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ARTICLE

RESEARCH ARTICLE

Effects of maize, ryegrass and sorghum silages on performance, meat quality and some blood variables of lambs

Efectos de los ensilajes de maíz, raigrás italiano y sorgo sobre el rendimiento productivo, la calidad de la carne y algunas variables sanguíneas en corderos

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Abstract: *Aim of study:* This study evaluated the effects of *ad libitum* feeding of maize, sorghum and ryegrass silages on growth performance, blood gas and biochemical variables, and carcass characteristics of Ile de France male lambs. *Area of study:* The experiment was conducted in Sakarya province, Türkiye. *Material and methods:* Twenty-four lambs (2-3 months old; 26.53±0.21 kg) were individually housed and randomly assigned to four dietary groups. The control group received straw *ad libitum*, while the other groups were fed maize (*Zea mays L.*), sorghum (*Sorghum bicolor* (L.) Moench) or Italian ryegrass (*Lolium multiflorum* Lam.) silage *ad libitum* for 70 days, together with a standard concentrate-based basal ration. Average daily gain was calculated for each lamb as the slope of the linear regression of live weight on time over the entire experimental period. Blood gas and biochemical variables were measured on days 35 and 70 using an EDAN i15 VET analyser. Growth performance, carcass characteristics, and blood variables were analysed using appropriate statistical models, including repeated measures analysis for blood data. *Main results:* Dietary group did not affect growth performance, average daily gain, carcass characteristics, blood gas variables or biochemical profiles (P > 0.05). Several blood variables showed significant changes over time (P < 0.05), but these changes were consistent across all dietary groups and were not diet-dependent. Meat colour, texture properties and water activity of the *musculus longissimus dorsi* were similar among experimental groups. *Research highlights:* Feeding maize, sorghum and ryegrass silages *ad libitum* maintained normal metabolic status and resulted in comparable growth performance and carcass traits in lambs. Under the conditions of this study, all three silage types can be considered nutritionally safe forage alternatives for intensive lamb-fattening systems.

Keywords: biochemistry; blood gases; carcass traits; feed efficiency; forage intake; lamb nutrition.

Resumen: *Objetivo del estudio:* Este estudio evaluó los efectos de la alimentación *ad libitum* con ensilajes de maíz, sorgo y raigrás italiano sobre el rendimiento productivo, las variables de gases sanguíneos y bioquímicas, y las características de la canal en corderos machos Ile de France. *Área de estudio:* El experimento se llevó a cabo en la provincia de Sakarya, Türkiye. *Material y métodos:* Veinticuatro corderos (2–3 meses de edad; 26.53±0.21 kg) fueron alojados individualmente y asignados aleatoriamente a cuatro grupos dietéticos. El grupo control recibió paja *ad libitum*, mientras que los otros grupos fueron alimentados *ad libitum* con ensilaje de maíz (*Zea mays L.*), sorgo (*Sorghum bicolor* (L.) Moench) o raigrás italiano (*Lolium multiflorum* Lam.) durante 70 días, junto con una ración basal estándar a base de concentrado. La ganancia media diaria se calculó para cada cordero como la pendiente de la regresión lineal del peso vivo en función del tiempo durante todo el período experimental. Las variables de gases sanguíneos y bioquímicas se midieron en los días 35 y 70 utilizando un analizador EDAN i15 VET. El rendimiento productivo, las características de la canal y las variables sanguíneas se analizaron mediante modelos estadísticos apropiados, incluyendo análisis de medidas repetidas para los datos sanguíneos. *Resultados principales:* El grupo dietético no afectó el rendimiento productivo, la ganancia media diaria, las características de la canal, las variables de gases sanguíneos ni los perfiles bioquímicos (P > 0.05). Varias variables sanguíneas mostraron cambios significativos a lo largo del tiempo (P < 0.05), pero estos cambios fueron consistentes en todos los grupos dietéticos y no dependieron de la dieta. El color de la carne, las propiedades de textura y la actividad de agua del *Musculus longissimus dorsi* fueron similares entre los grupos experimentales. *Aspectos destacados de la investigación:* La alimentación *ad libitum* con ensilajes de maíz, sorgo y raigrás italiano mantuvo un estado metabólico normal y dio lugar a un rendimiento productivo y características de la canal comparables en corderos. En las condiciones de este estudio, los tres tipos de ensilaje pueden considerarse alternativas forrajeras nutricionalmente seguras para sistemas intensivos de engorde de corderos.

Palabras clave: bioquímica; características de la canal; consumo de forraje; eficiencia alimenticia; gases sanguíneos; nutrición de corderos.

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Supplementary information ↓

1. INTRODUCTION

Sheep production plays a strategic role in global livestock systems by converting low-quality forage resources into high-value animal protein (Aygün & Çelikyürek, 2020). Türkiye is one of the world's leading countries in sheep production, with small ruminant farming-predominantly based on indigenous breeds-playing a critical role in the national livestock sector and rural economy (Semerci & Çelik, 2016; Aydın et al., 2024). According to FAO (2023) data, Türkiye ranks among the top ten countries globally in sheep population. Lamb meat production constitutes the major economic component of the sheep sector, and improving per-animal productivity and feeding efficiency remains essential for meeting increasing demand (Demiral & İşcan, 2012). Despite improvements achieved through breeding programs, feed continues to represent nearly 70% of total production costs in sheep enterprises (Kara & Eroğlu, 2018). Consequently, the need for cost-effective and nutritionally reliable forage sources has intensified, positioning silage as a valuable option for sustainable lamb fattening systems.

Maize (*Zea mays L.*), sorghum (*Sorghum bicolor* (L.) Moench) and Italian ryegrass (*Lolium multiflorum* Lam.) silages differ widely in energy density, protein content, drought tolerance and fermentation characteristics, which may influence nutrient intake and growth performance in lambs (Çolak & Sancak, 2016; Pino & Heinrichs, 2017; Kemešytė et al., 2023). Although these silages have been widely studied in cattle, comparative studies in intensively fed lambs remain limited.

Evaluating the effects of different silage sources on lambs requires a multidimensional set of biological indicators. Growth performance traits provide direct measures of nutrient utilization and efficiency under intensive feeding systems (Wu et al., 2021). Serum biochemical markers are widely used to assess metabolic adaptation to dietary inputs and to detect shifts in hepatic, renal, and muscular function (Očenáš et al., 2025). Blood gas variables offer essential insight into acid-base balance and respiratorymetabolic interactions that may be influenced by forage composition and rumen fermentation profiles (Krištolaitytė et al., 2025). Carcass traits and meat quality parameters serve as critical economic and technological outcomes in lamb production, and these traits are highly responsive to dietary energy density and forage type (Wang et al., 2020). Together, these variables allow for a comprehensive and mechanistic assessment of how different silage types influence lamb performance, metabolic status and product quality.

Therefore, this study aimed to evaluate the effects of *ad libitum* feeding of maize, sorghum and ryegrass silages, compared with straw, on growth performance, blood variables, carcass characteristics and meat quality in Ile de France lambs.

