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Replacing Cottonseed Meal and Sorghum Grain with Corn Dried Distillers Grains with Solubles in Lamb Feedlot Diets: Growth Performance, Rumen Fluid Parameters, and Blood Serum Chemistry[1]

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Abstract

Effects of replacing cottonseed meal (CSM) and sorghum grain with dried distillers grains with solubles (DDGS) in Dorper ram lamb (*n* = 46) feedlot diets on growth performance, rumen fluid parameters, and blood serum chemistry were evaluated. In a 56-d randomized design study, lambs were provided ad libitum 70.9% concentrate diets in individual pens. The positive control diet (CNTL; representative of a traditional feedlot diet) contained CSM, sorghum grain, and other concentrates, but no DDGS. Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain. Lambs fed CNTL were compared to 0DDGS and linear and quadratic effects were evaluated within the four DDGS diets. A treatment × day interaction was observed ($P < 0.001$) for lamb BW but not for ADG, DMI, or G:F ($P \geq 0.78$). Lambs fed CNTL had greater ($P \leq 0.02$) BW on d 42 and 56 and greater ($P < 0.008$) overall ADG and G:F than lambs fed 0DDGS. On d 42 and 56, lamb BW quadratically increased ($P \leq 0.04$) as DDGS increased in the diet. Averaged across all days, ADG quadratically increased ($P < 0.001$) and DMI and G:F tended to quadratically increase ($P \leq 0.08$) as DDGS increased in the diet. On d 56, ruminal pH quadratically decreased ($P < 0.001$), ruminal ammonia-N quadratically increased ($P < 0.001$), acetate linearly increased ($P < 0.001$), and acetate:propionate tended to linearly increase ($P = 0.08$) as DDGS increased in the diet. Various blood serum profiles were affected by diet, but data suggested that diet did not negatively affect lamb health. Results indicated that lamb growth performance is enhanced when CSM is used to increase dietary CP (CNTL vs. 0DDGS) and that, within the diets that did not contain CSM, the 66DDGS diet resulted in the greatest growth performance.

Introduction

Cottonseed meal (CSM) and sorghum grain are widely used as protein and energy sources, respectively, in sheep feedlot rations, especially in Texas. However, some feedlot operators are beginning to seek alternative protein and energy sources due to seasonality and highly variable CSM and sorghum grain pricing. Nutritional characteristics of dried distillers grain with solubles (DDGS), a corn ethanol production co-product, suggests that it can be an economical alternative to CSM and sorghum grain. Corn DDGS are an excellent source of protein and energy for ruminants (Lardy, 2003) and have become more available in recent years due to the ever-growing ethanol industry (FAPRI, 2017). Even though NRC (2007) states that CSM is greater in CP and degradable protein than DDGS, previous studies have shown that completely replacing CSM with DDGS (up to 20% of the diet; DM basis) resulted in no differences in average daily DMI, ADG, or G:F in feedlot lambs (McEachern et al., 2009). However, feeding high concentrations of DDGS in lamb feedlot rations has been of concern to the industry due to S content that originates with industry cleaning practices. This concern is based upon the evaluation of DDGS in cattle feedlot diets, which have been reported to cause polioencephalomalacia (PEM) when incorporated at more than 20% of the diet (Lardy, 2003). However, in sheep, Schauer et al. (2008) reported that diets as high as 60% DDGS can be fed to feedlot lambs with no detrimental growth or health effects. Furthermore, Rios-Rincón et al. (2014) reported that dietary energy has a greater role on G:F than protein, suggesting that lambs on lower protein diets that are adequate in energy, gain as well as lambs on greater protein diets that are normally fed in the industry. Therefore, the hypothesis was that DDGS can completely replace CSM and grain sorghum in lamb feedlot diets without negatively affecting growth performance, health, or ruminal function.

Materials And Methods

Animals and Management

Forty-six Dorper ram lambs (approximate age = 4 mo; initial BW = 25 kg ± 6 kg), previously fed 80% alfalfa hay and a 20% commercial ration (DM basis), were brought into the Texas A&M AgriLife Research feedlot in San Angelo. Lambs received an ear tag and an oral dose of albendazole (anthelmintic: Valbazen, Zoetis, Parsippany, NJ). During the first 4 d of the adaptation period, lambs were group-fed and provided ad libitum access to long-stemmed hay, which was supplemented with a 60% concentrate diet (0.22 kg•d^{-1}•$lamb^{-1}$; DM basis). Data from two lambs (0DDGS) were removed from the statistical analysis because one sustained an injury to the stifle and one died from an unknown infection.

Seven days before study initiation, each lamb was weighed, stratified by BW, and randomly assigned to an individual, completely covered dirt pen (2.44 × 2.97 m) with an automatic watering system and feed bunk. Each lamb was randomly assigned to one of five treatment diets (n = 9 lambs/treatment; Table 1). The positive control diet (CNTL), representative of a traditional feedlot diet, contained CSM, sorghum grain, and other concentrates but no DDGS. Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain. Lambs fed CNTL were compared to 0DDGS and linear and quadratic effects were evaluated within the four DDGS diets. During the last 2 d of the adaptation period, lambs did not receive hay, but were fed a common 66% concentrate diet that was gradually replaced by the assigned treatment diet.

