mortality, or causing lambs to exhibit signs of acidosis, polioencephalomalacia, or urinary calculi (Schauer et al., 2008). Furthermore, DDG contain high levels of bypass protein and sulfur, both of which have enhanced growth and animal-fiber production (Throckmorton, et al., 1982; Reis and Sahlu, 1994). If DDG can effectively replace all of the CSM in lamb-finishing diets without negatively affecting lamb growth and end products, it would benefit corn growers and the ethanol industry and reduce feed costs associated with growing lambs. The objective of this study was to determine the effect of replacing CSM with DDG in lamb-finishing diets.

Materials and Methods

Animals and Management

The experimental protocol was approved by the Texas A&M University Institutional Animal Care and Use Committee (#2007-92). 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•trt^{-1}). Lambs developed coccidiosis during the adaptation period and were treated orally for 5 d with amprolium (Corid, Merial, Duluth, Ga.); one lamb had to be removed from the study due to the coccidia infection. Lambs received an ear tag and a subcutaneous injection of a clostridial vaccine (Vision 7 with SPUR, Inervet Inc., Millsboro, Del.). Lambs were randomly assigned to individual, completely covered dirt pens (2.44 × 2.97 m) with automatic watering systems and feed bunks. Pelleted diets contained corn DDG that replaced 0 percent (0DDG), 33 percent (33DDG), 66 percent (66DDG), or 100 percent (100DDG) of the cottonseed meal (CSM; Table 1). Urea was added at the rate of 0.09 percentage units for each 1 percentage unit increase in DDG to keep diets isonitrogenous. Monensin (Rumensin 80, Elanco, Indianapolis, Ind.) was added to each diet at 22g•metric ton^{-1} of feed. Lambs were individually fed once daily at 0800 at *ad libitum* intake, calculated for each lamb as the previous day's intake plus approximately 15 percent of dietary DM. Feed refusals were collected twice per week and weighed.

During the adaptation period, percentage of concentrate in the diet was gradually increased in non-amalgamated feed, and pelleted diets were gradually introduced. Lamb BW was recorded and blood serum collected on d 0, d 14, d 28, d 56, and d 84. Lamb BW on d 84 was adjusted by adding final grease fleece weight to shorn BW. Average daily gain and DMI were calculated between days that BW was recorded. Average-daily, degradable-protein intake (DPI) was calculated for each lamb as [((dietary CP × (degradable CP/100))/100) × average DMI]. Clinical signs related to coccidiosis, acidosis, and bloat were recorded daily. Lambs were shorn 5 d before study initiation and on d 82. Lambs were also evaluated for carcass characteristics and fatty acid profiles, the results of which will be presented in a companion paper.

Sample Collection and Measurements

Feeds

The DDG samples were randomly collected prior to feed pelletizing, and CSM samples were collected from a different source than that used in these diets. Samples of diets were randomly collected on d 0, d 19, d 41, and d 69, dried at 55°C in a forced-air oven for 48 h, ground in a Wiley Mill (Arthur H. Thomas Co., Philadelphia, Penn.) 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 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 and Na sulfite. Sulfur was evaluated by 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.). Distillers dried grains and diets were also evaluated for individual fatty acids, and these data will be presented in a companion paper.

Serum Collection and Laboratory Analysis.

A 15-mL blood sample was collected from each lamb 4 h after feeding via jugular venipuncture using a non-heparinized vacutainer collection tube (serum separator tube, gel and clot activator; Becton Dickenson, Franklin Lakes, N.J.). Blood samples were allowed to clot and then centrifuged (Beckman Coulter TJ6 refrigerated centrifuge, Fullerton, Calif.) at 970 × g for 25 min at 4°C. Serum was decanted and frozen at -20°C until analyzed for serum urea N (SUN), NEFA, and IGF-1 concentrations. Serum urea N concentrations were

