

Meat Quality Characteristics of Goats Fed Sericea Lespedeza- or Alfalfa-Based Diets Supplemented with Dried Distillers Grains with Soluble

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Abstract

Dried distillers grains with solubles (DDGS), a coproduct of the bioethanol industry, are a nutrient-rich feed ingredient that can serve as an economical alternative to conventional protein and energy sources in ruminant diets. However, information regarding their effects on meat quality in goats remains limited, particularly when combined with tannin-containing forages. This study evaluated the effects of dietary DDGS supplementation in alfalfa- and sericea lespedeza-based diets on the physicochemical characteristics and fatty acid composition of chevon. Thirty-six intact male Spanish goats (24 ± 1.8 kg body weight) were randomly assigned to one of four isonitrogenous and isocaloric diets: alfalfa hay (AL), alfalfa hay with DDGS (ALDS), sericea lespedeza hay (SL), or sericea lespedeza hay with DDGS (SLDS). Following a 60-day feeding period, longissimus dorsi muscle samples were analyzed for meat quality and fatty acid composition. Dietary treatment did not affect dry matter intake, average daily gain, instrumental color, muscle pH, moisture, crude protein, intramuscular fat, lipid oxidation, tenderness, or cooking loss ($P > 0.05$). Ash content was greater in goats fed the SL diet than in those fed the AL diet ($P < 0.05$). Although the major fatty acids were not altered, DDGS supplementation increased α -linolenic acid (C18:3n3) and eicosenoic acid (C20:1n9) ($P < 0.01$). These findings indicate that DDGS can be incorporated into alfalfa- and sericea lespedeza-based diets without compromising growth performance or meat quality while modestly improving the unsaturated fatty acid profile of chevon, supporting its use as a sustainable alternative feed ingredient for meat goat production.

Keywords

Dried Distillers Grains with Solubles, Meat Goats, Chevon Quality, Fatty Acid Composition, Alternative Feed Ingredients

1. Introduction

Meat goat production has expanded considerably in the United States over the past two decades owing to increasing consumer demand for chevon, the growth of ethnic markets, and diversification of livestock enterprises [1] [2]. Goats are well adapted to small-scale and forage-based production systems because of their ability to efficiently utilize diverse feed resources while producing high-value animal products. However, feed costs remain the largest production expense, making the identification of economical alternative feed ingredients essential for improving production efficiency and profitability [3]. The use of agricultural coproducts as livestock feed also contributes to sustainable production systems by reducing feed costs and increasing resource utilization.

The rapid expansion of the U.S. bioethanol industry has substantially increased the availability of dried distillers grains with solubles (DDGS), a coproduct generated during ethanol production [4] [5]. During fermentation, starch is removed from corn, concentrating crude protein, digestible fiber, lipid, minerals, and other nutrients in the remaining coproduct. Consequently, DDGS have become an economical source of both protein and energy for ruminants and can partially replace conventional concentrate ingredients such as corn and soybean meal. Previous studies have demonstrated that DDGS can be successfully incorporated into diets for dairy cattle, beef cattle, sheep, and goats without adversely affecting nutrient utilization or animal performance [6]-[8]. In meat goats, DDGS supplementation has maintained average daily gain, feed efficiency, and carcass performance while replacing conventional concentrate ingredients [9]-[11]. However, relatively little information is available regarding its effects on meat quality, despite evidence that dietary lipid sources can influence oxidative stability, intramuscular fat deposition, and fatty acid composition [12].

Meat quality has become an increasingly important consideration because consumers seek products with desirable sensory characteristics and improved nutritional value. Attributes such as color, tenderness, water-holding capacity, lipid oxidation, and fatty acid composition determine consumer acceptance and shelf life. Therefore, dietary strategies that improve these characteristics while maintaining animal performance are of considerable interest to both producers and the meat industry.

Forage sources are another important factor influencing nutrient utilization and meat quality in small ruminants [13]. Alfalfa (*Medicago sativa*) is widely used because of its high protein concentration and digestibility, whereas sericea lespedeza (*Lespedeza cuneata*) has gained attention in the southeastern United States because of its drought tolerance, persistence, and relatively low agronomic input requirements [14]-[16]. In addition to its agronomic advantages, sericea lespedeza contains condensed tannins that may improve nitrogen utilization by reducing ruminal protein degradation and increasing rumen bypass protein. Condensed tannins also possess antiparasitic activity that can improve goat health under grazing conditions [15] [17]. However, high tannin concentrations may reduce feed

intake and nutrient digestibility [18]. Moreover, condensed tannins can alter ruminal microbial activity and inhibit biohydrogenation of unsaturated fatty acids, potentially increasing the deposition of beneficial polyunsaturated fatty acids in muscle tissue [19] [20].

Diet composition is recognized as a major determinant of carcass characteristics and meat quality [21]. Supplementation of alfalfa- or sericea lespedeza-based diets with DDGS may modify ruminal fermentation through increased fermentable nutrients, while tannins in sericea lespedeza may further influence lipid metabolism by altering ruminal biohydrogenation pathways [8] [22] [23]. These complementary mechanisms suggest that the combination of DDGS and forage source could influence both the physicochemical properties and nutritional quality of chevon.