Treatment diets were formulated (NRC, 2007) to evaluate linear and quadratic trends. However, the 0DDGS diet was allowed to remain deficient in CP due to the experimental design. Since DDGS are high in P, Ca carbonate was added to maintain a Ca:P ratio between 1.5 and 2:1 as recommended by ARC (1980). Ammonium chloride was added to reduce the incidence of urinary calculi (Crookshank, 1970) and a mineral premix specifically blended for diets containing DDGS was used. Cost/metric ton of feed (DM basis) was calculated by using ingredient prices based on local markets. Average daily feed cost per kilogram of BW gain for each treatment group was calculated on a DM basis (DMI needed to gain 1 kg of BW, kg × $/kg of feed).

Sample Collection and Measurements

Lambs were fed their respective treatment diets throughout the entire

Table 1. Ingredient composition of feeds (% DM basis) of treatment diets.

Item[2]	Diet[1]				
	CNTL	0DDGS	33DDGS	66DDGS	100DDGS
Cottonseed hulls	29.1	29.1	29.1	29.1	29.1
Cottonseed meal	12.0	-	-	-	-
DDGS	-	-	22.0	43.0	64.0
Sorghum grain, rolled	53.4	65.7	43.1	21.5	-
Molasses, cane	3.0	3.0	3.0	3.0	3.0
Limestone	1.1	0.8	1.4	2.0	2.5
Ammonium Cl	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5
Mineral premix	0.4	0.4	0.4	0.4	0.4
Cost/t of feed	$270.99	$288.27	$278.84	$287.49	$296.18

[1] In a 56-d randomized design study, lambs were provided ad libitum 70.9% concentrate diets in individual pens. The positive control diet (CNTL) contained CSM, sorghum grain, and other concentrates, but no corn dried distillers grains with solubles (DDGS). Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain.

[2] Mineral premix = NaCl, KCl, S, MnO, ZnO, vitamins A, D, and E, $CaCO_3$, cottonseed meal, cane molasses, and animal fat. Cost/t of feed (DM basis; metric ton) was calculated by using ingredient prices based on local markets.

56-d trial. All mixed diets were non-pelleted and fed once daily at 0800 h with an approximate allowance of 10% refusal. Lamb BW was recorded on d 0, 14, 30, 42, and 56. Average daily gain and average daily DMI (aDMI) were determined between days that BW was recorded and G:F calculated between weigh-day by dividing ADG by average daily DMI. Ruminal fluid was collected on d 0 and 56 and blood serum collected on d 0, 14, and 56.

Subsamples of CSH, sorghum grain, DDGS, and the mixed treatment diets were individually collected three times during the trial, kept separate, and subsamples combined before being analyzed. Samples were dried at 55°C in a forced-air oven (model 630, NAPCO, Portland, OR) for 48 h, ground through a 1-mm screen (Wiley mill, Arthur H. Thomas Co., Philadelphia, PA), and stored at –20°C. Nitrogen was analyzed by a standard method (Method 990.03; AOAC Int., 2006) and CP calculated as 6.25 × N. The NDF and ADF was analyzed according to procedures of Van Soest et al. (1991), which were modified for an Ankom 2000 Fiber Analyzer (Ankom Technol. Corp., Fairport, NY) using -amylase and Na sulfite. In addition, N was analyzed in residue remaining after the ADF procedure and multiplied by 6.25 to determine acid detergent insoluble CP (ADICP). Standard methods were used to analyze lignin (AOAC 973.18; AOAC, 2006), crude fat (Method 2003.05; AOAC Int., 2006), ash (Method 942.05; AOAC Int., 2006), and minerals; the latter by a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma Radial Spectrometer (Thermo Instrument Systems, Inc., Waltham, MA).

An Ankom model DaisyII incubator was used to determine 48-h true IVDMD (tIVDMD) by incubating each treatment diet in separate F57 bags (3 replicates; Ankom Technol. Corp., Macedon, NY) for 48 h. Each bag contained 0.35 g of material that was hammermilled to pass a 2-mm screen (Wiley mill). Bags were placed into jars containing 400 mL of sheep rumen fluid (collected orally) and 1,600 mL of McDougal's buffer solution (1.0 g of urea/L; McDougal, 1948). One blank bag per jar was included and used to adjust for potential residue on the bags. After anaerobic incubation at 39°C, bags were gently rinsed under cold water for 5 min, subjected to the NDF procedure (using -amylase and omitting Na sulfite), gently rinsed in acetone, dried at 55°C in a forced-air oven for 48 h, and weighed.

Blood Serum and Rumen fluid Collection and Analysis.

A 10-mL blood sample was collected 4 h after feeding from each lamb via jugular venipuncture using a non-heparinized vacutainer collection tube (serum separator tube, gel, and clot activator; Becton Dickenson, Franklin Lakes, NJ). Blood was allowed to clot 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 until analyzed. Serum chemistry was analyzed by The Texas A&M Veterinary Diagnostic Laboratory, Amarillo, using an Olympus AU400E analyzer (Olympus America Inc., Center Valley, PA).

Rumen fluid was collected orally from each lamb 4 h after feeding, using a stomach tube. The pH of each subsample was immediately recorded and the remaining fluid was filtered through 4 layers of cheesecloth; a subsample was immediately placed on ice and stored at −80°C. Additional subsamples (1-mL) were acidified with 4 mL of 0.1 N HCl (Farmer et al., 2004) and stored at −80°C for ammonia-N analysis using a Beckman Coulter DU640 spectrophotometer (Beckman Instruments, Inc., Fullerton, CA; methods of Broderick and Kang, 1980), and VFA using an Agilent 6890N gas chromatograph (Agilent Technology, Inc., Wilmington, DE; Baumgardt, 1964; Fritz and Schenk, 1979).