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

Item	DDG[2]	CSM[2]	Diet (% of CSM replaced by DDG) 0DDG	33DDG	66DDG	100DDG
Cottonseed hulls			25.00	25.00	25.00	25.00
DDG			0.00	6.60	13.20	20.00
CSM			20.00	13.40	6.80	0.00
Milo, crushed			47.40	46.95	46.51	46.04
Molasses			3.00	3.00	3.00	3.00
Limestone			2.00	1.85	1.69	1.54
Ammonium Cl			0.75	0.75	0.75	0.75
Salt			0.85	0.85	0.85	0.85
Urea			0.00	0.60	1.20	1.82
Mineral premix			1.00	1.00	1.00	1.00
CP, %	22.50	50.80	18.75	17.94	18.65	18.98
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	4.95	4.55	5.2
NDF, %	41.80	17.00	25.35	26.55	25.15	27.10
ADF, %	14.50	14.00	14.85	17.45	14.30	15.02
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, ppm	171.0	145.0	423.5	503.5	325.0	284.0
Zn, ppm	90.0	72.0	59.5	59.0	57.5	59.5
Cu, ppm	5.0	15.0	4.0	5.0	3.5	4.0
Mn, ppm	53.0	22.0	48.0	55.5	50.0	54.5
Mo, ppm	1.0	2.4	0.60	0.85	0.70	0.80
Cost•metric ton^{-1} feed	$180.78	$254.63	$221.46	$219.07	$216.68	$214.22
Cost of feed•kg^{-1} 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, cottonseed meal, cane molasses, animal fat, and 22g of Monensin (Rumensin 80)•metric ton^{-1} of feed. Soluble and degradable protein fractions = % of CP. Cost•metric ton^{-1} 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] x [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.

analyzed using a commercial kit (Teco Diagnostics, Anaheim, Calif.) with intra- and inter-assay CV less than 3.1 percent. Serum NEFA concentrations were also analyzed using a commercial kit (NEFA C; Wako Chemicals, Neuss, Germany) with intra- and inter-assay CV less than 7.6 percent. Serum IGF-1 concentrations were determined by RIA using procedures of Berrie et al. (1995). Intra- and inter-assay CV for IGF-1 were 9.4 percent and 19.2 percent, respectively, with a 95 percent recovery rate.

Wool

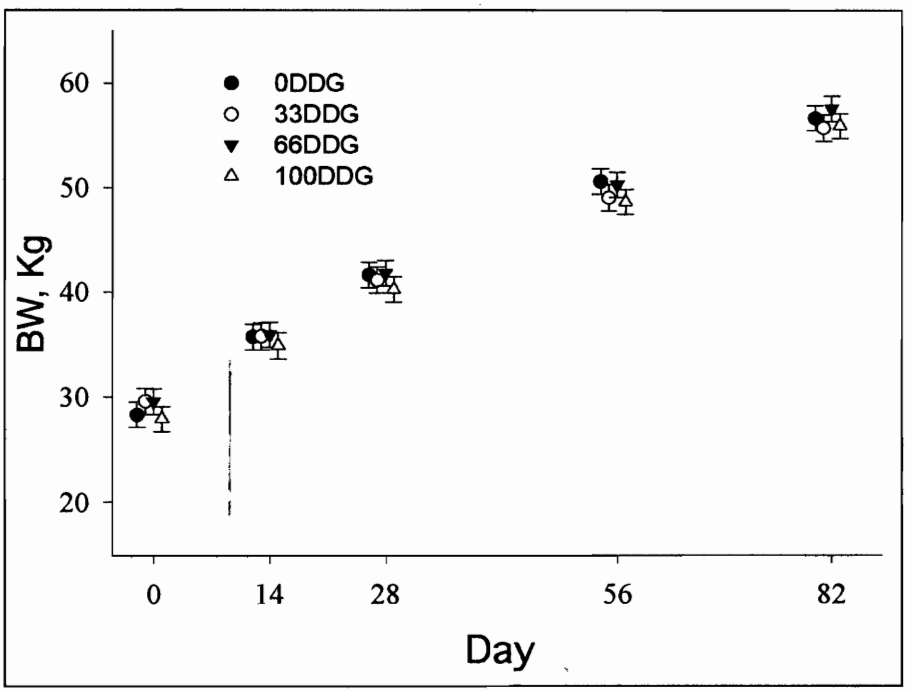
Fleece and fiber measurements were made at the Texas AgriLife Research Center in the Wool and Mohair Research Laboratory, San Angelo. After grease-fleece weights were obtained for each individual fleece, staples (n = 10) were removed from random positions in each fleece for staple strength (Agritest, 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 sub-samples were used to determine 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 percent rh (ASTM, 2007c). Conditioned snippets were then spread onto microscope slides (7 cm × 7 cm) and measured for fiber diameter distribution (mean, SD, and CV), comfort factor (percent fibers < or = 30 µm), and average-fiber curvature, SD, and CV, using an OFDA 100 (BSC Electronics, Ardross, Western Australia; Baxter et al., 1992; ASTM, 2008).

