REPLACING COTTONSEED MEAL AND SORGHUM GRAIN WITH CORN DRIED DISTILLERS GRAINS WITH SOLUBLES IN LAMB FEEDLOT DIETS: GROWTH PERFORMANCE, RUMEN FLUID PARAMETERS, BLOOD SERUM CHEMISTRY, CARCASS CHARACTERISTICS, AND SENSORY PANEL TRAITS

A Thesis

by

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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 randomized design study, lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets. At 48-h postmortem, the longissimus thoracis was removed from the carcass, frozen, thawed, cooked, and evaluated by a trained sensory panel. 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. Lambs fed CNTL had greater ($P \leq 0.03$) hot carcass weight (HCW) and ribeye area (REA) than lambs fed 0DDGS. As DDGS incrementally replaced sorghum grain, HCW and flank fat quadratically increased ($P \leq 0.05$), marbling linearly decreased ($P = 0.03$), rib eye area tended to linearly increase ($P = 0.06$), and skeletal maturity tended to linearly decrease ($P = 0.06$). No differences in sensory panel traits were observed ($P \geq 0.06$) between lambs fed CNTL or 0DDGS. As DDGS incrementally replaced sorghum grain, juiciness linearly increased ($P = 0.03$), cook loss quadratically increased ($P = 0.05$), lamb flavor identity tended to quadratically increase ($P = 0.09$) and certain flavor attributes quadratically increased (brown, roasted, umami; $P \leq 0.03$), quadratically decreased (metallic; $P = 0.004$), or linearly increased (bloody; $P = 0.003$). Results indicated that lamb growth performance is enhanced when CSM is used to increase dietary CP (CNTL vs. 0DDGS) and that the 66DDGS diet resulted in the greatest growth performance. Results also indicated that carcass and sensory characteristics are not negatively affected (some are enhanced) when DDGS replaces CSM and sorghum grain in Dorper lamb feedlot diets.

DEDICATION

This thesis is dedicated in memory of my Papaw, Clinton Hodges. He was a man who thought beyond his time and taught me the values of hard work and patience. Maybe someday if I try my hardest, I will be half the man that he was.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 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, especially within the past decade. Nutritional characteristics of dried distillers grain with solubles (DDGS), a corn ethanol production co-product, suggests that they 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, 2009). Even though NRC (2007) states that CSM is greater in crude protein (CP) and degradable protein than DDGS, previous studies have shown that completely replacing CSM with dried distillers grain (up to 20% of the diet) resulted in no differences in average daily dry matter intake (DMI), average daily gain (ADG), or gain to feed ratio (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 high sulfur concentrations. This concern is based upon the evaluation of DDGS in cattle feedlot diets, which have been reported to cause polioencephalomalacia 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 in lamb feedlot diets 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 a greater protein diets that are normally fed in the industry. Therefore, the hypothesis of this trial is that DDGS can completely replace CSM and grain sorghum in lamb feedlot diets without negatively affecting growth performance, health, or ruminal function.

1.2 Literature Review

As the ethanol industry continues to grow, the availability of corn ethanol coproducts concurrently expands. Dried distillers grains with solubles have been a common feedstuff in the Midwest and northern regions for many years now. However, they are beginning to gain popularity in the south as they steadily become more available and cost-effective . Corn DDGS are an underutilized feedstuff in the sheep feedlot industry in Texas. Many feeders, particularly in Texas, do not include DDGS in their rations due to storage and handling concerns, unavailability of a consistent product, high sulfur concentrations, and carcass quality concerns (personal communication, T. R. Whitney).

Feed costs are always a concern among lamb feedlot operators. Due to reoccurring and unpredictable droughts in West Texas causing fluctuations in feedstuff prices and availability, an alternative feedstuff that can help reduce total feedlot costs, while maintaining or improving animal health and performance, is generally attractive to feedlot operators. Seasonality of grain availability is another concern for West Texas feedlot operators. Cottonseed meal, cottonseed hulls, and milo grain prices tend to be greater during the winter months due to demand from producers needing winter supplementation for their livestock on pastures. For example, feed costs (delivered to San Angelo, TX; August 2018; Nathan Segal & Co.) were: DDGS $225/ton; CSM $400/ton; CSH $220/ton; and cracked milo $200/ton. However, more recent prices (February 2019; Nathan Segal & Co.) delivered to San Angelo, TX were: DDGS $235/ton; CSM

$300/ton; CSH $262/ton; and cracked milo $200/ton. Being able to eliminate a protein meal, e.g., cottonseed meal, which is the most expensive feedstuff incorporated into rations in the Southern United States, can potentially decrease total feed cost inputs and total cost per pound of gain.

As corn ethanol production continues to be a major growing industry in the United States, the availability of corn DDGS has increased to various areas of the United States, particularly West Texas. One bushel of corn (25 kg) can be used to produce 2.8 gallons of ethanol to be used a biofuel and approximately 8 kg of DDGS (Missouri Corn Merchandising Council, 2010). Former President George W. Bush signed the Energy Independence and Security Act of 2007. This act mandated that 9 billion gallons of renewable biofuels were to be used in 2008, with that number increasing to 36 billion gallons annually by 2022. With corn-based ethanol production set to increase, it is logical to assume that the production and availability of corn DDGS should increase.

Considering that corn grain is approximately 66% fermentable starches, the nutritional content of the corn usually increases three-fold during the production of corn ethanol (NRC, 2007). For example, if the corn grain used for ethanol production is 4% fat and 9% protein, the remaining DDGS should be approximately 12% fat and 27% protein (NRC, 2007).

Corn DDGS can be a more favorable option for feedlot operators in comparison to wet distillers grains with solubles due to the ease of storage, transportation, and shelf life of DDGS (Missouri Corn Merchandising Council, 2010). To dry the distillers grains with solubles to approximately 90% DM is an added cost, but it will greatly increase the ability of the feedstuff to be stored and transported across the nation.

