Effects of using ground redberry juniper and dried distillers grains with solubles in lamb feedlot diets: Growth, blood serum, fecal, and wool characteristics[1]

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ABSTRACT: Effects of using ground redberry juniper and dried distillers grains with solubles (DDGS) in Rambouillet lamb (n = 45) feedlot diets on growth, blood serum, fecal, and wool characteristics were evaluated. In a randomized design study with 2 feeding periods (Period 1 = 64% concentrate diet, 35 d; Period 2 = 85% concentrate diet, 56 d), lambs were individually fed 5 isonitrogenous diets: a control diet (CNTL) that contained oat hay but not DDGS or juniper or DDGS-based diets in which 0 (0JUN), 33 (33JUN), 66 (66JUN), or 100% (100JUN) of the oat hay was replaced by juniper. During Period 1, lambs fed CNTL had greater ($P < 0.05$) DMI and ADG and tended to have greater ($P < 0.10$) G:F than lambs fed 0JUN or lambs fed DDGS-based diets. Lamb DMI, ADG, and G:F quadratically increased ($P < 0.008$) as juniper increased in the DDGS-based diets. During Period 2, lambs fed CNTL had greater ($P < 0.05$) DMI than lambs fed 0JUN or lambs fed DDGS-based diets, but ADG was similar ($P > 0.41$). Compared to 0JUN, lambs fed CNTL had similar ($P = 0.12$) G:F and tended to have less G:F ($P = 0.07$) than lambs fed DDGS-based diets. Among lambs fed DDGS-based diets, DMI was similar ($P > 0.19$), ADG increased linearly ($P = 0.03$), and G:F tended to decrease quadratically ($P = 0.06$) as juniper increased in the diet. Serum IGF-1, serum urea N (SUN), and fecal N were greater ($P < 0.05$) and serum Ca and P and fecal P were similar ($P > 0.13$) for lambs fed CNTL vs. lambs fed DDGS-based diets (CNTL). Within lambs fed DDGS-based diets, SUN increased quadratically ($P = 0.01$) and fecal N increased linearly ($P = 0.004$), which can partially be attributed to increased dietary urea and condensed tannin intake. Most wool characteristics were not affected, but wool growth per kilogram of BW decreased quadratically ($P = 0.04$) as percentage of juniper increased in the DDGS-based diets. When evaluating the entire 91-d feeding trial, results indicated that replacing all of the ground oat hay with ground juniper leaves and stems in lamb growing and finishing diets is not detrimental to animal performance and that DDGS-based diets can reduce total feedlot costs, as compared to sorghum grain and cottonseed meal-based diets. However, compared to using juniper or oat hay as the sole roughage source, using both during the growing period (Period 1) enhanced growth performance and further reduced total feedlot costs.

Key words: blood serum, feedlot, insulin-like growth factor-1, juniper, lamb, secondary metabolites, wool

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INTRODUCTION

Feed costs are the greatest input in livestock operations and have risen dramatically over the past 10 yr. Factors such as inflation and drought-induced feed shortages increase feed-related inputs and threaten the sustainability of livestock operations. Alternative, cost-competitive feed ingredients are needed to reduce production costs without negatively affecting animal performance. Dried distillers grains with solubles (**DDGS**) are expected to remain abundant (FAPRI, 2009) and can eliminate the need for expensive protein meals (Schauer et al., 2008; McEachern et al., 2009); therefore, maximizing inclusion of DDGS in total mixed rations is warranted. Schauer et al. (2008) reported that lamb diets can contain up to 60% DDGS

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without affecting animal health or performance, but others have reported that lamb diets containing more than 40% DDGS negatively affect performance and digestibility (Felix et al., 2012).

Redberry juniper (*Juniperus pinchotii*) infests over 8.09 ha in Texas (Ansley et al., 1995) and has become an important range management issue (Taylor, 2008) that is costly to manage (Lee et al., 2001). Use of ground redberry juniper as a livestock feed ingredient would increase its value, which could subsidize the cost of its removal. Whitney and Muir (2010) reported that redberry juniper leaves were 67% digestible, contained 7.1% CP and 5.5% condensed tannins (**CT**), and could replace cottonseed hulls in lamb feedlot diets. Condensed tannins and volatile oil in redberry juniper can affect the animal and rumen function (Kumar and Singh, 1984; McIntosh et al., 2003). If DDGS and redberry juniper can effectively be used in lamb feedlot diets, it would not only reduce sheep production costs but may ultimately result in greater rangeland forage production and ecosystem health due to greater removal of juniper trees (Coultrap et al., 2008).

MATERIALS AND METHODS

Animals and Management

The experimental protocol was approved by the Texas A&M University Institutional Animal Care and Use Committee. Rambouillet wether lambs (n = 45; approximate age = 4 mo; initial BW = 28.4 ± 4.2 kg) were weighed at the beginning of the adaptation period (21 d before study initiation), stratified by BW, and randomly assigned to diets (n = 9/diet); lambs were not shorn before the study but did receive an ear tag and a subcutaneous clostridial vaccine (Vision 7 with SPUR; Intervet Inc., Omaha, NE). Lambs were randomly assigned to individual, completely covered dirt pens (2.44 by 2.97 m) with automatic watering systems and feed bunks. Lambs were fed isonitrogenous diets: a control diet (**CNTL**) that contained oat hay but not DDGS or juniper or DDGS-based diets where 0 (**0JUN**), 33 (**33JUN**), 66 (**66JUN**), or 100% (**100JUN**) of the oat hay was replaced by juniper. The DDGS were a byproduct of corn ethanol production (POET, Sioux Falls, SD). Diets were mixed once at the beginning of each feeding period and monensin (Rumensin 80; Elanco, Indianapolis, IN) was added to each diet at the rate of 22 g/t of feed.

Lambs were individually fed once daily at 0900 h with an approximate allowance of 15% refusals. After a 21-d transition period, during which percentage of concentrate in the ration increased from 50 to 64% and juniper was gradually introduced (in 33JUN, 66JUN, or 100JUN diets), lambs were fed for 2 feedlot periods for a total of 91 d. During Period 1 (d 0 to 35), lambs were fed a 64% concentrate ration; lambs were then transitioned over 4 d into Period 2 (d 36 to 91) onto an 85% concentrate ration. Lamb BW was recorded on d 0 and every 7 d throughout the trial, and blood serum was collected on d 77, 84, and 91. Average daily gain and average daily DMI were determined between days that BW was recorded and G:F was calculated between weigh days by dividing ADG by average daily DMI.

Sample Collection and Measurements

Juniper Harvesting, Feed Collection, and Analysis. During the spring, *J. pinchotii* branches less than 3.6 cm diameter were cut from mature redberry juniper trees. Within 2 d, branches were mechanically chipped (Bear Cat, model number 73554; ECHO, West Fargo, ND) and dried for 4 h to approximately 93% DM in a drying trailer equipped with a perforated metal bottom sieve and a jet dryer (26 to 31°C; model 2001; Peerless Manuf. Co., Shellman, GA). Four subsamples of the chipped juniper were dried at 55°C in a forced-air oven for 48 h before being weighed and separated by hand into leaves and stems to determine leaf to stem ratio (weight of leaves/total sample weight). Chipped material was fine ground in a hammermill to pass a 4.76-mm sieve (Sentry, model 100; Mix-Mill Feed Processing Systems, Bluffton, IN), bagged, and stored under cover. Oat hay was ground in a hammermill to pass a 6.35-mm sieve (Gehl 135, West Bend, WI).