2. MATERIAL AND METHODS

2.1. Experimental animals and study conditions

This study was approved by the Afyon Kocatepe University Local Ethics Committee for Animal Experiments (AKUHADYEK) under the decision number 49533702/159. The animals used in this study consisted of 24 male Ile de France lambs, aged 2-3 months, with an average live weight of 26.53±0.21 kg sourced from a private farm in Sakarya, Türkiye. The lambs were housed in individual pens within the private facility, and the study was conducted between February and May 2023. The research was designed to evaluate the effects of different roughage sources on lamb nutrition, metabolic responses, and carcass traits within the scope of animal nutrition and nutrition-related metabolic responses.

2.2. Preparation of silage materials

The maize, ryegrass, and sorghum silages used in this study were obtained from commercial cultivars grown on leased lands in the Sakarya province, Türkiye. Maize was harvested at the optimal stage for silage production, corresponding to the two-thirds milk-dough phase, while ryegrass and sorghum were wilted for 24 hours following mowing. All three forage crops were ensiled using a silage packing machine into approximately 40 kg silage bags under appropriate conditions for use in the study. The concentrate feeds were sourced from a commercial feed manufacturer to ensure uniformity across treatments. The nutrient content of the silage types is presented in Table 1.

Table 1. The nutrient content of maize, ryegrass, and sorghum silages (%) fed to lambs

Nutrient Content	Maize Silage	Ryegrass Silage	Sorghum Silage
Dry Matter	27.69	33.27	23.94
Crude Ash	1.72	3.58	2.15
Crude Protein	2.34	3.14	2.73
Crude Fiber	7.64	11.75	7.43
Neutral Detergent Fiber	14.37	20.95	14.75
Acid Detergent Fiber	8.26	13.30	8.83
Lactic Acid	5.08	4.69	3.36
Acetic Acid	0.85	1.33	0.70
Butyric Acid	0.00	0.00	0.00
pH	3.54	3.93	3.74
Sugar	0.63	0.32	0.26
Starch	3.31	Not Detected	1.50

2.3. Feeding management and basal ration

The basal ration was formulated according to the feeding standards of the National Research Council (NRC) to meet the minimum maintenance and growth requirements of lambs and was kept constant across all experimental groups throughout the study. The basal ration was not considered a treatment factor, as the primary objective of the experiment was to evaluate the effects of *ad libitum* access to different silage sources. The basal ration was offered in fixed amounts and was completely consumed by all animals throughout the experimental period. Therefore, the detailed analytical nutrient composition of the basal ration ingredients was not determined. The basal ration served as a standardized nutritional background to isolate the effects of silage type on growth performance, metabolic responses, and carcass traits.

2.4. Chemical analysis of silages

The forage crops used for silage production were cultivated, harvested, and ensiled by the authors. During harvest, dry matter content of the fresh forage materials was determined using the Weende analytical method (AOAC, 1990) at the Adapazarı Commodity Exchange Private Food Laboratory (Sakarya, Türkiye) to monitor optimal harvest timing for ensiling.

After completion of the ensiling process and silage maturation, the first silage bag of each silage type was opened prior to the start of the feeding trial. At that time, two representative samples were collected from each silage type. One sample was submitted for chemical analyses through an external laboratory service at the Department of Animal Science, Faculty of Agriculture, Ege University (İzmir, Türkiye), while the second sample was stored as a backup at -20 °C until the end of the feeding period. Silage sampling was performed only once, immediately after opening the silage bags and before the feeding trial commenced. As silages were prepared in small sealed bags (approximately 40 kg) and consumed within a short period after opening, additional sampling during the feeding period was not conducted.

Dry matter (DM), crude ash, and crude protein (CP) contents of the silages were analysed according to the Weende analytical method (AOAC, 1990). Crude fibre was determined as part of the routine feed evaluation conducted by the service laboratory; however, this variable was not used for interpretation of fibre characteristics in ruminant nutrition. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined following the detergent fibre system described by Van Soest et al. (1991), with methodological principles consistent with the recommendations of Mertens (2002). Silage pH was measured using a calibrated pH meter. Concentrations of lactic, acetic, and butyric acids were determined using the Lepper distillation method, a classical wet-chemistry approach widely applied in forage analysis laboratories (Akyıldız, 1984; McDonald et al., 1991). Starch content was analysed by the polarimetric method (ISO 6493:1997), and sugars were determined by inversion and titrimetric methods. All chemical analyses were performed at the Department of Animal Science, Faculty of Agriculture, Ege University (İzmir, Türkiye).

2.5. Selection of experimental groups and experimental design

The study was conducted at a private farm located in Sakarya province, Türkiye, at 40.8771° N latitude and 30.3790° E longitude. A total of 24 male Ile de France lambs were used and randomly allocated into four groups: control, maize silage, sorghum silage, and ryegrass silage. Prior to the feeding trial, lambs underwent a 14-day adaptation period during which all animals received the same basal concentrate diet, while the silage corresponding to their assigned treatment group was offered *ad libitum*. This standard adaptation protocol is widely used in small ruminant feeding studies to stabilize rumen function and minimize pre-experimental variation.

During the experimental phase, the lambs were housed individually in pens measuring 1.5 × 1.5 meters and were provided with *ad libitum* access to their respective test diets and fresh water. *Ad libitum* feeding was ensured using a standard offer-refusal approach: silage or straw was offered twice daily (morning and evening) after being weighed; additional feed was supplied whenever an animal finished the provided amount, and refusals were collected and weighed before each feeding to determine actual intake. A refusal level of approximately 10% of the offered feed was maintained to guarantee continuous *ad libitum* availability.

At the beginning of the trial, the average initial body weight of the lambs was 26.53±0.21 kg. The amount of concentrate feed was set at 2% of live body weight and adjusted biweekly based on weight gain (Table 2). The intake of the basal ration was not measured separately because alfalfa and sunflower meal were supplied in fixed daily amounts that did not vary across the experimental period. Only the lamb grower feed component was adjusted according to body weight, whereas daily silage or straw intake was recorded individually.

Table 2. Changes in the amount of concentrated feed provided at 2% of live weight (kg) in experimental groups of lambs over two-week periods

Groups	0-14 Days	15-28 Days	29-42 Days	43-56 Days	57-70 Days
Control	0.52	0.52	0.56	0.60	0.64
Maize Silage	0.52	0.54	0.60	0.64	0.70
Sorghum Silage	0.52	0.54	0.58	0.61	0.66
Ryegrass Silage	0.52	0.54	0.58	0.62	0.64

The basal ration consisted of a fixed daily formulation of 0.075 kg alfalfa, 0.40 kg lamb grower feed, and 0.12 kg sunflower meal (Table 3). Among these components, only the lamb grower feed portion was adjusted every-two-week biweekly according to the 2% body weight criterion, whereas alfalfa and sunflower meal remained constant throughout the trial. Therefore, Table 2 presents the scheduled every-two-week biweekly adjustments in the amount of lamb grower feed offered to each group and does not represent actual intake values; actual concentrate and silage intake data are presented in Table 4.