Although DDGS supplementation and sericea lespedeza have each been evaluated independently, information regarding their combined effects on goat meat quality remains limited. Therefore, the objective of this study was to determine the effects of replacing conventional corn and soybean meals with DDGS in alfalfa- or sericea lespedeza-based diets on the physicochemical characteristics, proximate composition, and fatty acid profile of goat meat.

2. Materials and Methods

2.1. Animals, Feeding Trial, and Sample Collection

All animal handling and experimental procedures were conducted in accordance with protocols approved by the Institutional Animal Care and Use Committee (IACUC) of Fort Valley State University (Fort Valley, GA, USA). The study was designed to evaluate the effects of dietary dried distillers grains with solubles (DDGS) incorporated into two forage-based feeding systems on subsequent meat quality characteristics of Spanish meat goats. Thirty-six intact male Spanish goats approximately 5 months of age with an initial body weight of 24 ± 1.8 kg were used. All experimental animals were dewormed and given appropriate vaccination prior to the start of a feeding trial. A 30-d adjustment period was used to adapt goats to the new feeding facilities and allowed goats to recover from stresses associated with weaning. Prior to initiation of the experiment, animals were individually weighed and individually housed in $1.2 \text{ m} \times 1.2 \text{ m}$ elevated pens with ad libitum access to water. Goats were then randomly assigned to one of four dietary treatments using a completely randomized design, with each animal serving as an experimental unit.

Animals were fed one of four isonitrogenous ($17.1 \pm 0.1\%$ crude protein) and isocaloric (3.2 ± 0.09 Mcal/kg dry matter) experimental diets for a period of 60 d. The dietary treatments consisted of: 1) an alfalfa hay-based diet (AL); 2) an alfalfa hay-based diet supplemented with DDGS (ALDS), in which DDGS replaced conventional corn and soybean meal; 3) a sericea lespedeza hay-based diet (SL); and 4) a sericea lespedeza hay-based diet supplemented with DDGS (SLDS), with DDGS similarly replacing corn and soybean meal (Table 1).

Table 1. Ingredient and nutrient composition of alfalfa- and sericea lespedeza-based diets with or without corn dried distillers gain with solubles (DDGS) fed to meat goats.

Item	Diet ^a			
	AL	ALDS	SL	SLDS
<u>Ingredients of diets, % as-fed basis</u>				
Sericea lespedeza hay	-	-	47.3	54.8
Alfalfa hay	40.5	51.7	-	-
Corn meal	26.0	-	20.0	-
Soybean meal	13.0	-	13.0	-
Soybean hulls	8.0	14.0	8.0	12.5
DDGS	-	18.0	-	20.5
Molasses	5.0	8.5	4.0	5.0
TM salt, red salt	2.0	2.5	2.0	2.0
Vitamin premix	2.0	2.3	2.0	2.0
Poultry fat	3.0	2.3	3.0	2.5
Monocalcium phosphate	0.5	0.7	0.7	0.7
<u>Nutrient composition, %DM</u>				
Dry matter, DM	89.7	89.1	90.4	89.1
Crude protein, CP	17.2	17.1	17.1	16.9
Ether extract	5.7	5.9	5.2	5.3
Ash	6.1	7.0	5.2	5.0
Acid detergent fiber, ADF	25.6	36.1	27.3	37.4
Netural detergent fiber, NDF	30.3	40.4	30.9	40.6
Condensed tannins, CT g/kg	-	-	9.3	10.1
Digestible energy Mcal/kg	3.2	3.2	3.2	3.2
<u>Fatty acid, %</u>				
C12:0	0.08	0.26	0.07	0.22
C14:0	0.49	0.77	0.48	0.49
C14:1n5	0.11	0.14	0.11	0.11
C16:0	21.3	15.6	21.1	13.5
C16:1n7	5.09	1.11	4.93	1.09
C18:0	4.86	2.42	4.94	2.48
C18:1n9	33.7	24.2	33.8	25.0
C18:2n6	25.1	48.0	25.1	49.4
C18:3n3	3.69	0.99	3.73	1.88

^aAL = alfalfa hay-based diet; ALDS = AL supplemented with DDGS by replacing corn and soybean meals with DDGS; SL = sericea lespedeza hay-based diet; SLDS = SL supplemented with DDGS by replacing corn and soybean meal with DDGS.

Throughout the feeding period, forage and concentrating portions of each diet were offered *ad libitum* once daily at 0700 h. Fresh drinking water was continuously available. Feed refusals were collected and weighed every 24 h to estimate voluntary dry matter intake and verify feed consumption among treatments. Formulation of the experimental diets ensured that observed responses could be attributed primarily to forage source and DDGS inclusion rather than differences in dietary protein or energy concentrations.