One of the greatest concerns of feeding DDGS, especially in the cattle industry, is excessive sulfur concentrations (Lardy, 2003). Lardy (2003) states that DDGS can be fed up to 40% dry matter (DM) in a finishing cattle diet without detrimental effects, but recommends that the optimum total DDGS levels in the ration be kept below 30% of the total ration in cattle feedlot diets in order to prevent polioencephalomalacia (PEM). Polioencephalomalacia, also known as cerebrocortical necrosis, is a neurological disease that can be caused by many different vitamin and mineral imbalances, such as lead poisoning, thiamine deficiency, and excess sulfur in the diet and water (Olkowski et al., 1992). Malacic areas, or soft spots in the brain, form when PEM occurs. This causes the lamb to express symptoms such as loss of appetite, inability to stand, uncontrolled muscle contractions, and eventually death (Olkowski et al., 1992). Olkowski et al (1992) determined that excess sulfur in the feed (0.63% of the ration) led to decreased thiamine concentrations in the blood of lambs and the onset of PEM after three weeks. Thus, when feeding diets that contain high concentrations of sulfur, it appears that thiamine supplementation can help prevent PEM.

It should be noted that in Olkowski et al. (1992) the sulfur in the diets was in the form of potassium sulfate and magnesium sulfate, both of which are highly biologically available sources of sulfur. However, Schauer et al. (2008) fed a ration that consisted of 60% DDGS, which had a sulfur concentration of 0.55%. The maximum recommended sulfur concentration in growing lambs that are fed a concentrate-based diet is 0.3% of total DM (NRC, 2007). Schauer et al. (2008) reported that there were no incidences of PEM. The form of sulfur in a diet could play a role in the bioavailability. Methionine and cysteine are common organic compounds that contain sulfur and are good sources of sulfur for rumen microbes (Underwood and Suttle, 1999). In addition, rapid fermentation of sulfur-containing compounds, as well as reduced rumen pH, can lead to increased sulfide production in the rumen (Gould, 1998). This could potentially lead to the neurological disease PEM mentioned earlier. Inorganic sources of sulfur that are commonly included in mineral supplement packages in mixed rations include sodium sulfite, sodium sulfate, calcium sulfite, ammonium sulfite, and magnesium sulfate (Henry and Ammerman, 1995). These are also good sources of sulfur for microbes to utilize, but care must be taken to prevent the overfeeding of sulfur when utilizing a premixed mineral package in a mixed ration. Specialized premixed mineral packages that contain little to no sulfur can be used when mixing rations that contain DDGS to avoid overfeeding of sulfur.

Corn DDGS are high in methionine and cysteine, the two primary sulfur containing amino acids, 0.49% and 0.52%, respectively (Shurson et al., 2004). However, the type of sulfur that is most commonly found in DDGS is generally in the form of sulfuric acid because sulfuric acid is added during liquefaction of dry milled corn to further hydrolyze starches, causing them to be more quickly fermented as well as to maintain a proper pH level in the slurry that is optimal for yeast fermentation (Xu et al., 2011; Felix and Loerch, 2011). This not only increases concerns for acidosis, but also raises the question if the sulfur from sulfuric acid is biologically available for the microbes. Felix et al. (2014) determined that sulfuric acid is more readily reduced into toxic hydrogen sulfide gas than sodium sulfate, another common inorganic sulfur containing supplement. This led to decreased ADG to lambs fed 60% DDGS diets and to lambs fed corn-based diets that were treated with sulfuric acid. According to Whitney et al. (2014), the pH of DDGS mixed in water is 3.77, indicating a strong presence of sulfuric acid. These results suggest that the high sulfur content found in the chemical analysis of DDGS can primarily be attributed to the presence of sulfuric acid. It is unknown exactly why lambs can tolerate greater concentrations of sulfur in a diet compared to cattle. Sulfuric acid is a biologically available source of sulfur to microbes in the rumen, however sulfates in the diet are typically the culprit that causes microbes to produce toxic hydrogen sulfide gas (NRC, 2007). Hydrogen sulfide gas production in the rumen can be reduced by including monensin in the ration. Felix and Leorch (2011) concluded that in the inclusion of monensin can reduce hydrogen sulfide gas production by roughly 30%-40%. Excessive sulfur in the diet can also prevent the absorption of other microminerals, such as copper and zinc (NRC, 2007).

Corn DDGS are a unique feedstuff because they are high in energy, CP, and bypass protein. Approximately 50% to 60% of the CP in DDGS is bypass protein, which means that it is not degraded by the rumen microbial population (NRC, 2007). The high amounts of bypass protein can be attributed to the high concentrations of zein, the primary protein in corn grain that is roughly 40% bypass protein (McDonald, 1954; Klopfenstein et al., 2008). Instead, bypass protein is enzymatically digested in the small intestine and amino acids are available for absorption vs. being degraded into N (McDonald, 1954; Lardy, 2003).

Corn DDGS are also high in phosphorus and potassium (Lardy, 2003). It is imperative that a specialized mineral premix package that is low in phosphorus, potassium, and sulfur is used when formulating a ration that contains significant amounts of DDGS to not only prevent potential overdoses of those particular minerals, but to help maintain an appropriate calcium to phosphorus ratio. The ARC (1980) states that the ideal range for Ca:P is 7:1 to 1:1. However, the upper end of this range (7:1) is only safe if the diet contains sufficient phosphorus. Wan Zahari et al. (1990) performed a study with a ration that had a 3.6:1 Ca:P ratio and a phosphorus deficiency. This ration led to decreased growth rates and the formation of urinary calculi even though the proper Ca:P ratio was met. This suggests that the minimum Ca and P requirements can affect the Ca:P requirement Assuming that the diets are sufficient in phosphorus, supplemental calcium in the form of calcium carbonate or dicalcium phosphate can be added to maintain the proper Ca:P ratio to help prevent urinary calculi (NRC, 2007).