Table 3. Basal ration composition (kg/animal/day) and feeding program of lambs

Groups	Number of Animals	*Ad libitum*	Basal ration composition		
			Alfalfa	Lamb Grower Feed	Sunflower Meal
Control	6	Wheat Straw	0.075	0.4	0.12
Maize Silage	6	Maize Silage	0.075	0.4	0.12
Sorghum Silage	6	Sorghum Silage	0.075	0.4	0.12
Ryegrass Silage	6	Ryegrass Silage	0.075	0.4	0.12

Table 4. Total roughage intake of lambs based on dry matter during the experimental period (kg DM/animal)

Feed	Control	Maize Silage	Sorghum Silage	Ryegrass Silage	P Value (<0.05)
Day 14	0.70±0.22a	2.78±0.40b	2.48±0.78b	1.87±0.43a/b	0.04
Day 28	1.13±0.33a	4.67±0.92b	3.85±0.83b	2.93±0.56a/b	0.01
Day 42	1.19±0.36a	4.98±0.84b	3.25±0.65a/b	2.96±0.79a/b	0.01
Day 56	1.19±0.37a	4.54±0.62b	4.54±0.62b/c	4.15±0.78b	0.00*
Day 70	2.04±0.52a	6.14±0.81b	4.17±0.72a/b	4.78±0.91b	0.01
Total	6.25±1.73a	24.95±3.69b	18.29±3.52b	16.70±3.18b	0.00**

*P değer: 0,0002;**P Değer: 0,004; Values represent 14-day accumulated dry matter intake per lamb. a–c: Means within the same row with different superscript letters differ significantly (P<0.05) according to Duncan's multiple range test. Values represent 14-day accumulated dry matter intake per lamb.

The daily intake of straw and silage offered *ad libitum* was recorded twice daily by weighing the residuals. Live weights of the lambs were measured biweekly in the morning before feeding. Vaccination and parasite control protocols were completed prior to the trial, and no medical interventions were required during the experimental period.

2.6. Serum biochemical analyses

2.6.1. Blood gas measurements

Blood samples were collected from the jugular vein using sterile vacutainer tubes. Lithium-heparinized tubes were used for blood gas measurements, while plain tubes without anticoagulant were used for serum biochemical analyses. During the experimental period, blood samples were collected twice from the same animals, once in the 5th week of the trial (day 35) and again at the end of the experiment (day 70), in order to evaluate changes in blood variables over time. All blood samples were obtained in the morning before feeding, following an overnight fasting period of approximately 12 hours.

Immediately after blood collection, the EDAN i15 VET blood gas and biochemical analyzer (Edan Instruments, China) was calibrated according to the manufacturer's instructions. The following variables were analyzed and recorded: pH, partial pressure of carbon dioxide (pCO_2), partial pressure of oxygen (pO_2), hematocrit (Hct), total hemoglobin (tHb), oxygen saturation (sO_2), sodium (Na), potassium (K), calcium (Ca), chloride (Cl), lactate (Lac), actual bicarbonate (HCO_3^-), base excess (BE), buffer base (BB), total carbon dioxide ($ctCO_2$), and anion gap (AnGap).

2.6.2. Comprehensive Metabolic Panel (CMP) analyses

Serum tubes were allowed to clot at room temperature and centrifuged at 3,000 rpm for 10 min to obtain serum. Serum samples were collected only once, on the final day of the feeding trial, and were analyzed using the FUJI DRI-CHEM NX600 system with the Comprehensive Metabolic Panel (CMP). The measured biochemical parameters included total protein (TP), albumin (ALB), alkaline phosphatase (ALP), glucose (GLU), total bilirubin (TBIL), inorganic phosphate (IP), total cholesterol (TCHO), gamma-glutamyl transferase (GGT), alanine transaminase (GPT), calcium (Ca), creatinine (CRE), and blood urea nitrogen (BUN).

2.7. Evaluation of carcass parameters

2.7.1. Carcass analyses

At the end of the trial, lambs were fasted overnight and slaughtered the following morning in a private abattoir. To assess the effects of different silage sources, live weight, carcass yield, hot and cold carcass weights, temperatures, and pH levels were recorded. Carcass temperature and pH were measured at approximately 45 min post-slaughter (hot carcass), at the end of the dressing process. Carcass temperature was measured using a digital thermometer (Testo 106, Germany). Cold carcass pH was recorded after 24 h of chilling at +4 °C using a digital pH probe (Testo 205, Germany).

2.7.2. Meat texture, color and water activity analysis

For tissue analysis, samples were collected from the *M. longissimus dorsi* muscle between the 12th and 13th ribs. Texture Profile Analysis (TPA) was conducted using a TA-HD Plus texture analyzer (Stable Micro Systems, UK). The color scale values and water activity (aw) of lamb meat samples from different silage sources were measured using a Minolta CR-400 colorimeter (Konica Minolta Sensing, Osaka, Japan) and a Novasina water activity meter (Novasina AG, Switzerland), respectively. Color measurements were taken from different surface locations, while water activity was recorded to assess the moisture levels in the meat.

2.8. Statistical analyses

All statistical analyses were performed using IBM SPSS Statistics software (version 25.0; IBM Corp., Armonk, NY, USA). Data distribution was assessed using the Shapiro-Wilk normality test (Shapiro & Wilk, 1965).

Blood gas and biochemical variables obtained from the same animals at two sampling times (day 35 and day 70) were analysed using a General Linear Model (GLM) for repeated measures. Sampling day (35 vs 70) was defined as the within-subject factor, dietary group (Control, Maize silage, Sorghum silage and Ryegrass silage) as the between-subject factor, and the Day × Dietary group interaction was tested to evaluate whether temporal changes differed among dietary groups. With only two sampling points, the assumption of sphericity was inherently satisfied; therefore, results are reported under the sphericity-assumed model. When significant effects were detected, pairwise comparisons of estimated marginal means were performed using Bonferroni adjustment (Bonferroni, 1936).

Serum biochemical parameters obtained from the Comprehensive Metabolic Panel, which were measured only once at the end of the experimental period, were analysed using one-way analysis of variance (ANOVA). Average daily gain (ADG) was calculated for each lamb as the slope of the linear regression of live weight on time over the entire experimental period. The resulting ADG values were compared among dietary groups using one-way ANOVA. When appropriate, post hoc comparisons for parametric data were performed using Duncan's multiple range test (Duncan, 1955). Statistical significance was declared at $P < 0.05$.

3. RESULTS

3.1. Live weight performance and feed utilisation of lambs

Lambs were weighed at the beginning of the trial and at 14-day intervals thereafter, always in the morning before feeding. Live weight measurements recorded throughout the experimental period did not differ significantly among dietary groups at any weighing point ($P > 0.05$). Nevertheless, lambs fed maize silage consistently exhibited numerically higher live weights at most measurement times, whereas the control group fed straw showed the lowest numerical values.