To evaluate (not statistically) nutritive value, random samples of juniper, oat hay, sorghum grain, DDGS, and cottonseed meal (**CSM**) were collected during both periods and nutritive values averaged (Table 1). Random samples of treatment diets were collected weekly during both periods; samples were combined every 3 or 4 wk during Periods 1 and 2, respectively, and analyzed separately, and average values were presented by period (Table 2). Samples were 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. Nitrogen was analyzed by a standard method (AOAC Int., 2006) and CP calculated as 6.25 × N. Crude fat was analyzed by a standard ether extraction method (AOAC Int., 2006). Additional subsamples were soaked in acetone to remove fat before analyzing NDF and ADF according to procedures of Van Soest et al. (1991), which were modified for an Ankom 2000 Fiber Analyzer (Ankom Technol. Corp., Fairport, NY) and not corrected for residual ash. The NDF procedure used α-amylase and Na sulfite. In addition, N was analyzed in residue remaining after ADF procedure and multiplied by 6.25 to determine acid detergent insoluble CP (ADICP). Ash was analyzed by a standard method (AOAC Int., 2006) and Ca, P, and S were analyzed by a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma Radial Spectrometer (Thermo Instrument

Table 1. Chemical composition and digestibility (% DM basis) of ground juniper, oat hay, sorghum grain, dried distillers grains with solubles (DDGS), and cottonseed meal (CSM) used in treatment diets

	Ingredient[2]				
Item,[1] %	Ground juniper	Ground oat hay	Rolled sorghum grain	DDGS	CSM
Nutrient composition					
DM	93.5	92.9	90.5	92.7	92.6
CP	7.6	12.6	12.6	29.8	47.4
ADICP	1.5	0.8	1.3	1.6	1.1
ADICP/CP	26.3	6.8	11.4	5.8	2.5
NDF	39.9	58.3	10.9	29.3	19.0
ADF	36.7	35.3	5.2	12.8	14.8
Crude fat	7.0	2.1	6.4	11.4	4.1
Lignin	17.6	6.4	1.0	3.0	3.0
Ca	1.61	0.3	0.07	0.03	0.23
P	0.06	0.14	0.50	0.96	1.06
Ca:P	26.83	2.14	0.14	0.03	0.22
Ash	5.5	6.0	2.1	4.7	6.6
Volatile oil	0.43	–	–	–	–
Condensed tannins					
Extractable	3.6	–	0.0	–	–
Protein bound	1.9	–	0.28	–	–
Fiber bound	0.5	–	0.27	–	–
Total	6.0	–	0.55	–	–
True IVDMD	55.0	57.4	92.0	79.5	87.9

[1]ADICP = acid detergent insoluble CP; true IVDMD = true 48-h *in vitro* dry matter digestibility.

[2]Ground juniper = leaves and stems < 3.6 cm diameter fine ground to pass a 4.76-mm sieve; Ground oat hay = ground to pass a 6.35-mm sieve; DDGS = from corn ethanol production; DDGS contained 0.97% sulfur; CSM values are from NRC, 2007.

Systems, Inc., Waltham, MA). Using methods reported by Felix and Loerch (2011), 20-g subsamples of DDGS, sorghum grain, juniper, and oat hay (hammermilled through a 1-mm screen) were mixed for 5 min in 80 mL of 39°C water and pH was recorded. Using these same solutions, the quantity of McDougal's buffer solution needed to titrate to pH 6.5 was recorded (Felix and Loerch, 2011).

Subsamples were exhaustively steam distilled using a modified circulator Clevenger-type apparatus to determine volatile oil concentration according to Adams (1991). Condensed tannins in the ground juniper and sorghum grain were assayed for soluble, protein-bound, and fiber-bound fractions by methods described by Terrill et al. (1992); samples were oven dried and standards were prepared from blueberry juniper as recommended by Wolfe et al. (2008). Feed fatty acid profiles were analyzed according to procedures of Murrieta et al. (2003). In addition, part of each sample was dried to constant weight in a forced-air oven at 103°C to determine DM concentration; all chemical analyses are reported on a DM basis. In addition, cost/metric ton of feed (DM basis) was calculated by using ingredient prices based on local markets; the price of juniper (US $100/dry t) was based on estimated harvesting, drying, and processing costs, after consulting with local brush control specialists; transportation costs were not included for any ingredient. Feed costs were then divided by kilogram of BW to determine cost of feed per kilogram of BW. Total feedlot cost was calculated as (total DMI × $/kg of feed DM) + (additional kg of feed intake to reach final BW of CNTL × $ kg of feed DM) + ($0.727·kg^{-1} of gain·d^{-1} [yardage + interest] × additional days on feed needed to reach final BW of CNTL), calculated by period and summed.

An Ankom model DaisyII incubator was used to determine 48-h true *in vitro* dry matter digestibility by incubating individual ingredients and each treatment diet in separate F57 bags (3 replicates; Ankom Technol. Corp.) for 48 h. Each bag contained 0.40 g of material that was ground to pass a 2-mm screen (Wiley mill). Bags containing any amount of juniper were incubated separately from other material in jars containing 400 mL of sheep rumen fluid (donors grazed native pasture) and 1,600 mL of McDougal's buffer solution (1.0 g of urea/L; McDougal, 1948). After anaerobic incubation at 39°C, all bags were gently rinsed under cold water for 5 min, subjected to the NDF procedure (using α-amylase and omitting Na sulfite), rinsed in acetone, dried at 55°C in a forced-air oven for 48 h, and weighed.

Methods similar to Bailoni et al. (1998) were modified to determine percentage of buoyant particles in 1.4 g of ground juniper (4.76-mm) and oat hay (6.35-mm) subsamples after being incubated in a ruminal fluid-buffer mixture (25:75 mL; specific gravity = 1.0) for either 10 min or 2, 6, or 24 h. Three replicates per feed source were evaluated at each time point along with 1 blank (rumen fluid and buffer only). After incubation, the solution was rinsed with water into a funnel that contained a 30-cm tube. After the material was allowed to settle for 10 min, the tube was pinched just below the funnel spout and the top and bottom regions were filtered (Whatman 54 paper) separately, dried at 103°C, and weighed. Percentage of buoyant particles (DM basis) was calculated as (particles in the top region, g – particles from the blank, g)/total incubated material, g.

