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Forage Type and Transportation Stress Effects on Gut Microbial Counts and Meat Quality in Goats

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Abstract

An experiment was conducted to determine the effects of feeding high condensed tannin legume (sericea lespedeza, SL; *Lespedeza cuneata*) forage on gastrointestinal tract microbial counts and meat quality in goats. Intact male Spanish kids were kept in 0.40 ha paddocks of SL, bermudagrass (BG; *Cynodon dactylon*; Control), or a combination of SL + BG (n = 10 goats/treatment group) for 8 weeks. All goats were supplemented with a commercial feed pellet at 0.45 kg/head/d for the first 4 weeks and 0.23 kg/head/d for the final 4 weeks of the trial. At the end of the experiment, half the goats from each paddock were subjected to 3-hour transportation stress, and all animals were humanely slaughtered. Diet or stress did not have a significant effect on skin *Escherichia coli*, coliform, or aerobic plate counts, and carcass, rumen and fecal bacterial counts. Muscle pH at 24 h postmortem tended ($P = 0.06$) to be higher in transported compared to non-transported goats. The results indicate that SL consumption by goats for 8 weeks did not significantly affect gastrointestinal tract, skin, and carcass microbial counts or meat quality, although preslaughter stress could influence meat quality due to changes in the course of postmortem pH decline.

Key Words: Sericea lespedeza, Stress, Goat, *E. coli*, Muscle pH

Introduction

The bacterial contamination level of carcasses at slaughter is affected by multiple factors, but depends to a large extent on fecal contamination of animal skin prior to slaughter. The hide of the live animal becomes contaminated with both pathogenic and non-pathogenic microorganisms derived from a wide range of sources, such as feces, soil, water and vegetation (McEvoy et al., 2000). Animals can spread the contamination to other animals during transport and holding, either directly via body contact, indirectly via contact with contaminated floors, or

both (Reid et al., 2002). Reduction of fecal shedding of bacteria and skin contamination are considered viable preharvest intervention strategies, and these generally involve feed deprivation and handling methods that minimize animal stress.

Tannins are polyphenolic compounds capable of binding proteins and forming tannin-protein complexes that are reported to be harmful to gastrointestinal microbes (Patra et al., 2012). The mechanisms involved could be dysfunctioning of bacterial cell membranes, reduction in enzyme activity, and deprivation of substrate metal ions and minerals (Scalbert, 1991). Sericea lespedeza (SL; *Lespedeza cuneata*) is a perennial warm-season legume well-adapted to the clay and loam soils of the southeastern United States. It is a useful hay and grazing crop, yielding 2-3 tons DM per acre of good-quality forage (Hoveland et al., 1990). Daily gains in goats grazing SL (Mechineni et al., 2014) or consuming it as hay (Moore et al., 2008) at up to 75% of the ration were similar to or higher than goats consuming bermudagrass (*Cyanodon dactylon*) pasture or hay-based diets. Sericea lespedeza contains a high concentration of a unique type of condensed tannin (close to 100% pro-delphinidin), which has been suggested to explain its high level of bioactivity against internal parasites in livestock (Kommuru et al., 2014; Mechineni et al., 2014; Shaik et al., 2006). It has also been reported to have bioactivity against methanogenic ruminal bacteria (Liu et al., 2018), mastitis-causing bacteria in dairy goats (Min et al., 2008), and domestic fly larvae in manure (Littlefield et al., 2011). However, the effects of a high CT diet on gastrointestinal microbial populations have not been fully understood, although Lee et al. (2009) reported that a ground SL diet reduced the total plate counts in feces compared to a bermudagrass hay diet, both at 75% of daily intake.

Minimizing stress in goats during loading, transportation, unloading and holding prior to slaughter is very important in reducing meat hygiene risks. Defecation is a frequently noticed

stress response in ruminants. Stress combined with light physical exercise can accelerate gastrointestinal tract emptying, while vigorous exercise slows gastric emptying (Gregory, 1998). Stress can speed up emptying of cecum into the colon and increase the rate of excretion, which can in turn increase the likelihood of contaminating the hide/skin of pathogen-free animals and increase the food safety risk in the slaughter plant (Berends et al., 1996; Rostagno, 2009).