At the completion of the 60-d feeding trial, goats were transported to the USDA-inspected abattoir located at Fort Valley State University (Fort Valley, GA, USA) and harvested using standard humane slaughter procedures consistent with USDA regulations. Following slaughter, carcasses were chilled at 2°C for 24 h to allow completion of postmortem glycolysis and stabilization of muscle biochemical characteristics prior to sample collection. Ultimate muscle pH was determined 24 h postmortem between the 12th and 13th ribs using a calibrated portable pH meter (Pakton® Model OKPH1000 N; Fisher Scientific, Pittsburgh, PA, USA) equipped with a penetrating electrode.

Carcasses were subsequently split longitudinally along the vertebral column into left and right sides and fabricated into 2.5-cm-thick loin chops using a commercial band saw. Four loin chops from the right side of each carcass containing the longissimus dorsi muscle were collected, finely ground under liquid nitrogen to minimize lipid oxidation and enzymatic activity, packaged in polyethylene bags (NASCO Inc., Fort Atkinson, WI, USA), and stored at −28°C until proximate composition and fatty acid analyses were performed. An additional four chops from the right side were designated for determination of myoglobin concentration, metmyoglobin formation, and lipid oxidation. Four corresponding loin chops obtained from the left side of each carcass were reserved for instrumental color evaluation, Warner-Bratzler shear force determination, and cooking loss measurements to ensure consistent sample allocation among analytical procedures.

2.2. Analyzing Physical Properties

Surface color of loin chops was evaluated using the Commission Internationale de l'Éclairage (CIE) color system. Prior to measurement, chops were allowed to bloom for 30 min at 4°C to permit oxygenation of myoglobin and development of a stable meat surface color. Color measurements were obtained using a Minolta Chromameter (Model CR-200, Minolta, Osaka, Japan) calibrated with illuminant D65. Three independent readings were collected from different locations on each chop to account for normal surface variation, and average values were calculated for lightness (L^*), redness (a^*), and yellowness (b^*) before statistical analysis.

Following instrumental color evaluation, loin chops were cooked according to the standardized procedures described by Lee *et al.* [17]. Samples were heated until reaching an internal endpoint temperature of 71°C, as monitored using a calibrated thermocouple thermometer. This endpoint temperature is widely used for

objective assessment of meat quality characteristics. Cooking loss was calculated as the percentage reduction in sample weight following cooking relative to the initial uncooked weight. After cooling, two cylindrical cores were removed from each chop parallel to the orientation of the muscle fibers. Warner-Bratzler shear force (WBSF) was measured using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY, USA) equipped with a Warner-Bratzler shear attachment. The average shear force obtained from the two cores represented the tenderness value for each chop.

2.3. Analyzing Chemical Properties

Myoglobin concentration and percentage metmyoglobin (MetMb) formation were determined using 5.0 g ground longissimus dorsi muscle samples according to the procedure described by Krywicki [24]. Absorbance values were measured at 525, 572, and 700 nm using a Shimadzu UV-2401 PC spectrophotometer (Shimadzu Corp., Columbia, MD, USA). Myoglobin concentration (mg/g muscle) and MetMb percentage were subsequently calculated using the equations developed by Krywicki [24].

Lipid oxidation was evaluated using the thiobarbituric acid reactive substances (TBARS) assay following the procedure of Buege and Aust [25]. Briefly, 0.5 g of ground muscle tissue was analyzed, and a standard calibration curve was prepared using 1,1,3,3-tetramethoxypropane. Results were expressed as milligrams of malondialdehyde (MDA) per kilogram of muscle tissue.

Moisture, crude protein, ash, and intramuscular fat contents of longissimus dorsi muscle samples were determined according to the official methods of AOAC [26].

Total lipids were extracted from 3.0 g of muscle tissue using a chloroform:methanol (2:1, v/v) extraction system. Samples were homogenized at 30,000 rpm for three 30-s intervals following the procedure of Lee *et al.* [27]. Lipid extracts were subsequently saponified and converted to fatty acid methyl esters (FAME) according to the American Oil Chemists' Society official procedures [28]. Fatty acid methyl esters were analyzed using a TRACE GC Ultra gas chromatograph (Thermo Electron Corp., Austin, TX, USA) equipped with an AS-3000 autosampler and flame ionization detector. Separation was achieved using a 60-m SP-2380 fused silica capillary column (0.25 mm internal diameter; Supelco, Bellefonte, PA, USA). The injector temperature was maintained at 240 °C, while the oven temperature was programmed from 130 to 220 °C at a rate of 4 °C/min. Helium served as the carrier gas at a flow rate of 1.6 mL/min using a split ratio of 30:1. Individual fatty acids were identified by comparison of retention times with authenticated standards and quantified according to AOCS recommendations [28].

2.4. Statistical Analysis

All experimental data were analyzed using the General Linear Model (GLM) procedure of SAS (Version 9.4; SAS Institute Inc., Cary, NC, USA). The experiment

was analyzed as a completely randomized design, with individual goats serving as the experimental unit. Least-squares means were calculated for each response variable, and treatment means were separated using the PDIFF option when the overall F-test indicated significant treatment effects. Statistical significance was declared at $P < 0.05$, whereas values of $0.05 \leq P < 0.10$ were considered to indicate a statistical tendency.

