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Flavor Compounds and Quality Parameters of Chevon As Influenced by Sericea Lespedeza Hay

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ABSTRACT: This research assessed the utilization of sericea lespedeza (SL, *Lespedeza cuneata*) hay, a highly condensed tannin (CT) forage (87−181 g CT/kg), as a dietary regimen of meat goats, and thereby the effects on physicochemical properties of goat meat (chevon) and flavor compounds in cooked chevon chops were evaluated. Although it is commonly believed that higher amounts of CT can have deleterious effects on animal performance due to low digestibility and low voluntary intakes in ruminants, feeding meat goats with SL hay increased the body weight compared to goats fed bermudagrass hay without altering the chemical composition and meat quality of chevon. Feeding SL hay to meat goats also did not significantly influence the flavor volatiles in cooked chevon chops. The findings indicate that SL hay can be used as a low-input forage to replace expensive forages.

KEYWORDS: *goats, sericea lespedeza, condensed tannins, meat quality of chevon, flavor volatiles*

INTRODUCTION

Sericea lespedeza (SL, *Lespedeza cuneata*) is a perennial legume grown in the southern regions of the United States. It has been recognized as a quality forage because of its high concentration of crude protein.[1] However, the forage quality of SL has been limited due to the relatively high concentration of condensed tannins (CT; 87−181 g CT/kg).[2] Condensed tannins have either beneficial or detrimental effects on the ruminant performance, depending on the concentration and nature.[3] In general, all nutritional benefits of feeding CT to ruminants are associated with protein digestion. Low concentrations of CT (20−49 g of CT/kg) can protect dietary protein from rumen degradation and increase the subsequent release of essential amino acids available in the small intestines for digestion and adsorption.[4] However, high concentrations of CT (63−106 g CT/kg) can have deleterious effects on the performance of sheep[5] that can be improved by either drying or binding CT to salivary protein or other compounds. According to Terrill et al.,[2] the high CT levels in SL can temporarily reduce intake of this forage by grazing animals, but intake can be improved by processing SL into hay because this lowers the extractable CT content and improves fiber digestibility. Compared to other ruminants, goats more easily utilize forages containing relatively high levels of CT because they have a large amount of saliva containing active tannase enzyme and tannin-resistant bacteria in the rumen.[6,7] Hence, SL hay has the potential to be used as a postweaning diet while maintaining acceptable goat performance.

The CT are phenolic compounds that limit the activity of ruminal microorganisms during digestion. In vitro studies showed that dietary tannins inhibit the growth of microorganisms that are responsible for ruminal biohydrogenation of fatty acids.[8,9] However, modifying ruminant fat by feeding CT with various lipid supplements has had limited success[10] because of a discrepancy between in vitro and in vivo studies. Phenolic compounds in CT also have antioxidant properties; however, the CT molecule itself is not absorbed in ruminants.[11] Therefore, the objective of this research was to determine the effect of high dietary CT on the chemical composition and meat quality of chevon, as well as flavor volatile compounds in cooked chevon chops.

MATERIALS AND METHODS

Feeding Trials and Meat Sampling. Experimental procedures involving animals were conducted with the approval of the Fort Valley State University (FVSU) Institutional Animal Care and Use Committee. Twenty crossbred (Kiko ×x Spanish) intact male goats (6 months old, body weight (BW) = 19.2 ± 0.74 kg) were assigned in a completely randomized design to a feeding trial consisting of 75% hay (either SL or bermudagrass (BG, *Cynodon dactylon*)) and 25% concentrate. The concentrate portion of each ration was formulated to balance the diets for crude protein (CP) and energy (Table 1), and the chemical compositions of SL and BG hay, as well as the supplemented concentrates used to balance the CP and energy are presented in Table 2. The SL and BG hays

Table 1. Composition of Concentrates (25% of Feed Offered) Used To Balance the Protein and Energy Contents of Sericea Lespedeza (SL) or Bermudagrass (BG) Hay Rations Fed to Meat Goats (on DM Basis)

ingredient component	SL ration	BG ration
corn, %	63.0	61.0
soybean meal, %	28.2	31.0
poultry fat, %	4.4	4.0
trace mineral salt,[a] %	2.2	2.0
vitamin premix,[b] %	2.2	2.0

[a]Contained >12% Zn, 10% Mn, 5% K, 2.5% Mg, 1.5% Cu, 0.3% I, 0.1% Co, and 0.02% Se. [b]Contained 2 000 000 IU of vitamin A, 400 000 IU of vitamin D_3, and 230 IU vitamin E/kg.