As mentioned earlier, the fat content of DDGS is typically three times greater than the original corn grain. Feeding high fat diets can be detrimental to animal performance and high fat diets are a concern in cattle feedlot diets. Zinn et al. (1994) reported that feeding excess fat in steer feedlot rations can lead to various issues. As the total fat content in the form of tallow in the ration increased (4%, 8%, and 12% DM of total diet), ADG, DM conversion, and dietary NE decreased. Furthermore, another experiment by Zinn et al. (1994) utilizing cannulated dairy steers demonstrated that that ruminal digestion of OM, ADF, and dietary N also decreased linearly as the inclusion of fat in the diet increased from 4 to 12%. However, increasing the fat content in a lamb feedlot ration can have similar effects according to Stanford et al. (1999). Canola screenings were incorporated into diets in order to have the fat content of the treatment diets range from 2.81% (control diet) to 13.17% (95% canola screenings). As the proportion of canola screenings in the mixed diets increased, and subsequently crude fat, DM digestibility, OM digestibility, NDF digestibility, and ADF digestibility decreased. Furthermore, N retention was significantly less in lambs fed the high fat diet compared to lambs fed the control diet (Stanford et al., 1999). It was also reported that the growth, feed conversion, and carcass fat saturation was also linearly reduced (Stanford et al., 1999). Stanford et al. (1999) concluded that the linear decreases in growth performance could be attributed to the high fat content of the diets. As mentioned above, DDGS are a high fat feedstuff and elevated inclusion rated could result in a decrease in lamb growth and performance could occur as the inclusion of DDGS in a diet gets high. Furthermore, DDGS are high in ADF and lower in NDF (NRC, 2007). This unique property of DDGS reduces the risk of as the rate of fermentation in the rumen is decreased due to the higher fiber content (Clark and Armentano, 1993).

Lardy (2003) and Klopfenstein et al. (2008) also discussed one of the greatest concerns of some cattle and lamb feeders: the problem with consistency of nutrient composition of varying batches of DDGS from different ethanol plants. The easiest way to remedy this is to routinely sample new batches of DDGS and adjust the diet formulation accordingly to ensure that there are no potential risks of mineral toxicities and that minimum requirements of energy, protein, minerals, and vitamins are met.

Another concern among Texas lamb feeders is the effect that DDGS may have on carcass quality characteristics, as well as the total concentration of DDGS that can be included in a diet before negatively effecting animal growth performance. Buckner (2007) reported that the optimum inclusion level of DDGS in steer feedlot diets was between 20 to 30%. Buckner (2007) also reported no significance difference in 12th-rib fat thickness, rib eye area, yield grade, or marbling score in the finished steers. However, there tended to be a positive quadratic relationship between rations in terms of hot carcass weight. This is likely due to the fact that there was a strong positive quadratic relationship between rations in regards to the final live weight of the steers.

The maximum inclusion rate of DDGS is still yet to be determined in lamb feedlot diets. Schauer et al (2005) reported that DDGS can be included in lamb feedlot rations up to 15% of the total ration without any detrimental effects on carcass. It should be noted at the time of the trial DDGS was a relatively new feedstuff for lambs, thus previous research in beef and dairy cattle diets was variable at the time (Firkins et al., 1985; Ham et al., 1994). However, with today's new generation ethanol plants, a more consistent product can be produced that has an energy value (ME, 3592 kcal/kg) near that of corn grain (ME, 3843 kcal/kg), on a DM basis (Shurson et al., 2003). McEachern et al. (2009) demonstrated that it is possible to entirely replace CSM in a lamb feedlot ration without affecting ADG and efficiency of gain. A ration that was 20% CSM served as the baseline and CSM was replaced with DDGS in increments of 33, 66, and 100%. It should be noted that urea was added to the rations to make them isonitrogenous. Furthermore, Schauer et al. (2008) reported that it is possible to entirely replace soybean meal and a portion of the barley in a lamb feedlot ration without negatively effecting performance or carcass characteristics. Results of these studies are promising as proteinaceous concentrates (CSM and soybean meal) are usually the costliest parts of a ration. Being able to replace them with a more cost-effective feedstuff, such as DDGS, could result in decreased costs per unit of gain in feedlot lambs. In addition, eliminating urea and excess protein in a diet can lead to reduced SUN concentrations, which will lead to decreased N excretion.

Huls et al. (2006) and Schauer et al. (2006) determined that up to 22.5% of a feedlot finishing ration can be DDGS with no negative effects of carcass or performance. Whitney et al. (2014) fed growing lambs a diet that was 40% DDGS and reported that there was no negative effect on lamb performance and health that could be attributed to the DDGS in the diet. Schauer et al (2008) determined that there was no negative effect on lamb carcass qualities that could be attributed to the inclusion of large amounts of DDGS in a feedlot ration. In that trial, DDGS was incorporated into the rations in increments of 0, 20, 40, 60%. There were no differences in lamb carcass characteristics. Additionally, there was no difference in lamb final BW, ADG, and G:F. There was a positive quadratic trend with flank streaking of the carcasses as well. Lastly, Whitney and Braden (2010) reported that the replacement of CSM with DDGS led to no differences in carcass quality in growing lambs. These results are promising as high inclusion rates of DDGS in a feedlot lamb diet has not resulted in any negative impact on carcass quality.

Impacts on carcass quality are important aspects to consider when utilizing different feedstuffs for finishing rations as the quality of the lamb meat must not be negatively affected by the inclusion of DDGS. However, the overall flavor and juiciness of the meat is important to the consumer. Unlike beef cattle, information regarding to the sensory characteristics of lamb fed DDGS is limited. Gill et al. (2008) concluded that feeding DDGS to feedlot yearling steers resulted in strip loins that had no difference in terms of tenderness, flavor, juiciness, and shear force in comparison to the strip loins that came from cattle fed a conventional control ration. Whitney and Braden (2010) (extension of McEachern et al., 2009) completely replaced CSM with DDGS (20% DM of total ration) and reported reduced cook-loss, enhanced juiciness, and increased sustained juiciness. However, there were no effects on the initial tenderness, sustained tenderness, flavor intensity, and off-flavor of the loins. In Whitney and Braden (2010), only the proteinaceous concentrate (CSM) was replaced with DDGS. Sensory panel analysis has shown that the inclusion of DDGS in a lamb feedlot ration should lead to no significant changes or could potentially enhance these characteristics.

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CHAPTER II

REPLACING COTTONSEED MEAL AND SORGHUM GRAIN WITH CORN DRIED DISTILLERS GRAINS WITH SOLUBLES IN LAMB FEEDLOT DIETS: LIVE ANIMAL

2.1 Materials and Methods

2.1.1 Animals and Management

Forty-six Dorper ram lambs (approximate age = 4 mo; initial BW = 25 kg ± 6 kg), previously on 80% alfalfa hay and a 20% commercial ration, 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 had *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 of the lambs (0DDGS) were removed from the statistical analysis; 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 a one of five treatment diets (n = 9 lambs/treatment; Table 1). 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 in the treatment diets. 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, calcium carbonate was added to maintain a calcium:phosphorus ratio between 1.5 and 2:1 as recommended by ARC (1980). Ammonium chloride, an anionic salt, was also added to reduce the incidence of urinary calculi (Crookshank, 1970). A mineral premix specifically blended for diets containing DDGS was used.