Statistical Analysis

Data for growth performance, blood serum, and ruminal fluid characteristics were analyzed using the PROC MIXED procedure for normal data sets, or PROC GLIMMIX for non-normal data sets (ammonia-N, albumin, serum urea N (SUN), Ca, creatine, creatine kinase (CK), AST, GGT, GLDH, Mg, Na, K, Na:K ratio, and Cl), procedure of SAS (Version 9.3; SAS Inst. Inc., Cary, NC) using a model that included treatment with lamb as the random error. Data was reported as least squares means with greatest standard errors. Treatment effects were tested using the following orthogonal contrasts: (1) CNTL vs. 0DDGS and (2) linear and (3) quadratic effects of 0DDGS, 33DDGS, 66DDGS, and 100DDGS diets. PROC IML was used to generate orthogonal coefficients for the linear and quadratic contrasts; only the highest order contrast with a P-value < 0.10 was discussed.

Results And Discussion

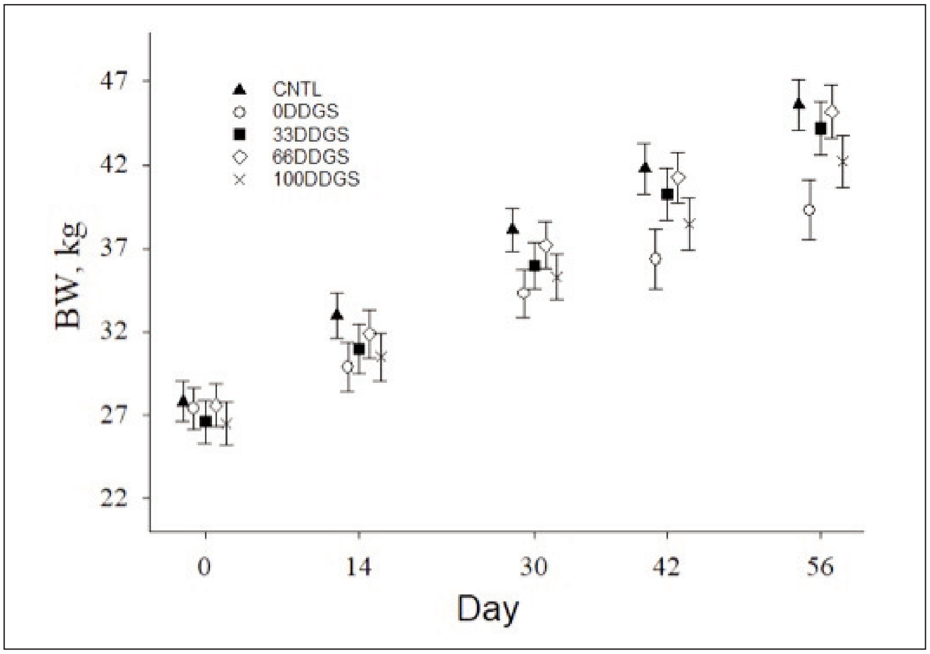
Animal Performance

A treatment × day interaction ($P < 0.001$) was observed for lamb BW (Figure 1). By design, initial lamb BW was similar ($P > 0.78$) on d 0. Lambs fed CNTL tended to have greater ($P = 0.06$) BW on d 30 and had greater ($P \leq 0.02$) BW on d 42 and 56 than lambs fed 0DDGS. Over the entire trial, ADG and G:F was greater ($P \leq 0.008$) for lambs fed CNTL vs. lambs fed 0DDGS, but DMI was similar ($P = 0.22$). Per experimental design, 0DDGS was deficient in CP (NRC, 2007), which likely resulted in decreased growth.

On d 42 and 56, lamb BW quadratically increased ($P \leq 0.04$) as DDGS increased in the diet. Positive quadratic trends were observed for ADG, DMI, and G:F ($P < 0.001$; = 0.08; = 0.06, respectively). McEachern et al. (2009) did not report any differences in final BW, ADG, or G:F when CSM was completely replaced by DDGS in lamb feedlot diets; however, urea was added to make the rations isonitrogenous, thus CP concentrations were similar. Schauer et al. (2008) reported a linear increase in lamb DMI as the concentration of DDGS increased, thus CP increased in the diet but G:F and ADG remained similar.

The observed differences in DMI are likely linked to differences in dietary CP and ADF (Table 2). Glimp et al. (1989) concluded that excessive starch in a diet can lead to decreased DMI, which could explain the reduced DMI for lambs fed 0DDGS. Fenderson and Bergen (1976) fed diets that exceeded the CP requirement of steers and reported that DMI was initially reduced but recovered after 10 d. Schauer et al. (2008) fed up to 60% DDGS and reported no decrease in DMI. In the current trial, visual inspection of the residual feed suggested that lambs tended to sort against DDGS. Thus, hammer-

Figure 1. Effects of feeding increasing levels of dried distillers grains with solubles (DDGS) on lamb BW. In a 56-d randomized design study, lambs were provided ad libitum 70.9% concentrate diets in individual pens. The positive control diet (CNTL) contained CSM, sorghum grain, and other concentrates, but no DDGS. Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain. A treatment × day interaction was observed ($P < 0.001$) for lamb BW. Lambs fed CNTL tended to have greater ($P = 0.06$) BW on d 30 and had greater ($P \leq 0.02$) BW on d 42 and 56 than lambs fed 0DDGS. On d 42 and 56, lamb BW quadratically increased ($P \leq 0.04$) as DDGS increased in the diet. Vertical bars represent standard errors.



milling the diets may reduce sorting but rumen acidosis would need to be monitored (Welch, 1982).