In addition to diet, preslaughter stress can also greatly affect muscle metabolism and negatively impact meat quality characteristics in goats (Kannan et al., 2003; Galipalli, 2004). Depletion of muscle glycogen prior to slaughter can interfere with the normal course of pH decline and conversion of muscle to meat.

Studies are very limited on the effects of high-CT forage and preslaughter stress on gastrointestinal tract bacterial populations and meat quality in goats. The results reported in this paper are a part of a larger study conducted to evaluate the effects of sericea forage on controlling gastrointestinal nematodes in goats, in addition to its effects on food safety and meat quality characteristics. It is expected that feeding a diet high in CT will mitigate any negative effects of stress on gastrointestinal microbial counts and meat quality in goats. The objective of this study was to determine the separate and combined effects of forage type and transportation stress on gastrointestinal tract, skin and carcass bacterial counts and meat quality characteristics in intact male Spanish kids.

Materials and Methods

Animals and Management

The animal use protocols were duly approved by the Fort Valley State University (Fort Valley, GA, USA) Agricultural and Laboratory Animal Care and Use Committee prior to the beginning of this experiment. Thirty intact male Spanish kids (9 months old, 20.7 ± 1.1 kg) were

used for this study. Three paddocks (0.40 ha) were randomly allotted to the three treatments (forage type, FT): fresh sericea lespedeza forage (SL), fresh grass comprised of a mixture of warm season perennial species, predominantly (>90%) bermudagrass (BG, Control), and a combination (approximately 50:50) of SL and BG forage (SL + BG). Based upon daily visual observation, goats on the SL + BG paddocks grazed predominantly BG for the first 14 – 21 days and grazed both components more evenly thereafter. Goats in the SL paddocks began grazing the SL immediately. Concentration of condensed tannins were higher in SL leaves than stems (16.0 g vs, 3.3 g/100 g dry weight) and consisted of almost pure prodelphinidin (PD)-type tannins in each case (98% PD in leaves, 94% in stems; Mechineni et al., 2014).

The area selected for laying out the paddocks had not been used for animal grazing for more than a year. Spring and early summer growth on each of the paddocks was removed prior to the start of the trial, and grazing was initiated on late summer, autumn regrowth. Goats were set-stocked on each paddock throughout the study. A pellet supplement feed (14% crude protein, 4 % crude fat, and 10% crude fiber) was given to all animals at 0.45 kg/head/day for the first 4 weeks and 0.23 kg/head/d for the remaining 4 weeks of the trial to ensure adequate nutrition. There was enough forage leaf material available throughout the 8-week trial period and the goats consumed all of the supplemental feed provided. On dry matter basis, crude protein was 6.3%, 14.7% and 10.8%, neutral detergent fiber was 71.7%, 35.4%, and 56.0%, and acid detergent fiber was 35.2%, 25.2%, and 33.4%, respectively, in BG, SL, and SL + BG forages. Throughout the trial, the goats had *ad libitum* access to water.

At the end of the feeding trial, goats were moved to the holding pens at the slaughter facility. Animals were withdrawn from feed overnight prior to slaughter (14 h) at the holding pens, but had continuous access to water. On the day of slaughter, half the number of animals

were subjected to a stress treatment (ST) that is normally seen in a commercial operation. Within each forage diet group, 5 goats were randomly assigned to a 3-hour transportation (Transported, T) and the remaining 5 goats were held in pens as non-transported controls (C). All 15 animals (5 goats from each FT group) were transported using a livestock trailer with a floor space of 0.6 m²/animal. All animals were then slaughtered using humane standard procedures for microbial and meat quality evaluations.

Microbial Sampling and Analyses

Skin swabs (before and after transport and before slaughter at holding pens), carcass swabs, rumen and fecal samples were collected during slaughter and transported to the laboratory on ice for analysis within 24 h. Sterile sponges, hydrated with 10 mL buffered peptone water (BioPro Enviro- Sponge bags, International Byproducts, Redmond, WA) and disposable, sterile paper templates with an internal area measuring 5 × 5 cm, were used for sampling skin and carcass. Skin swabs at the hind leg region were made before and immediately after subjecting the animals to transport (3 h) and before slaughter. The control animals were also sampled at corresponding times. Swab samples were made in the leg region, within the 25 cm² template area, using 5 wipes vertically and 5 wipes horizontally according to the procedures of Kannan et al. (2007). The rationale is that the leg region is more prone to fecal contamination than other areas of skin.

