

Comparative evaluation of lactation performance, milk composition and physicochemical characteristics of indigenous dual-purpose sheep breeds in Kosovo

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Abstract. Performance in lactation parameters, milk components, and udder health traits of native dual-purpose sheep breeds raised on semi-extensive management practices in Kosovo were investigated in this study. A total of 180 sheep belonging to the following three breeds - Sharri (SHA), Balusha (BAL), and Bardhoka (BAR) were selected from 15 farms in 2024. The animals were grouped in four parity classes (L1 to L4+), and milk production was measured monthly for a period of 150 days of lactation. Parameters related to milk quantity and quality such as milk yield, fat, protein, lactose content, physicochemical parameters, Somatic Cell Count (SCC), and age of first lambing (AFL) were examined applying mixed linear models where the effects of breed, parity class, and lactation stage served as fixed variables and farm as a random variable. Breed and parity showed significant effect ($P < 0.05$) on the lactation characteristics, while the breed $\times$ parity interaction was significant only for selected traits. Milk production increased from L1 to L3 parities and then declined as expected for normal physiological lactation process. The highest milk yield was detected in BAR sheep (156.1 ± 23.1 kg in L3) as well as low SCC values implying excellent udder health and dairy type orientation. There were negative correlations between milk yield and fat content, protein content, and SCC. These results indicate significant breed-specific differences regarding milk yield ability, milk composition, and udder health among local sheep breeds in Kosovo. Therefore, these findings support their target the native sheep breeds should be used in future breeding specific selection, management and conservation schemes aiming sustainability of local sheep genetic resources.

Key words: milk production, milk composition, correlated, mixed linear models, semi-extensive management.

INTRODUCTION

Sheep farming represents one of the most significant branches within animal husbandry in Kosovo and contributes greatly to socio-economic stability among families living in the rural parts of Kosovo. Sheep farming usually employs the semi-extensive

approach whereby the animals are allowed to graze in natural pasture with additional feeding of some supplements (Bytyqi et al., 2015). The systems of livestock production are related to traditional systems of agricultural production and can be practiced mainly in hillsides and other marginal areas where agriculture is difficult or impossible (FAO, 2018). Local dual-purpose breeds such as SHA, BAL, and BAR represent one of the main sources of earnings based on meat and milk production and play a very important role in the sustainability of Kosovo family farms. Breeds of sheep in Kosovo are adaptive because of their prolonged selection in nature as well as in the farms of local farmers within a low-input production environment. The above-discussed sheep breeds could be characterized based on the breed's resistance to climate change, feed conversion efficiency, adaptation to mountainous regions, and reproductive performance stability (Bytyqi et al., 2014; Bytyqi et al., 2015).

Although the dairy breeds specialized in high milk yield production under intensive management systems are valued due to their higher milk output, indigenous sheep breeds from the Balkans and Mediterranean region are preferred based on consistency, resistance to environmental challenges, and ease of handling rather than high milk yields (Pulina et al., 2018; Vacca & Dettori, 2020; Scano & Caboni, 2021). In Mediterranean territories, semi-intensive sheep production systems have been found to offer enhanced sustainability and desirable milk traits (Kasap et al., 2021; Moorby et al., 2021). Grazing can be considered as an animal feeding system that can improve the milk fatty acid profile (Cabiddu et al., 2022), for instance, by having high content of polyunsaturated fatty acids and conjugated linoleic acids than any other feeding system (Zongo et al., 2021; Massouras et al., 2023). Additionally, grazing production systems increase biodiversity, preserve rural landscape, reduce dependence on purchased feed ingredients, and preserve the indigenous animal population (Angeles Hernández et al., 2016; Bilotto et al., 2024). Moreover, they are also compatible with other sustainable policies in Europe, such as the EU Farm to Fork and Biodiversity strategies that aim at livestock production and conservation of traditional animal husbandry (European Commission, 2021a, 2021b).

There is no doubt about the economic and environmental value of indigenous sheep breeds of Kosovo. Nevertheless, there is scarce information about their lactation characteristics and features of milk and udder health. The majority of previous studies concerning indigenous breeds conducted in Kosovo are mostly concentrated on phenotypic traits description, breed identification, and production systems (Bytyqi et al., 2014; Bytyqi et al., 2015). At the same time, comparative studies evaluating milk yield characteristics during different stages of lactation and parities are still missing. In this regard, insufficient information is currently available regarding the impact of lactation stage and parity on milk yield and milk quality parameters for BAL, BAR, and SHA breeds kept in semi-extensive farms.

Furthermore, there is no systematic analysis of correlations between milk yields, milk components, SCC, and age at sexual maturity in native sheep breeds. Such comparative studies are necessary as milk productivity in sheep greatly depends on numerous factors such as breed, parity, physiological condition, nutrition, and production system (Marshall et al., 2023; Massouras et al., 2023). Thus, the knowledge of lactation peculiarities of each breed may be helpful for implementing appropriate selection and feeding strategies. Moreover, no systematic research on correlations

between milk yield, milk composition, SCC, and reproductive maturity of indigenous breeds has been performed (Souza et al., 2012; Salomone-Caballero et al., 2024).