The incidence of PEM is a general concern and NRC (2007) recommends that dietary S concentrations in a concentrate-based diet be kept less than 0.3% of feed (DM basis). Schauer et al. (2008) used up to 60% DDGS in lamb feedlot diets that contained dietary S concentrations of 0.55% without observing PEM; however, thiamin was included, which has been reported to reduce PEM occurrence (Edwin et al., 1979). Olkowski et al. (1992) induced PEM in two-month old feedlot lambs by feeding a diet with excess S (0.63%) and no supplemental thiamin and reported that seven of the 22 lambs on the high-S, low-thiamin diet, developed neurological signs associated with PEM.

The ethanol industry uses sulfuric acid during the cleaning process, which can result in high concentrations of S in DDGS. In the current trial, dietary S levels (from 0.36 to 0.72 %, DM basis) exceeded that of the rations fed by Schauer et al. (2008) and Olkowski et al. (1992) and the 100DDGS contained twice the amount of S recommended by NRC (2007). However, no incidence of PEM occurred, which may be due to the lambs not being at risk for acidosis. Low ruminal pH would facilitate the activity of thiaminase-producing bacteria such as *B. thiaminolyticus* (Boyd and Walton, 1977). Furthermore, S in DDGS is mainly attributed to sulfuric acid (Gray et al., 2006) that originates from the cleaning process, while Olkowski et al (1992) added S in the form of magnesium sulfate.

In a study by Huls et al. (2006), DDGS were included at 22.9% of the diet (DM basis), replacing soybean meal and a portion of corn. In the current trial, S in the 0DDGS diet was relatively low in comparison to 33DDGS, 66DDGS, and 100DDGS diets (0.36%, 0.54%, and 0.72% S, respectively). However, Huls et al. (2006) fed soy hulls, which are highly fermentable and contain less effective fiber in comparison to CSH (NRC, 2000). Cottonseed hulls are a sufficient source of dietary fiber and effective at reducing acidosis and bloat.

Corn DDGS are high in sulfuric acid and thus, acidic, as indicated by the presence of S (1.0% DM) in the DDGS used in this trial. This is supported by Whitney et al. (2014) as the DDGS when mixed in a water solution had a pH of 3.77. Acidic feedstuffs can decrease rumen pH, digestibility, and DMI (Mould et al., 1983). However, DDGS are low in starch and high in fiber, thus the risk of acidosis is reduced when feeding DDGS in mixed rations (Schingoethe, 2006). Acidic sources of dietary S can have an impact on lamb growth performance (Felix et al., 2014). Felix et al. (2014) determined that S from DDGS, primarily in the form of H2SO4, is more readily reduced to H2S in the rumen than other sources of dietary S such as Na_2SO_4. This caused reduced growth performance in lambs fed high S diets in comparison to another treatment group fed a corn-based diet supplemented with 1.4% Na_2SO_4 (Felix et al., 2014).

Rumen Fluid Profiles

Treatment × day interactions ($P \leq 0.003$) were observed for ammonia-N and acetate production (Table 4). Treatment × day interactions ($P < 0.10$) tended to be present for acetate:propionate and ruminal pH. Lambs fed CNTL had significantly greater ruminal N ($P < 0.001$) than lambs fed 0DDGS. Lambs fed 0DDGS had a more neutral ruminal pH than lambs fed CNTL ($P < 0.001$). A positive linear increase ($P < 0.001$) was observed among treatments on d 56 for ruminal acetate concentration. On d 56, a positive quadratic change ($P < 0.001$) and a negative quadratic change ($P < 0.001$) were observed for ammonia-N and ruminal pH, respectively. No treatment × day interactions ($P > 0.21$) were observed for propionate or butyrate concentrations.

Even though DDGS are an acidic feedstuff due to the presence of sulfuric acid (Whitney et al., 2014), it is low in readily digestible starches and high in fiber (NRC, 2007; Whitney et al., 2014). This explains why ruminal pH increased and tIVDMD decreased as the proportion of DDGS increased in the diet. Fimbres et al. (2002) reported that

Table 2. Chemical composition (% DM basis) of ingredients and treatment diets.

Item[2]	Diet[1] CNTL	0DDGS	33DDGS	66DDGS	100DDGS	Sorghum	DDGS	CSH
Nutrient composition								
DM, %	91.6	92.6	93.0	93.0	93.4	91.8	91.9	89.7
CP, %	13.7	10.3	15.0	19.8	24.6	11.0	33.0	6.8
ADICP, %	1.9	1.7	2.9	3.3	4.3	1.4	5.5	3.7
aNDF, %	31.8	28.4	37.0	35.3	41.2	7.6	26.3	82.1
ADF, %	23.0	21.7	25.4	26.3	25.2	5.7	16.2	66.3
Lignin, %	6.8	5.8	6.6	6.3	6.7	1.2	3.0	21.1
Crude fat, %	3.9	4.6	5.4	7.0	8.3	3.7	12.8	2.7
Ash, %	4.8	4.0	5.1	5.4	7.1	1.8	7.2	2.8
Ca, %	0.50	0.46	0.67	0.84	0.96	0.09	0.05	0.17
P, %	0.33	0.26	0.40	0.56	0.71	0.29	1.1	0.15
S, %	0.21	0.19	0.36	0.54	0.72	0.14	1.00	0.13
K, %	0.91	0.83	0.99	1.13	1.24	0.39	1.25	1.19
Mg, %	0.21	0.17	0.21	0.26	0.29	0.12	1.03	0.20
Na, %	0.30	0.32	0.34	0.38	0.35	0.10	0.13	0.02
Fe, ppm	156	86	96	124	137	47	78	45
Zn, ppm	35	42	43	50	59	23	66	13
Cu, ppm	5	4	5	5	6	3	5	5
True IVDMD	72.65	73.41	71.51	69.77	66.93	98.38	79.18	31.85
Cost of feed/kg of BW gain	$1.44	$1.71	$1.40	$1.55	$1.55			