In order to minimize cross carcass contamination, care was taken while skinning to prevent skin/hide roll over and while evisceration to prevent accidental puncture of the gastrointestinal tract. Carcass swab sampling was made following the procedures of Kannan et al. (2007). The procedure was similar to the one prescribed by the US Department of Agriculture (USDA) for generic *E. coli* testing (FSIS-USDA, 1996) but with modifications. A template with

smaller sampling area (5 cm × 5 cm) and fewer vertical and horizontal passes were used to suit the smaller goat carcasses instead of a 10 cm × 10 cm template recommended by USDA. Carcass swab samples were made after skinning and evisceration, but before washing the carcass. Swab samples from carcasses were made using a 25 cm² disposable sterile template at three different anatomical locations (flank, brisket, leg) for a total sampling area of 75 cm². Swabbing at each carcass site, within the 25 cm² template area, consisted of 5 wipes vertically and 5 wipes horizontally. Swab samples were made aseptically using sterile gloves, which were changed between samplings. After sampling, sponge bags were kept in an icebox and transported to the laboratory for analysis.

Immediately after evisceration, the intact gastrointestinal tract from esophagus to rectum was separated and placed in a shallow rectangle bucket and taken to the rumen and rectum sampling station, established away from the slaughter and processing line to prevent any cross contamination of carcasses. Using a sterile scalpel, an incision was made on the ventral ruminal sac and the contents (approx. 50 g) were scooped using an aseptic, labeled 50 mL tube. For collecting fecal samples, an incision was made on the rectal wall and the contents were squeezed into the 50 mL sampling tube. The tubes were screw-capped immediately after sample collection and kept on ice until being transported to the laboratory for microbial analysis. Rumen and rectal sampling of each animal was completed within 15 min post-slaughter. To prevent cross contamination, the buckets used were thoroughly washed after sampling rumen and rectal contents and discarding the offals from each animal.

In the laboratory, sponges were transferred into stomacher bags with 90 mL of 0.1% sterile buffered peptone water (Difco Laboratories, Detroit, MI) added to each bag. The bags with the contents were pummeled in a stomacher (Seward Model 400, Tekmar Company,

Cincinnati, OH) for 1 min. Serial dilutions (10^{-1} , 10^{-2} , 10^{-3} , 10^{-4} , 10^{-5}) were then made with 0.1% sterile buffered peptone water. For rumen and rectal samples, 10 g of sample was added to 90 mL of 0.1% sterile buffered peptone water in the stomacher bag and then pumped in the stomacher for 2 min. Serial dilutions were then prepared with 0.1% sterile buffered peptone water.

Appropriate dilutions were inoculated on Petrifilms (Petri film™ 3M) to determine generic *Escherichia coli*, total coliform and aerobic plate counts. Colonies were counted after 24 h incubation at 35° C for *E. coli* and total coliform counts, and after 48 h incubation for aerobic plate counts. Bacterial counts of skin and carcass samples were converted to $\log_{10}$ CFU/cm².

Meat Sampling and Analysis

Muscle pH was recorded at 15 min (initial pH, immediately after skinning) and 24 hour postmortem (ultimate pH) using a portable pH meter with a penetrating probe (Pakton® Model OKPH1000N, Vernon Hills, IL). The probe was inserted directly into the *Longissimus dorsi* muscle to determine pH.

The dressed carcasses were weighed and stored at 2° C for 24 h before fabrication. Each carcass was split along the vertebral column into left and right halves and then sliced into 2.5-cm loin/rib chops using a band saw. To the furthest extent possible, the cuts were carefully made such that the cut surfaces were at right angles to the axes of *Longissimus* muscle (LM) fibers. Four loin chops from each carcass were allowed to bloom for 45 min at 4 °C and then L*, a*, and b* color coordinate values were determined on the cut surfaces using a MiniScan® XE Plus colorimeter (Serial No. 6130; HunterLab, Reston, VA). The instrument was calibrated according to the manufacturer's instructions prior to recording color values of samples.