Comparative studies regarding lactation characteristics are critical since milk productivity in sheep depends significantly on factors such as breed, parity, physiological status, feeding, and farm management system (Marshall et al., 2023; Massouras et al., 2023). An understanding of the specific patterns of lactation for each breed would contribute to the development of efficient selection methods and feeding regimes and could facilitate the selection of suitable breeds for milk-based sustainable agriculture in Kosovo. Moreover, there is a close interrelation between lactation efficiency and milk composition and they are affected not only by breed features but also by the environment and management factors. Variations in milk production in different breeds can be accompanied by variations in levels of milk constituents such as fat, protein, and lactose content affecting milk physicochemical and technological features (Carta et al., 2023). In semi-extensive sheep production systems, these characteristics may additionally reflect differences in feeding, management practices and production environment. Somatic cell count (SCC) is an important indicator of udder health and milk quality because elevated SCC may affect milk composition and its technological properties, with implications for processing characteristics and the economic value of milk (Sossidou et al., 2013; Albenzio et al., 2019; Halasa & Kirkeby, 2020). Therefore, the comparative evaluation of indigenous breeds should consider lactation performance together with milk composition, physicochemical characteristics and udder-health indicators to provide a more comprehensive assessment of their productive and technological potential importance of milk (Albenzio et al., 2019; Halasa & Kirkeby, 2020).

Evaluation of the impact that milk production will have on the condition of the udder is extremely essential in increasing production levels and making sure that the milk produced will be of high quality. Although specialized dairy breeds such as the Chios, East Friesian, and Lacaune breeds produce larger amounts of milk, their production requires greater care (Banos et al., 2007; Kasapidou et al., 2021; Zhelyazkova et al., 2023) than can be offered at the smallholders' farms of Kosovo because of better feeds and increased inputs (Bytyqi et al., 2014; Bytyqi et al., 2015). An evaluation of the local breeds in their production environment is, therefore, required to establish their efficiency and capacity for adaptation to the environment and sustainability potential. The main objective of this research was to analyse the impact of breed and parity on milk yield, milk parameters, and milk quality in SHA, BAL, and BAR sheep rose under semi-extensive systems in Kosovo. A secondary objective was to examine the association between milk yield parameters, SCC, and the age at which the first lamb was born in order to assess the impacts of udder health and reproduction on milk yield.

MATERIALS AND METHODS

Animals and diets

In this study, the milk yield, lactation characteristics, milk composition traits, and udder health parameters of dual-purpose sheep breeds raised under semi-extensive production systems in Kosovo during 2004 have been assessed. Fifteen semi-extensive sheep farms located in Kosovo were included in the study. The farms were chosen based on the presence of any of the three native sheep breeds used in this study: SHA, BAL

and BAR (Figs 1, 2 & 3). In this study, the total number of farms was thus 15. It is important to note, however, that since the farms chosen were those with at least one breed of sheep used in this study, the number of farms shown for each breed in Table 2 is thus the number of farms where the breed is present.



Figure 1. SHA sheep.



Figure 2. BAR sheep.



Figure 3. BAL sheep.

The selection of the breeds was based on their widespread use in rural farm production systems, making them vital in terms of developing sustainable small-scale farming systems in Kosovo. For all breeds and combinations of breed and parities (four levels - first parity L1, second parity L2, third parity L3, and fourth or more parities L4+), 15 animals per parity and per each breed were selected in total, making up a population of 180 ewes. Animals were selected by considering the phenotypic characteristics of the breed to maintain breed purity. Healthy animals only were taken into consideration, while to avoid data uncertainty those less than 12 months or over 8 years old were not considered in the study. Ewes were additionally grouped according to parity to minimize physiological variation among experimental groups. The farming was based on conventional semi-extensive management, which is typically utilized in Kosovo. The sheep grazed natural pastures during all but three months when supplementary feed was supplied to pregnant and lactating ewes. The availability and intensity of the grazing changed seasonally depending on the climate and forage produced (Table 1).

Milk sampling and milk quality characteristics

The technique of milking was based on conventional milking by hand as practiced in rural sheep-farming communities in Kosovo (Bytyqi et al., 2014; Pardo & Del Prado, 2020). The sampling of milk was performed monthly for five months to reflect the average duration of lactation lasting about 150 days in local sheep breeds. Lambs were generally suckled for approximately 90 days and were separated from their dams on the day of milk sampling. Disinfection of the teats of sheep took place using 70% alcohol prior to milking. Milk (50–100 mL) was collected by hand milking in sterile polypropylene tubes and homogenized while keeping them refrigerated at 4 °C. The analyses done on the milk sample entailed determining the percentage of fat, protein, and lactose contents of milk. Other milk properties analyzed included pH, density, and freezing point. SCC was also evaluated and reported as log₁₀ SCC. For milk content analyses, pH and determination of SCC, MilkoScan FT 120 (Infrared spectrophotometry, ISO 9622 - ISO, 2013), pH meter (benchtop pH analyzer) and Fossomatic™ Minor

(Fluoro-optic electronic method, ISO 13366-2 - ISO, 2006) devices (ISO, 2006), respectively were used at referent laboratory of Kosovo Food and Veterinary Agency. Age at first lambing was recorded as a reproductive trait to evaluate its potential relationship with milk production and udder health characteristics. Procedures for all animal management and milk samples adhered to ethical guidelines set forth by the institution and country regarding animal care and research studies.