1 In a 56-d randomized design study, lambs were provided ad libitum 70.9% concentrate diets in individual pens. The positive control diet (CNTL) contained CSM, sorghum grain, and other concentrates, but no DDGS. Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain.

2 ADICP = acid detergent insoluble CP; True IVDMD = true 48-h IVDMD. Cost of feed/kg of BW gain= average daily feed cost per kilogram of BW gain for each treatment group was calculated on a DM basis as: (DMI needed to gain 1 kg of BW, kg × $/kg of feed)

Table 3. Effects of replacing cottonseed meal (CSM) and sorghum with dried distillers grains (DDGS) on lamb growth performance.

Item	Diet[1] CNTL	0DDGS	33DDGS	66DDGS	100DDGS	SEM	*P*-value[2] D	T × D	1	L	Q
ADG, kg											
d 0 to 56	0.32	0.23	0.31	0.31	0.28	0.02	0.29	0.91	<0.001	0.03	<0.001
DMI, kg/d											
d 0 to 56	1.60	1.45	1.56	1.67	1.47	0.96	<0.001	0.78	0.22	0.65	0.08
G:F, kg/kg											
d 0 to 56	0.20	0.16	0.20	0.19	0.19	0.01	<0.001	0.93	0.008	0.08	0.06

1 In a 56-d randomized design study, lambs were provided ad libitum 70.9% concentrate diets in individual pens. The positive control diet (CNTL) contained CSM, sorghum grain, and other concentrates, but no DDGS. Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain.

2 Contrast 1 = CNTL vs. 0DDGS, Linear and quadratic orthogonal polynomial contrasts.

the starch content of a ration has a major influence on the rate of fermentation and pH of the rumen 4 h after feeding. Anderson et al. (2006) reported no differences in acetate production when feeding DDGS at 10% or 20% of the total diet (DM basis) fed to dairy cattle. Furthermore, no differences in butyrate, propionate, or acetate:propionate were observed according to Anderson et al. (2006). Results of Anderson et al. (2006) partially support the results of the current trial but the maximum DDGS inclusion rate was much greater in the current trial (20% compared to 65%, DM basis). The proportions of ADF and NDF in the diets fed by Anderson et al. (2006) were similar between the CNTL,

Table 4. Effects of replacing cottonseed meal (CSM) and sorghum with dried distillers grains (DDGS) on lamb rumen fluid profile.

	Diet[1]						*P*-value[2]				
Item	CNTL	0DDGS	33DDGS	66DDGS	100DDGS	SEM	D	T × D	1	L	Q
pH							<0.001	0.08			
d 0	5.94	5.81	5.95	5.85	6.25	0.17			0.52	0.10	0.42
d 56	6.34	6.87	6.31	6.45	6.57	0.09			<0.001	0.11	<0.001
Ammonia-N, mg/dL							<0.001	<0.001			
d 0	6.71	4.63	5.37	6.51	6.17	1.25			0.17	0.25	0.60
d 56	2.95	1.33	3.76	6.15	7.02	0.74			<0.001	<0.001	<0.001
Acetate, mol/100 mol							<0.001	0.003			
d 0	62.9	66.9	62.6	64.6	62.7	1.5			0.04	0.10	0.40
d 56	50.3	50.7	48.8	56.8	58.6	2.0			0.88	<0.001	0.27
Propionate, mol/100 mol							<0.001	0.21			
d 0	23.7	21.1	26.0	22.0	25.7	1.6			0.21	0.15	0.74
d 56	34.9	31.3	40.1	29.5	31.5	2.6			0.29	0.35	0.15
A:P							<0.001	0.09			
d 0	2.7	3.2	2.6	3.0	2.5	0.2			0.09	0.09	0.67
d 56	1.6	1.7	1.3	2.0	2.0	0.2			0.48	0.08	0.21
Butyrate, mol/100 mol							0.09	0.44			
d 0	11.8	11.3	10.1	11.8	10.5	1.1			0.99	0.73	0.99
d 56	10.3	10.5	9.4	12.7	8.9	1.0			0.75	0.61	0.15

[1] In a 56-d randomized design study, lambs were provided ad libitum 70.9% concentrate diets in individual pens. The positive control diet (CNTL) contained CSM, sorghum grain, and other concentrates, but no DDGS. Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain.

[2] Contrast 1 = CNTL vs. 0DDGS, Linear and quadratic orthogonal polynomial contrasts.

10% DDGS, and 20% DDGS rations. This could also explain why no differences were observed, whereas in the current trial, there were differences in aNDF, ADICP, and crude fat. As reported in Table 2, this resulted in a linear decrease in the overall tIVDMD of the diet as the amount of DDGS increased.