A minimum of three chops were vacuum-packed and stored at -30 °C until assessment of Warner-Bratzler shear force (WBSF) values (< 1 month). The cuts were thawed at 4°C and cooked according to the procedures described by Kannan et al. (2002). Cooled samples were wrapped in aluminum foil and cooled at 4 °C overnight before core removal. Cooled cuts were then tempered at room temperature for 2 h, and then 1 cm diameter cores were removed parallel to muscle fiber orientation (Kannan et al., 2002). Two cores were taken from each chop and WBSF values were assessed using a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) with the samples being sheared at right angles to the orientation of muscle fibers using a Warner-Bratzler shear attachment (Texture Technologies Corp., Scarsdale, NY). The texture analyzer was set with a 25 kg load cell and a crosshead speed of 200 mm/min. Chops were weighed before and after cooking to calculate cooking losses.

Statistical Analysis

The data were analyzed using Mixed Procedures in SAS (release 9.1, SAS Institute, Cary, NC, USA) as a completely randomized design with FT and ST as fixed effects in a 3 × 2 factorial treatment arrangement. The means were separated using the LSD test.

Results

Microbial Counts

Forage type, ST, or FT × ST interaction effects on skin bacterial counts sampled at different times prior to slaughter are shown in Table 1. Skin coliform counts did not exceed 1.4 log₁₀ CFU/cm² before transport, but the counts generally decreased after transport in all groups and reached undetectable levels when sampled prior to slaughter. *E. coli* counts did not exceed 1.1 log₁₀ CFU/cm² prior to transport, decreased after transport, and reached undetectable levels when sampled prior to slaughter in all treatment groups. Aerobic plate counts also followed

similar trends in all treatment groups, although the pattern was clearer in the transported group than the control group (Figure 1). Carcass coliform, *E. coli*, and aerobic plate counts were not significantly influenced by FT, ST, or FT $\times$ ST interaction. Carcass coliform and *E. coli* counts were $< 1.0 \log_{10}$ CFU/cm² in all groups (Table 2). Rumen and fecal microbial counts were also not affected by FT, ST, or FT $\times$ ST interaction (Table 3). Sericea grazed goats subjected to transportation stress tended to have the lowest *E. coli* and coliform counts in the rumen (2.48 ± 0.29 and $1.06 \pm 0.58 \log_{10}$ CFU/g, respectively) and feces (5.51 ± 0.63 and $5.51 \pm 0.63 \log_{10}$ CFU/g, respectively).

Meat Quality

Carcass weights were similar among the three forage groups. The weights were 14.0 ± 0.7 kg, 15.0 ± 0.6 kg, and 15.0 ± 0.6 kg, respectively in BG, SL, and SL + BG groups. Carcass yields were 54%, 58%, and 60%, respectively, in BG, SL, and SL + BG groups.

Since FT did not have any effects on meat quality characteristics, the main effects of ST are presented in Table 4. The initial (15 min postmortem) and ultimate (24 h postmortem) muscle pH were not influenced by transportation stress. However, the ultimate pH of LM tended to be higher ($P = 0.06$) in the transported group compared with the non-transported controls. The WBSF values and cooking loss percentages were not affected by ST. The L^* values of loin chops (LM) were also not influenced by preslaughter transportation stress; however, a^* values tended to be lower ($P = 0.06$) in the transported group compared with the control group. The b^* values were significantly lower ($P < 0.05$) in the transported group.

Discussion

Dietary manipulations, including high condensed tannin-containing diets, in ruminants have shown promise in minimizing gut microbial populations. Several possible mechanisms

have been proposed as to the effects of condensed tannins on rumen bacterial populations. Wang et al. (2013) reported that condensed tannins disrupted the outer membrane structure of *E. coli* O157:H7 and suggested the mechanism of action as alteration of the fatty acid composition of the cell membrane. Based on *in vitro* studies, Molan et al. (2001) suggested that condensed tannins attach to bacterial cells more strongly than they would bind to plant proteins. Smith et al. (2003) reported that condensed tannins can reduce *E. coli* populations by releasing reactive oxygen species (H_2O_2) in aerobic conditions *in vitro*.