2.1.2 Sample Collection and Measurements

Lambs were fed their respective treatment diets throughout the entire 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 days 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 days 0 and 56 and blood serum collected on days 0, 14, and 56.

Subsamples of CSH, sorghum grain, DDGS, and the mixed treatment diets were individually collected three times during the trial and subsamples combined separately 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 α-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 Daisy^{II} 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 hours. 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 α-amylase and omitting Na sulfite), gently rinsed in acetone, dried at 55°C in a forced-air oven for 48 h, and weighed.

2.1.3 Rumen Fluid and Blood Serum Collection and Analysis.

A 10-mL blood sample was collected 4 h after feeding 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 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 hours 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 of the filtered fluid 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; methods of Baumgardt, 1964 and Fritz and Schenk, 1979).

2.1.4 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 nonnormal data sets (ammonia N, albumin, serum urea N, Ca, creatine, creatine kinase, AST, GGT, GLDH, Mg, Na, K, Na:K ratio, and Cl), procedure of SAS (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) control 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.

2.2 Animal Performance

Lamb growth performance data are presented in Table 3. A treatment × day interaction ($P < 0.001$) was observed for lamb BW (Fig. 1). By design, initial lamb BW was similar ($P > 0.78$)

on day 0. Lamb BW quadratically increased ($P < 0.05$) at the end of the study. 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 replaced by DDGS in lamb feedlot diets. However, in their study, urea was added to make the rations isonitrogenous, thus CP concentrations were similar for each diet. Schauer et al. (2008) reported a linear increase in DMI as the concentration of DDGS, thus CP, increased in the diet as well as no statistical difference in G:F and ADG.

Decreases in DMI for lambs fed 0DDGS and 100DDGS could potentially be linked to differences in dietary CP and ADF in the rations. Glimp et al. (1989) concluded that excessive levels of starches in a diet can lead to decreased DMI, which can explain the decrease in DMI for the lambs fed 0DDGS. In addition, feeding high amounts of DDGS in a diet led to excess levels of ruminal nitrogen and serum urea nitrogen. Fenderson and Bergen (1976) fed diets that well exceeded the steers' crude protein requirements. Intake was initially reduced, however, DMI recovered after 10 days. Schauer et al. (2008) fed up to 60% DDGS and reported no decrease in DMI that could be attributed to the DDGS in the ration. Lambs being fed 100DDGS also exhibited the greatest tendency to sort feed against DDGS. Hammermilling 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 sulfur concentrations in a concentrate-based diet be kept below 0.3% of feed DM and below 0.5% of feed DM in high-forage diets. In a study by Schauer et al (2008), DDGS was included up to 60% in a ration and completely replaced soybean meal and a portion of the barley grain in the diets; however, dietary sulfur concentrations were 0.55% of feed DM and no incidence of PEM was reported. However, thiamin was included in the rations to ensure that the lambs received 142 mg•hd^{-1}•d^{-1}. Olkowski et al. (1992) induced polioencephalomalacia in two-month old feedlot lambs by feeding a diet with excess sulfur (0.63%) and no supplemental thiamin. These authors reported that seven of the twenty-two lambs on the high-S, low-thiamin diet, developed neurological signs associated with PEM. In the current trial, dietary sulfur levels exceeded that of the rations fed by Schauer et al. (2008) and Olkowski et al. (1992). The 100DDGS contained dietary sulfur levels of 0.72%, which is over twice the recommended threshold of 0.03% that is recommended by NRC (2007). Thiamin was not supplemented in the diets in the current trial and no incidence of PEM occurred. This suggests that supplemental thiamin may not be necessary in sheep when feeding higher concentrations of S in the form of DDGS as the microbial population in the rumen produces sufficient thiamin to prevent PEM (Huls et al., 2008). This also could have been due to the source of dietary sulfur in DDGS. High S concentrations in DDGS can be attributed to sulfuric acid (Gray et al., 2006). Meanwhile, Olkowski et al (1992) added sulfur in the diets in the form of magnesium sulfate.

Huls et al. (2006) also experimented with the inclusion rate of DDGS in lamb feedlot diets. The DDGS were included at 22.9% of feed DM, replacing soybean meal and a portion of corn. In the current trial, the S concentrations in the 0DDGS diet is relatively low in comparison to the 33DDGS, 66DDGS, and 100DDGS diets in this study (0.36%, 0.54%, and 0.72% respectively). However, Huls et al. (2006) fed soy hulls, which are highly fermentable and contain significantly less effective fiber in comparison to CSH (NRC, 2000). Cottonseed hulls are a sufficient source of dietary fiber and are effective at reducing the incidence of acidosis and bloat.

Corn DDGS are high in sulfuric acid and thus, slightly acidic, as is indicated by the presence of S (1.0% DM) in the batch of 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 and required 230 mL of McDougall's buffer solution to titrate the pH to 6.5. Acidic feedstuffs, such as DDGS, 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 can be 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 H_2SO_4, is more readily reduced to H_2S in the rumen than other sources of dietary S such as Na_2SO_4. This caused reduced growth performance to lambs being fed high sulfur diets in comparison to another treatment group fed a corn-based diet supplemented with 1.4% Na_2SO_4 (Felix et al., 2014).