Average daily gain (ADG) was calculated for each lamb as the slope of the linear regression of live weight on time over the entire 70-day experimental period. The resulting ADG values did not differ significantly among dietary groups ($P = 0.974$). Lambs fed maize silage showed the highest numerical ADG, while the control group exhibited the lowest numerical gain, with sorghum and ryegrass silage groups showing intermediate values. The ADG results of the experimental groups are presented in Table 5.

Table 5. Average daily gain (ADG, g/day) of lambs calculated as the slope of the regression of live weight on time over the entire experimental period

Groups	ADG (g/day)
Control	771.00±246.98*
Maize Silage	754.17±118.09*
Sorghum Silage	675.67±116.60*
Ryegrass Silage	762.83±135.04*
P-value	0.974

*Standard deviation

Total roughage intake was recorded throughout the experimental period, and dry matter intake was calculated at 14-day intervals. Total roughage intake differed significantly among dietary groups (P < 0.05), with all silage-fed groups consuming greater amounts of roughage compared with the control group fed straw. Among the silage treatments, maize silage resulted in the highest total roughage intake, whereas sorghum and ryegrass silages exhibited intermediate intake levels. The results of roughage intake based on dry matter consumption are presented in Table 5.

Feed conversion ratio (FCR), calculated as the ratio of total dry matter intake to live weight gain over the experimental period, did not differ significantly among dietary groups (P > 0.05). Feed conversion ratio results are presented in Table 6.

Table 6. Feed conversion ratio (FCR) of lambs during the experimental period

Experimental Group	FCR (Mean±SD)	P Value (<0.05)
Control	9.56±2.20*	0.65
Maize Silage	6.45±0.78*	
Sorghum Silage	8.90±2.99*	
Ryegrass Silage	7.16±0.97*	

*Standard Deviation

3.2. Serum biochemical analyses results

3.2.1. Blood gas and acid-base variables

Blood gas and acid-base variables measured on days 35 and 70 were analysed using a General Linear Model (GLM) for repeated measures, with sampling day as the within-subject factor and dietary group as the between-subject factor.

For most variables, neither the main effect of dietary group nor the Day × Dietary group interaction was significant (P > 0.05), indicating that temporal changes did not differ among silage sources. However, a significant main effect of sampling day was observed for several variables, including glucose, chloride, hematocrit, total hemoglobin, lactate, and cH (P < 0.05). These findings reflect physiological changes over time that occurred consistently across all dietary groups and were therefore independent of diet.

Despite these time-related variations, all measured blood gas and acid-base variables remained within established physiological reference ranges for lambs. This indicates that *ad libitum* feeding of maize, sorghum, or ryegrass silages did not adversely affect acid-base balance, oxygenation status, or overall metabolic stability. The mean ± SD values of blood gas and acid-base variables measured on days 35 and 70 are presented in Table 7.

Table 7. Blood gas and acid-base variables of lambs measured on days 35 and 70

Parameter	Control Day 35	Control Day 70	Maize Day 35	Maize Day 70	Sorghum Day 35	Sorghum Day 70	Ryegrass Day 35	Ryegrass Day 70
pH	7.40±0.02	7.34±0.05	7.43±0.04	7.37±0.04	7.39±0.04	7.31±0.07	7.40±0.04	7.33±0.07
pO_2 (mmHg)	36.50±3.65	35.17±5.87	34.83±3.65	35.67±5.87	37.17±3.65	35.67±5.87	35.17±3.65	39.17±5.87
pCO_2 (mmHg)	41.52±6.52	44.02±6.29	41.02±3.90	54.16±21.69	44.28±7.15	49.04±6.03	44.90±4.61	51.84±9.67
Hct (%)	29.83±3.06	32.33±1.63	29.67±2.50	33.50±2.74	30.83±2.79	34.83±2.79	30.83±3.06	33.17±3.37
tHb (g/dL)	10.13±1.00	11.07±0.53	10.10±0.82	11.48±0.92	10.43±1.07	11.88±0.94	10.50±1.07	11.25±1.17
sO_2 (%)	69.17±6.37	61.83±12.61	69.00±5.83	65.00±9.62	69.80±6.26	62.00±9.98	69.00±2.92	69.00±12.02
Na (mmol/L)	145.67±2.07	146.67±1.86	144.50±1.87	144.17±1.94	144.83±1.47	145.67±1.51	145.17±2.40	146.67±3.56
K (mmol/L)	5.53±0.74	5.75±0.56	5.43±0.66	5.65±0.52	5.18±0.26	5.53±0.73	5.85±0.24	5.80±0.58
Ca (mmol/L)	1.28±0.06	1.23±0.05	1.28±0.06	1.28±0.08	1.27±0.10	1.31±0.16	1.29±0.07	1.28±0.06
Cl (mmol/L)	105.67±2.07	110.00±2.76	103.83±1.47	106.83±1.72	104.80±1.92	106.40±2.41	104.67±2.16	106.17±2.93
Ca (7.4)	1.28±0.06	1.20±0.06	1.30±0.06	1.26±0.07	1.26±0.12	1.26±0.13	1.30±0.08	1.25±0.06
Glukoz	3.50±0.26	3.40±0.50	3.40±0.28	4.10±0.52	3.60±0.11	3.98±0.29	3.33±0.30	4.07±0.43
Lac	3.53±2.41	4.86±3.23	1.58±0.51	3.60±0.89	3.10±1.69	5.03±1.94	2.52±1.09	3.85±2.23
cH	39.73±2.31	46.30±6.10	37.17±3.17	43.18±3.68	40.72±4.02	48.85±7.66	40.17±3.65	47.53±8.62
HCO_3^- (act,r)	25.33±4.88	23.15±3.87	26.48±1.19	29.94±10.72	25.76±1.97	25.36±2.99	26.72±2.44	25.66±2.88
HCO_3^- (std,r)	24.53±4.04	21.65±3.17	25.80±1.20	27.38±8.38	24.44±1.18	23.04±3.28	25.28±2.16	23.18±2.70
BE (ecf)	0.55±5.13	−2.67±4.39	2.20±1.45	4.56±10.59	0.72±1.73	−0.58±3.86	1.78±2.74	−0.46±3.32
BE (B)	0.45±4.51	−2.67±3.93	2.00±1.36	3.58±8.83	0.83±1.97	0.73±3.96	1.46±2.47	−0.94±3.13
BB	46.45±4.53	43.68±3.97	47.86±1.38	50.00±8.95	46.66±1.19	45.82±3.41	47.44±2.65	45.40±3.10
$ctCO_2$	26.50±4.93	24.50±4.04	28.00±1.23	31.60±11.63	27.20±2.28	26.80±3.27	28.00±2.45	27.40±2.97
An gap	20.17±3.76	19.50±2.59	19.00±1.87	14.40±6.03	19.80±3.77	20.20±4.82	18.80±2.28	20.80±4.92
m0sm,r	296.40±4.40	299.05±4.27	294.37±4.26	294.85±4.72	294.82±3.51	297.33±2.99	295.95±5.35	299.43±7.77

In the blood gas analysis table, the following parameters are presented: 35: Measurement on day 35, 70: Measurement on day 70, pH: Acidity-alkalinity, pO2: Oxygen pressure, pCO2: Carbon dioxide pressure, Hct: Hematocrit, tHb: Total hemoglobin, sO2: Oxygen saturation, Na: Sodium, K: Potassium, Ca: Calcium, Cl: Chloride, Lac: Lactate, cH: Hematocrit concentration, HCO3 act,r: Actual bicarbonate, HCO3 sdt,r: Standard bicarbonate, BE (ecf): Base excess in extracellular fluid, BE (B): Base excess in blood, BB: Buffer base in blood, ctCO2: Total carbon dioxide, An Gap: Anion gap, m0sm,r: Molality values. Units are as follows: pO2, pCO2: mmHg, THB: g/dL, m0sm,r: mOsm/L, and vd: mmol/L.