Ruminal ammonia-N increased quadratically ($P < 0.001$) on d 56 as DDGS increased in the diet, which was expected due to greater dietary CP. In addition, ruminal ammonia-N was less on d 56 for lambs fed 0DDGS vs. lambs fed CNTL. This was expected because 0DDGS was deficient in CP according to NRC (2007). Even though Rios-Rincón et al. (2014) reported that dietary energy has a greater role on G:F than protein, their low protein diets contained greater than 14% CP. Thus, the decreased growth performance of the lambs fed 0DDGS can be attributed to reduced ruminal ammonia-N.. However, 66DDGS and 100DDGS diets contained excess dietary CP (approximately 7% and 13, respectively; NRC, 2007). This would likely result in dietary energy inefficiently being used to excrete excess circulating N. In contrast, as observed in the current trial with lambs fed 0DDGS, feeding diets low in N can reduce lamb performance because microbial growth and function are reduced due to ruminal N being limited (NRC, 2007; Kaya et al., 2009).

Blood Serum Profiles

Lamb blood serum chemistry profiles are presented in Table 5. Treatment × day interactions ($P < 0.05$) were observed for glucose, SUN, creatinine, albumin, GGT, Mg, and Cl. Treatment × day interactions ($P < 0.10$) tended to be observed for TSP, CK, and P. Blood SUN was greater ($P < 0.001$) for lambs fed CNTL on d 14 and 56 compared to lambs fed 0DDGS. Albumin was also greater ($P < 0.001$) on d 56 for lambs fed CNTL compared to lambs fed 0DDGS. Positive quadratic trends ($P < 0.05$) were observed for glucose, SUN, albumin, AST, P, Mg, and Cl. Positive linear changes ($P < 0.05$) were observed for TSP and GLDH. The primary purpose for analyzing blood serum chemistry was to display metabolic issues that may have occurred, which may be linked to the inclusion of high concentrations of DDGS in the diet. Although there were differences among certain enzymes (GGT and CK), minerals (Mg, Cl, and Ca), and other constituents (TSP, creatine, and glucose), values were within the normal biological range for growing lambs (Cornelius, 1989; Stämpfli and Oliver-Espinosa, 2015). This suggested that including 64% of DDGS in a mixed ration did not negatively affect lamb health. Serum GGT and alanine aminotransferase function as indicators of hepatic function disorders (Cornelius, 1989; Stämpfli and Oliver-Espinosa, 2015). Serum CK is an enzyme that

Table 5. Effects of replacing cottonseed meal (CSM) and sorghum with dried distillers grains (DDGS) on lamb blood serum profiles.

	Diet[1]						P-value[2]					
Item[3]	CNTL	0DDGS	33DDGS	66DDGS	100DDGS	SEM	T	D	T × D	1	L	Q
Glucose							0.007	<0.001	0.04			
d 0	79.1	77.1	82.4	77.3	76.9	2.77				0.58	0.63	0.28
d 14	87.8	79.4	87.9	88.8	77.8	3.38				0.08	0.79	0.006
d 56	85.7	78.8	78.2	79.3	66.2	3.24				0.12	0.01	0.05
SUN							<0.001	<0.001	<0.001			
d 0	9.07	8.19	10.35	8.68	8.18	0.94				0.42	0.72	0.13
d 14	8.43	4.53	9.76	14.60	19.64	2.16				<0.001	<0.001	0.04
d 56	11.09	4.28	12.82	17.33	18.60	1.45				<0.001	<0.001	<0.001
Creatinine							0.20	0.005	0.009			
d 0	0.59	0.61	0.61	0.60	0.65	0.04				0.61	0.46	0.43
d 14	0.72	0.74	0.71	0.61	0.57	0.04				0.65	<0.001	0.81
d 56	0.74	0.78	1.26	0.65	0.61	0.31				0.90	0.20	0.25
Albumin							0.15	<0.001	0.02			
d 0	2.75	2.75	2.65	2.67	2.73	0.06				0.91	0.92	0.21
d 14	2.75	2.49	2.77	2.78	2.79	0.12				0.10	0.07	0.22
d 56	3.12	2.82	3.02	3.12	3.05	0.06				0.002	0.01	0.05
Globulin, d 14 and 56	3.26	3.20	3.07	3.37	3.31	0.11	0.32	0.85	0.49	0.69	0.20	0.75
A:G ratio, d 14 and 56	0.92	0.83	0.95	0.88	0.90	0.03	0.46	0.15	0.78	0.29	0.52	0.33
TSP							0.12	<0.001	0.09			
d 0	6.15	6.08	5.64	5.82	6.01	0.14				0.68	0.98	0.02
d 14	6.07	5.68	5.89	6.14	6.06	0.18				0.12	0.09	0.41
d 56	6.32	6.15	6.02	6.51	6.40	0.14				0.38	0.05	0.95
AST, d 14 and 56	87.89	68.79	85.92	97.65	81.06	6.92	0.02	<0.001	0.77	0.02	0.06	0.006
GGT, d 14 and 56	57.63	58.02	57.40	65.10	58.32	4.30	0.63	0.15	0.04	0.94	0.64	0.46
GLDH, d 14 and 56	21.84	18.10	23.24	32.65	30.37	6.17	0.18	0.34	0.95	0.47	0.03	0.40
CK, d 14 and 56	212.6	165.9	178.8	181.0	185.6	21.4	0.55	<0.001	0.08	0.10	0.47	0.82
Ca, d 14 and 56	9.94	10.90	9.52	9.72	9.61	0.66	0.52	0.38	0.48	0.27	0.20	0.31
P						0.009	0.008	0.06				
d 0	9.84	10.44	10.42	10.36	10.24	0.50				0.36	0.75	0.92
d 14	8.69	8.91	10.03	10.01	10.60	0.42				0.70	0.01	0.53
d 56	9.83	8.82	11.41	10.72	10.95	0.47				0.12	0.009	0.01
Mg, d 14 and 56	2.60	2.30	2.74	2.52	2.46	0.09	0.01	0.53	0.008	0.01	0.45	0.006
Cl						0.29	<0.001	0.006				
d 0	113.9	112.9	113.5	113.8	111.0	1.2				0.50	0.28	0.12
d 14	107.4	112.3	108.6	111.0	110.8	1.1				0.002	0.63	0.10
d 56	107.8	107.6	108.7	109.3	104.5	1.6				0.93	0.23	0.063
Na, d 14 and 56	143.8	145.2	145.0	144.5	142.8	1.4	0.70	0.30	0.24	0.47	0.21	0.54
K, d 14 and 56	5.32	6.68	5.77	5.60	6.24	0.64	0.43	0.85	0.67	0.09	0.58	0.17
Na:K ratio, d 14 and 56	0.27	0.25	0.25	0.26	0.26	0.01	0.08	<0.001	0.76	0.01	0.14	0.93