2.3 Rumen Fluid Profiles

Lamb rumen fluid profile data are presented in Table 4. Treatment × day interactions ($P \leq 0.003$) were present for ammonia N and acetate VFA production. Treatment × day interactions ($P < 0.10$) tended to be present for acetate:proprionate and ruminal pH. A strong positive linear trend ($P < 0.001$) was present among treatments at the termination of the trial (d 56) for ruminal acetate concentration. A strong positive quadratic trend ($P < 0.001$) and a strong negative quadratic trend ($P < 0.001$) were present for ammonia N and ruminal pH, respectively, on d 56. 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, it is very low in readily digestible starches and high in fiber (NRC, 2007; Whitney et al., 2014). This could explain why ruminal pH increased as the proportion of DDGS increased in the diet. This reduction in rapidly digestible starches in the DDGS containing rations decreased the rate of fermentation. This suggests that the starch content of a ration has a major influence on the rate of fermentation and pH of the rumen 4-h after feeding (Fimbres et al., 2002). Anderson et al. (2006) reported no differences in acetate production when feeding DDGS at 10% or 20% of the total diet 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 of was much greater in the current trial (20% compared to 65% DM). The proportions of ADF and NDF in the diets fed by Anderson et al. (2006) were similar between the control, 10% DDGS, and 20% DDGS rations. This could also explain why no differences were reported, whereas in the current trial, there were differences in aNDF, ADICP, and crude fat. As reported in Table 2, this leads to a linear decrease in the overall in vitro dry matter digestibility (IVDMD) of the diet as the amount of DDGS increased in the ration. Ruminal ammonia N increased quadratically ($P <$ 0.001) at the conclusion of the trial (Day 56) as DDGS increased in the diet. This was to be expected as the CP% of the treatment rations increased linearly as the inclusion of DDGS increased from 0% of the total concentrate (0DDGS) to 100% of the total concentrate (100DDGS). In addition, ruminal ammonia N was less on day 56 for lambs fed 0DDGS vs. lambs fed CNTL. This was expected because 0DDGS was deficient in CP% according to NRC (2007). The decreased growth performance can be partially attributed to reduced ruminal ammonia N and thus, decreased microbial protein production. However, 66DDGS and 100DDGS diets contained excess CP%. This would likely result in excess ruminal ammonia N that must be excreted by the lamb in the form of fecal and urinary 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).

2.4 Blood Serum Profiles

Lamb blood serum chemistry profiles are presented in Table 5. Treatment × day interactions ($P < 0.05$) were present for glucose, SUN, creatinine, albumin, GGT, Mg, and Cl. Treatment × day interactions ($P < 0.10$) tended to be present for TSP, and creatine kinase. Positive quadratic trends ($P < 0.05$) were present for glucose, SUN, albumin, AST, P, Mg, and Cl. Positive linear trends ($P < 0.05$) were present for TSP and GLDH. The primary purpose for analyzing blood serum chemistry was to display any metabolic issues that may have occurred, which be linked to the inclusion of high concentrations of DDGS in the diet. Although there were statistical differences among certain enzymes (GGT and creatine kinase), minerals (Mg, Cl, and Ca), and other serum proteins and compounds (TSP, creatine, and glucose), values were within the normal biological parameters for growing lambs (Cornelius, 1989; Stämpfli and Oliver-Espinosa, 2015), suggesting that there were no negative effects observed when using up to 64% of DDGS in a mixed diet. Blood serum gamma-glutamyl transferase (GGT) and alanine aminotransferase (ALT) function as indicators of hepatic function disorders (Cornelius, 1989; Stämpfli and Oliver-Espinosa, 2015). Creatine kinase (CK) is an enzyme that 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.

Ruminants absorb little to no glucose in the small intestine. Thus, the quadratic increases on d 14 and 56 can be attributed to differences in gluconeogenic precursors (e.g., propionate). Bergman et al. (1965) estimated that propionate only accounts for 20% to 40% of glucose requirements and other metabolizable proteins.

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CHAPTER III

REPLACING COTTONSEED MEAL AND SORGHUM GRAIN WITH CORN DRIED DISTILLERS GRAINS WITH SOLUBLES IN LAMB FEEDLOT DIETS: HARVESTED ANIMAL

3.1 Materials and Methods

3.1.1 Animals and Management

A detailed description of animals and management and ration formulation are included in the previous chapter on page 15. In summary, forty-six Dorper ram lambs (approximate age = 4 mo; initial BW = 25 kg ± 6 kg) were weighted 7 d prior to initiation of the trial during the transition period, stratified by BW, and randomly assigned to diets and individual pens. Once the trial initiated, lambs were fed either a control (CNTL) diet or fed mixed diets that contained corn DDGS that entirely replaced CSM and incrementally replaced sorghum grain in increments of 0 percent (0DDGS), 33 percent (33DDGS), 66 percent (66DDGS), and 100 percent (100DDGS) as described in Table 1.

3.1.2 Carcass Characteristics and Sensory Panel Evaluation

Lambs were harvested after a 24-h fast, shrunk BW and HCW recorded, and carcasses chilled at 2 ± 1 °C. At 48 h postmortem, each carcass was cut through the vertebrae and longissimus thoracis between the 12th and 13th ribs for carcass evaluation. Carcasses were analyzed to determine loin eye area, backfat thickness at the 12th rib (BF), dressing percent (HCW ÷ shrunk BW just prior to harvest × 100), body wall thickness, and circumference of both legs across the femur-acetabulum joints on the intact carcass (USDA, 1997). At 48 h postmortem, the Longissimus dorsi muscle was removed from the loin, vacuum packaged individually as a whole muscle, and frozen. These samples were shipped to Texas A&M University and held at -10°C until flavor compound and sensory analysis. Samples from the frozen loin were cut into 2.54-cm thick chops and individually re-packaged. Each sample received a random three-digit code for sensory analysis.

Chops were thawed in refrigerated storage (4°C) for 12 to 24 h and cooked on a 2.54-cm thick flat top Star Max 536TGF 91.44cm Countertop Electric Griddle with Snap Action Thermostatic Controls (Star International Holdings Inc. Company, St. Louis, MO) set at 117°C within a range of ± 2.8°C. Grill temperature was monitored by randomly selecting locations within the set temperature range using a handheld instantaneous surface thermometer (Pro-Surface ThermaPen, SKU: #THS-231-279, ThermoWorks, American Fork, UT). Chops were turned at an internal temperature of 35°C and removed at 71°C (medium degree of doneness). Internal meat temperatures were monitored by iron-constantan thermocouples (Omega Engineering, Stanford, CT) inserted into the geometric center of the sample, and temperatures were displayed using an Omega HH501BT Type T thermometer (Omega Engineering, Stanford, CT).

An expert trained meat flavor descriptive attribute panel, consisting of six panelists with over 200 hours of training and 10 years of experience, was trained on 38 basic flavors and three texture attributes adapted from the beef lexicon (Adhikari et al., 2011) as defined in Table 6 for six days prior to testing. Panelists were trained to scale each attribute on a 16-point intensity scale (0 = none and 15 = extremely intense; Table 6). Each day, panelists were served one "warm up" sample, which was verbally discussed to insure proper scaling and precision of scoring. Thereafter, panelists were served at random two representative cubes (1.3 cm x 1.3 cm x chop thickness) of a sample in a plastic soufflé cup at a round table under red lighting. The outer edges and fat were avoided when cutting chops. Saltless crackers and double distilled were offered as palette cleansers. Panelists tested 11 samples per day for 4 d total. Panelists evaluated each sample individually and recorded their score for the attribute on ballots.