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Table 2. Chemical Composition of Sericea Lespedeza (SL) and Bermudagrass (BG) Hays, as well as Supplementing Concentrates (25% of Feed Offered) Used To Balance the Protein and Energy Contents of Experimental Diets Fed to Meat Goats

	diet			
item	SL	BG	SL supplement	BG supplement
chemical composition, % DM				
dry matter (DM)	93.0	93.6	92.4	92.4
organic matter (OM)	95.9	95.4	94.9	95.1
crude protein (CP)	12.5	11.3	22.0	21.8
ether extract	1.5	1.4	6.0	8.6
ash	4.1	4.6	5.1	4.9
acid detergent fiber (ADF)	30.6	34.6	4.0	4.0
neutral detergent fiber (NDF)	46.7	73.7	26.5	29.3
fatty acid, %				
C8:0	0.22			
C12:0	0.30	0.43	0.07	0.08
C13:0	0.43			
C13:1n9	2.41	1.49	0.27	0.27
C14:0	0.51	1.54	0.48	0.49
C14:1n5	6.56	2.77	0.11	0.11
C15:0		0.58	0.11	0.11
C16:0	27.16	27.67	21.09	21.32
C16:1n7	1.14	1.15	4.93	5.09
C17:0	0.41	1.36	0.16	0.16
C18:0	5.85	11.60	4.94	4.86
C18:1n9	6.23	12.82	33.75	33.70
C18:2n6	17.25	13.58	25.09	25.08
C18:3n3	15.91	11.02	3.73	3.69
C20:0			0.30	0.30
C20:1n9			0.04	0.04
C20:5n3			0.09	0.09
C22:0			0.10	0.10
C22:5n3			0.16	0.16

were harvested at approximately 60 cm height from pure stands. Extractable, protein-bound, fiber-bound, and total CT (% dry matter) were 1.35 ± 0.049, 4.68 ± 0.085, 0.44 ± 0.007, and 6.47 ± 0.134 for SL hay and 0.0, 0.29 ± 0.019, 0.53 ± 0.009, and 0.82 ± 0.028 for BG hay, respectively.

Each diet was replicated in two pens, with five goats per pen. Experimental animals were housed in feeding pens located at the Georgia Small Ruminant Research and Extension Center at the FVSU Agricultural Research Station (Fort Valley, GA, USA). Pens were in a closed barn and provided 9.3 m^2 of floor space. Goats were initially fed at 4% of BW once daily, with feed offered, orts recorded, and adjustments made daily to allow 10% feed refusal, with ad libitum access to water for 14 weeks.

At the conclusion of the feeding trial, the goats were slaughtered in the USDA-approved abattoir at FVSU using standard procedures. Carcasses were kept at 4 °C for 24 h before fabrication. After 24 h of cooling, each carcass was split along the vertebral column into left and right halves and then sliced into 2.5 cm loin chops using a band saw. Longissimus muscle (LM) was sampled from three loin chops from each carcass. All of the LM samples were ground with liquid nitrogen, placed in polyethylene bags (NASCO Inc., Fort Atkinson, WI, USA), and stored at −28 °C for proximate and fatty acid analyses, as well as for thiobarbituric acid reactive substances (TBARS) and metmyoglobin (MetMb) analyses. Other loin chops from each carcass were allotted for analysis of fresh meat color (CIE L^* a^* b^*), Warner−Bratzler shear force (WBSF) values, cooking losses, and flavor volatiles.

Chemical Composition of LM. Proximate composition of LM samples was analyzed according to AOAC[12] methods. Moisture and ash contents (%) were determined by the oven-drying (AOAC 950.46) and furnace methods (AOAC 942.05), respectively. The ether extraction method (AOAC 920.39) was used to determine total lipid content (%) in the LM, and protein content (%) was estimated using a carbon/nitrogen analyzer (Vario Max CN Elementar Americas, Inc., Mt. Laurel, NJ, USA).

Total lipids were extracted from 2.0 g of LM samples with chloroform/methanol (2:1 v/v) using a homogenizer (Cyclone IQ^2, Virtis Co., Gardiner, NY, USA) for 3 × 30 s at 30000 rpm.[13] Extracted lipid was saponified and esterified according to the AOCS method[14] of preparation of fatty acid methyl esters (FAME). The prepared FAME were analyzed using a Thermo Electronic (Austin, TX, USA) gas chromatograph (model TRACE GC Ultra) equipped with an automatic sampler model AS-3000 (Thermo Electronic Co.). A 0.25 mm i.d. with 0.25 μm film thickness by 60 m long fused silica SP-2380 capillary column (Supelco, Inc., Bellefonte, PA, USA) was used to separate the methyl esters, which were detected with a flame ionization detector (FID). The injection temperature was 240 °C, and the column temperature was programmed from 130 to 220 °C at 2 °C/min. Helium was the carrier gas, with a flow rate of 1.6 mL/min and a split ratio of 30:1. The identification of individual FAME in the sample was achieved by matching the retention time of the unknown FAME with that of known FAME standard mixtures (Alltech Associates, Inc., Deerfield, IL, USA; Sigma-Aldrich Corp., Bellefonte, PA, USA). For quantitative analysis of the sample FAME, standards containing known weight percentages of individual FAME, present in levels similar to those in the samples, were analyzed by the GC, and the correction factors relative to palmitic (C16:0) acid were calculated according to the AOCS[14] for fatty acid analysis. The area of individual sample FAME was corrected using its correction factor. The relative weight percentages of each FAME (C10:0−C22:6) in each sample were then calculated using their corrected areas.[14]

Quality Characteristics of Loin Chops. The CIE L^* a^* b^* color coordinate values were measured on the fresh-cut surface of loin chops from each carcass after 30 min of bloom time at 4 °C using a Hunter-Lab Color instrument (Minolta Chromameter, model CR-200, Minolta, Japan) with illuminant D65 as the light source.[13] Three measurements were taken from each chop. The average of the three measurements was recorded as a color coordinate value for each chop. After measurement of color coordinate values, the chops were vacuum-packed, frozen, and stored at −28 °C for tenderness and cooking loss, as well as flavor analyses.