3. Results

3.1. Growth Performance and Carcass Yield

Dry matter intake (DMI) was not affected by dietary treatment ($P > 0.42$), averaging 1.08, 1.12, 1.29, and 1.12 ± 0.10 kg/d (SE = 0.10) for goats fed AL, ALDS, SL, and SLDS diets, respectively. Similarly, inclusion of dried distillers grains with solubles (DDGS) in either alfalfa- or sericea lespedeza-based diets did not influence average daily gain (ADG; $P > 0.25$). Mean ADG values were 107.5, 97.1, 126.8, and 110.4 ± 15.76 g/d for goats fed AL, ALDS, SL, and SLDS diets, respectively. Final body weight ranged from 29.9 to 32.5 ± 1.95 kg and carcass yield ranged from 45.9 to $48.6 \pm 1.12\%$, with no significant differences among dietary treatments ($P > 0.13$).

3.2. Meat Quality Characteristics

Ultimate pH of the longissimus dorsi (LD) muscle ranged from 6.24 to 6.36 ± 0.104 and was not affected by dietary treatment ($P > 0.85$; **Table 2**). Similarly, instrumental color measurements (CIE L*, a*, and b*) did not differ among treatments ($P > 0.05$). Cooking loss and Warner-Bratzler shear force (WBSF) values were also unaffected by dietary treatment ($P > 0.05$), indicating similar water-holding capacity and tenderness across all dietary groups.

Myoglobin concentration and percentage metmyoglobin formation were not influenced by dietary treatment ($P > 0.23$ and $P > 0.16$, respectively). Myoglobin concentrations ranged from 4.41 to 4.57 ± 0.230 mg/g LD muscle. Likewise, thiobarbituric acid reactive substances (TBARS) values did not differ among treatments ($P > 0.08$), indicating similar levels of lipid oxidation regardless of forage source or DDGS inclusion.

Proximate composition of the LD muscle, including moisture, crude protein, and intramuscular fat content, was not affected by dietary treatment (**Table 2**). However, ash content was greater ($P < 0.05$) in goats fed the sericea lespedeza (SL) diet than in those fed the alfalfa (AL) diet, whereas goats receiving DDGS-containing diets exhibited intermediate values.

3.3. Fatty Acid Composition

A total of 25 fatty acids were identified in the intramuscular fat of the longissimus dorsi (LD) muscle from goats receiving the four experimental diets (**Table 3**). These included eleven saturated fatty acids (SFA; C10:0-C22:0), six monounsaturated fatty acids (MUFA; C14:1n5-C20:1n9), and eight polyunsaturated fatty acids

Table 2. Quality characteristics of loin chops from meat goats (n = 9) fed alfalfa- and sericea lespedeza-based diets with or without corn dried distillers gain with solubles (DDGS).

	Diet ^a				
Parameter	AL	ALDS	SL	SLDS	SE
<u>Fresh</u>					
L* value	38.36	37.71	38.07	38.58	0.862
a* value	9.90	10.13	10.12	9.69	0.483
b* value	9.29	8.86	9.28	9.78	0.412
Myoglobin, mg/g	4.44	4.57	4.41	4.41	0.230
Metmyoglobin, %	13.37	15.65	13.55	12.45	1.168
TBARS ^b , mg MDA/kg	0.24	0.18	0.34	0.16	0.083
Ultimate pH	6.36	6.24	6.34	6.31	0.104
<u>Cooked</u>					
Cooking loss, %	17.75	23.80	19.86	23.25	2.537
WBSF ^c , kg/cm ³	3.08	2.66	2.87	2.80	0.207

^aAL = alfalfa hay-based diet; ALDS = AL supplemented with DDGS by replacing corn and soybean meals with DDGS; SL = sericea lespedeza hay-based diet; SLDS = SL supplemented with DDGS by replacing corn and soybean meal with DDGS

^bTBARS = thiobarbituric acid reactive substances calculated as milligrams malondialdehyde per kg of flesh

^cWBSF = Warner-Bratzler shear force values

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

Table 3. Proximate and fatty acid composition, weight percent of fatty acid methyl esters, of longissimus dorsi (LD) muscle, intramuscular fat, from meat goats fed alfalfa- and sericea lespedeza-based diets with or without corn dried distillers gain with solubles (DDGS).