3.1.3 Statistical Analysis

Data for carcass characteristics and sensory characteristics were analyzed using JMP version 14.0 (SAS Inst., Inc., Cary, NC, USA) using ANOVA for a completely randomized design with finishing diet (CNTL, 0DDGS, 33DDGS, 66DDGS, or 100DDGS) as a fixed treatment effect. Least squares means were generated and separated using Student's *t*-test when a significant ($P < 0.05$) *F*-test was indicated.

3.2 Carcass Characteristics

Carcass characteristics are presented in Table 7. Two lambs, both on 0DDGS (n = 7), were not fit for travel and slaughter (injury sustained to rear stifle and unable to travel, and the other lamb began showing signs of acidosis at the conclusion of the trial) from the Texas A&M AgriLife Research and Extension Center to Mountain States Lamb Cooperative in Greeley, CO, so carcass data was not collected from those lambs.

Incorporating incrementally higher levels of DDGS into a lamb feedlot ration resulted in differences in hot carcass weight and ribeye area ($P < 0.05$). Positive quadratic trends ($P < 0.05$) were reported for both hot carcass weight and flank fat. A negative linear trend ($P < 0.05$) was reported for marbling. There were significant differences ($P < 0.05$) reported with Contrast 1 (0DDGS vs. 100DDGS) between hot carcass weight and rib eye area.

Whitney et al. (2010) reported no statistical differences in carcass characteristics when replacing the proteinaceous concentrate (CSM) with DDGS. Schauer et al. (2008) also reported no differences in carcass characteristics when feeding diets containing upwards of 60% DDGS, with the exception of flank fat streaking and USDA quality grade. The decreased hot carcass weight reported in this trial from lambs on 0DDGS can be attributed to the lighter BW at the conclusion of the trial. Reductions in loin eye area can be attributed to the lighter HCW of the 0DDGS lambs, as these two carcass characteristics are highly correlated in lambs (Borton et al., 2005). Some studies have shown that backfat thickness of finished lambs and steers declined as the inclusion of DDGS in a feedlot ration increases (Gordon et al., 2002; Huls et al., 2006; Depenbusch et al., 2009). However, in this trial there was no statistical difference in backfat thickness.

It should be noted that all lambs, with the exception of two lambs (one on 66DDGS and the other on 33DDGS) due to ‘no trotter’, a processing error, had an acceptable quality. These carcasses (with the exception of the two with processing errors) would either be considered acceptable or possibly receive a premium based on a quality grid of Yield Grade 1 and 2 for the Mountain States Lamb Cooperative (Boland et al., 2007). Results from this trial show that the complete replacement of the concentrate in a lamb feedlot ration with DDGS led to no negative effects on carcass quality and characteristics.

3.3 Sensory Panel Traits

Sensory characteristics for lamb chops are presented in Table 8. Two lambs, both on 0DDGS (n = 7), were not fit to travel (injury sustained to rear stifle and unable to travel, and the other lamb began showing signs of acidosis) from the Texas A&M AgriLife Research and Extension Center, so loins were not collected from them. One loin that was on 100DDGS treatment group was discarded from the trial as it was dropped on the ground prior to being cut into chops in preparation for cooking (n = 8 for 100DDGS treatment group). One of the trained panelist’s data was also removed prior to statistical analysis due to significant discrepancies and a misunderstanding of the scoring system. Sensory characteristics measured are included and described in Table 6.

Incorporating incrementally higher levels of DDGS into a lamb finishing ration resulted in increases in juiciness, bloody, and metallic flavors ($P < 0.05$), as well as a positive linear trend ($P < 0.03$) for juiciness and bloody sensory characteristics. Whereas the inclusion of incrementally higher levels of DDGS led to differences ($P < 0.007$) for brown and roasted characteristics. Positive quadratic trends ($P = 0.03$) for the brown, roasted, and umami characteristics of the lamb chops were also present. A linear decrease in lamb flavor identity was also present (P > 0.05). A negative quadratic trend (P = 0.004) was present for the metallic flavor attribute. No statistical differences in sensory characteristics and cook loss were reported ($P > 0.07$) for Contrast 1 (CNTL vs. 0DDGS). Enhanced juiciness was also reported by Whitney and Braden (2010) in lambs fed DDGS. However, Gill et al. (2008) reported no statistical differences in tenderness and juiciness in beef strip loins. Enhanced juiciness in steaks harvested from cattle fed DDGS was reported by Leupp et al. (2009). Due to the linear increases in juiciness, it would be expected that tenderness would also linearly increase due to a halo effect that was described by Roeber at al. (2000). However, this was not the case as there was no difference or linear trends in muscle fiber tenderness reported by the sensory panel in this trial.

Lamb flavor intensity decreased linearly ($P = 0.03$), which suggests that the fatty acid profile of the lamb loins is being changed slightly. Hornstein and Crowe (1963) hypothesized that species specific flavors come from the lipid fraction of the meat, where the meaty flavors come from the water-soluble fraction. The linear decrease in lamb flavor identity can be attributed a potential change in fatty acid composition. Fatty acid composition has been shown to make a substantial impact on sensory characteristics (Kemp et al., 1981; Larick and Turner, 1990; Melton, 1990). A fatty acid analysis of the loins, rations, and feedstuffs will be performed and analyzed at a later time.

Adhikari et al. (2011) also described that bloody and metallic flavor characteristics are highly correlated. In this trial, statistical differences were noted with the bloody and metallic flavor characteristics. These flavors are highly associated with the presence of oxidized metals, such iron, and blood in the meat. This suggests that the amount of iron present in the meat in the form of hemoglobin, which also explains the presence of blood and myoglobin are elevated.