Table 1. Main feed resources provided to the indigenous sheep breeds under the semi-extensive production system during the study period in Kosovo

Feed resource	Type/category	Period of use	Main animals receiving the feed	Main purpose in the production system
Natural grassland/pasture	Grazed forage	Most of the year	All sheep	Main source of energy, protein and fibre during the grazing season
Hay from natural meadows	Conserved forage	Winter and periods of limited pasture availability	Ewes and other sheep	Maintenance and roughage supply during periods when grazing is restricted
Cereal straw (mainly wheat straw)	Crop residue/roughage	Mainly winter	Adult sheep, particularly non-lactating animals	Fibre and roughage source; commonly used as a low-cost feed resource
Maize/wheat grain mixture	Cereal concentrate	Mainly late pregnancy and lactation	Pregnant and lactating ewes	Additional energy supply to support pregnancy and milk production
Bran (wheat bran)	Cereal by-product	Mainly during supplementation periods	Pregnant and lactating ewes	Supplementary energy and protein source
Legume hay (e.g., alfalfa)	Conserved forage	Winter and supplementation periods	Pregnant and lactating ewes	Higher-quality forage and supplementary protein
Crop residues and other locally available forage resources	Agricultural by-products	Mainly after harvest/winter	Sheep according to farm practice	Low-cost supplementary roughage

Statistical analysis

Descriptive and inferential statistical analysis was done using R statistical software, version 4.3.1 (R Core Team, 2023). The mean and standard deviation (SD), of all recorded characteristics were calculated; standard error was calculated as: $SE = SD/\sqrt{n}$. To evaluate the effects of breed, parity, and lactation stage on milk yield and composition traits, linear mixed models (LMM) were applied. Breed (SHA, BAL, and BAR), parity group (L1–L4+), and month of lactation were treated as fixed effects, while farm was included as a random effect to account for environmental and management variability among farms and to avoid pseudo-replication. The general mixed-model equation used was:

$$Y_{ijklm} = \mu + B_i + P_j + M_l + (B \times P)_{ij} + (B \times M)_{il} + F_k + e_{ijklm} \quad (1)$$

where Y_{ijklm} = Observed value for dependent trait; μ = Overall mean value; B_i = Fixed effects of breed; P_j = Fixed effect of parity; M_l = Monthly repeated measures during lactation period; $(B \times P)_{ij}$ = Interaction between breed and parity; $(B \times M)_{il}$ = Interaction between breed and month; F_k = Random effect of farm and e_{ijklm} = Residual effects. Monthly and daily milk yield were analysed using a mixed linear model, with breed considered as a fixed effect and the relevant repeated/random effects included according to the experimental design. Differences among breed means were evaluated within the mixed-model framework at $P < 0.05$. Pearson's correlation coefficients were also calculated. In addition to the current 150-day lactation analysis, recent dairy sheep studies increasingly apply random regression test-day models (RRM) for dynamic lactation curve and genetic evaluation analyses (Kominakis et al., 2001; Banos et al., 2007; Zhelyazkova et al., 2023).

RESULTS AND DISCUSSION

Milk yield and lactation performance

As shown in Table 2, the selected three breeds of dual-purpose indigenous sheep (SHA, BAL, and BAR) had a well-balanced experimental cohort with 15 ewes per lactation group (L1-L4+). Differences in AFL across breeds indicated some differences among breeds with respect to reproductive maturation and adaptation in semi-extensive production systems.

Table 2. Number of ewes per breed and parity group, and mean AFL First Lambing (Months $\pm$ SD)

Breed	Breed-represented farms (n)	n(L1)	n(L2)	n(L3)	n(L4+)	AFL first (mean $\pm$ SD)
SHA	5	15	15	15	15	15.8 $\pm$ 1.5
BAR	5	15	15	15	15	16.2 $\pm$ 1.5
BAL	5	15	15	15	15	14.7 $\pm$ 1.2
Total	15	45	45	45	45	15.6 $\pm$ 1.4

The lowest AFL was found for BAL breed (14.7 $\pm$ 1.2 months), with intermediate AFL noted for SHA breed (15.8 $\pm$ 1.5 months), while the highest AFL was observed for BAR breed (16.2 $\pm$ 1.5 months). In spite of relatively minor differences in AFL, they indicate some breed-dependent variability in sexual maturation. Early reproductive maturation is regarded as an important economically valuable trait for increasing life-time productivity of the sheep herd. Indeed, early lambing and subsequent rapid body maturation and early weaning are key characteristics of Mediterranean sheep breeds bred on pasture-based systems with good adaptation of animals to low input environmental conditions (Furesi et al., 2015; Marshall et al., 2023; Koluman et al., 2024).

Milk yield performances in accordance with lactation parities showed the physiological tendency of increasing milk yields from first to third parities and later stabilization or reduction in the older parities (Fig. 4, Table 3).

Such physiological behavior was evident for all breeds tested, due to progressive development of the mammary glands, increased activity of secretory tissue and efficient

metabolism in mature parities (Wendorff & Haenlein, 2017). Younger parities were known for their nutritional needs towards body growth apart from producing milk, thus having low milk yields.