The TBARS assay was performed as described by Buege and Aust.[15] The ground LM sample (0.5 g) was mixed with 2.5 mL of 0.375% thiobarbituric acid−15% trichloroacetic acid−0.25 N HCl stock solution in a glass test tube. The mixture was heated for 10 min in a boiling water bath (∼100 °C) to develop a pink color. The test tube was cooled with tap water and then centrifuged at 3500*g* for 25 min. Absorbance of supernatant was measured at 532 nm using a Shimadzu (model UV-2401 PC) spectrophotometer (Shimadzu Corp., Columbia, MD, USA). The TBARS were calculated from a standard curve of malondialdehyde (MDA) and expressed as milligrams of MDA per kilogram of sample.

The percent MetMb was determined according to the method of Krzywicki.[16] The ground LM sample (5.0 g) was placed into a 50 mL polypropylene conical tube, which contained 25 mL of ice-cold phosphate butter solution (pH 6.8, 40 mM). The tube contents were homogenized using a Cyclone IQ^2 homogenizer (Virtis Co.) for 10 s at 13500 rpm and centrifuged for 30 min at 3500*g* in a Sorvall Superspeed RC2-B automatic refrigerated centrifuge (Netwon, CT, USA) at 4 °C to separate MetMb from the mixture. Subsequently, the supernatant from the centrifuged mixture was filtered through a Whatman no 1. filter paper (Fisher Scientific, Suwannee, GA, USA). The MetMb content was measured at 525, 572, and 700 nm using a Shimadzu (model UV-2401 PC) spectrophotometer, and the percent MetMb was determined using Krzywicki's formula.[16]

The loin chops were thawed at 4 °C and cooked according to the procedures described by Kannan et al.[17] The chops were cooked in a

convection oven (Maytag Corp., model MER6550B, Newton, IA, USA) to an internal temperature of 71 °C. Cooked chops were wrapped in aluminum foil and cooled at 4 °C overnight before core removal. The chops were allowed to come to room temperature, and then 1 cm diameter cores were removed parallel to muscle fiber orientation. Two cores were taken from each chop and Warner–Bratzler shear force (WBSF) values assessed using a TA-XT2 texture analyzer fitted with a Warner–Bratzler shear attachment (Texture Technologies Corp., Scarsdale, NY, USA). The instrument was set with a 25 kg load cell and a cross-head speed of 200 mm/min. The difference in weight of samples before and after cooking was expressed as percentage cooking loss.

Flavor Volatiles in Cooked Loin Chops. One loin chop from each carcass was cooked to an internal temperature of 71 °C in a convection oven (model MER6550B, Maytag Corp.). The flavor compounds of cooked chops were extracted by a solid phase microextraction (SPME) method[18] and identified using a gas chromatography–mass spectrometry (GC-MS). The cooked chops were frozen in liquid nitrogen and homogenized with a Waring blender (Fisher Scientific). A portion (4.0 g) of the homogenized samples was transferred into a 15 mL vial and then sealed with a PTFE silicon septum (Supelco, Inc.). The vial was heated at 45 °C on a SPME sampling stand using a heat/stir plate (model PC-400; Corning Inc., Corning, NY, USA). Subsequently, the volatiles in the headspace were collected for 15 min on a 50/30 μm fused silica fiber, coated with polydimethylsiloxane–divinylbenzene and carboxen (Supelco, Inc.), inserted through the silicon septum. The volatiles were desorbed for 5 min by inserting the SPME needle and exposing the fiber directly into the injection port (230 °C) of a gas chromatography (TRACE GC Ultra; Thermo Electron Corp.), separated on a fused silica SP-2380 capillary column (60 m × 0.25 mm i.d., 0.20 μm; Supelco, Inc.), and detected with a mass selective detector (Finnigan TRACE DSQ MS; Thermo Electron Corp.). Helium was used as a carrier gas with a flow rate of 1.6 mL/min. The injection port was in the splitless mode, and the column temperature was programmed from 50 to 230 °C (4 °C/min) and held at 230 °C for 10 min. The mass spectrometer operated in the electron impact mode with an electron energy of 70 eV, a multiplier voltage of 1100 V, and a data collection rate of 1.5 scan/s over a range of m/z 40–450. Volatile compounds were identified either by comparing their mass spectra and retention times with those from standard compounds (Sigma-Aldrich Corp.) or by comparing their mass spectra with those contained in a mass spectra library (Thermo Electron Corp.) with a similarity index of 800 or greater.