Blood Serum and Fecal Collection and Analysis. A 10-mL blood sample was collected 4 h after feeding (at 1300 h on d 77, 84, and 91) from each lamb via jugular venipuncture using a nonheparinized vacutainer collection tube (serum separator tube, gel, and clot activator; Becton Dickenson, Franklin Lakes, NJ). Blood samples were 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 for urea N, IGF-1, Ca, and P concentrations. Serum urea N (**SUN**) concentrations were analyzed using a commercial kit (Teco Diagnostics, Anaheim, CA)

Table 2. Ingredient and chemical composition (% DM basis) and digestibility of treatment diets and cost of feed and cost of feed/kilogram of BW gain

	Diet[1]									
	Period 1[2]					Period 2[2]				
Item[3]	CNTL	0JUN	33JUN	66JUN	100JUN	CNTL	0JUN	33JUN	66JUN	100JUN
Ground juniper	–	–	12.0	24.0	36.0	–	–	5.0	10.0	15.0
Oat hay	36.0	36.0	24.0	12.0	–	15.0	15.0	10.0	5.0	–
Dried distillers grains	–	40.0	40.0	40.0	40.0	–	40.0	40.0	40.0	40.0
Cottonseed meal	8.0	–	–	–	–	8.0	–	–	–	–
Sorghum grain	46.33	14.15	14.55	14.93	15.32	67.17	35.05	35.19	35.31	35.43
Molasses	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Limestone	1.5	2.75	2.2	1.67	1.13	1.65	2.85	2.62	2.40	2.19
Ammonium chloride	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Salt	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Mineral premix	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Urea	1.07	–	0.15	0.30	0.45	1.08	–	0.09	0.19	0.28
Nutrient composition, %										
DM	90.6	91.8	91.9	91.9	92.0	89.9	91.0	91.7	91.8	91.8
CP	21.7	22.8	22.9	22.5	22.0	22.8	23.3	24.1	23.2	23.9
ADICP	0.7	0.7	0.8	1.0	1.1	1.4	0.7	1.3	1.8	1.7
ADICP/CP	3.5	3.3	3.8	4.8	5.4	6.8	3.3	5.9	8.5	7.3
NDF	30.5	33.8	32.9	30.7	29.7	19.8	28.0	27.2	26.1	24.2
ADF	18.9	17.2	18.1	18.0	19.0	11.9	13.8	14.6	15.3	13.9
Crude fat	3.1	7.0	7.6	8.0	8.2	3.4	7.5	8.0	7.9	8.2
Total saturated FA, % of extracted oil	20.8	17.3	17.2	17.3	17.2	19.6	16.5	16.6	16.8	16.7
Lignin	4.0	3.8	5.3	5.6	7.7	2.9	2.5	3.5	5.2	5.2
Ca	0.9	1.2	1.1	1.1	1.0	0.9	1.4	1.4	1.5	1.3
P	0.3	0.6	0.6	0.6	0.6	0.35	0.62	0.67	0.66	0.68
Ca:P	3.0	2.5	1.8	1.8	1.7	2.6	2.3	2.1	2.3	1.9
Ash	8.3	10.1	8.7	8.4	7.7	7.9	10.2	9.7	9.7	7.5
Volatile oil	<0.01	0.04	0.11	0.07	0.11	<0.01	0.04	0.03	0.03	0.03
True IVDMD	78.7	74.5	73.8	71.9	72.2	86.5	81.1	81.5	80.0	79.6
Cost/t of feed	$340	$323	$316	$309	$302	$390	$372	$370	$367	$364
Cost of feed/kg BW gain	$1.97	$2.21	$1.98	$1.82	$2.37	$2.26	$1.99	1.98	$2.13	$1.79

[1]Treatment diets were isonitrogenous, nonagglomerated feedlot growing rations containing ground juniper that replaced 0 (0JUN), 33 (33JUN), 66 (66JUN), or 100% (100JUN) of the ground oat hay. An additional control diet (CNTL) similar to 0JUN but using sorghum grain vs. DDGS was used to evaluate any negative effects of using 40% DDGS.

[2]Lambs were transitioned over 21 d onto their respective diets. During Period 1 (d 0 to 35), lambs were fed a 64% concentrate ration. Lambs were transitioned over 4 d into Period 2 (d 36 to 91) onto an 85% concentrate ration.

[3]Monensin (Rumensin 80, Elanco, Indianapolis, IN) was added to each diet at 22 g/t of feed. Cost/t of feed was calculated using ingredient prices based on local markets and the price of juniper ($100/dry t) was based on estimated harvesting, drying, and processing costs, after consulting with local brush control specialists; transportation costs were not included for any ingredient. ADICP = acid detergent insoluble CP; true IVDMD = true 48-h *in vitro* dry matter digestibility.

with intra- and interassay CV less than 4%. Serum IGF-1 concentrations were determined by RIA using procedures of Berrie et al. (1995); intra-assay CV for IGF-1 was 11.3% with a 95% recovery rate. Serum Ca and P concentrations were analyzed using commercial kits (Olympus, Center Valley, PA). Fecal samples were collected rectally from each lamb on d 91, dried at 55°C in a forced-air oven for 48 h, ground in a Wiley Mill to pass a 1-mm screen, and stored at –20°C. Fecal nitrogen was analyzed by a standard method (AOAC Int., 2006) and P analyzed using procedures of Eaton et al. (1995).

Wool Collection and Analysis. Fleece and fiber measurements were made at the Texas AgriLife Research Center in the Bill Sims Wool and Mohair Research Lab, San Angelo, TX. Mid-side samples were collected just before shearing on d 92 and measured for fiber diameter distribution (mean, SD, and CV), fiber curvature distribution (mean, SD, and CV), and staple length using the OFDA2000 instrument (BSC Electronics, Ardross, Western Australia). After lambs were shorn, grease fleece weights were obtained from each individual fleece and staples ($n = 10$) were removed from random positions in each fleece for staple length measurements (ASTM Int., 2009b). The remainder of the fleece was then pressure cored (32- by 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 Int., 2009a). One of the washed and dried duplicates was mini-cored (ASTM Int., 2008) to obtain 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 Int., 2009c). Conditioned snippets were then spread onto microscope slides (7 by 7 cm) and measured for fiber diameter distribution (average, SD, and CV), along-fiber average fiber diameter, SD, and CV, and average fiber curvature, SD, and CV using an OFDA 100 instrument (BSC Electronics, Ardross, Western Australia; Baxter et al., 1992; ASTM Int., 2008). Wool production per kilogram of BW was calculated as clean-wool production divided by final shorn BW.

Statistical Analysis

Data were analyzed using PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Lamb BW, DMI, ADG, and G:F were analyzed by period using a model that included treatment, day, and treatment × day with day as the repeated measure and lamb as the subject. Within period, when treatment × day interactions ($P < 0.05$) were observed, data were analyzed by day using a model that included treatment with lamb as the random error. Blood serum IGF-1, urea N, Ca, and P were analyzed only during Period 2 using a model that included treatment, day, and treatment × day with day as the repeated measure and lamb as the subject; no treatment × day interactions ($P > 0.12$) were observed for any serum variables; therefore, averages across day are presented. Fecal P, N, and wool characteristics were evaluated only once (during Period 2) using a model that included treatment with lamb as the random error. Covariance structures were compared to determine the most appropriate structure for each repeated measures model. Data are reported as least squares means with greatest standard errors. Treatment effects were tested using the following orthogonal contrasts: 1) CNTL vs. 0JUN and 2) CNTL vs. average of DDGS-based diets: 0JUN, 33JUN, 66JUN, and 100JUN and 3) linear and 4) quadratic effects of 0JUN, 33JUN, 66JUN, and 100JUN diets. Proc IML was used to generate orthogonal coefficients for the linear and quadratic contrasts with unequal spacing; only highest order linear or quadratic contrasts that were significant ($P < 0.10$) were discussed.