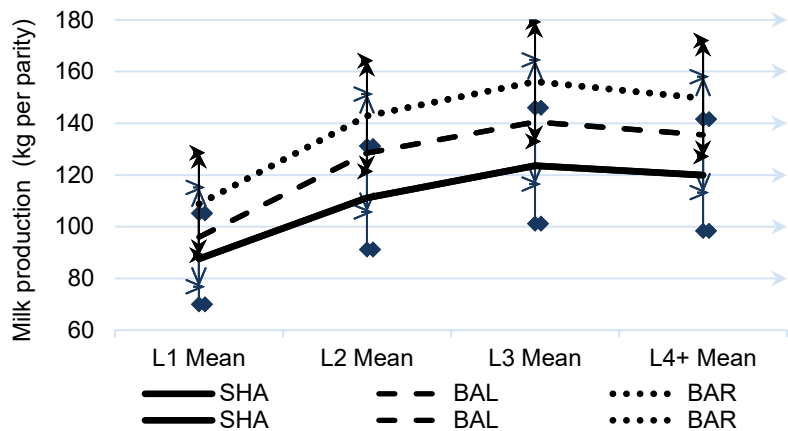


Figure 4. Total 150 days' milk production (150-DMY, kg) by breed and parity (order of lactation). 150-DMY refers to total milk production accumulated during the 150 days of lactation. Data are shown for three breeds of indigenous sheep (SHA, BAL, and BAR) in four categories of parities (L1, L2, L3, and L4+), with $n = 15$ animals for each category of breeds and parities (total $n = 180$ animals).

Peak performance is typically reached during middle parities, while later decline may be associated with tissue aging and reduced endocrine responsiveness. Among the breeds studied, BAR showed the highest milk yield throughout the lactation period. Total milk yield increased from 108.8 ± 19.8 kg in first lactation to 156.1 ± 23.1 kg in third lactation before declining slightly in L4+. BAL exhibited moderate lactational performance, achieving a maximum level of 140.5 ± 24.0 kg in L3, whereas SHA showed poor but relatively stable lactation levels, achieving a maximum of 123.6 ± 22.4 kg in L3.

The lactation curves of monthly production followed a normal biological trend where production increased substantially throughout Month 1 and reached its peak either in Month 2 or Month 3, after which production gradually decreased towards the end of the lactation period of 150 days. In terms of parities, BAR exhibited the highest levels of production curve, BAL exhibited moderately high levels, and SHA consistently produced low levels.

Table 3 demonstrates variations in the milk output for the three indigenous breeds and by parity and lactation month. The total milk yield in 150 days was highest for BAR compared to BAL and SHA. For each indigenous breed, the milk production was increased from L1 to L3, where the maximum milk production was obtained at L3, and the amount of this production was 156.1 ± 23.1 kg for BAR, 140.5 ± 24.0 kg for BAL, and 123.6 ± 22.4 kg for SHA. It has been found in the mixed linear model that there is a statistically significant difference between breeds in the milk yield per month and day. A very significant finding in terms of the results obtained from the pairwise comparison for the mixed model was that the difference observed among the breeds was indeed

evident. There was a statistical effect for breed ($P < 0.001$), parity or lactation ($P = 0.015$), and lactation month ($P < 0.001$). Breed by parity ($P = 0.042$), and breed by lactation month ($P = 0.031$) interactions statistically contributed to validating this observation. Monthly milk yield followed a broadly similar pattern across breeds, increasing from the first month to a peak around the third month, followed by a gradual decline during the fourth and fifth months. BAR consistently showed the highest monthly yields, reaching 33.3 ± 4.7 kg in L3 during month 3, whereas SHA generally recorded the lowest values. These results indicate substantial breed-specific differences in productive capacity while demonstrating a broadly comparable lactation trajectory. Under Kosovo's semi-extensive production conditions, the superior performance of BAR and intermediate performance of BAL may reflect differences in genetic potential and adaptation to variable pasture availability, seasonal feed resources, and management conditions. Regarding this matter, BAR and BAL exhibited comparable productivity in comparison with other Mediterranean adaptive breeds like Awassi and Sarda (Vacca & Dettori, 2020; Pulina et al., 2021). The findings support breed-specific breeding and management strategies for sustainable utilization of Kosovo's indigenous sheep genetic resources.

Table 3. Monthly and Total 5-Month Milk Yield (kg) in Ewes by Breed and Parity Group (Mean $\pm$ SD) with Significance Effects of Lactation, Breed and Month