In this study, SL or SL + BG forage did not influence the gut microbial counts. These results support the findings of a previous study with SL (Lee et al., 2009). These authors fed Kiko × Spanish goats either ground SL or BG hay at 75% of daily intake with a corn-based supplement (25%) for 14 weeks before slaughter to determine effects on fecal *E. coli* shedding. The SL-hay fed goats had higher rumen pH due to lower production of total volatile fatty acids, a condition that favored *E. coli* and total coliform growth in the rumen, although such an effect was absent in the rectum. However, the authors found that the total plate count in the rectum samples from goats fed SL was lower than that from goats fed BG hay (Lee et al., 2009). In the present study, *E. coli* counts in fecal samples in the SL transported group was at least 1.5 log₁₀ CFU/g lower than the BG and SL + BG forage groups irrespective of whether the goats were subjected to transportation stress or not. It is evident that SL feeding, either in ground form (Lee et al., 2009) or as fresh forage, does not have a marked effect on rumen microbial counts, but may influence fecal microbial counts, although the mechanism involved needs further investigation. The antibacterial effects of tannins may depend on their polymer type and class. Phlorotannins, a group of polyphenols present in brown seaweed (*Ascophyllum nodosum*), has been shown to reduce rumen *E. coli* populations in goats (Kannan et al., 2019). The antibacterial

activity of phlorotannins is considered to be more potent than hydrolysable terrestrial tannins or condensed tannins (Wang et al., 2009). This may explain the lack of rumen antibacterial effect of the condensed tannins present in SL, which are almost pure prodelphinidin-type tannins (Kommuru et al., 2014; Mechineni et al., 2014).

Skin bacterial counts in the current investigation decreased over time, with *E. coli* and coliform counts reaching undetectable levels when sampled immediately prior to slaughter. This trend is probably related to the feed deprivation and gut emptying rate effects. As feed was withdrawn overnight (14 hours) prior to slaughter in this study, the gut contents in goats would have already decreased significantly on the day of stress imposition and processing. Since defecation is a frequently noticed behavior in response to a stressor (Gregory, 1998), gut emptying rate could have increased during the initial phases of preslaughter handling. Stress combined with feed deprivation could have resulted in earlier emptying of the gut, and in turn resulted in reduced defecation and skin bacterial counts when sampled before slaughter than when sampled before or after transportation. The effect of transportation stress on gut emptying rate and possible reduction in microbial shedding requires further investigation.

Animal diet can influence carcass composition (Warren et al., 2008) and muscle pH decline (Cameron et al., 1999). However, in the present study, forage type did not have any effect on the meat quality characteristics studied, although SL forage improved average daily gain (Mechineni et al., 2014) and carcass yield of the goats.

Preslaughter stress in small ruminants can greatly affect muscle metabolism and may negatively impact meat quality characteristics (Kannan et al., 2003; Kadim et al., 2006; Miranda-de la Lama et al., 2009). Antemortem depletion of muscle glycogen and the consequent inability of muscles to develop adequate acidity and to undergo a normal course of pH decline is the most

important effect of stress in regard to meat quality (Gregory, 1998). Muscles with higher ultimate pH postmortem (24 hours) can result in dark meat and lower economic returns. In the present study, a 3-hour transportation stress did not affect initial pH, WBSF values, or cooking losses of loin chops (LM muscle). However, ultimate pH tended to be higher in transported goats compared to control goats due to preslaughter depletion of muscle glycogen. In contrast, Kannan et al. (2003) reported that a 2-hour transportation stress decreased muscle glycogen, but did not affect the ultimate pH of LM muscle in young castrated Alpine goats. In that study, the authors also found that the negative effects of prolonged and intense preslaughter stress on meat quality are more pronounced in younger goats than in older animals. There was also a trend toward a lower a^* value in transported goats in this study, which was in agreement with the results reported by Kannan et al. (2003). Stress also had a significant effect on b^* value of LM; however, b^* value is of less importance in determining fresh red meat color, since it is unlikely to affect consumer perception.