Statistical Analyses

Data were analyzed using PROC MIXED (SAS Inst. Inc., Cary, N.C.). Lamb BW, ADG, daily DMI, G:F, and SUN, NEFA, and IGF-1 were initially analyzed using a model that included diet, day, and diet × day interaction, with day as the repeated measure and lamb within diet as the subject. Only SUN had a diet × day interaction ($P < 0.001$), thus the SUN model was analyzed by day. 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-fiber diameter of the fleece, and initial BW was used as a covariate for clean- fleece weight, but covariates were removed because they were not significant. Wool production per unit of BW ($g \bullet kg^{-1}$) was calculated as clean-wool production divided by final shorn BW. Non-normal data were transformed using natural-log or arcsin square-root functions. Covariance structures (compound symmetry, heterogeneous-compound symmetry, and heterogeneous-autoregressive order-1) were used to determine the most appropriate structure for each model. Data are reported as least squares means with greatest standard errors, except for BW where all standard errors are reported in Figure 1. Treatment 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 the linear and quadratic 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.

Figure 1. Effect on lamb BW of replacing dietary cottonseed meal with distillers dried grains. Distillers dried grains replaced 0% (0DDG), 33% (33DDG), 66% (66DDG), or 100% (100DDG) of the cottonseed meal. A diet x d interaction ($P > 0.43$) was not observed and BW were similar ($P > 0.50$) among diets throughout the study.



Results and Discussion

Lamb growth

No diet × d interactions ($P > 0.12$) were observed for lamb BW (Fig. 1), ADG, daily DMI, DPI or G:F (Table 2). By design, initial lamb BW was similar ($P > 0.30$) among treatments and relative weights remained similar ($P > 0.50$) throughout the study, even though ADG and G:F decreased quadratically ($P = 0.08$). All lambs had similar average-daily DMI ($P > 0.70$). Huls et al. (2006) discussed possible palatability issues related to ammonium chloride fed at 0.5 percent of diet DM, but diets in the current study containing 0.75 percent ammonium chloride did not reduce intake. The unexpected quadratic trends for ADG and G:F are attributed to the lesser ADG of lambs fed 33DDG diet and the lesser G:F of lambs fed 33DDG and 66DDG diets, respectively. These results suggest that negative associative effects occurred, which reduced growth (33DDG diet) and efficiency (33DDG and 66DDG diets) of lambs fed diets containing both CSM and DDG.

Growth rates in the current study did not increase as percentage of DDG increased in the diets. Schauer et al. (2008) reported no linear or quadratic trends in ADG or G:F in wether lambs fed diets (> 20 percent CP) with DDGS replacing portions of barley and soybean meal, but did report a linear increase in DMI and greater ADG for lambs fed the highest level of DDGS (60 percent) than those fed the lowest level (0 percent). Differences in ADG and G:F observed in the experiment of Schauer et al. (2006) was attributed to low CP (11.7 percent) in the control diet (no DDGS), which increased to 18.4 percent CP in the diet with the greatest DDGS concentration. In the current study, lambs fed the diet in which all of the CSM was replaced by DDG (100DDG) had similar ($P > 0.23$) ADG, average DMI, and G:F compared to lambs fed the 0DDG diet.

Huls et al. (2006) replaced all the soybean meal and a portion of the corn with DDGS (22.9 percent of DM) in pelleted wether lamb diets that included