Parameter	Diet ^a				SE
	AL	ALDS	SL	SLDS	
Moisture	76.74	76.71	76.64	76.06	0.563
Protein	20.74	20.08	20.41	20.37	0.256
Fat	2.19	2.19	2.55	2.32	0.296
Ash	1.28 ^h	1.55 ^{gh}	2.28 ^g	1.92 ^{gh}	0.204
<u>Fatty acid, %</u>					
C10:0	0.11	0.12	0.12	0.14	0.014
C12:0	0.09	0.10	0.09	0.12	0.013
C13:0	0.03	0.04	0.05	0.05	0.007
C14:0	1.46	1.49	1.60	1.70	0.139
C14:1n5	0.26	0.25	0.23	0.29	0.019
C15:0	0.38	0.35	0.32	0.37	0.020

Continued

C16:0, <i>iso</i>	0.09	0.10	0.09	0.11	0.013
C16:0	19.14	19.53	19.68	19.60	0.418
C16:1, <i>trans</i>	1.01	0.89	0.81	0.94	0.052
C16:1n7	1.29	0.90	1.33	1.29	0.144
C17:0	1.51	1.38	1.26	1.21	0.177
C18:0	17.76	18.17	18.91	19.00	0.830
C18:1, <i>trans</i>	0.15	0.15	0.13	0.13	0.009
C18:1n9	39.45	36.94	36.31	36.16	2.219
C18:2n6	6.47	7.16	5.76	7.66	0.533
C18:2, <i>CLA</i>	0.13	0.10	0.10	0.11	0.014
C18:3n3	0.46 ^h	0.67 ^g	0.46 ^h	0.68 ^g	0.049
C18:3n6	0.63 ^h	0.66 ^h	0.85 ^{gh}	0.91 ^g	0.060
C20:0	0.11	0.10	0.10	0.09	0.007
C20:1n9	0.09 ^h	0.12 ^g	0.08 ^h	0.13 ^g	0.012
C20:3n6	0.20	0.20	0.20	0.20	0.022
C20:4n6	0.92	1.02	0.99	0.94	0.128
C20:5n3	0.41	0.42	0.35	0.40	0.038
C22:0	0.35	0.40	0.32	0.35	0.041
C22:5n3	0.52	0.55	0.54	0.55	0.077
ΣSFA ^b	41.03	41.78	42.54	42.74	0.953
ΣMUFA ^c	42.25	39.25	38.89	38.94	1.958
ΣPUFA ^d	9.74	10.78	9.25	11.45	1.115
Σn-3 ^e	1.39	1.64	1.35	1.63	0.135
Σn-6 ^f	8.35	9.14	7.90	9.82	0.797

^aAL = alfalfa hay-based diet; ALDS = AL supplemented with DDGS by replacing corn and soybean meals with DDGS; SL = sericea lespedeza hay-based diet; SLDS = SL supplemented with DDGS by replacing corn and soybean meal with DDGS

^bSFA = saturated fatty acids, C10:0 to C22:0

^cMUFA = monounsaturated fatty acids, C14:1n5 to C20:1n9

^dPUFA = polyunsaturated fatty acids, C18:2n6 to C22:5n3

^en-3 = n-3 PUFA, C18:3n3, C20:5n3, and C22:5n3.

^fn-6 = n-6 PUFA, C18:2n6, C18:2, CLA, C18:3n6, C20:3n6, and C20:4n6

^{g,h}Within a row, least squares means that do not have a common letter differ ($P < 0.05$).

(PUFA; C18:2n6-C22:5n3). Palmitic (C16:0), stearic (C18:0), oleic (C18:1n9), and linoleic (C18:2n6) acids were the predominant fatty acids, collectively accounting for approximately 81% - 83% of the total fatty acids.

Most saturated and monounsaturated fatty acids were not affected by dietary treatment ($P > 0.05$). However, dietary inclusion of dried distillers grains with solubles (DDGS) increased ($P < 0.01$) the proportions of α-linolenic acid (C18:3n3) and

eicosenoic acid (C20:1n9). Goats fed the sericea lespedeza diet supplemented with DDGS (SLDS) also exhibited greater ($P < 0.01$) concentrations of γ -linolenic acid (C18:3n6) than goats receiving the other dietary treatments. The PUFA:SFA ratio ranged from 0.22 to 0.27 among treatments, while the n-6:n-3 fatty acid ratio ranged from 5.57 to 6.02. Neither ratio differed significantly among dietary treatments (**Table 3**).

4. Discussion

4.1. Growth Performance and Carcass Yield

The absence of treatment effects on dry matter intake (DMI), average daily gain (ADG), final body weight, and carcass yield indicates that replacing conventional corn and soybean meal with DDGS did not adversely affect growth performance or carcass characteristics of Spanish meat goats. These findings are consistent with previous studies demonstrating that DDGS can partially replace conventional concentrate ingredients without compromising feed intake, growth rate, or carcass yield in small ruminants [9]–[11]. Because all experimental diets were formulated to be isonitrogenous ($17.1 \pm 0.1\%$ crude protein) and isocaloric (3.2 ± 0.09 Mcal/kg DM), comparable animal performance was anticipated, suggesting that nutrient supply remained adequate regardless of forage source or DDGS inclusion.