Flavor volatiles extracted from the homogenized chops by the SPME method were also analyzed with a Thermo Electron gas chromatograph (Trace GC Ultra; Thermo Electron Corp.) equipped with a FID under the same column and conditions described for the GC-MS. Volatiles were extracted with the same SPME and conditions described for the SPME method. The concentration of individual flavor volatiles in each sample was determined as percentage of total area of the peaks in the GC chromatogram.

Statistical Analysis. All data were analyzed as a completely randomized design using the GLM procedure of SAS (SAS Institute Inc., Cary, NC, USA), with individual goats as the experimental units. Least-squares means were generated and separated using the PDIFF options of SAS (pairwise t test). Significant effects were determined at $P < 0.05$, but differences with $P < 0.1$ were considered as trends.

RESULTS AND DISCUSSION

Body Weight Gain. Average daily weight gain (ADG) of the goats was influenced ($P < 0.05$) by the experimental diets. The SL-fed goats had a higher ADG than the BG-fed goats, 107.1 and 75.5 (±8.88) g/day, respectively. Subsequently, differences ($P < 0.05$) were also found in the final live weight of the goats, which was greater for SL-fed (32.2 ± 1.34 kg) than for BG-fed goats (26.2 ± 1.34 kg). The differences in the ADG and final live weight were due to the greater quantities of hay being consumed by the SL groups (4.94 ± 0.33 kg/day, pen basis) compared to the BG groups (3.25 ± 0.33 kg/day, pen basis). The SL contains high concentrations of CT that can restrict intake and reduce overall weight gains by livestock; however, meat goats tend to tolerate and perform well when consuming high-CT-containing plants.[19] Preservation of SL forage as hay has a major effect with regard to reducing extractable tannin content;[20] therefore, goats' intake and digestibility might be further increased. In general, legumes are usually more digestible than grasses, therefore allowing more nutrients to be available for growth.[21] Because the diets in the present study were balanced for protein and energy, improved performance of SL-fed goats may be related to increased rumen bypass, leading to more efficient utilization of protein due to the action of CT in the SL diet.

Chemical Composition. No significant differences were found in the proximate composition of LM from goats fed the experimental diets (Table 3). In ruminants, the chemical composition of muscle has been reported to be influenced by diet and breed, as well as age and gender.[22,23] Development of muscle depends on nutrient composition and utilization; therefore, the energy contents of the diet might partially explain the difference in chemical composition of muscle.[23] In the present study, meat goats were offered isoenergy diets, but

Table 3. Proximate and Fatty Acid Composition of (Weight Percent of Fatty Acid Methyl Esters) of Longissimus Muscle (Intramuscular Fat) from Goats (n = 10) Fed either Sericea Lespedeza (SL) or Bermudagrass (BG) Hay Supplemented with Concentrate[a]

	diet		
component	SL	BG	SE
proximate composition, %			
moisture	73.2	72.8	0.48
crude protein	24.7	23.8	0.43
ether extracted	2.71	3.11	0.53
ash	1.83	1.59	0.23
fatty acid, %			
C10:0	0.10	0.10	0.027
C12:0	0.10	0.18	0.026
C14:0	1.68	1.80	0.143
C14:1n5	0.13	0.20	0.024
C15:0	0.43	0.50	0.047
C16:0, *iso*	0.94	0.82	0.123
C16:0	22.27	22.19	0.628
C16:1, *trans*	0.72 b	0.85 a	0.023
C16:1n7	1.76	1.68	0.142
C17:0	1.44 b	1.64 a	0.042
C17:1	1.28	1.31	0.136
C18:0	19.22	20.69	0.945
C18:1, *trans*	1.27	1.33	0.117
C18:1n9	41.64	40.76	0.787
C18:2n6	4.38	3.40	0.509
C18:2, *CLA*	0.18	0.18	0.009
C18:3n3	0.26	0.20	0.069
C20:0	0.13	0.10	0.034
C20:1n9	0.48	0.34	0.067
C21:0	0.44	0.60	0.161
C22:0	0.12	0.12	0.019
C20:4n6	1.18	1.21	0.220

[a]Within a row, least-squares means that do not have a common letters differ ($P < 0.05$).

the goats fed the SL diet had a higher BW than those fed the BG diet because of the greater quantities of hay being consumed by the SL group. Consequently, higher concentrations of protein and fat were expected from the LM of the SL-fed goats. However, none of these expected trends was observed in the present study. The differences in intake and BW might not be enough to change the proximate composition of LM in these studies because of the younger age of animals. The results of the current study are in agreement with those of Priolo et al.,[24] who found that LM from lambs fed fresh sulla (*Hedysarum coronarium* L.) either with or without polyethylene glycol (PEG; a binding agent that eliminates the effects of CT) was not different in proximate composition. However, Barry et al.[25] reported a lower percentage of fat and a higher content of crude protein in LM from tannin-fed lambs compared with lambs fed the same diet supplemented with PEG.