RESULTS AND DISCUSSION

Chemical Composition and Digestibility of Individual Ingredients and Treatment Diets

Chemical composition and digestibility of individual ingredients and treatment diets (Tables 1 and 2) were not statistically analyzed. Compared with oat hay, ground juniper contained approximately 40% less CP and 31% less NDF but had similar ADF concentration (Table 1). However, the ground juniper contained 47% greater ADICP, 74% greater ADICP as a percent of total CP, 64% greater lignin, 70% greater fat, and 81% greater Ca than the oat hay. Crude fat concentration in the juniper contains not only true fat but also volatile oil, which is not nutritive energy (Cook et al., 1952). Even though chemical composition would appear to significantly reduce juniper digestibility, juniper was only 2.4% units less digestible than oat hay. The juniper contained approximately 74% leaf material (SD ± 5.6) and redberry juniper leaves have been reported to be 67% digested and contain 38% NDF and 31% ADF concentrations (Whitney and Muir, 2010); therefore, using small stems and leaves vs. only leaves does not seem to greatly increase total fiber concentration. In addition, after being incubated in a ruminal fluid-buffer mixture for 10 min and 2, 6, and 24 h, the percentage of buoyant particles for hammermilled oat hay was 72, 72, 61, and 59%, respectively, and 32, 12, 20, and 16%, respectively, for hammermilled juniper material.

The ground juniper contained only 0.43% volatile oil. Fresh *J. pinchotii* leaves have been reported to contain 1.96% volatile oil (DM basis) when assuming 50% DM in as-fed values reported by Riddle et al. (1996). Adams et al. (2013b) reported that fresh *J. pinchotii* leaves contained 0.94 to 1.08% volatile oil (DM basis). Considering that air drying reduced total volatile oil in *J. pinchotii* (Adams, 2010) and *Juniperus monosperma* (Utsumi et al., 2006), it can be concluded that drying the juniper in the current study with forced heated air (26 to 31°C) volatilized much of the volatile oil, resulting in the diets containing low volatile oil concentrations (Table 2). Total CT concentration in the ground juniper (6% DM basis; Table 1) is similar to previously reported values for air-dried *J. pinchotti* leaves (5.5% DM basis; Whitney and Muir, 2010) and oven-dried juniper leaves and small stems (7.3% DM basis; Whitney et al., 2011).

Most of the nutrient differences between oat hay and juniper and between sorghum grain and DDGS (Table 1) are mirrored in the mixed diets (Table 2). The main difference between CNTL and 0JUN is that 0JUN contained twice as much crude fat as CNTL, which is mainly attributed to the DDGS containing 43.9% more crude fat than rolled sorghum grain. As juniper incrementally replaced oat hay in the DDGS-based diets, ADICP, ADICP as a percentage of total CP, and lignin increased while ash decreased. *In vitro* dry matter digestibility of CNTL was greater than the other diets, but digestibility was relatively similar among the DDGS-based diets. Cost per metric ton of feed (DM basis) was less for DDGS-based diets than the control diet and further decreased as juniper incrementally replaced oat hay.

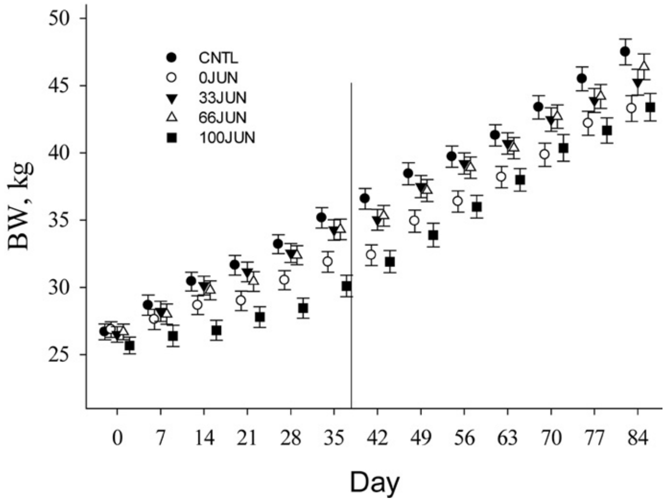

Figure 1. Effects of dried distillers grains with solubles (DDGS) and replacing oat hay with ground juniper on lamb BW. Treatment diets were isonitrogenous, nonagglomerated feedlot growing diets: a control diet (CNTL) that contained oat hay but not DDGS or juniper or DDGS-based diets in which 0 (0JUN), 33 (33JUN), 66 (66JUN), or 100 (100JUN) of the oat hay was replaced by juniper. Lambs were transitioned over 21 d onto their respective diet. During Period 1 (d 0 to 35), lambs were fed a 64% concentrate ration. Lambs were transitioned over 4 d into Period 2 (d 36 to 91) onto an 85% concentrate ration.

Animal Performance

Period 1. A treatment × day interaction was observed for BW ($P = 0.004$; Fig. 1) and DMI ($P = 0.01$) but not for ADG or G:F ($P > 0.79$; Table 3). Lambs fed the sorghum grain-based diet (CNTL) had greater ($P < 0.001$) DMI and ADG and tended to have greater ($P = 0.09$) G:F than lambs fed 0JUN. These differences resulted in lambs fed CNTL weighing 3.3 kg more ($P = 0.004$) than lambs fed 0JUN at the end of this period (d 35). Mechanisms that regulate DMI are complex, but differences in growth performance can be partially attributed to 0JUN containing 3.9% units more fat and being 4.2% units less digestible than CNTL. Leupp et al. (2009) reported that ruminal NDF and ADF digestibility decreased as percentage of DDGS in the diet increased from 0 to 60%. Furthermore, 0JUN had a greater concentration of unsaturated fatty acids in the total fat vs. CNTL (Table 2). It is well known that dietary fat, especially unsaturated fatty acids (Pantoja et al., 1994) can reduce organic matter and fiber digestibility, especially with low-quality roughages (White et al., 1958).

Sulfuric acid can reduce ruminal pH and potentially reduce digestibility and DMI (Mould et al., 1983). The DDGS used in 0JUN contained 0.97% sulfur, indicating the presence of sulfuric acid according to Felix and Loerch (2011). The presence of sulfuric acid is also supported by the fact that pH of DDGS, sorghum grain, juniper, and oat hay mixed in a water solution were 3.77, 5.82, 5.33, 6.02, respectively, and that these solutions required 230, 50, 24, and 20 mL of McDougal's buffer solution to titrate to pH 6.5, respectively.

Greater DMI of lambs fed CNTL vs. 0JUN could have also been due to the CSM and urea being in the CNTL diet and not in the 0JUN diet. Associative effects of true protein and nonprotein N are known to occur (Merchen et al., 1979; Zinn et al., 2003), which can positively affect OM and starch digestibility (Milton et al., 1997). Furthermore, dietary urea can accelerate cellulose digestion and increase DMI (Burroughs et al., 1950; Minson and Milford, 1968), especially in the presence of readily available carbohydrates (Belasco, 1956). Crude protein in all the diets was greater than 21%, and even though it does not seem plausible that ruminal microbes in lambs fed 0JUN would benefit from additional N, more than 50% of the CP in corn ethanol DDGS escapes ruminal fermentation (Waller et al., 1980; Firkins et al., 1984). In addition, using urea in combination with DDGS can be complementary (Waller et al., 1980) and can enhance microbial protein synthesis and postruminal amino acid supply as reviewed by Merchen and Titgemeyer (1992).