Sericea lespedeza has been reported to contain condensed tannins that may reduce voluntary feed intake and animal performance when present at excessive concentrations because of their effects on nutrient digestibility and palatability. However, goats receiving sericea lespedeza-based diets in the present study did not exhibit reductions in feed intake or growth performance, indicating that the concentration and biological activity of condensed tannins under these dietary conditions were insufficient to produce measurable anti-nutritional effects. These observations agree with recent reviews demonstrating that the effects of condensed tannins on intake and growth are highly dependent on tannin concentration, chemical structure, diet composition, and animal adaptation, with beneficial, neutral, or negative responses reported under different feeding conditions [14] [29].

Recent investigations have also suggested that DDGS supplementation can modify ruminal microbial populations and fermentation characteristics without necessarily producing measurable changes in feed intake or growth performance [29]. Likewise, condensed tannins may increase the proportion of rumen undegradable protein by reducing ruminal protein degradation [30]. Although these mechanisms could theoretically enhance amino acid availability to the small intestine, no improvements in animal performance were observed in the present study. This likely reflects the fact that dietary protein and energy concentrations were already balanced across treatments, minimizing the potential for additional nutritional benefits from DDGS supplementation or tannin-mediated increases in bypass protein.

Collectively, these results demonstrate that DDGS can successfully replace conventional corn and soybean meal in either alfalfa- or sericea lespedeza-based diets without negatively affecting growth performance or carcass yield. From a practical perspective, these findings support the use of DDGS as a nutritionally adequate and economically attractive alternative feed ingredient for forage-based meat goat production systems, particularly where reducing feed costs and improving sustainability are important production objectives.

4.2. Meat Quality Characteristics

Ultimate muscle pH is one of the most important indicators of postmortem muscle metabolism because it influences meat color, water-holding capacity, tenderness, microbial stability, and shelf life. In the present study, dietary supplementation with DDGS or substitution of alfalfa with sericea lespedeza did not alter ultimate pH of the longissimus dorsi muscle. The observed pH values (6.24 - 6.36) are consistent with recent reports describing goat meat as frequently exhibiting an intermediate ultimate pH, which is influenced by preslaughter stress, muscle glycogen reserves, and postmortem glycolysis [31]. In contrast to previous reports in lambs where condensed tannin-containing diets resulted in elevated ultimate pH, possibly because of altered energy metabolism or nutritional stress [32] [33], no evidence of impaired postmortem glycolysis was observed in goats receiving sericea lespedeza-based diets. These findings suggest that incorporation of sericea lespedeza and DDGS did not adversely affect muscle energy metabolism prior to slaughter.

Instrumental color is among the most important quality attributes affecting consumer purchasing decisions because it serves as an immediate indicator of freshness and wholesomeness. Meat color is influenced by multiple factors, including myoglobin concentration, pigment oxidation, lipid oxidation, and microbial activity [34] [35]. Neither DDGS supplementation nor forage source affected CIE L*, a*, or b* values, indicating that dietary treatments did not alter the visual appearance of fresh chevon. Similar observations have been reported in goats fed DDGS, where modifications in fatty acid composition occurred without significant changes in instrumental color or discoloration during retail display [36]. Likewise, although tannin-containing diets have occasionally produced lighter-colored meat in lambs, possibly because of reduced muscle pigment concentrations [33], no comparable response was detected in the present study. The absence of treatment differences in CIE b* values is also consistent with the similar intramuscular fat concentrations observed among dietary treatments, since yellowness may be influenced by lipid deposition and associated pigments. Collectively, these results indicate that replacing conventional concentrate ingredients with DDGS and incorporating sericea lespedeza into forage-based diets did not compromise the visual quality of goat meat.

Water-holding capacity and tenderness are critical determinants of eating quality and consumer satisfaction. Neither cooking loss nor Warner-Bratzler shear

force differed among dietary treatments, indicating that neither forage source nor DDGS supplementation altered muscle structural characteristics associated with moisture retention or tenderness. These findings agree with previous reports in lambs fed condensed tannin-containing diets, where tenderness was similarly unaffected by dietary treatment [33]. Warner-Bratzler shear force values observed in the present study (2.66 - 3.08 kg) fall within the range generally considered acceptable for tender lamb and goat meat [37]. Recent reviews further suggest that tenderness is influenced more strongly by animal age, muscle type, postmortem ageing, and carcass handling than by moderate dietary modifications, particularly when carcass composition remains unchanged [31]. The similar carcass characteristics observed in the present study likely contributed to the absence of dietary effects on tenderness.

Myoglobin concentration and metmyoglobin formation are major determinants of meat color stability during storage and retail display. Myoglobin concentration in the present study was comparable with previously reported values for goat meat [38] and was not influenced by dietary treatment. Likewise, metmyoglobin formation remained unchanged across treatments, indicating that dietary inclusion of DDGS or sericea lespedeza did not alter pigment oxidation. Because the conversion of oxymyoglobin to metmyoglobin contributes directly to surface discoloration [39] [40], the absence of differences in these measurements is consistent with the similar instrumental color values observed among treatments.