Twenty-two fatty acids were isolated and identified in the total lipids of LM from the goats fed experimental diets, which consisted of 11 saturated (C10:0, C12:0, C14:0, C16:0 *iso*, C16:0, C17:0, C18:0, C20:0, C21:0, and C22:0), 7 monounsaturated (C14:1n5, C16:1 *trans*, C16:1n7, C17:1, C18:1 *trans*, C18:1n9, and C20:1n9), and 4 polyunsaturated (C18:2n6, C18:2 *CLA*, C18:3n3, and C20:4n6) fatty acids (Table 3). The major fatty acids in the LM lipid from SL- and BG-fed goats were palmitic (C16:0), stearic (C18:0), and oleic (C18:1n9) acids, which accounted for 83.1 and 83.6% of total fatty acids, respectively. No significant differences were found in the concentrations of total saturated (46.9 or 48.7%), monounsaturated (47.3 or 46.8%), and polyunsaturated (6.0 or 5.0%) fatty acids in the LM lipids from goats fed the SL or BG diets. In the saturated fatty acids (SFA) portion, goats fed the BG diet had a higher ($P < 0.05$) percentage of margaric (C17:0) acid in the LM lipids than those fed the SL diet. Of the monounsaturated fatty acids (MUFA), the mean concentration of *trans*-palmitoleic (C16:1, *trans*) acid of the LM lipid of goats that consumed the BG diet was higher ($P < 0.05$) than that of the goats fed the SL diet (Table 3). No differences ($P > 0.05$) were observed in any of the LM polyunsaturated fatty acids (PUFA). However, inclusion of CT in the ruminant diet has been shown to decrease the rate of ruminal biohydrogenation of unsaturated fatty acids (USFA) in vitro and to increase the content of USFA in meat and milk fat. Lambs fed sulla, containing CT, had lower ($P < 0.05$) concentrations of C16:1 but higher ($P < 0.05$) amounts of C18:3n3 in the LM lipids compared with lambs fed sulla supplemented with PEG.[24] Vasta et al.[9] also reported that tannin-containing diets resulted in increased ($P < 0.05$) percentage of PUFA in the LM compared with that of lambs fed tannin-free diets. These studies supported that CT may manipulate bacterial populations involved in ruminal biohydration, such as *Butyrivibro fibrisolvens*, to modify the fatty acid composition of ruminant meat and milk fat.[8] However, there is limited information on modification of ruminant fat by feeding CT with various different lipid supplements because of discrepancy between in vitro and in vivo studies.[10] A possible explanation of the results in the present study is that ruminant microbes in goats have adapted to CT from the SL hay because of the presence of tannin-resistant bacteria in the rumen.[7] Hence, the reduction of ruminal biohydrogenation induced by the SL in the present study might not be enough to modify the fatty acid profile in the LM. Additional studies are needed to investigate CT tolerance of bacterial species in the rumen of goats, as well as to identify the bacterium engaged in ruminal biohydrogenation.

Quality Characteristics of Chevon Chops. The visual appearance of fresh meat is based on color, marbling, and water-holding capacity.[26] The color of fresh meat is an important criterion used by consumers to evaluate meat quality. Changes in meat color are closely associated with lipid and pigment oxidation, as well as with microbial load.[27] In the present study, no significant differences were found in the CIE L^* (lightness), a^* (redness), and b^* (yellowness) values of the LM from goats fed either the SL or BG diet (Table 4).

Table 4. Quality Characteristics of Loin Chops ($n = 10$) from Goats Fed either Sericea Lespedeza (SL) or Bermudagrass (BG) Hay Supplemented with Concentrate[a]

	loin chop		
parameter	SL	BG	SE
fresh			
L^* value	46.53	48.46	1.768
a^* value	10.15	10.34	0.298
b^* value	14.12	13.83	0.643
MetMb,[b] %	34.66 a	24.58 b	1.859
TBARS,[c] mg MDA/kg	1.08	1.42	0.453
cooked			
cooking loss, %	19.63	19.11	1.068
WBSF,[d] kg/cm^3	4.76	4.66	0.428

[a]Within a row, least squares means that do not have a common letter differ ($P < 0.05$). [b]MetMB = metmyoglobin. [c]TBARS = thiobarbituric acid reactive substances calculated as milligrams malondialdehyde per kg of fresh sample. [d]WBSF = Warner−Bratzler shear force values.