Within the DDGS-based diets (0JUN, 33JUN, 66JUN, and 100JUN), lamb BW (Fig. 1), DMI, ADG, and G:F increased quadratically ($P < 0.008$; Table 3) as percentage of juniper incrementally increased in the diet. These results are attributed to oat hay and juniper having different chemical characteristics such as CP, ADICP, NDF, hemicellulose, lignin, fat, fat composition, CT, and volatile oil and different physical characteristics such as particle size, buoyancy, hemicellulose (related to hydration), and physical effectiveness. These characteristics can affect mastication, rumination, rumen physiology, microbial species composition and diversity, total tract nutrient digestibility, satiety, and postingestive feedback, either directly or through complex interactions.

The oat hay was hammermilled through a 33% larger screen and was more than twice as many buoyant particles as the juniper throughout a 24-h *in vitro* digestion period as previously stated. In addition, most of the buoyant juniper particles were highly digestible leaves as previously described (Whitney and Muir, 2010), which are not defined as an effective fiber source (Mertens, 1997). Particles are not uniformly distributed throughout stratified ruminal layers (Van Soest, 1982) and fermentation parameters differ among ruminal sites; most notable is that pH is generally greater in the cranial dorsal vs. ventral region (Li et al., 2009; Shen et al., 2012). Furthermore, feeding steers diets without roughage increased the incidence of abnormal papillae and lesions in ventral areas of the rumen without affecting animal growth performance (Greene et al., 1974). Theoretically, using a combination of oat hay and juniper (33JUN and 66JUN) that differ in buoyancy and physical effectiveness could have promoted a more equal distribution of effective fiber throughout the rumen (Van Soest, 1982; Mertens et al., 1984), reducing the degree of pH fluctuation and latent acidosis (Huntington, 1988; Mertens, 1997).

Table 3. Effects of dried distillers grains with solubles (DDGS) and replacing oat hay with ground juniper on lamb performance and total feedlot costs

	Diet[2]						*P*-value[3]			
Item/d[1]	CNTL	0JUN	33JUN	66JUN	100JUN	SEM	CNTL vs. 0JUN	CNTL vs. DDGS	Linear	Quadratic
Period 1										
DMI, kg/d										
d 7	1.24	0.88	1.12	1.11	0.97	0.06	<0.001	0.003	0.46	0.002
d 14	1.32	0.88	1.32	1.19	1.03	0.09	<0.001	0.03	0.38	<0.001
d 21	1.40	0.94	1.45	1.31	1.05	0.10	0.001	0.04	0.67	<0.001
d 28	1.46	1.03	1.56	1.40	1.02	0.10	0.002	0.04	0.62	<0.001
d 35	1.55	1.06	1.41	1.53	1.05	0.07	<0.001	<0.001	0.80	<0.001
DMI, kg; overall	1.39	0.96	1.38	1.30	1.02	0.07	<0.001	0.006	0.73	<0.001
ADG, kg; overall	0.24	0.14	0.22	0.22	0.13	0.02	<0.001	<0.001	0.41	<0.001
G:F, kg/kg; overall	0.17	0.15	0.16	0.17	0.12	0.01	0.09	0.07	0.17	0.007
Period 2										
DMI, kg/d										
d 42	1.45	1.11	1.32	1.48	1.23	0.07	<0.001	0.03	0.11	0.001
d 49	1.32	1.18	1.28	1.34	1.23	0.06	0.11	0.35	0.48	0.09
d 56	1.43	1.23	1.33	1.41	1.34	0.06	0.02	0.13	0.14	0.15
d 63	1.53	1.32	1.33	1.48	1.35	0.08	0.04	0.06	0.46	0.37
d 70	1.55	1.33	1.35	1.47	1.41	0.08	0.04	0.05	0.30	0.57
d 77	1.64	1.40	1.35	1.49	1.48	0.08	0.03	0.02	0.29	0.84
d 84	1.59	1.34	1.37	1.46	1.44	0.08	0.03	0.04	0.28	0.78
d 91	1.60	1.33	1.40	1.44	1.53	0.09	0.03	0.07	0.13	0.91
DMI, kg/d; d 42 to 91	1.51	1.28	1.34	1.45	1.38	0.06	0.01	0.04	0.19	0.31
ADG, kg; d 42 to 91	0.26	0.24	0.25	0.25	0.28	0.01	0.42	0.93	0.03	0.29
G:F, kg/kg										
d 42	0.14	0.06	0.08	0.10	0.21	0.05	0.52	0.59	0.01	0.24
d 49	0.20	0.31	0.28	0.20	0.23	0.05	0.30	0.32	0.85	0.36
d 56	0.13	0.17	0.19	0.18	0.23	0.04	0.29	0.07	0.27	0.65
d 63	0.16	0.19	0.16	0.13	0.21	0.03	0.69	0.78	0.61	0.14
d 70	0.19	0.18	0.19	0.24	0.25	0.04	0.94	0.44	0.12	0.94
d 77	0.19	0.24	0.16	0.14	0.16	0.03	0.14	0.81	0.07	0.13
d 84	0.18	0.12	0.13	0.22	0.18	0.03	0.06	0.32	0.02	0.41
d 91	0.18	0.22	0.28	0.19	0.22	0.03	0.36	0.14	0.61	0.62
G:F, kg/kg; overall	0.17	0.19	0.18	0.18	0.20	0.01	0.12	0.07	0.41	0.06
Entire trial, d 0 to 91										
DMI	1.47	1.16	1.34	1.39	1.24	0.06	<0.001	0.01	0.27	0.004
ADG	0.25	0.20	0.24	0.24	0.22	0.01	0.003	0.03	0.30	0.02
G:F	0.17	0.18	0.18	0.17	0.18	0.01	0.68	0.60	0.87	0.68
BW, kg; final shorn	47.3	43.5	46.1	46.6	43.8	1.1	0.01	0.05	0.74	0.01
Total feedlot cost	$49.50	$47.90	$46.38	$45.97	$47.98	–	–	–	–	–

[1]Lambs were transitioned over 21 d onto their respective diet. During Period 1 (d 0 to 35), lambs were fed a 64% concentrate ration. Lambs were transitioned over 4 d into Period 2 (d 36 to 91) onto an 85% concentrate ration. Total feedlot cost = (total DMI × \$/kg of DM) + (additional kg of feed intake to reach final BW of CNTL on d 91 × \$/kg of feed DM) + (\$0.727·kg of gain^{-1}·d^{-1} [yardage + interest] × additional days on feed needed to reach final BW of CNTL on d 91); calculated by period and summed.

[2]Treatment diets were isonitrogenous and nonagglomerated and contained ground juniper that replaced 0 (0JUN), 33 (33JUN), 66 (66JUN), or 100% (100JUN) of the ground oat hay. An additional control diet (CNTL) similar to 0JUN but using sorghum grain vs. DDGS was used to evaluate negative effects of using 40% DDGS.

[3]Orthogonal contrasts. CNTL vs. DDGS = CNTL vs. average of DDGS-based diets (0JUN, 33JUN, 66JUN, and 100JUN). Linear and quadratic contrasts of 0JUN, 33JUN, 66JUN, and 100JUN diets.