Overall, forage type or transportation stress did not have any significant effects on gastrointestinal tract, skin, and carcass bacterial counts or meat quality. There was a trend in the ultimate pH value of longissimus muscle that indicates that stress could alter the normal course of postmortem muscle metabolism.

Conclusions

This study shows that SL forage improves carcass yield and does not have any adverse effects on meat quality characteristics, and therefore could be safely included in the diet. Grazing Bermudagrass, sericea lespedeza, or sericea lespedeza plus Bermudagrass paddocks for 8 weeks did not significantly affect gastrointestinal tract, skin or carcass bacterial counts in goats. However, there is evidence that skin coliform and *E. coli* counts are reduced during

preslaughter holding, since the counts decreased after transportation and reached undetectable levels when sampled prior to slaughter. This trend was also noticed in skin aerobic plate counts, particularly in transported goats. The effect of transportation stress on gastrointestinal emptying rate and bacterial shedding needs further investigation.

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Figure 1. Aerobic plate counts (mean $\pm$ SEM) in skin swab samples collected at three different times prior to slaughter in (A) goats subjected to transportation stress and (B) goats not transported (control), but held in pens and time sampled.

For Review Only

Table 1. Effect of forage type (FT, n = 10 goats/FT) and stress treatment (ST, n = 5 goats/ST/FT) on skin bacterial loads in goats.

Bacterial Group	FT						P-value by ANOVA		
	Bermuda		Sericea		Sericea + Bermuda				
	<i>(Cyanodon dactylon)</i>		<i>(Lespedeza cuneata)</i>						
	ST		ST		ST				
	T	C	T	C	T	C	FT	ST	FT × ST
<i>T0, log₁₀ CFU/cm²</i>									
Coliform	1.09 ± 0.35	0.77 ± 0.39	1.37 ± 0.35	0.85 ± 0.35	0.87 ± 0.35	0.95 ± 0.35	0.83	0.40	0.69
<i>E. coli</i>	0.86 ± 0.34	0.32 ± 0.38	1.09 ± 0.34	0.26 ± 0.34	0.49 ± 0.34	0.43 ± 0.34	0.83	0.11	0.54
Aerobic	3.53 ± 0.39	3.54 ± 0.43	2.59 ± 0.39	2.93 ± 0.39	2.82 ± 0.39	2.28 ± 0.39	0.06	0.84	0.53
<i>T1, log₁₀ CFU/cm²</i>									
Coliform	0.63 ± 0.30	0.50 ± 0.33	0.60 ± 0.30	0.46 ± 0.30	0.57 ± 0.30	1.10 ± 0.30	0.55	0.74	0.47
<i>E. coli</i>	0.40 ± 0.15	0.00 ± 0.17	0.14 ± 0.15	0.00 ± 0.15	0.00 ± 0.15	0.37 ± 0.15	0.66	0.67	0.06
Aerobic	3.27 ± 0.34	2.77 ± 0.38	2.92 ± 0.34	2.49 ± 0.34	2.99 ± 0.34	3.16 ± 0.34	0.52	0.39	0.58
<i>T2, log₁₀ CFU/cm²</i>									
Coliform	0.00 ± 0.11	0.25 ± 0.12	0.00 ± 0.11	0.20 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.54	0.13	0.54
<i>E. coli</i>	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	-	-	-
Aerobic	2.73 ± 0.29	2.86 ± 0.32	2.15 ± 0.29	2.57 ± 0.29	2.27 ± 0.29	2.19 ± 0.29	0.17	0.54	0.69

Note: Values shown are least squares means ± SEM

T = Transported group (transported for 3 hours by road using a livestock trailer)

C = Control group (held in pens, not transported)

T0 = Before transport

T1 = After transport

T2 = Before slaughter (in holding pens)

Table 2. Effect of forage type (FT, n = 10 goats/FT) and stress treatment (ST, n = 5 goats/ST/FT) on carcass bacterial loads (log₁₀ CFU/cm²) in goats.