10 percent soy hulls. There were no differences in lamb final BW, average daily DMI, ADG, or G:F among diets. Even though no signs of acidosis were observed, they discuss the possibility that the greater fermentability of soy hulls could have contributed to subclinical acidosis. The 100DDG diet fed in the current study was 75 percent concentrate and used 25 percent CSH as the sole roughage source. Cottonseed hulls contain greater NDF and ADF than soy hulls (Hsu et al., 1987; NRC, 2007), and 48-hr true *in vitro* DM digestibility of CSH has been reported to be 20.8 percent (Whitney and Muir, 2010). Apparent *in situ* digestibilities before the duodenum of CSH and soy hulls have been reported to be 16.4 percent and 40.2 percent, respectively (Hsu et al., 1987). The nutrient composition of CSH suggests a low feeding value (Torrent et al., 1994; NRC, 2007; Whitney and Muir, 2010). However, feeding a less rumen-fermentable roughage source than soy hulls (i.e. CSH) in high-energy rations containing DDG may be beneficial due to positive associative effects. For example, Hsu et al. (1987) reported greater ruminal pH and less total VFA for sheep fed a CSH diet compared to a soy hull diet. These results can be attributed to CSH fiber characteristics, which can increase rumen buffer capacity (Van Soest, 1994).

Chemical compositions of diets (Table 1) were not statistically analyzed, but are similar except for a few nutritional differences. For example, percentage of dietary urea was increased in the diets as DDG increasingly replaced CSM to make diets isonitrogenous, which resulted in greater soluble and degradable protein (Table 1), except for 33DDG diet having the least degradable protein. This resulted in a quadratic increase ($P < 0.001$) of DPI and greater DPI ($P < 0.001$) for lambs fed 100DDG diet compared to lambs fed 0DDG diet (Table 2), because average DMI was similar among all lambs. All lambs consumed at least twice as much degradable protein as required for lambs gaining between 0.34 $kg \bullet d^{-1}$ to 0.38 $kg \bullet d^{-1}$ (NRC, 2007). Therefore, additional dietary urea in diets containing DDG could have probably been excluded without reducing growth, which would have further reduced the cost of diets containing DDG; especially the 100DDG diet, which contained the most dietary urea and was the least expensive diet with the lowest $cost \bullet kg^{-1}$ gain (Table 1). In contrast, some dietary urea may be needed when roughages, such as CSH, are used in diets containing DDG, because urea can enhance cellulose digestion (Burroughs et al., 1951; Belasco, 1954).

Consuming an excessive amount of DPI can negatively affect rumen and tissue metabolism and increase energy expenditure related to excretion (McBride and Kelly 1990; Reynolds, 2002). Even though lambs fed 100DDG diet consumed the greatest ($P < 0.001$) amount of degradable protein, their growth rate was similar ($P > 0.23$) to lambs fed 0DDG diet. One explanation may be related to the condensed tannin (CT) concentration of CSH. Previous reports indicate that CSH contained 5.63 percent CT (percent of DM, no cotton fiber included in analysis; data not shown; Whitney and Muir, 2010), which can bind nutrients (Yu et al., 1993; Yu et al., 1996) and reduce solubility and degradability of protein (Yu et al., 1995a,b) and ruminal NH3-N concentrations (Waghorn et al., 1987). Research evaluating the use of feeds containing CT, in diets containing high concentrations of DDG (thus, high CP concentrations) and interactions and associative effects of CT, degradable CP, fermentable carbohydrates, and source and concentration of roughage is warranted.

Dietary crude fat was greater in 100DDG diet than 0DDG diet (Table 1), but lambs fed 100DDG diet had ADG and G:F similar ($P > 0.23$) to lambs fed 0DDG diet. Therefore, dietary crude fat concentrations up to 5.2 percent of diet DM did not reduce growth or efficiency of gain. Schauer et al. (2008) reported that wether lambs consuming diets containing 60 percent

Table 2. Effects of replacing cottonseed meal (CSM) with distillers dried grains (DDG) on lamb growth and serum urea N (SUN), NEFA, and IGF^{-1} concentrations