Lastly, as described by Adhikari et al., (2011) brown and roasted sensory characteristics are also highly correlated. In this trial, significant differences ($P < 0.007$) and positive quadratic trends were reported ($P < 0.03$) with both brown and roasted sensory characteristics. Both of these sensory panel characteristics are associated with a lamb suet that has been broiled (score of 8.0), and 80% lean ground lamb (score of 10.0). Loins from the lambs on the 33DDGS treatment diet exhibited the greatest brown and roasted scores. Determining differences in aromatic compounds could explain these differences. Gas chromatography was also performed on the cooked samples, but data is still being analyzed.

The incremental inclusion of DDGS led to no negative effects on the sensory characteristics of loins from lambs. This data suggests that DDGS could potentially enhance the juiciness of loin chops and also potentially cause the meat to have a milder flavor. This is promising as one of the major concerns lamb feeders in West Texas have is the potential for DDGS to cause an off-flavor, which has been proven to be incorrect.

3.4 References

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CHAPTER IV

CONCLUSIONS

As the availability of DDGS continues to increase due to the ever-growing ethanol industry, producers and feedlot operators have another high-quality and versatile feed ingredient at their disposal. Corn DDGS are a unique feed ingredient as it is high in both energy and protein. Corn DDGS continues to be a viable and safe feedstuff to include in lamb feedlot diets, even at levels upwards of 65% DM of the total diet as no lambs became ill due to the inclusion of DDGS in the ration. In addition, the inclusion of DDGS in the lambs finishing ration led to no negative effects on carcass characteristics and sensory characteristics of loins collected from lambs on the trial. The optimum inclusion rate appears to be approximately 33% of the total concentrate (22% DM of the total ration) when removing CSM from the ration formulation in order to avoid overfeeding protein, leading to excess nitrogen waste and excretion. Feeding a ration that is 22% DDGS led to similar growth performance in comparison to lambs being fed a typical finishing ration containing CSM as the primary protein source. Corn DDGS continue to be a proven feed ingredient that needs to be further utilized by lamb feedlot operators in West Texas.

APPENDIX A

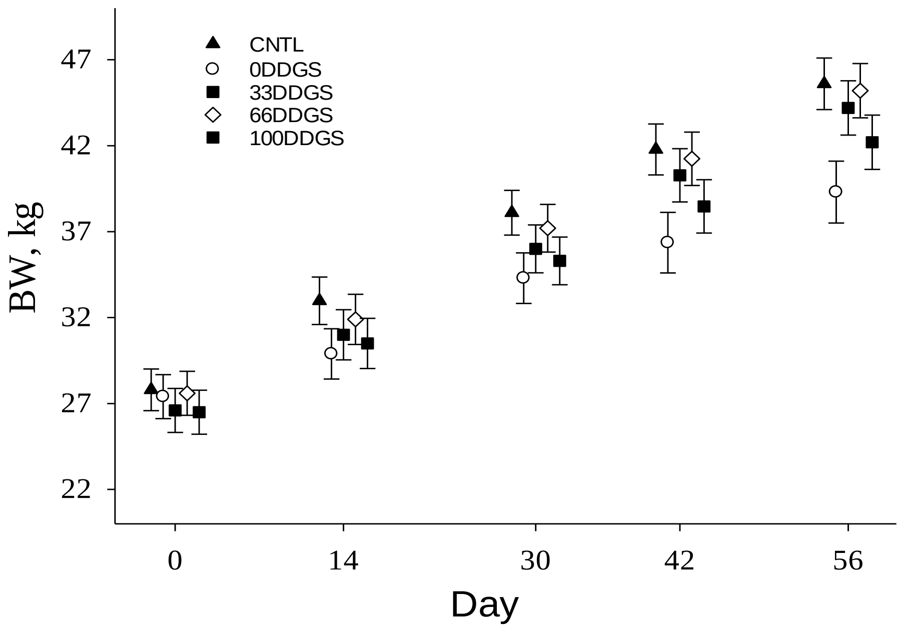

Fig. 1. Effects of feeding increasing levels of DDGS on lamb BW. Treatment diets only differed by proportion of sorghum grain replaced by DDGS. Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d in individual pens. The positive control diet (CNTL) contained CSM, sorghum grain, and 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 in the treatment diets.

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

	Diet[1]				
Item[2]	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

[1]Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets.

[2]DDGS = corn dried distillers grains with solubles are a byproduct of corn ethanol production. Mineral premix = NaCl, KCl, S, MnO, ZnO, vitamins A, D, and E, CaCO3, cottonseed meal, cane molasses, and animal fat.

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

	Diet[1]							
Item[2]	CNTL	0DDGS	33DDGS	66DDGS	100DDGS	Milo	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

[1]Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets.

[2]ADICP = acid detergent insoluble CP; True IVDMD = true 48-h IVDMD.

Table 3. Effects of replacing CSM and milo with DDGS on lamb growth performance

	Diet[1]						*P*-value[2]				
Item	CNTL	0DDGS	33DDGS	66DDGS	100DDGS	SEM	D	T × D	1	L	Q
BW, kg							<0.001	<0.001			
d 0	27.8	27.4	26.6	27.6	26.5	1.3			0.82	0.78	0.90
d 14	33.0	29.9	31.0	31.9	30.5	1.5			0.13	0.68	0.39
d 30	38.1	34.3	36.0	37.2	35.3	1.5			0.06	0.53	0.22
d 42	41.8	36.4	40.3	41.2	38.5	1.8			0.02	0.33	0.04
d 56	45.6	39.3	44.2	45.2	42.3	1.8			0.01	0.20	0.02
ADG, kg							0.29	0.91			
d 0 to 56	0.32	0.23	0.31	0.31	0.28	0.02			<0.001	0.03	<0.001
DMI, kg/d							<0.001	0.78			
d 0 to 56	1.60	1.45	1.56	1.67	1.47	0.96			0.22	0.65	0.08
G:F, kg/kg							<0.001	0.93			
d 0 to 56	0.20	0.16	0.20	0.19	0.19	0.01			0.008	0.08	0.06

[1]Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets.

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

Table 4. Effects of replacing CSM and milo with 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]Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets.

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

Table 5. Effects of replacing CSM and milo with 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	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	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	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	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	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	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	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	2.60	2.30	2.74	2.52	2.46	0.09	0.01	0.53	0.008	0.01	0.45	0.006

Table 5. Continued

Item[3]	Diet					SEM	*P*-value[2]					
	CNTL	0DDGS	33DDGS	66DDGS	100DDGS		T	D	T × D	1	L	Q
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	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	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	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]Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets.