Lipid oxidation is a major factor affecting flavor deterioration, color stability, and shelf life of meat products. Thiobarbituric acid reactive substances (TBARS) are widely used to estimate the extent of oxidative degradation through quantification of malondialdehyde generated during lipid peroxidation [41] [42]. Despite modest increases in selected unsaturated fatty acids associated with DDGS supplementation, lipid oxidation remained unchanged among dietary treatments. Although condensed tannins have frequently been proposed to possess antioxidant properties, their effectiveness depends on tannin concentration, chemical structure, and deposition of phenolic metabolites within muscle tissue. Consequently, measurable reductions in TBARS are not consistently observed. Dahmer *et al.* [36] similarly reported that goats fed DDGS exhibited increased polyunsaturated fatty acid concentrations without corresponding increases in lipid oxidation or deterioration of meat quality during storage. These findings suggest that the modest enhancement of unsaturated fatty acids associated with DDGS supplementation does not necessarily increase oxidative susceptibility under the conditions evaluated in the present study.

Muscle proximate composition is influenced by numerous factors including genetics, age, sex, nutritional management, and muscle development [43]. In the present study, moisture, crude protein, and intramuscular fat contents were similar among treatments, reflecting the comparable growth performance observed across dietary groups and the formulation of isonitrogenous and isocaloric diets. However, goats receiving the sericea lespedeza diet exhibited greater ash content

than those fed the alfalfa diet. This response may reflect alterations in mineral metabolism associated with condensed tannins, which are known to interact with dietary minerals and proteins, thereby influencing ruminal nutrient transformations, mineral availability, and tissue deposition. Recent reviews likewise indicate that condensed tannins can modify nutrient partitioning and mineral utilization, although responses vary depending on tannin concentration and chemical characteristics [29]. Additional research is warranted to determine whether the increased ash concentration observed in goats fed sericea lespedeza reflects differences in mineral intake, ruminal availability, intestinal absorption, or tissue mineral deposition.

Overall, the present findings demonstrate that replacing conventional concentrate ingredients with DDGS in either alfalfa- or sericea lespedeza-based diets maintained the physicochemical quality characteristics of chevon. The absence of adverse effects on pH, color, tenderness, lipid oxidation, and proximate composition indicates that DDGS can be incorporated into forage-based meat goat production systems without compromising fresh meat quality while providing flexibility in feed formulation. This supports the use of DDGS as a sustainable alternative feed ingredient capable of reducing dependence on conventional concentrate sources without negatively affecting consumer-relevant quality attributes.

4.3. Fatty Acid Composition

Fatty acid composition is an important determinant of both the nutritional value and oxidative stability of meat. In ruminants, dietary fatty acids undergo extensive microbial biohydrogenation within the rumen, resulting in relatively high proportions of saturated fatty acids in muscle tissue. Consequently, dietary strategies capable of increasing the deposition of unsaturated fatty acids without negatively affecting meat quality are of considerable interest for improving the nutritional profile of red meat.

In the present study, palmitic (C16:0), stearic (C18:0), oleic (C18:1n9), and linoleic (C18:2n6) acids were the predominant fatty acids in intramuscular fat, together accounting for more than 80% of the total fatty acid content. This distribution agrees with previously reported fatty acid profiles for goat meat and reflects the characteristic lipid metabolism of ruminants. The lack of significant dietary effects on most saturated and monounsaturated fatty acids further suggests that replacement of conventional concentrate ingredients with DDGS did not substantially alter overall lipid metabolism or the major pathways of fatty acid deposition.

In contrast, dietary supplementation with DDGS increased the concentrations of α -linolenic acid (C18:3n3) and eicosenoic acid (C20:1n9), while goats fed the sericea lespedeza diet supplemented with DDGS exhibited greater concentrations of γ -linolenic acid (C18:3n6). These responses are generally consistent with the results of Dahmer *et al.* [36], who directly evaluated DDGS supplementation in Boer goats and reported that feeding 33% DDGS increased total polyunsaturated fatty acids, including linoleic (C18:2n6), eicosapentaenoic (C20:5n3), and docosa-

pentaenoic (C22:5n3) acids, without adversely affecting meat color or lipid oxidation. Together, these studies indicate that DDGS can modify the concentrations of selected unsaturated fatty acids in chevon while maintaining desirable physico-chemical characteristics; however, the magnitude and specific fatty acids affected appear to depend on diet composition and experimental conditions.

Several mechanisms may explain the observed alterations in fatty acid composition. DDGS contain residual corn oil that provides additional unsaturated fatty acids compared with conventional concentrate ingredients. Previous studies in meat goats indicate that DDGS supplementation can influence fatty acid deposition, although effects on ruminal fermentation have not been consistent. Dahmer *et al.* [36] reported increased concentrations of several polyunsaturated fatty acids in muscle from Boer goats fed DDGS, while Sorensen *et al.* [23] observed greater polyunsaturated fatty acid concentrations in adipose tissue as DDGS replaced soybean meal in Boer-cross goat diets. In contrast, Ale *et al.* [44] found that inclusion of up to 30% low-fat DDGS did not significantly affect ruminal acetate, propionate, butyrate, or acetate-to-propionate ratios in Kiko-cross goats. Collectively, these findings suggest that the changes in tissue fatty acid composition associated with DDGS may reflect increased dietary supply and subsequent deposition of unsaturated fatty acids rather than substantial alterations in overall ruminal fermentation. However, because ruminal fatty acid intermediates and biohydrogenation rates were not directly measured in these studies or in the present experiment, the contribution of altered ruminal biohydrogenation remains uncertain.