	Diet (% of CSM replaced by DDG)					P-value		
Item	0DDG	33DDG	66DDG	100DDG	SEM	Linear	Quadratic	0DDG vs. 100DDG
ADG, kg	0.38	0.34	0.36	0.36	0.01	0.46	0.08	0.23
DMI, kg	1.978	1.924	2.057	1.966	0.063	0.70	0.73	0.90
DP intake, kg	0.213	0.157	0.233	0.254	0.006	<0.001	<0.001	<0.001
G:F, $kg \bullet kg^{-1}$	0.195	0.178	0.179	0.190	0.007	0.80	0.08	0.75
SUN, $mg \bullet dL^{-1}$								
d 0	9.6	12.3	14.1	17.4	1.2	<0.001	0.85	<0.001
d 14	16.4	18.1	20.2	18.5	1.5	0.22	0.25	0.33
d 28	18.3	17.4	20.5	19.7	1.0	0.11	0.99	0.33
d 56	18.6	15.1	21.0	23.7	0.9	<0.001	0.002	<0.001
d 84	18.2	17.3	18.7	22.4	1.0	0.003	0.03	0.004
NEFA, $mEq \bullet L^{-1}$	97.3	97.2	86.9	84.3	6.4	0.08	0.96	0.15
IGF^{-1}, $ng \bullet mL^{-1}$	217.0	183.8	191.9	199.4	11.0	0.45	0.05	0.33

DP intake = degradable protein intake; calculated as [((dietary CP x (degradable CP/100))/100) x lamb DMI].

DDGS and 8.3 percent crude fat actually had greater daily DMI compared to diets containing 2.5 percent to 6.7 percent crude fat. These results are in contrast to others, which have indicated reduced feed consumption and ADG of lambs fed diets with 5 percent or more added fat (Hale et al., 1954; Jordan et al., 1958). Growth performance inconsistencies across studies could be associated with large variations that exist in DDG nutritive value (Spiehs et al., 2002), yet environmental and physiological differences would likely have greater significance on performance outcomes.

Serum Urea N, NEFA, and IGF-1

A diet × day interaction was observed for SUN concentration ($P < 0.001$; Table 2). Serum urea N increased on d 0 (linear, $P < 0.001$) and d 56 and d 84 (quadratic, $P < 0.04$). Lambs fed 100DDG diet had greater ($P < 0.005$) SUN than lambs fed 0DDG diet on d 0, d 56, and d 84. Differences in SUN can be attributed to DPI. For example, lambs fed 33DDG diet consumed the least amount of degradable protein, which was the primary reason for quadratic trends observed for SUN on d 56 and d 84. As percentage of DDG increased in diets, dietary urea was also increased to make the diets isonitrogenous. Dietary urea is rapidly hydrolyzed in the rumen and can rapidly increase rumen NH3-N, which is then absorbed by the liver and detoxified mainly to urea (Carter et al., 1989; Awawdeh et al., 2005). In addition, SUN was correlated (0.51, $P < 0.001$) to average-daily, degradable-protein intake.

Bunting et al. (1992) reported that dietary fat increased rumen NH3-N concentrations in lambs, but reduced circulating urea N concentrations, which was attributed to greater N accretion rates. Dietary fat did not seem to affect SUN in the current study because 100DDG diet had a greater concentration of crude fat, but lambs consuming this diet had greater SUN than 0DDG at times. The contrast between the current study and Bunting et al. (1992) supports the fact that DPI was the primary factor affecting SUN.

Greater SUN can be beneficial to ruminants by recycling urea to the rumen, but can also increase urinary N excretion (Cocimano and Leng, 1967; Kohn et al., 2005), which is an inefficient use of nutrients. The transfer of circulating urea N into the rumen reaches a plateau when it reaches 16 mg to 18 mg N 100•mL^{-1} serum (Weston and Hogan, 1967; Vercoe, 1969). Harmeyer and Martens (1980) discussed upper limits of 16.8 mg N•100 mL^{-1} serum where urea transfer into the rumen stops being linearly related to circulating urea N. Therefore, urinary N excretion of lambs in the current study was likely greater where urea was added to diets containing DDG.

A diet × day interaction was not observed for serum NEFA concentrations ($P > 0.16$), but NEFA slightly decreased (linear, $P = 0.08$), as percentage of DDG increased in the diet. Lambs fed 100DDG diet had similar ($P = 0.15$) serum NEFA concentrations compared to lambs fed 0DDG diet. Minimal NEFA concentrations indicate that very little fat mobilization was occurring (Chilliard et al., 2000) and that effects were mainly related to dietary nutrient intake. Greater degradable protein consumption did not result in greater NEFA concentrations, which contradicted results of Fernandez et al. (2001).