Breed $\times$ Parity	Month 1	Month 2	Month 3	Month 4	Month 5	Total (150d)
SHA L1	14.4 $\pm$ 3.6	20.0 $\pm$ 3.6	20.8 $\pm$ 3.6	18.4 $\pm$ 3.6	14.0 $\pm$ 3.6	87.6 $\pm$ 17.6
SHA L2	18.4 $\pm$ 4.1	24.0 $\pm$ 4.1	25.6 $\pm$ 4.1	23.2 $\pm$ 4.1	20.0 $\pm$ 4.1	111.2 $\pm$ 19.5
SHA L3	20.0 $\pm$ 4.6	26.4 $\pm$ 4.6	28.0 $\pm$ 4.6	25.6 $\pm$ 4.6	23.3 $\pm$ 4.6	123.6 $\pm$ 22.4
SHA L4+	19.2 $\pm$ 3.7	25.6 $\pm$ 3.7	27.2 $\pm$ 3.7	24.8 $\pm$ 3.7	23.2 $\pm$ 3.7	120.0 $\pm$ 21.6
BAL L1	16.0 $\pm$ 3.8	22.4 $\pm$ 3.8	23.2 $\pm$ 3.8	20.8 $\pm$ 3.8	14.4 $\pm$ 3.8	96.0 $\pm$ 19.2
BAL L2	20.9 $\pm$ 4.6	27.2 $\pm$ 5.7	28.8 $\pm$ 5.7	27.2 $\pm$ 5.7	24.5 $\pm$ 5.7	128.5 $\pm$ 22.8
BAL L3	22.5 $\pm$ 4.8	29.6 $\pm$ 4.8	30.5 $\pm$ 4.8	28.8 $\pm$ 4.8	29.2 $\pm$ 4.8	140.5 $\pm$ 24.0
BAL L4+	21.2 $\pm$ 4.6	28.8 $\pm$ 4.6	30.6 $\pm$ 4.6	28.0 $\pm$ 4.6	27.6 $\pm$ 4.6	135.6 $\pm$ 22.4
BAR L1	18.4 $\pm$ 3.9	24.8 $\pm$ 3.9	25.2 $\pm$ 3.7	23.2 $\pm$ 3.7	17.7 $\pm$ 3.7	108.8 $\pm$ 19.0
BAR L2	24.5 $\pm$ 4.3	30.0 $\pm$ 4.3	31.3 $\pm$ 4.3	30.0 $\pm$ 4.3	27.2 $\pm$ 4.3	142.8 $\pm$ 21.4
BAR L3	25.8 $\pm$ 4.7	32.6 $\pm$ 4.7	33.3 $\pm$ 4.7	32.0 $\pm$ 4.7	31.9 $\pm$ 4.7	156.1 $\pm$ 23.1
BAR L4+	24.5 $\pm$ 4.5	32.0 $\pm$ 4.5	32.7 $\pm$ 4.5	30.6 $\pm$ 4.5	29.9 $\pm$ 4.5	149.6 $\pm$ 22.4
<i>Sources of variations</i>						<i>p-value</i>
Breed						<0.001
Parity (lactation group)						<0.015
Month						<0.001
Breed $\times$ parity						0.042
Breed $\times$ month						0.031

Milk compositional parameters

According to Table 4, there is a reliable positive parity-specific correlation in both fat and protein milk contents regardless of breed. In SHA, the fat content increases steadily from 6.2% in first lactation (L1) to 6.7% in L4+. Similarly, BAR and BAL had somewhat lesser, yet comparable, values of fat content. Likewise, the protein content demonstrates an increase from 5.1% to 5.3% (in L1) to 5.4%–5.6% in L4+.

Table 4. Milk composition by breed and parity group (Mean $\pm$ SD)

Breed	L1	L2	L3	L4+
Fat (%)				
SHA	6.21 $\pm$ 0.72	6.44 $\pm$ 0.70	6.64 $\pm$ 0.81	6.73 $\pm$ 0.84
BAL	6.06 $\pm$ 0.75	6.23 $\pm$ 0.72	6.44 $\pm$ 0.82	6.56 $\pm$ 0.82
BAR	5.87 $\pm$ 0.64	6.04 $\pm$ 0.62	6.25 $\pm$ 0.73	6.36 $\pm$ 0.74
Protein (%)				
SHA	5.32 $\pm$ 0.53	5.42 $\pm$ 0.53	5.53 $\pm$ 0.64	5.60 $\pm$ 0.64
BAL	5.23 $\pm$ 0.51	5.33 $\pm$ 0.54	5.44 $\pm$ 0.64	5.53 $\pm$ 0.63
BAR	5.14 $\pm$ 0.44	5.27 $\pm$ 0.53	5.35 $\pm$ 0.55	5.44 $\pm$ 0.51
Lactose (%)				
SHA	4.75 $\pm$ 0.34	4.72 $\pm$ 0.33	4.64 $\pm$ 0.33	4.65 $\pm$ 0.36
BAL	4.74 $\pm$ 0.33	4.72 $\pm$ 0.34	4.66 $\pm$ 0.34	4.64 $\pm$ 0.35
BAR	4.80 $\pm$ 0.31	4.83 $\pm$ 0.33	4.71 $\pm$ 0.33	4.76 $\pm$ 0.33

These findings indicate increasing solids concentration with physiological maturity. Lactose concentration remained relatively stable across breeds and parities (approximately 4.6–4.8%), consistent with its central osmotic role in milk secretion. In summary, SHA milk contained the richest components, especially in terms of fat and protein, while BAR milk produced the highest yields but with low solid content. The mentioned characteristics are quite relevant to dairy sheep production with dual purpose of cheese making, which can be done more effectively when milk solid contents are high.

Physicochemical Characteristics and Udder Health

Udder health and physicochemical properties of milk were constant through lactation (Table 5). Milk pH values fluctuated from around 6.60 to 6.64, being gradually reduced with the increase of parity. Density of milk stayed at low fluctuations (approximately 1.035–1.037 g mL⁻¹), while freezing point was in the range of -0.570– -0.582 °C.