More uniform fiber distribution throughout the rumen is even more critical when feeding high fat diets and dense (less buoyant) ingredients such as DDGS that can reduce pH, especially in the ventral rumen. Even though dense lignin particles in the juniper could have acted as an innate buffer within the DDGS particles in the ventral region of the rumen as described by Van Soest et al. (1991), lambs fed 100JUN may have required an additional roughage source (i.e., oat hay) in the diet. Feeding calves mixed diets with 25% shortleaf southern pine (*Pinus echinata*) sawdust did not induce impaction in the rumen or omasum, but feeding 35% resulted in ruminal and omasal impaction, without reducing animal growth performance or health (Cody et al., 1972); however, in 1 instance, impaction was cleared by feeding free-choice alfalfa hay. Increasing cottonseed hulls (e.g., effective fiber) in lamb feedlot diets containing 40% corn dried distillers grains (brewer's industry) increased DMI and ADG without affecting G:F (Whitney and Lupton, 2010). Felix and Loerch (2011) also reported that feedlot steers benefited from greater dietary forage when fed diets containing 60% DDGS.

The small juniper particle size did not appear to increase passage rate in lambs fed 100JUN because DMI was less than lambs fed 33JUN and 66JUN. Therefore, the amount of dense particles in 100JUN could have been great enough to increase ruminal fill and reduce DMI because very dense particles do not readily pass through the reticulo-omasal orifice even if they are smaller than the opening (Welch, 1986). However, others have reported that ground mesquite (Marion et al., 1957), aspen (Mellenberger et al., 1971), and alder (Kitts et al., 1969) trees can be used as roughage sources in ruminant diets without negatively affecting animal performance or health and at times, actually increase animal health by decreasing liver abscesses and parakeratosis (El-Sabban et al., 1971).

Secondary compounds such as CT and volatile oil have been reported to either enhance or reduce animal performance, health, metabolism, end products, or rumen microbial function, depending on concentration, intake, structure, and bioactivity of the secondary compounds and dietary nutrient composition and intake. Condensed tannins were only analyzed in the juniper and sorghum grain because the other ingredients are either known to contain no CT or volatile oil (i.e., oat hay, molasses, and mineral) or contain very minute concentrations (i.e., 0.05% CT in CSM; Nunez-Hernandez et al., 1991). Based on CT concentrations in the juniper and sorghum grain, estimated total CT intake (DM basis) for lambs fed CNTL, 0JUN, 33JUN, 66JUN, and 100JUN was 3.5, 0.8, 11.0, 19.8, and 22.9 g/d, respectively, which equals 0.10, 0.02, 0.32, 0.58, and 0.76 g CT intake/kg of BW, respectively.

Whitney et al. (2013) reported that feeding lambs a diet similar to 100JUN did not reduce DMI (4.5% of BW) but did reduce ADG as compared to lambs fed a diet containing grass hay. Even though Whitney et al. (2013) partially attributed the reduced ADG to CT intake (19.2 g CT/d; 0.86 g CT intake/kg of BW, DM basis), goats have been reported to increase consumption of ground sericea lespedeza hay (69 g CT intake/d; 1.7 g CT intake/kg of BW, DM basis) during a study with no reported growth performance or health problems (Terrill et al., 2007). In addition, Chafton (2006) fed lambs ground sericea lespedeza hay (128 g CT intake/d; 3.74 g CT intake/kg of BW, DM basis) and did not report any negative effects on growth performance. Moore et al. (2008) reported that DMI and ADG increased when kid goats were fed a diet containing 75% sericea lespedeza vs. 75% bermudagrass hay (62 g CT intake/d; 3.28 g CT intake/kg of BW, DM basis). Compared to these studies, lambs in the current study were fed more nutrient-dense feeds, which would have further reduced any negative consequences of consuming CT due to nutrient–toxin interactions (Freeland and Janzen, 1974). Therefore, reduced growth performance of lambs fed 100JUN is unlikely attributed to CT intake, but should be further investigated.

It is also plausible that lambs fed 33JUN and 66JUN consumed an optimal amount of CT as observed in the quadratic effect on DMI, ADG, and G:F. Condensed tannins can reduce solubility and degradability of protein (Pritchard et al., 1988; Yu et al., 1996) and bind carbohydrates (McLeod, 1974), which could be beneficial in mixed diets containing high concentrations of protein and energy. The majority of the CT-protein complexes dissociate in the abomasum, thus increasing the supply of amino acids to the small intestine (Waghorn et al., 1987), which can enhance animal growth performance (Newbold et al., 1987; Gunn et al., 2009). Condensed tannins can also enhance growth performance via enhanced rumen microbial efficiency by reducing energy lost to methane production either by directly inhibiting methanogens (Tavendale et al., 2005), inhibiting protozoa (Hegarty, 1999), or both (Bhatta et al., 2009).

Total volatile oil intake for lambs fed CNTL, 0JUN, 33JUN, 66JUN, or 100JUN was 0.04, 0.42, 1.56, 0.94, and 1.12 g/d (DM basis), respectively, which equals 0.001, 0.013, 0.046, 0.027, and 0.037 g volatile oil intake/kg of BW (BW at d 35), respectively. Determining if volatile oil positively or negatively affected lamb growth performance is difficult because there are approximately 15,000 volatile oil compounds (Gershenzon and Croteau, 1991) and literature related to effects of intake of the plant or its volatile oil on animal growth performance, rumen microbial function, and health is more complex and not nearly as extensive as literature related to CT. In addition, most literature that report effects of juniper leaf consumption, volatile oil, or both on animal performance and health do not report one or more of the variables needed to accurately calculate terpenoid oil intake, that is, BW, as-fed, or DM basis, or percentage of DMI or volatile oil concentration (Riddle et al., 1996, 1999; Pritz et al., 1997; Bisson et al., 2001; Campbell et al., 2007; Dietz et al., 2010). Furthermore, these studies were generally short duration (<37 d; majority less than 15 d) and used high-roughage (>49% roughage) basal diets. To our knowledge, previous studies have not evaluated effects of feeding dried or fresh juniper leaves or leaves and stems in total mixed diets containing less than 40% roughage.

Angora mutton goats (BW = 40 kg) consumed a diet of 57% fresh *J. ashei* leaves and 43% bermudagrass hay (DM basis) with no reported negative effects on growth performance or health (Riddle et al., 1999). Percentage of terpenoids in *J. ashei* was not reported, but if 2.82% oil in fresh *J. ashei* leaves is assumed (Adams et al., 2013a), then these goats consumed approximately 15.7 g volatile oil/d (0.39 g/kg of BW, DM basis). Goats consumed *Juniperus virginiana* up to 22.6% of their diet (DM basis), resulting in the consumption of 1.9 g of terpenoid oil/d (5.98 g of/kg of BW), without negatively affecting growth performance or health (Animut et al., 2004).

In vitro studies have evaluated effects of terpenoid oil and individual terpenoids on ruminal function and microbial species, but extrapolating *in vitro* results to a feeding trial is difficult, given that up to 80% of the terpenoid oil can be lost due to mastication, rumination, or absorption (Welch and Pederson, 1981; Cluff et al., 1982; White et al., 1982). In addition, simulating nutrient–toxin interactions that occur in the rumen (Freeland and Janzen, 1974) is difficult in an enclosed *in vitro* system as reviewed by Calsamiglia et al. (2007) because the rumen is a complex compartmentalized ecosystem.