[1] In a 56-d randomized design study, lambs were provided ad libitum 70.9% concentrate diets in individual pens. The positive control diet (CNTL) contained CSM, sorghum grain, and other concentrates, but no DDGS. Four treatment diets were similar to CNTL but did not contain CSM: corn DDGS replaced 0% (0DDGS), 33% (33DDGS), 66% (66DDGS) or 100% (100DDGS) of the sorghum grain.

[2] Contrast 1 = CNTL vs. 0DDGS, Linear and quadratic orthogonal polynomial contrasts.

[3] SUN = serum urea N; A:G = albumin:globulin; TSP = total serum protein; AST = aspartate aminotransferase; GGT = gamma-glutamyl transferase; CK = creatine kinase. GLDH = glutamine dehydrogenase.

functions as an indicator of smooth muscle breakdown (Beatty and Doxey, 1983).

Differences in SUN can mainly be attributed to greater degradable protein intake (NRC, 2007). Lambs fed 66DDGS and 100DDGS received an excess of CP, which is shown by excessively high SUN concentrations on d 14 and d 56. This can increase urinary N excretion into the environment. The process of rapidly metabolizing excess ammonia into urea requires energy (Lobley et al., 2000). This, along with the reduced DM digestibility of the 100DDGS diet, potentially caused the reduced growth performance.

Conclusions

Results suggested that DDGS can entirely replace CSM and a significant portion of sorghum grain in high-concentrate finishing diets without negatively impacting ADG, DMI, G:F, or the health of the lamb. Furthermore, results support the fact that growth performance is hindered when lambs are fed diets containing less than 10.5% CP (DM basis). In addition, even though complications related to excess P in DDGS diets do not exist, feeders should remain cautious and continue to include Ca and ammonium chloride when elevated amounts of DDGS are incorporated into finishing rations.

Literature Cited

Anderson, J. L., D. J. Schingoethe, K. F. Kalscheur, and A. R. Hippen. 2006. Evaluation of dried and wet distillers grains included at two concentrations in the diets of lactating dairy cows. J. Dairy Sci. 89:3133-3142.

AOAC. 2006. Official methods of analysis. 18th ed. Arlington (VA): Association of Official Analytical Chemists.

ARC. 1980. The Nutrient Requirements of Ruminant Livestock. Slough, UK: Commonwealth Agricultural Bureaux.

Baumgardt, B. R. 1964. Practical observations on the quantitative analysis of free volatile fatty acids (VFA) in aqueous solutions by gas-liquid chromatography. Dep. Bulletin 1. Dep. Dairy Sci., Univ. of Wisconsin, Madison, WI.

Beatty, E. M., and D. L. Doxey. 1983. Lactate dehydrogenase and creatine kinase isoenzyme levels in the tissues and serum of normal lambs. Res. Vet. Sci. 35:325-330.

Boyd, J. W. and J. R. Walton. 1977. Cerebrocortical necrosis in ruminants: an attempt to identify the source of thiaminase in affected animals. J. Comp. Path. 87:581-589.

Broderick, G. A., and J. H. Kang. 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and in vitro media. J. Dairy Sci. 63:64–75.

Cornelius, C. E. 1989. Liver function. In: J. J. Kaneko, editor, Clinical biochemistry of domestic animals. 4th ed. Acad. Press, Inc., San Diego, CA. p. 364–397.

Crookshank, H. R. 1970. Effect of ammonium salts on the production of ovine urinary calculi. J. Anim. Sci. 30:1002-1004.

Edwin, E. E., L. M. Markson, and J. Shreeve. 1979. Diagnostic aspects of cerebrocortical necrosis. Vet Rec. 104:4-8.

FAPRI. 2017. Food and Agricultural Policy Research Institute. International biofuels baseline briefing book. FAPRI-MU Report #02-17. Univ. of Missouri, Columbia, MO. www.fapri.missouri.edu/wp-content/uploads/2017/05/International-Biofuel-Baseline-final.pdf (Accessed 17 December 2019).