Table 5. Physical properties and udder health indicators of milk by breed and parity (Mean $\pm$ SD)

Breed	L1	L2	L3	L4+
pH (20 °C)				
SHA	6.64 $\pm$ 0.06	6.63 $\pm$ 0.06	6.62 $\pm$ 0.06	6.61 $\pm$ 0.06
BAL	6.64 $\pm$ 0.06	6.63 $\pm$ 0.06	6.62 $\pm$ 0.06	6.61 $\pm$ 0.06
BAR	6.63 $\pm$ 0.05	6.62 $\pm$ 0.05	6.61 $\pm$ 0.05	6.60 $\pm$ 0.05
Density (g mL ⁻¹ at 20 °C)				
SHA	1.036 $\pm$ 0.002	1.036 $\pm$ 0.002	1.037 $\pm$ 0.002	1.037 $\pm$ 0.002
BAL	1.036 $\pm$ 0.002	1.036 $\pm$ 0.002	1.037 $\pm$ 0.002	1.037 $\pm$ 0.002
BAR	1.035 $\pm$ 0.002	1.035 $\pm$ 0.002	1.036 $\pm$ 0.002	1.036 $\pm$ 0.002
Freezing Point (°C)				
SHA	-0.575 $\pm$ 0.015	-0.578 $\pm$ 0.015	-0.580 $\pm$ 0.016	-0.582 $\pm$ 0.016
BAL	-0.575 $\pm$ 0.015	-0.578 $\pm$ 0.015	-0.580 $\pm$ 0.016	-0.582 $\pm$ 0.016
BAR	-0.570 $\pm$ 0.014	-0.574 $\pm$ 0.014	-0.578 $\pm$ 0.015	-0.580 $\pm$ 0.015
log ₁₀ SCC mL ⁻¹				
SHA	5.30 $\pm$ 0.25	5.32 $\pm$ 0.25	5.35 $\pm$ 0.26	5.38 $\pm$ 0.26
BAL	5.28 $\pm$ 0.25	5.30 $\pm$ 0.25	5.33 $\pm$ 0.26	5.36 $\pm$ 0.26
BAR	5.25 $\pm$ 0.24	5.27 $\pm$ 0.24	5.30 $\pm$ 0.25	5.33 $\pm$ 0.25

It means that there were no traces of adulteration in milk samples, while osmotic pressure was steady. SCC increased progressively along with the increase of parity from log₁₀ 5.25 in BAR L1 up to 5.38 in SHA L4+. These values are still normal in sheep milk. Similar breed differences in mammary immune response have been described previously (Riggio, 2012). However, although SCC levels were somewhat increased in the case of SHA, they fell within the limits of normal biological variations, which may imply adaptation of specific breeds to semi-extensive rearing conditions, rather than clinical mastitis.

In general, stability of physicochemical parameters can be considered an indication of satisfactory milk hygienic conditions and stable product quality despite environmental variations. Similarly, the same stability levels have been reported among Mediterranean breeds raised under grazing conditions (Nguyen, 2022; Jirillo, 2024; Koluman et al., 2024).

Combined effects of breed and parity

From the results of a MLM analysis (Table 6), the effects of the breed, lactation, and their interaction were very highly significant in relation to milk production ($F = 55.4$, $p < 0.001$; $F = 82.9$, $p < 0.001$; $F = 5.2$, $p < 0.001$).

Table 6. The mixed linear model results for effects of breed, parity, and their interaction on milk yield and composition

Trait	Effect	F	<i>p</i> -value	Significant effect
Milk Yield	Breed	92.4	< 0.001	Yes
	Lactation	138.1	< 0.001	Yes
	Breed × Lactation	5.2	< 0.001	Yes
Fat (%)	Breed	10.3	< 0.001	Yes
	Lactation	14.6	< 0.001	Yes
	Breed × Lactation	2.4	0.028	Yes
Protein (%)	Breed	7.8	0.0005	Yes
	Lactation	11.1	< 0.001	Yes
	Breed × Lactation	2.1	0.051	No (trend)
Lactose (%)	Breed	6.2	0.002	Yes
	Lactation	4.7	0.003	Yes
	Breed × Lactation	1.6	0.14	No

(df: Breed = 2; Lactation = 3; Interaction = 6; Residual = 112; $n = 180$).

Consequently, it would be appropriate to conclude that milk production depends on both genetics and physiological maturation of each breed, which implies some lactation responses among breeds. The fat and protein contents were significantly influenced by breed and lactation, while the breed and lactation interaction was significant for the fat content only ($p = 0.028$) and borderline significant for protein content ($p = 0.051$). Hence, the aforementioned evidence shows that milk production and fat content depend on both genetics and physiology, while protein and lactose are influenced primarily by main effects rather than interactions, in line with other studies (Selvaggi et al., 2017; Kasap et al., 2021).

These comparisons reinforce the strong breed-based production potential of BAR and BAL. From a practical perspective, BAR appears most suitable for dual-purpose production because it combines high milk output, relatively low SCC, and stable milk

quality. BAL demonstrated intermediate performance and balanced adaptability. SHA produced lower milk volumes but higher concentrations of fat and protein, which may offer particular value for traditional cheese-making and artisanal dairy systems.

Correlations among milk yield, composition, and udder health traits

Table 7 illustrated biologically relevant correlations between milk yield and milk composition traits.