Bacterial Group	FT						P-value by ANOVA		
	Bermuda (<i>Cyanodon dactylon</i>)		Sericea (<i>Lespedeza cuneata</i>)		Sericea + Bermuda				
	ST		ST		ST		FT	ST	FT × ST
	T	C	T	C	T	C			
Coliform	0.38 ± 0.46	0.65 ± 0.51	0.95 ± 0.46	0.83 ± 0.46	0.14 ± 0.46	0.66 ± 0.46	0.54	0.57	0.78
<i>E. coli</i>	0.38 ± 0.44	0.50 ± 0.49	0.52 ± 0.44	0.83 ± 0.44	0.00 ± 0.44	0.52 ± 0.44	0.64	0.39	0.91
Aerobic	2.59 ± 0.43	3.21 ± 0.48	2.38 ± 0.43	2.85 ± 0.43	2.62 ± 0.43	2.19 ± 0.43	0.54	0.54	0.44

Note: Values shown are least squares means ± SEM
T = Transported group (transported for 3 hours by road using a livestock trailer)
C = Control group (held in pens, not transported)

Table 3. Effect of forage type (FT, n = 10 goats/FT) and stress treatment (ST, n = 5 goats/ST/FT) on bacterial loads in the gastrointestinal tract of goats.

Bacterial Group	FT						P-value by ANOVA		
	Bermuda		Sericea		Sericea + Bermuda				
	(Cyanodon dactylon)		(Lespedeza cuneata)						
	ST		ST		ST				
T	C	T	C	T	C	FT	ST	FT × ST	
Rumen, log ₁₀ CFU/g									
Coliform	2.78 ± 0.29	3.05 ± 0.32	2.48 ± 0.29	3.00 ± 0.29	3.40 ± 0.29	2.80 ± 0.29	0.49	0.80	0.16
E. coli	2.55 ± 0.58	2.42 ± 0.65	1.06 ± 0.58	1.89 ± 0.58	3.29 ± 0.58	1.87 ± 0.58	0.14	0.63	0.18
Aerobic	6.24 ± 0.13	6.12 ± 0.14	5.93 ± 0.13	6.24 ± 0.13	5.85 ± 0.13	5.92 ± 0.13	0.11	0.48	0.32
Fecal, log ₁₀ CFU/g									
Coliform	7.13 ± 0.63	7.03 ± 0.70	5.51 ± 0.63	6.71 ± 0.63	7.36 ± 0.63	7.03 ± 0.63	0.19	0.63	0.44
E. coli	7.13 ± 0.63	7.03 ± 0.70	5.51 ± 0.63	6.71 ± 0.63	7.36 ± 0.63	7.02 ± 0.63	0.19	0.64	0.44
Aerobic	7.76 ± 0.27	7.84 ± 0.31	7.37 ± 0.27	7.37 ± 0.27	7.73 ± 0.27	7.40 ± 0.27	0.34	0.72	0.74

Note: Values shown are least squares means ± SEM

T = Transported group (transported for 3 hours by road using a livestock trailer)

C = Control group (held in pens, not transported)

Table 4. Effects of stress treatment (ST) on meat quality characteristics (*Longissimus* muscle, LM) in goats.

Meat Quality Characteristics	ST	
	T	C
Initial pH (15 min postmortem)	7.06 ± 0.04	6.97 ± 0.04
Ultimate pH (24 h postmortem)	6.83 ± 0.07 [†]	6.62 ± 0.07
WBSF , Kg	3.7 ± 0.36	5.0 ± 0.38
L* value	31.1 ± 1.96	30.6 ± 2.04
a* value	12.4 ± 0.70 [†]	14.3 ± 0.73
b* value	13.5 ± 0.51 ^b	15.0 ± 0.53 ^a
Cooking loss, %	15.4 ± 1.28	16.5 ± 1.33

Note: Means in the same row with different superscripts differ significantly ($P < 0.05$, $n = 15$ goats/ST main effect).
T = Transported group (transported for 3 hours by road using a livestock trailer)
C = Control group (held in pens, not transported)
WBSF = Warner Bratzler shear values.
[†]P = 0.06, main effect of ST

Figure 1.