3.2.2. Serum biochemical parameters

Serum biochemical parameters obtained from the Comprehensive Metabolic Panel and measured once at the end of the experimental period did not differ significantly among dietary groups (P > 0.05). Although minor numerical differences were observed in some variables, these variations were not biologically meaningful, and all values remained within normal physiological reference ranges for lambs.

These results indicate that feeding different silage sources had no adverse effects on liver function, protein metabolism, renal function, or overall metabolic status under the conditions of this study. The results of serum biochemical analyses are presented in Table 8.

Table 8. Serum biochemical parameters of lambs at the end of the experimental period

Parameters	**Control**	**Maize Silage**	**Sorghum Silage**	**Ryegrass Silage**	**P value (<0.05)**
TP	6.62±0.34	6.92±0.34	6.93±0.34	6.88±0.34	0.76
ALB	3.07±0.11	3.15±0.11	3.13±0.11	3.20±0.11	0.65
ALP	503.50±118.87	645.50±118.87	558.33±118.87	601.50±118.87	0.67
GLU	76.83±5.05	87.67±5.05	87.17±5.05	83.33±5.05	0.15
TBIL	0.40±0.07	0.38±0.07	0.42±0.07	0.42±0.07	0.95
IP	8.57±0.68	9.53±0.68	8.70±0.68	9.03±0.68	0.50
TCHO	50.17±5.13	45.50±5.13	47.50±5.13	50.17±5.13	0.76
GGT	77.50±7.53	82.17±7.53	84.33±7.53	74.67±7.53	0.58
GPT	22.00±3.45	21.83±3.45	17.83±3.45	24.17±3.45	0.35
Ca	9.95±0.20	10.28±0.20	10.05±0.20	10.42±0.20	0.11
CRE	0.85±0.07	0.75±0.07	0.74±0.07	0.74±0.07	0.30
BUN	20.82±2.36	18.12±2.36	21.23±2.36	18.72±2.36	0.49

In the blood serum biochemical analysis table, the following parameters are represented: TP: Total protein, ALB: Albumin, ALP: Alkaline phosphatase, GLU: Glucose, TBIL: Total bilirubin, IP: Inorganic phosphorus, TCHO: Total cholesterol, GGT: Gamma-glutamyl transferase, GPT: Alanine aminotransferase, Ca: Calcium, CRE: Creatinine, and BUN: Blood urea nitrogen. The units are as follows: TP, ALB: g/dL; ALP, GGT, GPT: U/L; GLU, TBIL, IP, TCHO, Ca, CRE, BUN: mg/dL.

3.3. Carcass parameters analysis results

3.1. Carcass characteristics

Carcass characteristics, including slaughter weight, hot and cold carcass weights, dressing percentage, and rumen weight expressed as a proportion of live weight, did not differ significantly among dietary groups (P > 0.05). Although some numerical differences were observed, lambs fed maize and sorghum silages tended to exhibit slightly higher carcass-related values compared with the control group; however, these differences were not statistically significant. Overall, the results indicate that *ad libitum* feeding of maize, sorghum, or ryegrass silages did not markedly influence carcass development or yield under the experimental conditions applied in this study. The carcass characteristics of lambs fed different silage sources are presented in Table 9.

Table 9. Carcass characteristics of lambs fed different silage sources

Parameters	Control	Maize Silage	Sorghum Silage	Ryegrass Silage	P Value (<0.05)
Slaughter Live Weight (kg)	36.34±1.65	41.66±1.75	38.68±1.32	39.72±1.42	0.15
Carcass Yield (%)	45.78±0.96	47.00±1.46	44.62±0.43	45.10±2.27	0.68
Hot Carcass Weight (kg)	16.68±1.02	19.64±1.35	17.24±0.45	18.00±1.42	0.31
Hot Carcass Temperature (°C)	33.00±0.06	33.12±0.19	34.06±0.17	33.16±0.82	0.47
Hot Carcass pH	6.35±0.07	6.24±0.06	6.28±0.07	6.08±0.11	0.18
Cold Carcass Weight (kg)	16.44±1.05	19.40±1.35	17.04±0.51	17.80±1.42	0.32
Cold Carcass Temperature (°C)	1.86±0.38	1.98±0.57	2.24±0.40	1.74±0.26	0.85
Cold Carcass pH	5.43±0.10	5.70±0.15	5.74±0.08	5.64±0.16	0.37
Five-piece Set Weight (kg)	4.42±0.18a	5.59±0.27b	5.23±0.24b	5.13±0.28a/b	0.03
Rumen Weight (kg)	18.77±2.22	18.85±0.72	21.19±2.27	16.51±1.18	0.34

*Five-piece set weight; heart, liver, spleen, lungs, trachea. a–b: Means within the same row with different superscript letters differ significantly (P<0.05) according to Duncan's multiple range test.

3.2. Meat texture, colour, and water activity

Meat texture parameters, colour values (L*, a*, and b*), and water activity (aw) of the *Musculus longissimus dorsi* were not significantly affected by dietary group (P > 0.05). Although minor numerical variations were observed among treatments, these differences did not indicate a consistent or biologically meaningful effect of silage source on meat quality traits. These findings suggest that the use of different silage sources did not adversely affect the technological quality characteristics of lamb meat, including texture, colour stability, or moisture-related properties. The results of meat texture, colour, and water activity analyses are presented in Table 10.

Table 10. Meat texture, colour parameters (L*, a*, b*), and water activity of lambs fed different silage sources

Parameters	Control	Maize Silage	Sorghum Silage	Ryegrass Silage	P Value (<0.05)
Hardness	1673.64±4.25	3475.09±5.95	1846.03±4.97	2404.92±3.74	0.07
Stickiness	-22.69±5.04	-21.86±5.75	-16.75±6.26	-22.95±9.16	0.90
Elasticity	0.86±0.01	0.84±0.02	0.84±0.05	0.81±0.04	0.74
Cohesiveness	0.71±0.00	0.69±0.01	0.67±0.03	0.65±0.01	0.16
Gumminess	1180.93±2.93	2415.66±4.15	1233.48±3.48	1565.66±2.35	0.06
Chewiness	1015.26±2.45	2010.65±3.27	1091. 89±3.84	1248.26±1.76	0.11
Springiness	0.39±0.01	0.44±0.02	0.38±0.03	0.39±0.01	0.18
L	46.61±1.19	44.38±1.37	46.14±0.66	44.96±0.34	0.38
a	19.51±0.65	18.31±0.74	19.63±0.23	20.02±1.02	0.40
b	6.04±0.65	6.06±0.82	6.867±0.25	6.52±0.75	0.79
aw	0.67±0.0037b	0.64±0.0077a	0.66±0.0071b	0.61±0.012a	0.001

Hardness, gumminess: N (Newton); Stickiness: N-s (Newton-second); Elasticity: mm (millimeter); Chewiness: N-mm (Newton-millimeter); Cohesiveness, springiness: dimensionless. a–b: Means within the same row with different superscript letters differ significantly (P<0.05) according to Duncan's multiple range test.