Table 7. Pearson Correlation Coefficients (r) and statistical significance among milk yield, milk composition, somatic cell count, and age at first lambing in indigenous sheep breeds of Kosovo

Traits	R	<i>p</i> -value	Interpretation
Fat	-0.35	<0.001	Moderate association (dilution effect)
Protein	-0.40	<0.001	Moderate association
Lactose	+0.20	0.007	Weak trend
log10 SCC	-0.45	<0.001	Negative, higher yield = lower SCC
Age at 1 st lamb	+0.25	<0.001	Weak trend (older ewes yield slightly more)
Protein	+0.55	<0.001	Moderate positive
Lactose	-0.30	<0.001	Weak association
log10 SCC	+0.20	<0.001	Slight positive
Lactose	-0.25	<0.001	Weak association
log10 SCC	+0.30	0.007	Weak trend
log10 SCC	-0.35	<0.001	Negative

Correlations among milk yield, composition, udder health, and reproductive traits

The analysis of correlations (Pearson correlation) between milk yield, milk composition, SCC, and the age of first lambing revealed several interesting features (Table 7). Milk yield had negative correlations with fat ($r = -0.35$, $P < 0.001$) and protein ($r = -0.40$, $P < 0.001$) levels, implying that the level of milk secretion is inversely related to the concentration of the major milk components. Such an association between the milk yield and the major milk components is quite common for dairy sheep because of the so-called "dilution effect" occurring when higher levels of milk secretion reduce the concentrations of major components of milk. Similar negative correlations between milk yield and major components of milk were found in other Mediterranean breeds of dairy sheep such as Sarda and Awassi breeds (Pulina et al., 2021; Massouras et al., 2023). From a physiological point of view, the increased secretion of milk involves increased transfer of water into milk, leading to reduced concentrations of some solid components. On the contrary, lower-yielding ewes secrete smaller amounts of milk with relatively high concentrations of milk solids, which is beneficial for artisanal cheese production. There is a statistically weak and significant positive correlation between milk yield and lactose ($r = 0.20$, $P = 0.007$). There is a positive correlation between milk yield and lactose content ($r = 0.20$, $P = 0.007$). The above correlation can be explained by the role of lactose in regulating the milk production and secretion of mammary glands during lactation. Conversely, there is a moderate negative correlation between milk yield and log₁₀ SCC ($r = -0.45$, $P < 0.001$). From the above result, it can be concluded that the ewes with higher milk production had low SCC in the current experiment. However, it should be stated that the correlation between milk production and somatic cell count

should be treated with caution since there is no direct causality between the two factors under consideration. It was found out that the positive correlation exists between milk yield and age at first lambing ($r = 0.25$, $P < 0.001$). It should be admitted that the most essential relation between the milk components could be defined between the fat and protein components ($r = 0.55$, $P < 0.001$). Milk composition metrics revealed a distinct negative correlation of lactose with both fat content ($r = -0.25$), $P < 0.001$) and protein content ($r = -0.30$), $P < 0.001$). Conversely, somatic cell tracking indicated that $\log_{10}$ SCC shares weak but statistically significant positive associations with both fat ($r = 0.30$, $P < 0.001$) and protein percentages ($r = 0.20$, $P = 0.007$). On the other hand, it can be said that there is a moderate inverse correlation between lactose content and $\log_{10}$ SCC ($r = -0.35$, $P < 0.001$). In summary, this research provides one of the initial assessments in relation to the relationship between lactational performance, milk quality, and mammary gland health in indigenous sheep breeds within Kosovo under semi-extensive farming practices. This assessment indicates that both breed and parity have a clear effect on each of these areas. BAR appears particularly promising where milk volume and flock productivity are primary objectives, BAL offers balanced dual-purpose performance, and SHA contributes valuable milk solids and product quality. These results support the conservation and strategic improvement of Kosovo's indigenous sheep genetic resources and provide a scientific basis for sustainable breeding programs in the Balkans.

CONCLUSIONS

In the present study, there were clear influences of breed and parity on the milk productivity, milk composition and health traits of indigenous dual purpose sheep breeds (SHA, BAL, and BAR) kept in the semi-extensive husbandry system in Kosovo. Breed BAR had the highest level of milk production accompanied by the lowest somatic cell counts, which suggests its dairy-type disposition and high udder health status, thus this breed is best for high-volume milk production. The performance of BAL is moderate but stable, and this supports its adaptation ability, while being of lower performance compared to BAR. SHA breed had lower levels of milk production and higher concentrations of milk fat and protein. Such compositional traits have been known to be one of the characteristics of cheese production capacity, but in this case, it has not been considered for this research. From the data gathered, it can be observed that the maximum milk yield was at the third lactation before dropping off. It is clear from the above information that there is need to conserve and protect the local sheep genetics of Kosovo. Future research should include larger populations, genomic analyses, random regression models for lactation curves, and direct cheese-making trials to empirically validate the technological and processing potential of milk from these native breeds.

REFERENCES

- Albenzio, M., Figliola, L., Caroprese, M., Marino, R., Sevi, A. & Santillo, A. 2019. Somatic cell count in sheep milk. *Small Ruminant Research* **176**, 24–30. <https://doi.org/10.1016/j.smallrumres.2019.05.013>