However, Priolo et al.[28] reported that the LM from lambs fed carob pulp, containing CT, had a higher ($P < 0.05$) L^* value (lighter) than that from lambs fed carob pulp supplemented with PEG because of lower hemoglobin and myoglobin contents in the LM from lambs fed carbo pulp only. The color of fresh meat is greatly influenced by the myoglobin content and oxidation state of the pigment.[29] The percentage of MetMb of the LM from SL-fed goats was higher ($P < 0.05$) than that from BG-fed goats (Table 4). However, the dietary treatments did not have significant effects on the TBARS values. The reaction of MDA with 2-thiobarbituric acid is widely used for measuring the extent of oxidative deterioration of fat in muscle foods.[30] Lipid oxidation results in the production of free radicals, which may lead to the oxidation of meat pigments and the generation of rancid odors and flavors.[31] In the present study, lipid oxidation of meat was not affected by dietary treatments because of the limitation of variation in fatty acid composition in the LM from both diets, especially unsaturated fatty acids (Table 3). In addition, many factors, such as light, temperature, relative humidity, pH, and the presence of specific bacteria, also influence the stability of meat pigments.[32]

No significant differences were found in the cooking losses and shear force values of loin chops from goats fed either the SL or BG diet (Table 4). Priolo et al.[28] also reported no difference in cooking losses and shear force of LM from lambs fed carob pulp either with or without PEG. In the present study, the higher CT concentration in the SL hay diet did not affect the eating quality of chevon. The acceptable limit for lamb tenderness is about a 3 kg Warner−Bratzler shear force for Australian and New Zealand consumers.[33] The tenderness value of chevon from the present study was over this acceptable limit (Table 4). Many internal and external factors influence the

shear force values of meat, such as the treatment of animals prior to slaughter, post-mortem methodologies, the sampled muscle, and method of sample preparation; moreover, fiber type and total and soluble collagen contents mainly affect sensory tenderness of meat.[33]

Flavor Volatiles in Cooked Chevon Chops. Nineteen flavor volatiles were isolated and positively identified from cooked loin chops from goats fed either the SL or BG diet (Table 5). The identified volatile compounds were mainly segregated into aldehyde, ketone, and lactone groups. In the aldehyde group, alkanals, alkenals, and alkadienals are responsible for oxidized flavor occurring in meat and milk products.[34] Most of these flavors are derived from the oxidation of the PUFA with C18 and C20 carbons. However, these precursor fatty acids are usually present in small amounts in meat products. Heptanal, octanal, nonanal, and *trans*-2-decenal are formed from the oxidation of C18:1n9; moreover, heptanal and octanal are also derived from the oxidation of C18:2n6.[35,36] No significant differences in the percent concentrations of these aldehyde compounds in the cooked loin chops of SL- and BG-fed goats were expected because the concentrations of C18:1n9 and C18:2n6 in the LM from goats fed either the SL or BG diets were not significantly different (Table 3). However, goats fed the SL diet had a lower ($P < 0.05$) concentration of octanal in their cooked chops compared with chops from goats fed the BG diet and had a higher ($P < 0.05$) content of *trans*-2-decenal (Table 5). Hexanal, 2-*trans*-octenal, and 2-*trans*,4-*trans*-decadienal are derived from the oxidation of C18:2n6,[35,36] yet no differences were detected in the percent concentrations of these three aldehydes in cooked chops from the goats fed experimental diets. Tetradecanal and hexadecanal are formed by the oxidation of the SFA from C14:0 to C18:0.[35,36] In the present study, only flavor volatiles from the oxidation of the SFA from C14:0 to C18:0 from goats fed the SL diet had a higher ($P < 0.05$) concentration of tetradecanal than the chops from goats fed the BG diet. According to the fatty acid profile of LM from the goats fed experimental diets, aldehyde compounds such as *trans*,*trans*-2,4-undecadienal and 2-pentadecenal might not be detected in the present study. Perhaps they might be formed through several combined reactions such as oxidation and thermal degradation of fatty acids as well as degradation of the amino acids.

Table 5. Flavor Volatiles in Cooked Loin Chops ($n = 10$) from Goats Fed either Sericea Lespedeza (SL) or Bermudagrass (BG) Hay Supplemented with Concentrate[a]

		diet		
flavor volatile, %	RT, min	SL	BG	SE
hexanal	10.71	17.65	20.00	1.455
2-*n*-pentylfuran	12.36	0.58	0.82	0.142
heptanal	14.13	5.87	5.89	0.693
octanal	17.91	0.63 b	0.94 a	0.091
nonanal	20.29	4.19	5.02	0.621
trans-2-octenal	21.48	0.26	0.18	0.040
2-octanone	25.16	0.24	0.14	0.104
cyclohexen-1-one	27.79	0.18	0.15	0.045
benzaldehyde	28.61	0.24	0.25	0.125
trans-2-decanal	29.20	0.42 a	0.20 b	0.058
2-decanone	33.09	0.20	0.26	0.034
tridecanone	36.76	0.23	0.17	0.027
tetradecanal	40.07	0.68 a	0.25 b	0.048
trans,*trans*-2,4-decadienal	43.21	0.49	0.168	0.248
trans,*trans*-2,4-undecadienal	47.69	0.68	0.25	0.202
hexadecanal	48.26	0.66	0.29	0.490
heptadecanal	51.92	0.54	0.50	0.170
γ-nonalactone	53.08	0.41	0.38	0.063
2-pentadecenal	53.49	0.79	0.28	0.268

[a]Within a row, least-squares means that do not have a common letters differ ($P < 0.05$).