4. DISCUSSION

The use of silage in sheep nutrition has traditionally been limited compared with cattle systems; however, increasing pressure to reduce feeding costs and improve resource efficiency has renewed interest in silage-based roughage sources for intensive lamb production. In this context, maize, sorghum and ryegrass silages represent nutritionally distinct forage options that differ in energy density, fermentability and intake potential. The present study demonstrates that replacing straw with these silage sources under standardized concentrate supplementation does not compromise growth performance, feed efficiency, metabolic stability, carcass characteristics or meat quality in Ile de France lambs. The absence of detrimental effects on productive and physiological parameters indicates that silage-based feeding strategies can be safely integrated into intensive lamb-fattening systems, supporting both nutritional adequacy and production sustainability.

4.1. Growth performance and feed utilisation

Live weight development throughout the experimental period was not significantly affected by dietary group, indicating that all roughage sources supported comparable growth patterns. Average daily gain (ADG), calculated as the slope of the linear regression of live weight on time over the entire experimental period, did not differ among dietary groups ($P = 0.974$). Similar findings have been reported in lambs fed different silage sources when concentrate intake was standardized, suggesting that roughage type per se has limited influence on growth rate under intensive feeding conditions (Almeida Júnior et al., 2004; Van de Vyver et al., 2013; Wu et al., 2021).

Total roughage intake expressed on a dry matter basis differed among dietary groups, with all silage-fed lambs consuming greater amounts of roughage than the control group fed straw. This observation is consistent with previous studies showing that ensiled forages promote higher voluntary intake than low-quality roughages due to improved palatability, reduced rumen fill and enhanced fermentation characteristics (Bosman et al., 2000; Khan et al., 2011; Fluharty et al., 2017). Among the silage treatments, maize silage resulted in the highest roughage intake, which agrees with reports attributing higher intake of maize silage to its greater starch concentration and fermentable energy content (Malisetty et al., 2013; Torkestani et al., 2023).

Despite differences in intake, feed conversion ratio did not differ significantly among dietary groups. Comparable results have been documented in lambs and cattle where higher intake associated with maize or grass silages did not necessarily translate into improved growth efficiency when energy and protein supply from concentrates was balanced (Lind et al., 2009; Manarelli et al., 2019; Santos et al., 2021). These findings indicate that silage type mainly affects intake behaviour rather than efficiency of nutrient utilization.

4.2. Blood gas and acid-base variables

Blood gas and acid-base variables measured on days 35 and 70 were largely unaffected by dietary group or by the Day × Dietary group interaction, indicating that temporal changes occurred similarly across all feeding treatments. However, a significant main effect of sampling day was observed for glucose, chloride, hematocrit, total hemoglobin, lactate and cH. Time-related changes in these variables are commonly reported during growth and fattening periods and are generally attributed to physiological maturation and metabolic adaptation rather than to dietary disturbances (Lefter et al., 2019; Rodrigues et al., 2019; Krištolaitytė et al., 2025).

Importantly, all measured blood gas and acid-base parameters remained within established physiological reference ranges for lambs. Similar stability of blood gas variables has been reported in lambs fed maize, grass or sorghum-based diets, indicating that these forages do not compromise acid-base balance or oxygenation status when diets are nutritionally adequate (Sun et al., 2018; Sabertanha et al., 2021; Wang et al., 2022a).

4.3. Serum biochemical parameters

Serum biochemical parameters obtained from the comprehensive metabolic panel and measured at the end of the experimental period did not differ significantly among dietary groups. The absence of diet-related differences in indicators of liver, kidney and protein metabolism is consistent with previous studies evaluating different silage sources in lambs and goats (Przemysław et al., 2015; Zhang et al., 2023). Minor numerical variations observed in some parameters were within physiological limits and likely reflect normal biological variability rather than diet-induced metabolic effects.

These findings support the view that maize, sorghum and ryegrass silages, when combined with adequate concentrate supplementation, maintain metabolic homeostasis and do not impose metabolic stress on growing lambs (Sun et al., 2018; Wang et al., 2022b).

4.4. Carcass characteristics

Carcass characteristics, including slaughter weight, hot and cold carcass weights, dressing percentage and rumen weight relative to live weight, were not significantly influenced by dietary group. Similar outcomes have been reported in studies comparing maize, sorghum and grass silages, where carcass yield and composition were largely unaffected when dietary energy and protein were balanced (De Sousa et al., 2008; Van de Vyver et al., 2013; Keleş et al., 2018).

Although lambs fed maize and sorghum silages exhibited numerically higher carcass-related values, these differences did not reach statistical significance. Such numerical tendencies have been frequently reported in silage-based feeding studies and are generally considered biologically plausible but insufficient to support definitive conclusions in the absence of statistical significance (Manarelli et al., 2019; Wu et al., 2021).

4.5. Meat quality attributes

Meat quality parameters, including pH, colour (L*, a*, b*), texture characteristics and water activity, were not significantly affected by dietary group. Post-mortem pH values were within the normal range reported for lamb meat, indicating appropriate glycogen utilization and carcass acidification across all treatments (Madruga et al., 2008; Beukes, 2013; Carvalho et al., 2022).

The absence of significant differences in colour and texture parameters is consistent with previous reports showing that forage source has limited influence on meat quality when nutrient supply is balanced (Gois et al., 2017; Geletu et al., 2021; Estrada-León et al., 2022; Silva et al., 2024). Minor numerical variations in water activity and colour values did not follow a consistent dietary pattern and are therefore considered of limited biological relevance.

5. CONCLUSION

The use of silage in sheep nutrition has traditionally been limited compared with cattle systems; however, increasing pressure to reduce feeding costs and improve resource efficiency has renewed interest in silage-based roughage sources for intensive lamb production. In this context, maize, sorghum and ryegrass silages represent nutritionally distinct forage options that differ in energy density, fermentability and intake potential. The present study demonstrates that replacing straw with these silage sources under standardized concentrate supplementation does not compromise growth performance, feed efficiency, metabolic stability, carcass characteristics or meat quality in Ile de France lambs. The absence of detrimental effects on productive and physiological parameters indicates that silage-based feeding strategies can be safely integrated into intensive lamb-fattening systems, supporting both nutritional adequacy and production sustainability.

Supplementary information ↑

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Supplementary material

Not applicable.