Condensed tannins present in sericea lespedeza may have further contributed to these responses. Previous studies have demonstrated that condensed tannins can suppress specific ruminal microorganisms involved in biohydrogenation, thereby reducing the conversion of unsaturated fatty acids into saturated fatty acids [45] [46]. As a result, greater quantities of dietary polyunsaturated fatty acids may escape ruminal metabolism and become available for absorption and deposition within muscle tissue. Recent meta-analyses likewise indicate that dietary tannins can modify the fatty acid composition of meat in small ruminants, particularly with respect to omega-3 and omega-6 fatty acids, although the magnitude of these responses depends on tannin source, chemical structure, and dietary inclusion level [29].

Although increases in α -linolenic and γ -linolenic acids were observed, the aggregate fatty acid indices, including the PUFA and n-6 ratios, did not differ significantly among dietary treatments. The overall PUFA:SFA ratios remained below the value of approximately 0.45 generally recommended for human diets [47]. Likewise, the n-6:n-3 ratios were slightly above the commonly cited nutritional target of 5:1 or lower. Nevertheless, goat meat is naturally characterized by relatively greater concentrations of polyunsaturated fatty acids than many other red meat species, including appreciable amounts of linoleic, α -linolenic, and arachidonic acids [47]. Therefore, even modest improvements in the concentration of health-promoting unsaturated fatty acids may enhance the nutritional quality of

chevon without adversely affecting technological or sensory properties.

The increases in α -linolenic acid observed in both DDGS-containing diets suggest that DDGS itself contributed substantially to the observed changes in fatty acid composition. However, the additional increase in γ -linolenic acid observed in goats receiving the sericea lespedeza-DDGS diet may indicate an interaction between forage type and DDGS supplementation, although the present data do not establish that inhibition of ruminal biohydrogenation was responsible for this response. Because α -linolenic acid also increased in goats fed the alfalfa-DDGS diet, the relative contribution of DDGS supplementation and tannin-mediated inhibition of biohydrogenation cannot be clearly distinguished from the present experiment. This interpretation is consistent with current understanding that in vivo responses to dietary tannins frequently differ from in vitro observations because of microbial adaptation, variation in tannin chemistry, and interactions among dietary components [48] [49].

Overall, the present findings demonstrate that dietary inclusion of DDGS can alter concentrations of selected unsaturated fatty acids in chevon without adversely affecting the overall fatty acid profile or physicochemical quality of the meat. Because aggregate fatty acid ratios were not affected by dietary treatment, these changes should not be interpreted as evidence of a generalized improvement in the nutritional quality of chevon. Rather, the results indicate that DDGS can modify specific components of the fatty acid profile while maintaining product quality. Further research directly measuring ruminal fatty acid intermediates, duodenal fatty acid flow, microbial populations involved in lipid metabolism, and tissue fatty acid deposition would provide greater insight into the mechanisms governing fatty acid deposition and the interactive effects of DDGS and condensed tannins on meat lipid composition.

5. Conclusion

The present study demonstrated that incorporation of dried distillers grains with solubles (DDGS) into alfalfa- and sericea lespedeza-based diets did not adversely affect growth performance, carcass yield, or the physicochemical quality of chevon. Despite concerns regarding the potential anti-nutritional effects of condensed tannins, goats fed sericea lespedeza-based diets supplemented with DDGS exhibited comparable dry matter intake, average daily gain, muscle pH, instrumental color, tenderness, lipid oxidation, and proximate composition to those fed conventional alfalfa-based diets. Dietary DDGS supplementation also increased the concentrations of selected unsaturated fatty acids, including α -linolenic acid (C18:3n3) and eicosenoic acid (C20:1n9), while the combination of DDGS and sericea lespedeza further increased γ -linolenic acid (C18:3n6). However, these changes were limited to specific fatty acids, and aggregate fatty acid ratios did not differ among treatments, indicating that the dietary interventions altered selected components of the fatty acid profile rather than producing a broad improvement in the nutritional quality of chevon. Collectively, these findings support the use of

DDGS as a sustainable and economically viable alternative to conventional corn and soybean meal in forage-based meat goat production systems. When combined with sericea lespedeza, a drought-tolerant and low-input forage, DDGS provides producers with greater flexibility in feed formulation while maintaining animal performance and producing high-quality chevon. Further research investigating the effects of these dietary strategies on ruminal microbial ecology, fatty acid biohydrogenation, and consumer acceptance would improve understanding of the mechanisms underlying the observed changes in meat composition and facilitate wider adoption of these alternative feed resources.

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Conflicts of Interest

The authors confirm that they have no conflict of interest to declare for this publication.

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