For the ketone groups, there were no significant differences in the percent concentrations of 2-octaone, 2-decanone, cyclohexen-1-one, and tridecanone in the cooked chops of goats fed either the SL or BG diet (Table 5). These ketone compounds might be formed either by the oxidation or thermal degradation of fatty acids or by the degradation of the amino acids.[36,37] γ-Nonolactone can be formed via the thermal oxidation of C18:1n9, C18:2n6, and SFA.[35] The flavor compounds of 2-*n*-pentylfuran and benzaldehyde are derived from the oxidation of C18:3n3. The percent concentrations of these three flavor compounds were not different ($P > 0.05$) in the cooked chops from goats fed either the SL or BG diet because of no corresponding concentration differences in the precursor fatty acids such as SFA, C18:1n9, C18:2n6, and C18:3n3 of the total lipids in the LM from goats fed the SL or BG diet (Table 3).

Although it is commonly believed that higher amounts of condensed tannin can have deleterious effects on animal performance due to low digestibility and low voluntary intakes in ruminants, feeding meat goats with sericea lespedeza hay increased the body weight compared to goats fed bermudagrass hay without altering the chemical composition and meat quality of chevon, as well as flavor volatiles of cooked chops. Thus, sericea lespedeza hay might be used as a low-input forage to replace expensive forages.

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Notes

The authors declare no competing financial interest.

REFERENCES

(1) Puchala, R.; Min, B. R.; Goetsch, A. L.; Sahlu, T. The effect of a condensed tannin containing forage on methane emission by goats. *J. Anim. Sci.* **2005**, *83*, 182−186.

(2) Terrill, T. H.; Windham, W. R.; Hoveland, C. S.; Hamos, H. E. Forage preservation method influences on tannin concentration, intake and digestability of Sericea lespedeza by sheep. *Agron. J.* **1989**, *81*, 435−439.

(3) Makkar, H. P. S. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. *Small Rumin. Res* **2003**, *49*, 241−256.

(4) Waghorn, G. C.; Shelton, I. D. Effect of condensed tannins in *Lotus corniculatus* on the nutritive of pasture for sheep. *J. Agric. Sci.* **1997**, *128*, 365−372.

(5) Barry, T. N.; Duncan, S. J. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep. I. Voluntary intake. *Br. J. Nutr.* **1984**, *51*, 485−491.

(6) Tasi, C. G.; Gates, D. M.; Ingledew, W. M.; Jones, G. A. Products of anaerobic phloroglucinol degradation by *Coprococcus* spp. Pe_1S. *Can. J. Microbiol.* **1976**, *22*, 159−164.

(7) Brooker, J. D.; O'Donavon, L. A.; Skene, I.; Clarke, K.; Blackwell, L.; Muslera, P. *Streptococcus caprinus* spp. Nov, a tannin-resistant