Data availability

The datasets generated and analysed during the current study are not publicly available due to institutional regulations but are available from the corresponding author upon reasonable request.

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Authorship contribution statement

Alparslan Mutluhan Türedi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing-original draft, Writing-review & editing.

İbrahim Sadi Çetingül: Supervision, Validation, Project administration, Resources, Writing-review & editing.

Competing interests

The authors have declared that no competing interests exist.

Statement on the use of Artificial Intelligence

The authors employed ChatGPT (OpenAI, GPT-5 version, 2026) to assist with language refinement and clarity during the revision process in response to reviewer comments. In addition, the Spanish translation of the Title, Abstract and Keywords was generated using ChatGPT (OpenAI, GPT-5 version, 2026). All AI-assisted text was carefully reviewed and edited by the authors to ensure that the original intended meaning was accurately preserved. The authors take full responsibility for the content of this publication.

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REFERENCES

Akyıldız AR, 1984. Yemler bilgisi laboratuvar kılavuzu. Ankara Üniv Ziraat Fak Yay No. 895, Ankara, Türkiye.

Almeida Júnior GAD, Costa C, Monteiro ALG, Garcia CA, Munari DP, Neres MA, 2004. Live weight gain, carcass traits and economic results on lambs fed with high moisture corn silage in creep feeding. R Bras Zootec 33: 1048–1059. https://doi.org/10.1590/S1516-35982004000400025

AOAC, 1990. Official methods of analysis. 15th ed. Assoc Off Anal Chem, Washington, DC, USA.

Aydin KB, Bi Y, Brito LF, Ulutaş Z, Morota G, 2024. Review of sheep breeding and genetic research in Türkiye. Front Genet 15: 1308113. https://doi.org/10.3389/fgene.2024.1308113

Aygün T, Çelikyürek H, 2020. Recommended sheep husbandry model and body weights of Morkaraman lambs in Muş province. Lalahan Hay Araşt Enst Derg 60(1): 5-8. https://doi.org/10.46897/lahaed.661067

Beukes J, 2013. Maize silage-based diets for feedlot finishing of Merino lambs. Master's thesis. Stellenbosch Univ, South Africa. 105 pp.

Bonferroni CE, 1936. Teoria statistica delle classi e calcolo delle probabilità. Pubbl R Ist Sup Sci Econ Comm Firenze 8: 3-62.

Bosman MJC, Webb EC, Cilliers HJ, Steyn HS, 2000. Growth, carcass and sensory characteristics of *M. longissimus lumborum* from wethers fed silage diets made from maize or various sorghum varieties. S Afr J Anim Sci 30(1): 36-42.

Carvalho AFD, de Araújo MJ, Vallecillo SJA, Neto JPC, de Souza AR, Edvan RL, Bezerra LR, 2022. Tissue composition and meat quality of lambs fed diets containing whole-plant sesame silage as a replacement for whole-plant corn silage. Small Rumin Res 216: 106799. https://doi.org/10.1016/j.smallrumres.2022.106799

Çolak E, Sancak C, 2016. The effects of different nitrogen fertilizer doses on yield and some agricultural traits of Italian ryegrass (Lolium italicum L.) cultivars. Tarla Bitk Merkez Arast Enst Derg 25: 58–66. https://doi.org/10.21566/tbmaed.55211

De Sousa VS, Louvandini H, Scropfner ES, McManus C, Abdalla AL, Garcia JAS, 2008. Performance, carcass traits and body components in hair sheep fed with sunflower silage or corn silage. Ciênc Anim Bras 9(2): 284-291. https://revistas.ufg.br/vet/article/view/4223

Demiral K, İşcan KM, 2012. Effect of flushing application on fertility parameters in Akkaraman sheep. Erciyes Üniv Vet Fak Derg 9(1): 23–28. https://izlik.org/JA32NB87FE

Duncan DB, 1955. Multiple range and multiple F tests. Biometrics 11(1): 1-42.

Estrada-León RJ, Moo-Huchin VM, Mena-Arceo D, Cárdenas-Medina JV, Ortíz-Fernández A, Canto-Pinto JC, 2022. Meat quality physicochemical traits in hair sheep in southeast Mexico. J MVZ Córdoba 27: e2563. https://doi.org/10.21897/rmvz.2563

FAO, 2023. FAOSTAT: Crops and livestock products. FAO, Rome, Italy. https://www.fao.org/faostat/ [accessed 15 Jan 2025].

Fluharty FL, Zerby HN, Lowe GD, Clevenger DD, Relling AE, 2017. Effects of feeding corn silage, pelleted, ensiled, or pelleted and ensiled alfalfa on growth and carcass characteristics of lambs. S Afr J Anim Sci 47(5): 704–711. https://doi.org/10.4314/sajas.v47i5.14

Geletu US, Usmael MA, Mummed YY, Ibrahim AM, 2021. Quality of cattle meat and its compositional constituents. Vet Med Int: 7340495. https://doi.org/10.1155/2021/7340495

Gois GC, Santos EM, Sousa WH, Ramos JPF, Azevedo PS, Oliveira JS, Perazzo AF, 2017. Meat quality of finishing feedlot lambs fed diets of assorted sorghum cultivars. Arq Bras Med Vet Zootec 69: 1653–1659. https://doi.org/10.1590/1678-4162-9231

ISO, 1997. Native starch — Determination of starch content — Ewers polarimetric method.ISO 10520. Geneva, Switzerland.

Kara H, Eroğlu A, 2018. Capacity planning of intensive stock farming in Konya (Ereğli) by integer linear programming. Çukurova Tarım Gıda Bil Derg 33(2): 31–46. https://izlik.org/JA34ZD98RE

Keleş G, Kocaman V, Üstündağ AO, Zungur A, Özdoğan M, 2018. Growth rate, carcass characteristics and meat quality of growing lambs fed buckwheat or maize silage. Asian-Australas J Anim Sci 31(4): 522–528. https://doi.org/10.5713/ajas.17.0296

Kemešytė V, Statkevičiūtė G, Norkevičienė E, Jaškūnė K, 2023. Italian ryegrass as a forage crop for the Baltics: opportunities and challenges in light of climate change. Plants 12(22): 3841. https://doi.org/10.3390/plants12223841

Khan SH, Shahzad MA, Nisa M, Sarwar M, 2011. Nutrient intake, digestibility, nitrogen balance and growth performance of sheep fed different silages with or without concentrate. Trop Anim Health Prod 43: 795-801. https://doi.org/10.1007/s11250-010-9765-1

Krištolaitytė J, Džermeikaitė K, Rutkauskas A, Šertvytytė G, Lembovičiūtė G, Arlauskaitė S, Antanaitis R, 2025. Impact of blood metabolic profile and ingestive behaviours registered with noseband sensor on methane emission during transition period in dairy cows. Life 15(5): 760. https://doi.org/10.3390/life15050760

Lefter NA, Vasilachi A, Voicu D, Hăbeanu M, Gheorghe A, Grosu AI, 2019. Effect of sorghum grain inclusion in Montbeliarde dairy cows diet on health status. Slovak J Anim Sci 52(2): 63-68.