[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.

Table 6. Trained panel flavor attributes, definitions, and reference standards[1]

Attribute	Definition	Reference
Bitter	The fundamental taste factor associated with a caffeine solution	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody	The aromatics associated with blood on cooked meat products. Closely related to metallic aromatics.	USDA Choice strip steak = 5.5 Beef brisket = 6.0 Boneless pork chop, 57°C = 2.0
Brown	A round, full aromativ generally associated with beef/lamb suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0 Pork Fat, cooked and browned = 3.0
Burnt	The sharp/acrid flavor note associated with over-roasted beef muscle, something over-baked or excessively browned in oil	Alf's red wheat Puffs = 5.0
Cardboardy	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging.	Dry cardboard = 5.0 Wet cardboard = 7.0
Fat-like	The aromatics associated with cooked animal fat	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Green/Hay-like	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves	Dry parsley in ~30 mL cup = 6.0
Lamb Flavor Identity	Amount of lamb flavor identity in the sample	Grain-fed ground lamb (80% lean) = 9.0 Grass-fed ground lamb (80% lean) = 12.0
Liver-like	The aromatics associated with cooked organ meat/liver	Beef liver = 7.5 Oscar Mayer Braunschweiger liver sausage = 10.0 Pork liver, 71°C = 15.0 Chicken liver, 71°C = 9.0
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Roasted	A round, full aromativ generally associated with beef/lamb that has been broiled/roasted.	Same as Brown

Table 6. Continued

Attribute	Definition	Reference
Salty	The fundamental taste factor of which sodium chloride is typical	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of flutamate, salts of amino acids and other molecules called nucleotides	0.035% accent flavor enhancer solution = 7.5
Muscle Fiber Tenderness	The ease in which the muscle fiber fragments during mastication	Select eye of round steak cooked to 70°C = 9.0 Select tenderloin steak cooked to 70°C = 14.0
Connective Tissue Amount	The component of the muscle surrounding the during mastication	Cross cut beef shank cooked to muscle fiber that will not break down 70°C = 7.0 Select tenderloin cooked to 70°C = 14.0

[1]Intensities where 0 = none and 15 = extremely intense adapted from Adhikari et al. (2011).

Table 7. Effects of replacing CSM and Milo with DDGS on lamb carcass characteristics

	Diet[1]						*P*-value[2]			
Item	CNTL	0DDGS	33DDGS	66DDGS	100DDGS	SEM	*P* > *F*	1	L	Q
HCW	51.5a	43.6c	50.6ab	49.8ab	46.0bc	2.06	0.03	0.007	0.65	0.005
Dressing Percent	48.6	48.5	49.1	48.0	48.0	0.86	0.83	0.93	0.42	0.72
Rib eye area	2.63a	2.30b	2.79a	2.54ab	2.74a	0.11	0.02	0.03	0.06	0.23
12th rib back fat	0.19	0.13	0.17	0.17	0.18	0.03	0.41	0.16	0.18	0.56
Body wall thickness	0.59	0.53	0.66	0.60	0.62	0.54	0.45	0.39	0.41	0.33
Marbling	305	326	292	286	273	16.8	0.19	0.35	0.03	0.49
Flank fat	319	299	339	316	298	17.1	0.33	0.37	0.54	0.05
Leg Score	13.4	13.1	13.8	13.3	13.3	0.31	0.62	0.53	0.96	0.22
Skeletal Maturity	151	160	158	150	149	4.54	0.28	0.14	0.06	0.85
Lean Maturity	158	166	158	161	151	7.62	0.69	0.44	0.21	0.86

[1]Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets.

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

Table 8. Effects of replacing CSM and Milo with DDGS on lamb sensory characteristics

	Diet[1]						*P*-value[2]			
Item	CNTL	0DDGS	33DDGS	66DDGS	100DDGS	SEM[4]	*P* > *F*	1	L	Q
Juiciness	8.67ab	8.71ab	8.41b	9.16a	9.25a	0.24	0.05	0.88	0.03	0.44
Cook Loss	20.4	19.6	22.8	21.7	19.2	1.21	0.15	0.51	0.60	0.05
Lamb Flavor Identity	7.75a	7.58a	7.70a	7.51ab	6.83b	0.27	0.07	0.64	0.03	0.09
Muscle Fiber Tenderness	10.66	10.54	10.43	10.96	10.48	0.33	0.72	0.79	0.81	0.56
Connective Tissue Amount	11.41	11.25	11.09	11.73	11.35	0.23	0.28	0.59	0.36	0.60
Brown	8.07ab	7.30bc	8.81a	7.29c	7.43bc	0.31	0.001	0.07	0.28	0.03
Roasted	6.72ab	6.30bc	7.01a	6.2bc	5.98c	0.23	0.007	0.18	0.04	0.03
Bloody	1.65b	1.39b	1.16b	1.73ab	2.28a	0.24	0.012	0.41	0.003	0.10
Fat Like	1.91	1.72	1.79	1.89	2.05	0.15	0.51	0.34	0.09	0.73
Metallic	2.54a	2.33ab	2.15b	2.18b	2.5a	0.10	0.007	0.13	0.17	0.004
Bitter	2.58	2.56	2.40	2.49	2.58	0.11	0.69	0.90	0.70	0.21
Salty	1.54	1.34	1.51	1.44	1.4	0.11	0.68	0.20	0.91	0.37
Sweet	0.30	0.29	0.35	0.33	0.44	0.08	0.59	0.90	0.15	0.74
Sour	2.34	2.42	2.13	2.22	2.33	0.10	0.24	0.60	0.81	0.06
Umami	3.59	3.26	3.70	3.69	3.45	0.13	0.08	0.06	0.48	0.01
Burnt	0.02	0.03	0	0	0.05	0.03	0.62	0.82	0.57	0.30
Cardboardy	1.62	1.43	1.50	1.49	1.38	0.17	0.84	0.40	0.80	0.57
Green/Hay Like	0.02	0.11	0.07	0.07	0.10	0.04	0.40	0.08	0.86	0.32
Liver-like	0.35	0.63	0.36	0.33	0.48	0.12	0.36	0.09	0.43	0.07

[1]Lambs were individually fed ad libitum 70.9% concentrate diets for 56-d 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 in the treatment diets.

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