ruminal bacterium from feral goats. *Lett. Appl. Microbiol.* **1994**, *18*, 313−318.
(8) Molan, A. L.; Attwood, G. T.; Min, B. R.; McNabb, W. C. The effect of condensed tannins from *Lotus pedunculatus* and *Lotus corniculatus* on the growth of proteolytic rumen bacteria in vitro and their possible mode of action. *Can. J. Microbiol.* **2001**, *47*, 626−633.
(9) Vasta, V.; Mele, M.; Serra, A.; Scerra, M.; Luciano, G.; Lanza, M.; Priolo, A. Metabolic fate of fatty acids involved in ruminal biohydrogenation in sheep fed concentrate or herbage with or without tannins. *J. Anim. Sci.* **2009**, *87*, 2674−2684.
(10) Benchaar, C.; Chouinard, P. Y. Assessment of the potential of cinnamaldehyde, condensed tannins, and saponins to modify milk fatty acid composition of dairy cows. *J. Dairy Sci.* **2009**, *92*, 3392−3396.
(11) Luciano, G.; Monahan, F. J.; Vasta, V.; Biondi, L.; Lanza, M.; Priolo, A. Dietary tannins improve lamb meat colour stability. *Meat Sci.* **2008**, *81*, 120−125.
(12) AOAC. *Official Methods of Analysis of the AOAC International*, 16th ed.; Association of Official Analytical Chemists, International: Gaithersburg, MD, 1995.
(13) Lee, J. H.; Kouakou, B.; Kannan, G. Chemical composition and quality characteristics of chevon from goats fed three different post-weaning diets. *Small Rumin. Res.* **2008**, *75*, 177−184.
(14) AOCS. *Official and Tentative Methods of Analysis*, 5th ed.; American Oil Chemists' Society: Champaign, IL, 1993.
(15) Buege, C. E.; Aust, S. D. Microsomal lipid peroxidation. *Methos Enzymol.* **1978**, *52*, 302−304.
(16) Krzywicki, K. The determination of haem pigments in meat. *Meat Sci.* **1982**, *7*, 29−36.
(17) Kannan, G.; Terrill, T. H.; Kouakou, B.; Gelaye, S.; Amoah, E. A. Influence of packaging method and storage time on shear value and mechanical strength of intramuscular connective tissue of chevon. *J. Anim. Sci.* **2002**, *80*, 2383−2389.
(18) Harmon, A. D. Solid-phase microextraction for the analysis of flavors. In *Techniques for Analyzing Food Aroma*; Marshili, R., Ed.; Dekker: New York, 1997; pp 81−112.
(19) Turner, K. E.; Wildeus, S.; Collins, J. R. Intake, performance, and blood parameters in young goats offered high forage diets of lespedeza or alfalfa hay. *Small Rumin. Res.* **2005**, *59*, 15−23.
(20) Terrill, T. H.; Windham, W. R.; Evans, J. J.; Hoveland, C. S. Condensed tannins in sericea lespedeza: effect of preservation method on tannin concentration. *Crop Sci.* **1990**, *30*, 219−224.
(21) Goering, H. K.; Waldo, D. R.; Tyrrell, H. F.; Thomson, D. J. Composition of formaldehyde- and formic acid-treated alfalfa and orchardgrass silages harvested at two maturities and their effects on intake and growth by Holstein heifers. *J. Anim. Sci.* **1991**, *69*, 4634−4643.
(22) Banskalieva, V.; Sahlu, K.; Goetsch, A. L. Fatty acid composition of goat muscles and fat depots: a review. *Small Rumin. Res.* **2000**, *37*, 255−268.
(23) Wood, J. D.; Richardson, R. I.; Nute, G. R.; Fisher, A. V.; Campo, M. M.; Kasapidou, E.; Sheard, P. R.; Enser, M. Effect of fatty acids on meat quality: a review. *Meat Sci.* **2003**, *66*, 21−32.
(24) Priolo, A.; Bella, M.; Lanza, M.; Galofaro, V.; Biondi, L.; Barbagallo, D.; Ben Salem, H.; Pennisi, P. Carcass and meat qualtiy of lambs fed fresh sulla (*Hedysarum coronarium* L.) with or without polyethylene glycol or concentrate. *Small Rumin. Res.* **2005**, *59*, 281−288.
(25) Barry, T. N.; Allsop, T. F.; Redekopp, C. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep − 5. Effects on the endocrine system and on adipose tissue metabolism. *Br. J. Nutr.* **1986**, *56*, 607−614.
(26) Anderson, H. J.; Oksbjerg, N.; Young, J. F.; Therkildsen, M. Feeding and meat quality − a future approach. *J. Meat Sc.* **2005**, *70*, 543−554.
(27) Granti, S.; Angel, S.; Akiri, B.; Holzer, Z.; Aharoni, Y.; Orlov, A.; Kanner, J. Effects of vitamin E supplementation on lipid peroxidation and color retention of salted calf muscle from a diet rich in polyunsaturated fatty acids. *J. Agric. Food Chem.* **2001**, *49*, 5951−5956.
(28) Priolo, A.; Waghorn, G. C.; Lanza, M.; Biondi, L.; Pennisi, P. Polyethylene glycol as a means for reducing the impact of condensed tannins in carob pulp: effects on lamb growth performance and meat quality. *J. Anim. Sci.* **2000**, *78*, 810−816.
(29) Faustman, C.; Cassens, R. G. The biochemical basis for discoloration in fresh meat: a review. *J. Muscle Foods* **1990**, *1*, 217−243.
(30) Gray, J. I. Measurement of lipid oxidation: a review. *J. Am. Oil Chem. Soc.* **1978**, *55*, 539−546.
(31) Melton, S. L.; Amiri, M.; Davis, G. W.; Backus, W. R. Flavor and chemical characteristics of ground beef from grass-, forage-grain- and grain-finished steers. *J. Anim. Sci.* **1982**, *55*, 77−87.
(32) Kropf, D. H. Effects of retail display conditions on meat color. *Proc. Recip. Meat Conf.* **1980**, *33*, 15−32.
(33) Webb, E. C.; Casey, N. H.; Simela, L. Goat meat quality. *Small Rumin. Res.* **2005**, *60*, 153−166.
(34) Caporaso, F.; Sink, J. D.; Dimick, P. S.; Mussinan, C. J.; Sanderson, A. Volatile flavor constituents of ovine adipose tissue. *J. Agric. Food Chem.* **1977**, *25*, 1230−1233.
(35) Pokorny, J. Flavor chemistry of deep fat frying in oil. In *Flavor Chemistry of Lipid Foods*; Min, D. B., Smouse, T. H., Eds.; American Oil Chemists' Society: Champaign, IL, 1989; pp 113−155.
(36) deMan, J. H. Lipids. In *Principle of Food Chemistry*, 3rd ed.; deMan, J. H., Ed.; Aspen Publishers: Gaithersburg, MD, 1999; pp33−110.
(37) Durnford, E.; Shahidi, F. Flavor of fish meat. In *Flavor of Meat, Meat Products and Seafood*, 2nd ed.; Shahidi, F., Ed.; Chapman & Hall: London, U.K., 1998; pp 131−158.