A diet × day interaction was not observed for serum IGF-1 concentrations ($P > 0.30$), but serum IGF-1 decreased (quadratic, $P = 0.05$), as percentage of DDG increased in the diet. Lambs fed 100DDG diet had similar ($P = 0.33$) serum IGF-1 concentrations compared to lambs fed 0DDG diet. Serum IGF-1 was not correlated ($P > 0.72$) with growth, even though similar quadratic trends were observed for ADG and IGF-1 concentration. Others described serum IGF-1 as an indicator of growth rate (Breier, 1999), and it is positively correlated to ADG and G:F (Bishop et al., 1989; Stick et al., 1998; Hersom et al., 2004).

Wool Production and Characteristics

Genotype dictates the capacity of a sheep to produce wool. However, the expression of genetic potential for wool growth and its physical characteristics can be modified by plane of nutrition. In fact, rate of fiber growth in an adult Merino sheep has been shown to vary by as much as four-fold due to changes in nutrient supply (Reis, 1982). Wool growth can be influenced markedly by amount and specific type of protein in

Table 3. Effects of replacing cottonseed meal with distillers dried grains on lamb wool characteristics

	Diet (% of CSM replaced by DDG)					P-value[2]		
Item/d[3]	0DDG	33DDG	66DDG	100DDG	SEM	Linear	Quadratic	0DDG vs. 100DDG
Grease fleece weight, kg	1.40	1.28	1.23	1.27	0.06	0.10	0.15	0.12
Clean wool fiber, %	38.36	39.66	42.39	40.36	1.71	0.24	0.31	0.39
Clean fleece weight, kg	0.53	0.50	0.52	0.51	0.03	0.59	0.76	0.48
Clean wool production•unit BW^{-1}, g•kg^{-1}	9.74	9.26	9.23	9.29	0.51	0.53	0.58	0.51
Avg fiber diameter, µm	19.92	19.52	19.81	19.61	0.41	0.72	0.80	0.58
SD fiber diameter, µm	4.24	4.54	4.60	4.37	0.21	0.64	0.27	0.69
Avg staple length, mm	31.24	31.93	29.03	30.90	1.20	0.45	0.60	0.83
SD staple length, mm	3.12	3.12	3.23	3.35	0.30	0.21	0.51	0.19
Avg fiber curvature, deg•mm^{-1}	108.33	104.41	108.96	106.13	2.97	0.87	0.86	0.59
SD fiber curvature, deg•mm^{-1}	64.27	65.40	66.46	63.73	1.37	0.91	0.15	0.77

the diet, and to a lesser degree, by amount of accompanying energy. Other components in the diet, including tannins (Min et al., 1998), organic and inorganic S (Qi and Lupton, 1994), vitamins and trace elements (especially Cu and Zn; Reis, 1989) have also been shown to affect wool growth. In the current study, the range in CP among the four diets was small (17.94 percent to 18.98 percent) but the ranges in soluble (29.5 percent to 47.0 percent of CP) and degradable (45.5 percent to 68.0 percent of CP) protein were relatively large (Table 1). Condensed tannins from the CSH component of the diet were constant across diets. Dietary S ranged from 0.28 percent to 0.30 percent, and the concentrations of Cu and Zn were very similar. The measured differences in the types and amounts of protein supplied in the four diets did not produce any differences in clean-wool production or any of the measured-fiber characteristics. The important conclusion is that substituting CSM with DDG did not alter wool production or quality characteristics in these growing lambs.

Conclusions

Results indicated that DDG can replace all of the CSM in lamb-growing diets without negatively affecting ADG, efficiency of gain, or wool characteristics and has the potential to lower cost of feed•kg^{-1} gain. In contrast, lamb ADG and G:F were reduced when DDG replaced a portion of the dietary CSM, which needs to be further investigated. Lamb feeders can potentially reduce feed costs without sacrificing growth, feed efficiency, or wool characteristics, because at the time of this study, DDG was \$74•ton^{-1} less than CSM when averaged across various U.S. markets. At times, SUN was greater in diets containing higher percentages of DDG, which was attributed to an increase in soluble and degradable protein fractions and intakes. Further research is warranted to determine if dietary urea is required in lamb diets when DDG replaces all of the CSM. If dietary urea is not required or can be reduced, feed costs and the cost of feed•kg^{-1} gain would be reduced and SUN would decline, which would reduce N intake and excretion. Since nutrient concentrations of DDG from different sources can be highly variable, DDG composition should be reported independent of the overall ration composition.

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