Farmer, C. G., B. C. Woods, R. C. Cochran, J. S. Heldt, C. P. Mathis, K. C. Olson, E. C. Titgemeyer, and T. A. Wickersham. 2004. Effect of supplementation frequency and supplemental urea level on dormant tallgrass-prairie hay intake and digestion by beef steers and prepartum performance of beef cows grazing dormant tallgrass-prairie. J. Anim. Sci. 82:884–894.

Felix, T. L., C. J. Long, S. A. Metzger, and K. M. Daniels. 2014. Adaption to various sources of dietary sulfur by ruminants. J. Anim. Sci. 92:2503-2510.

Fenderson, C. L. and W. G. Bergen. 1976. Effect of excess dietary protein on feed intake and nitrogen metabolism. J. Anim. Sci. 42:1323-1330.

Fimbres, H., J. R. Kawas, G. Hernández-Vidal, J. F. Picón-Rubio, and C. D. Lu. 2002. Nutrient intake, digestibility, mastication and ruminal fermentation of lambs fed finishing ration with various forage levels. Small Ruminant Res. 43:275-281.

Fritz, J. S., and G. H. Schenk. 1979. Quantitative analytical chemistry. 4th ed. Allyn and Bacon, Inc., Boston, MA.

Glimp, H. A., S. P. Hart, and D. Von-Tungeln. 1989. Effect of altering nutrient density (concentrate to roughage ratio) and restricting energy intake on rate, efficiency and composition of growing lambs. J. Anim. Sci. 67:865-871.

Gray, A. K., L. Zhao, and L. Emptage. 2006. Bioethanol. Curr. Opin. Chem. Biol. 10:141-146.

Huls, T. J., A. J. Bartosh, J. A. Daniel, R. D. Zelinski, J. Held, and A. E. Wertz-Lutz. 2006. Efficacy of dried distillers grains with solubles as a replacement for soybean meal and a portion of the corn in a finishing lamb diet. Sheep & Goat Res. J. 21: 30-34.

Kaya, I., Y. Ünal, T. Sahin, and D. Elmali. 2009. Effect of different protein levels on fattening performance, digestibility and rumen parameters in finishing lambs. J. Anim. Vet. Adv. 8:309-312.

Lardy, G.P. 2003. Feeding coproducts of the ethanol industry to beef cattle. NDSU Ext. Serv. Bull. AS-1242.

Lobley, G. E., G. D. Milano, and J. G. van der Walt. 2000. The liver: integrator of nitrogen metabolism. In: P. B. Cronjé, editor, Ruminant physiology: digestion, metabolism, growth, and reproduction. CAB International, New York, NY. p. 149-156.

McDougall, E. I. 1948. Studies on ruminant saliva. 1. The composition and output of sheep's saliva. Biochem. J. 43:99–109.

McEachern, J. K., T. R. Whitney, C. B. Scott, C. J. Lupton, and M. W. Salisbury. 2009. Substituting distillers grains for cottonseed meal in lamb-finishing rations: growth, wool characteristics, and serum NEFA, urea N, and IGF-1 concentrations. Sheep and Goat Res. J. 24:32-40.

Mould, F. L., and E. R. Ørskov. Manipulation of rumen fluid pH and its influence on cellulolysis in sacco, dry matter degradation and the rumen microflora of sheep offered either hay or concentrate. Anim. Feed Sci. Technol. 10:1-14.

NRC. 2007. Nutrient Requirements of Small Ruminants. National Academy Press, Washington, DC.

Olkowski, A. A., S. R. Gooneratne, C. G. Rousseaux, and D. A. Christensen. 1992. Role of thiamine status in Sulphur induced polioencephalomalacia in sheep. Research in Veterinary Science. 52:78-85.

Ríos-Rincón, F. G., A. Estrada-Angulo, A. Plascencia, M. A. López-Soto, B. I. Castro-Pérez, J. J. Portillo-Loera, J. C. Robles-Estrada, J. F. Calderón-Cortes, and H. Dávila-Ramos. 2014. Influence of protein and energy level in finishing diets for feedlot hair lambs: growth performance, dietary energetics and carcass characteristics. Austral. J. Anim. Sci. 27:55–61.

Schauer, C. S., M. M. Stamm, T. D. Maddock, and P. B. Berg. 2008. Feeding of DDGS in lamb rations: Feeding dried distillers grains with solubles as 60 percent of lamb finishing rations results in acceptable performance and carcass quality. Sheep and Goat Res. J. 23:15-19.

Schingoethe, D. J. 2006. Utilization of DDGS by cattle. In Proceedings 27th western nutrition conference, 19-20 September 2006, Winnipeg, MB, Canada (pp. 61-74).

Stämpfli, H., and O. Oliver-Espinosa. 2015. Collection of samples and interpretation of laboratory tests. In: B. Smith, editor, Large animal internal medicine. 5th ed. Elsevier Mosby Inc., St. Louis, MO. p. 349–373.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Welch, J. G. 1982. Rumination, particle size and passage from the rumen. J. Anim. Sci. 54:885-894.

Whitney, T. R., C. J. Lupton, J. P. Muir, R. P. Adams, and W. C. Stewart. 2014. Effects of using ground redberry juniper and dried distillers grains with solubles in lamb feedlot diets: growth, blood serum, fecal, and wool characteristics. J. Anim. Sci. 92:1119-1132.