The combination of literature related to terpenoid consumption and the fact that lambs fed 33JUN had the greatest DMI even though they consumed more volatile oil than the other lambs without reduced growth performance suggests that volatile oil did not negatively affect lamb production, health, or ruminal function and may have actually been indirectly beneficial as reviewed by Calsamiglia et al. (2007). Dietary terpenoids have been reported to increase microbial efficiency, reduce methane production and acetate:proprionate ratio, increase microbial protein synthesis, reduce feed protein ruminal degradation, and increase bypass protein (reviewed by Calsamiglia et al., 2007). However, considering the discussion related to the treatment diets causing differences in stratified ruminal layers and the fact that terpenoid oil is hydrophobic, it is plausible that terpenoids affected the dorsal rumen environment more than the ventral region. Therefore, additional research is warranted to determine terpenoid concentrations within ruminal compartments and effects on buoyant vs. dense particle digestibility and passage rate.

Period 2. Lambs fed CNTL continued to have greater ($P < 0.05$; Table 3) DMI than lambs fed 0JUN, which can be attributed to the 0JUN diet having greater fat and fiber and being less digestible than the CNTL diet, as previously discussed for Period 1 results. Estimated total CT intake for lambs fed CNTL, 0JUN, 33JUN, 66JUN, and 100JUN was 5.58, 2.47, 6.6, 11.5, and 15.11 g/d, respectively, which equals 0.118, 0.057, 0.143, 0.247, and 0.345 g CT intake/kg of BW, respectively. Compared to Period 1, ADG for lambs fed 0JUN almost doubled, resulting in similar ADG and G:F ($P > 0.11$; Table 3) as compared to lambs fed CNTL. However, final shorn BW of lambs fed 0JUN was 3.8 kg less ($P = 0.01$) than lambs fed CNTL; therefore, an additional 19 d on feed would have been required to reach the final BW (d 91) of lambs fed CNTL. These results further support the fact that the combination of high roughage and 40% DDGS was limiting DMI, and thus ADG, in lambs fed 0JUN during Period 1. As discussed for Period 1, DDGS contained high concentrations of S, which can cause polioencephalomalacia, especially when ruminal pH is reduced on high concentrate diets (Gould, 1998; NRC, 2007). Even though percentage of DDGS remained 40% and a greater amount of concentrates were fed during Period 2, signs of polioencephalomalacia were not observed. Feeding greater than 50% DDGS in cattle diets has caused polioencephalomalacia (Buckner et al., 2007), but Schauer et al. (2008) fed lambs 60% DDGS without negatively affecting growth performance or health.

Within lambs fed DDGS-based diets, DMI was similar ($P > 0.19$), ADG increased linearly ($P = 0.03$), and G:F tended to decrease quadratically ($P = 0.06$) as juniper increased in the diet. These results suggest that previously discussed physiological restrictions on DMI were alleviated when lambs fed 0JUN and 100JUN were transitioned onto an 85% concentrate diet. Average daily DMI, ADG, and G:F in lambs fed 100JUN increased from Period 1 to 2 by 35, 115, and 67%, respectively. Greater ADG and G:F in lambs fed 100JUN is probably more attributable to greater particulate passage rate and a reduction in negative effects in the ventral rumen vs. a reduction in CT or terpene intake. If CT or terpenoid intake were primary factors in growth performance, it seems that DMI would have been greater during Period 2 vs. the end of Period 1 for lambs fed 33JUN and 66JUN. Furthermore, the growth performance of lambs fed 100JUN during Period 2 suggests that feeding 36% ground juniper in a mixed diet during a 35-d growing period (Period 1) does not negatively alter rumen or whole body morphology or physiology. However, lambs fed 100JUN would require an additional 12 d in the feedlot to reach the final shorn BW (d 91) of lambs fed 33JUN or 66JUN.

Serum Urea N, IGF-1, Ca, and P and Fecal P and N

The 0JUN diet did not contain any CSM or urea while lambs fed CNTL consumed a diet that contained 1.08% urea and 8% CSM, both of which are readily available N sources. The combined effect of lambs fed CNTL, consuming a diet that was 5.4% units more digestible, consuming 14.9 g of urea, and having greater DMI than lambs fed 0JUN, resulted in greater ($P < 0.001$; Table 4) SUN and fecal N. Greater protein consumption and absorption can result in greater circulating urea N (Cole and Hutcheson, 1988). Greater SUN can result in greater circulating IGF-1 (Lobley, 1992; Wester

Table 4. Effects of dried distillers grains with solubles (DDGS) and replacing oat hay with ground juniper on lamb serum urea N, IGF-1, Ca, and P, and fecal P and N during Period 2 (d 36 to 91)

Item[3]	Diet[1]					SEM	*P*-value[2]			
	CNTL	0JUN	33JUN	66JUN	100JUN		CNTL vs. 0JUN	CNTL vs. DDGS	Linear	Quadratic
Blood serum										
Urea N, mg/dL	31	19	22	21	18	1	<0.001	<0.001	0.39	0.01
IGF-1, ng/mL	225	162	195	196	192	17	0.01	0.04	0.24	0.28
Ca, %	9.7	9.2	9.8	10.0	10.3	0.4	0.32	0.68	0.03	0.63
P, %	8.4	8.5	8.6	8.7	8.6	0.4	0.84	0.56	0.73	0.78
Fecal, d 91										
P, %	0.69	0.77	0.84	0.76	0.87	0.06	0.45	0.13	0.42	0.77
N, %	2.9	2.4	2.5	2.5	2.7	0.08	<0.001	<0.001	0.004	0.17

[1]Lambs were transitioned over 21 d onto their respective diet. During Period 1 (d 0 to 35), lambs were fed a 64% concentrate ration. Lambs were transitioned over 4 d into Period 2 (d 36 to 91) onto an 85% concentrate ration. Blood serum was analyzed on d 77, 84, and 91 and average values are presented since no treatment × d interactions ($P > 0.12$) were observed. Fecal P and N were analyzed only on d 91.

[2]Treatment diets were isonitrogenous and nonagglomerated and contained ground juniper that replaced 0 (0JUN), 33 (33JUN), 66 (66JUN), or 100% (100JUN) of the ground oat hay. An additional control diet (CNTL) similar to 0JUN but using sorghum grain vs. DDGS was used to evaluate negative effects of using 40% DDGS.

[3]Orthogonal contrasts. CNTL vs. DDGS = CNTL vs. average of DDGS-based diets (0JUN, 33JUN, 66JUN, and 100JUN). Linear and quadratic contrasts of 0JUN, 33JUN, 66JUN, and 100JUN diets.

et al., 1995), which supports our results that lambs fed CNTL had greater ($P = 0.01$; Table 4) serum IGF-1 vs. lambs fed 0JUN. Serum Ca and P and fecal P were similar ($P > 0.32$) between lambs fed CNTL or 0JUN.