Lind V, Berg J, Eik LO, Eilertsen SM, Molmann J, Hersleth M, Haugland E, 2009. Effects of concentrate or ryegrass-based diets (*Lolium multiflorum*) on the meat quality of lambs grazing on semi-natural pastures. Acta Agric Scand A Anim Sci 59(4): 230-238. https://doi.org/10.1080/09064700903493699

Madruga MS, Costa RG, Silva AM, Marques AVMS, Cavalcanti RN, Narain N, Lira Filho GEE, 2008. Effect of silk flower hay (*Calotropis procera* Sw.) feeding on the physical and chemical quality of *Longissimus dorsi* muscle of Santa Inês lambs. Meat Sci 78(4): 469-474. https://doi.org/10.1016/j.meatsci.2007.07.016

Malisetty V, Reddy YR, Devanaboina N, Mallam M, Krishna CH, Reddy AR, Prakash MG, 2013. Effect of feeding maize silage supplemented with concentrate and legume hay on growth in Nellore ram lambs. Vet World 6(4): 209-213. https://doi.org/10.5455/vetworld.2013.209-213

Manarelli DM, Orrico Junior MAP, Retore M, Vargas Junior FMD, Silva MSJ, Orrico ACA, Neves FDO, 2019. Performance and carcass traits of lambs fed saccharine sorghum silage. Pesqui Agropecu Bras 54: e00577. https://doi.org/10.1590/S1678-3921.pab2019.v54.00577

McDonald P, 1991. The biochemistry of silage. Chalcombe Publications, Marlow, UK.

Mertens DR, Allen M, Carmany J, Clegg J, Davidowicz A, Drouches M, Frank K, Gambin D, Garkie M, Gildemeister B, et al., 2002. Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: collaborative study. J AOAC Int 85(6): 1217-1240. https://doi.org/10.1093/jaoac/85.6.1217

Očenáš P, Baloga M, Valko-Rokytovská M, Ivašková S, 2025. Determination of biochemical and metabolomic characteristics of sheep blood serum and their application in clinical practice. Life 15(7): 1141. https://doi.org/10.3390/life15071141

Pino F, Heinrichs AJ, 2017. Sorghum forage in precision-fed dairy heifer diets. J Dairy Sci 100(1): 224-235. https://doi.org/10.3168/jds.2016-11551

Przemysław S, Cezary P, Stanisław M, Krzysztof L, Barbara P, Zofia A, Ząbek K, 2015. The effect of nutritional and fermentational characteristics of grass and legume silages on feed intake, growth performance and blood indices of lambs. Small Rumin Res 123(1): 1-7. https://doi.org/10.1016/j.smallrumres.2014.11.008

Rodrigues TCDC, Freitas PM, Santos EM, de Araújo GG, Pires AJ, Ayres MC, de Carvalho GGG, 2019. Effects of ammoniated pearl millet silage on intake, feeding behavior, and blood metabolites in feedlot lambs. Trop Anim Health Prod 51: 2323-2331. https://doi.org/10.1007/s11250-019-01914-1

Sabertanha E, Rouzbehan Y, Fazaeli H, Rezaei J, 2021. Nutritive value of sorghum silage for sheep. J Anim Physiol Anim Nutr 105(6): 1034-1045. https://doi.org/10.1111/jpn.13548

Santos ACP, Santos EM, de Carvalho GGP, Pinto LFB, Pina DS, Perazzo AF, de Lima Cruz GFF, 2021. Productive and metabolic parameters, carcass and meat characteristics of lambs fed sorghum silage treated with urea and *Lactobacillus buchneri*. Livest Sci 251: 104603. https://doi.org/10.1016/j.livsci.2021.104603

Semerci A, Çelik AD, 2016. General overview of ovine breeding in Turkey. MKU Ziraat Fak Derg 21(2): 182-196. https://izlik.org/JA42WR35NH

Shapiro SS, Wilk MB, 1965. An analysis of variance test for normality. Biometrika 52(3–4): 591-611. https://doi.org/10.1093/biomet/52.3-4.591

Silva LA, Lima CL, Pina DDS, Alba HD, de Araújo ML, Cirne LG, de Carvalho GGG, 2024. Carcass traits and meat quality of lambs fed with rehydrated ground corn silage. Small Rumin Res 231: 107193. https://doi.org/10.1016/j.smallrumres.2023.107193

Sun HX, Gao TS, Zhong RZ, Fang Y, Di GL, Zhou DW, 2018. Effects of corn replacement by sorghum in diets on performance, nutrient utilization, blood parameters, antioxidant status, and meat colour stability in lambs. Can J Anim Sci 98(4): 723–731. https://doi.org/10.1139/cjas-2017-0136

Torkestani L, Sharifi MM, Tahmasbi R, Maddahian A, Dayani O, 2023. Effect of corn and millet silage and their particle size on feed intake, digestibility, rumen parameters, and feed intake behavior in Kermani sheep. J Livest Sci Technol 11(2): 13–23. https://doi.org/10.22103/jlst.2023.21564.1472

Van de Vyver WFJ, Beukes JA, Meeske R, 2013. Maize silage as a finisher feed for Merino lambs. S Afr J Anim Sci 43(5): 111–115. https://hdl.handle.net/10520/EJC141235

Van Soest PV, Robertson JB, Lewis BA, 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 74(10): 3583-3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Wang J, Cheng L, Chaudhry AS, Khanaki H, Abbasi IHR, Ma Y, Abbasi F, Guo X, Zhang S, 2022a. Silage mixtures of alfalfa with sweet sorghum alter blood and rumen physiological status and rumen microbiota of Karakul lambs. Animals 12(19): 2591. https://doi.org/10.3390/ani12192591

Wang M, Han H, Shang Y, Zhang L, Zhang Y, Su C, Lian H, Fu T, Gao T, 2022b. Effect of the replacement of maize silage and soyabean meal with mulberry silage in the diet of Hu lambs on growth performance, serum biochemical indices, slaughter performance, and meat quality. Animals 12(22): 3164. https://doi.org/10.3390/ani12223164

Wang Y, Wang Q, Dai C, Li J, Huang P, Li Y, Yang H, 2020. Effects of dietary energy on growth performance, carcass characteristics, serum biochemical index, and meat quality of female Hu lambs. Anim Nutr 6(4): 499-506. https://doi.org/10.1016/j.aninu.2020.05.008

Wu P, Fu X, Wang H, Hou M, Shang Z, 2021. Effect of silage diet (sweet sorghum vs. whole-crop corn) and breed on growth performance, carcass traits, and meat quality of lambs. Animals 11(11): 3120. https://doi.org/10.3390/ani11113120

Zhang J, Li F, Na R, Bai X, Ma Y, Yang Y, Wang X, 2023. The effect of replacing whole-plant corn silage with daylily on the growth performance, slaughtering performance, muscle amino acid composition, and blood composition of Tan sheep. Animals 13(22): 3493. https://doi.org/10.3390/ani13223493