Within lambs fed DDGS-based diets, SUN was predicted to increase linearly because even though diets were isonitrogenous, lambs fed 0JUN, 33JUN, 66JUN, or 100JUN consumed approximately 0, 0.12, 2.76, and 3.86 g of urea/d. However, SUN increased quadratically ($P = 0.01$) as percentage of juniper increased in the diet, suggesting that CT, terpenoids, or both were binding ruminal protein or altering the site of N metabolism as reviewed by Patra and Saxena (2011). This assumption is supported by the linear increase ($P = 0.004$; Table 4) in fecal N among lambs fed DDGS-based diets and the suggestion that CT can shift nitrogen excretion from urine to feces (Patra and Saxena, 2011). Furthermore, all lambs had high concentrations of SUN as compared to other reports (Pittroff et al., 2006; Kraft et al., 2009), suggesting that energy was wasted on urea excretion mechanisms as reviewed by McBride and Kelly (1990) and that dietary urea is probably not required when lambs are fed high concentrate diets (>85%) containing high concentrations of DDGS.

Serum IGF-1 concentrations were similar ($P > 0.23$; Table 4) among lambs fed DDGS-based diets. Serum was collected at the end of Period 2 (d 77, 84, and 91) when DMI was similar among lambs, partially explaining these results. However, due to greater urea intake and SUN increasing quadratically during this time, differences in serum IGF-1 would be expected (Lobley, 1992; Wester et al., 1995). Results could implicate interactions between SUN increasing IGF-1 and dietary CT indirectly reducing IGF-1 by decreasing rumen biohydrogenation (Vasta et al., 2009), resulting in greater postruminal CLA (Dhiman et al., 2000). Conjugated linoleic acid 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).

Wool Characteristics

Differences in lamb growth performance and serum characteristics did not affect most wool characteristics (Table 5); however, clean wool production per kilogram of BW decreased quadratically ($P = 0.04$) as percentage of juniper increased in the DDGS-based diets. Two plausible explanations are that 1) lambs were not shorn at study initiation, thus reducing sensitivity with this measure, and 2) of the lambs fed 66JUN had low wool production per kilogram of BW (12.6 and 13.0 g wool/kg of BW) that was not directly related to final BW.

Wool fiber diameter and fleece weight of Rambouillet rams can be altered by quality and quantity of nutrition (Lupton et al., 1997), specifically the supply of amino acids, especially those containing S, that is, cysteine and methionine (Reis and Sahlu, 1994). In addition, CT can positively affect wool growth at low concentrations (Terrill et al., 1992; Douglas et al., 1995), which has been attributed to greater branched chain amino acid supply (Min et al., 1999). However, specific to this study, neither DDGS nor juniper or CT consumption affected wool characteristics.

Conclusions

Feeding lambs a diet containing 40% DDGS with oat hay as the sole roughage source (0JUN) reduced

Table 5. Effects of dried distillers grains (DDGS) with solubles and replacing oat hay with ground juniper on final lamb wool characteristics

	Diet[2]						*P*-value[3]			
Item[1]	CNTL	0JUN	33JUN	66JUN	100JUN	SEM	CNTL vs. 0JUN	CNTL vs. DDGS	Linear	Quadratic
Whole fleece										
GFW, kg	2.15	1.99	1.96	1.69	1.92	0.15	0.44	0.12	0.50	0.41
LSY, %	52.0	54.0	53.3	52.0	56.8	2.1	0.47	0.35	0.43	0.17
CFW, kg	1.10	1.07	1.04	0.88	1.09	0.08	0.72	0.33	0.79	0.15
AFD, µm	18.1	17.9	18.1	17.6	17.7	0.5	0.72	0.52	0.57	0.98
SDFD, µm	4.27	4.00	3.77	3.78	3.67	0.19	0.30	0.03	0.28	0.76
CVFD, %	23.4	23.3	20.8	21.6	20.8	0.9	0.90	0.08	0.12	0.31
ASL, cm	7.1	6.8	6.9	6.5	6.3	0.3	0.50	0.12	0.09	0.65
SDSL, cm	0.4	0.5	0.5	0.5	0.6	0.5	0.40	0.19	0.34	0.46
AFC, degrees/mm	86.6	93.8	91.8	94.8	89.6	3.5	0.11	0.09	0.51	0.62
SDFC, degrees/mm	56.2	59.2	59.6	60.9	59.0	2.4	0.36	0.19	0.95	0.63
AFAFD, µm	18.2	17.9	18.1	17.6	17.7	0.5	0.68	0.50	0.61	0.97
AFSDFD, µm	0.78	0.77	0.76	0.78	0.73	0.03	0.79	0.63	0.55	0.48
Wool/BW, g/kg	23.3	24.6	22.9	18.9	24.8	1.9	0.62	0.79	0.69	0.04
Side sample										
AFD, µm	18.5	18.5	19.0	17.8	18.4	0.4	0.90	0.82	0.46	0.90
SDFD, µm	3.03	2.98	3.04	2.83	2.81	0.09	0.70	0.28	0.08	0.67
CVFD, %	16.4	16.1	16.0	16.0	15.3	0.3	0.39	0.08	0.06	0.26
ASL, mm	58.8	58.9	56.7	53.1	58.1	2.9	0.97	0.54	0.66	0.22
AFC, degrees /mm	72.3	81.1	80.6	80.2	77.9	3.8	0.10	0.08	0.54	0.80
SDFC, degrees /mm	53.3	56.5	58.8	58.2	55.0	2.6	0.37	0.19	0.64	0.28

[1]GFW = grease fleece weight; LSY = lab scoured yield; CFW = clean fleece weight; AFD = average fiber diameter; SDFD = SD of fiber diameter; CVFD = CV of fiber diameter; ASL = average staple length; SDSL = SD of staple length; AFC = average fiber curvature; SDFC = SD of fiber curvature; AFAFD = along fiber average diameter; AFSDFD = along fiber standard deviation of fiber diameter; Wool/BW = clean wool production/unit of BW.

[2]Treatment diets were isonitrogenous and nonagglomerated and contained ground juniper that replaced 0 (0JUN), 33 (33JUN), 66 (66JUN), or 100% (100JUN) of the ground oat hay. An additional control diet (CNTL) similar to 0JUN but using sorghum grain vs. DDGS was used to evaluate negative effects of using 40% DDGS.

[3]Orthogonal contrasts. CNTL vs. DDGS = CNTL vs. average of DDGS-based diets (0JUN, 33JUN, 66JUN, and 100JUN). Linear and quadratic contrasts of 0JUN, 33JUN, 66JUN, and 100JUN diets.

growth performance as compared to a traditional diet containing mainly oat hay, sorghum grain, CSM, and urea (CNTL). However, even though lambs fed 0JUN had a greater cost of feed per kilogram of BW gain vs. lambs fed CNTL, they had less estimated total feedlot costs and fecal N excretion. Results also indicate that ground juniper leaves and stems can effectively replace all of the oat hay in DDGS-based growing and finishing diets without negatively affecting animal health, performance, or wool characteristics. However, using a combination of juniper and oat hay during the growing period (Period 1; high roughage diet) increased growth performance and reduced total feedlot costs as compared to using juniper or oat hay as the sole roughage source. The economics of processing, storing, and mixing two roughage sources will need to be considered, but it appears that the most economical feeding regimen in this trial would have been to feed 66JUN (12% oat hay and 24% ground juniper as the roughage source) during the growing period and then feed 100JUN (15% juniper as the sole roughage source) during the finishing period.

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