- Angeles Hernández, J.C., Castelan Ortega, O.A., Radic Schilling, S., Angeles Campos, S., Ramirez Perez, A.H. & Gonzalez Ronquillo, M. 2016. Organic dairy sheep production management. In P. Konvalina (Ed.), *Organic farming – A promising way of food production*. IntechOpen. <https://doi.org/10.5772/61458>
- Banos, G., Arsenos, G., Abas, Z. & Basdagianni, Z. 2007. Population parameter estimation of daily milk yield of the Chios sheep using test day random regression models and Gibbs sampling. *Animal Science* **81**(2), 233–238. <https://doi.org/10.1079/ASC50030233>
- Bilotto, F., Harrison, M.T., Vibart, R., Mackay, A., Christie Whitehead, K.M., Ferreira, C.S.S., Cottrell, R.S., Forster, D. & Chang, J. 2024. Towards resilient, inclusive, sustainable livestock farming systems. *Trends in Food Science & Technology* **152**, 104668. <https://doi.org/10.1016/j.tifs.2024.104668>
- Bytyqi, H., Baumung, R., Mehmeti, H. & Fuerst-Waltl, B. 2014. Phenotypic characterization and description of production systems of autochthonous sheep breeds in Kosovo. *Animal Genetic Resources* **54**, 163–170. <https://doi.org/10.1017/S207863361400003>
- Bytyqi, H., Fuerst-Waltl, B., Mehmeti, H. & Baumung, R. 2015. Economic values for production traits for different sheep breeds in Kosovo. *Italian Journal of Animal Science* **14**(4), Article 3808. <https://doi.org/10.4081/ijas.2015.3808>
- Cabiddu, A., Carrillo, S., Contini, S., Spada, S., Acciaro, M., Giovanetti, V., Decandia, M., Lucini, L., Bertuzzi, T., Gallo, A. & Salis, L. 2022. Dairy sheep grazing management and pasture botanical composition affect milk macro and micro components: A methodological approach to assess the main managerial factors at farm level. *Animals* **12**(19), Article 2675. <https://doi.org/10.3390/ani12192675>
- Carta, S., Cesarani, A., Correddu, F. & Macciotta, N.P.P. 2023. Understanding the phenotypic and genetic background of the lactose content in Sarda dairy sheep. *Journal of Dairy Science* **106**(5), 3312–3320. <https://doi.org/10.3168/jds.2022-22579>
- European Commission. 2021a. *Farm to Fork strategy: For a fair, healthy and environmentally friendly food system*. https://ec.europa.eu/info/food-farming-fisheries/sustainability/farm-fork-strategy_en
- European Commission. 2021b. *EU biodiversity strategy for 2030: Bringing nature back into our lives*. https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/eu-biodiversity-strategy-2030_en
- Food and Agriculture Organization of the United Nations (FAO). 2018. *World livestock: Transforming the livestock sector through the Sustainable Development Goals*. FAO. <https://doi.org/10.4060/ca1201en>
- Furesi, R., Madau, F.A., Pulina, P. & Atzori, A.S. 2015. Sustainability of dairy sheep production in pasture lands: A case study approach to integrate economic and environmental perspectives. *Rivista di Studi sulla Sostenibilità* **5**(1), 117–134. <https://doi.org/10.3280/RISS2015-001008>
- Halasa, T. & Kirkeby, C. 2020. Differential somatic cell count: Value for udder health management. *Frontiers in Veterinary Science* **7**, Article 609055. <https://doi.org/10.3389/fvets.2020.609055>
- International Organization for Standardization (ISO). 2013. *ISO 9622:2013 Milk and liquid milk products - Guidelines for the application of mid-infrared spectrometry*. <https://www.iso.org/standard/56874.html>
- International Organization for Standardization (ISO). 2006. *ISO 13366-2:2006 Milk - Enumeration of somatic cells - Part 2: Guidance on the operation of fluoro-opto-electronic counters*. <https://www.iso.org/standard/40260.html>
- Jirillo, F. 2024. Healthy effects of milk and dairy product consumption in the Mediterranean area and Japan. *Current Nutrition & Food Science* **24**(15), 1813–1822. <https://doi.org/10.2174/0118715303289711240703080701>

- Kasap, A., Ramljak, J. & Špehar, M. 2021. Estimation of population-specific genetic parameters important for long-term optimum contribution selection-Case study on a dairy Istrian sheep breed. *Animals* **11**(8), 2356. <https://doi.org/10.3390/ani11082356>
- Kasapidou, E., Basdagianni, Z., Papadopoulos, V., Karaïskou, C., Kesidis, A. & Tsiotsias, A. 2021. Effects of intensive and semi-intensive production on sheep milk chemical composition, physicochemical characteristics, fatty acid profile, and nutritional indices. *Animals* **11**(9), Article 2578. <https://doi.org/10.3390/ani11092578>
- Koluman (Darcın), N. & Paksoy, Y. 2024. Sustainability of sheep farming in Eastern Mediterranean region. In *Sheep farming – Sustainability from traditional to precision production*. IntechOpen. <https://doi.org/10.5772/intechopen.114257>
- Kominakis, A.P., Volanis, M. & Rogdakis, E. 2001. Genetic modelling of test day records in dairy sheep using orthogonal Legendre polynomials. *Small Ruminant Research* **39**(3), 209–217. [https://doi.org/10.1016/S0921-4488\(00\)00191-7](https://doi.org/10.1016/S0921-4488(00)00191-7)
- Marshall, A.C., Lopez-Villalobos, N., Loveday, S.M., Ellis, A. & McNabb, W. 2023. Modelling lactation curves for dairy sheep in a New Zealand flock. *Animals* **13**(3), Article 349. <https://doi.org/10.3390/ani13030349>
- Massouras, T., Charmanta, A.-A., Koutsouli, P., Masoura, M., Politis, I. & Hettinga, K. 2023. The effect of milking frequency, breed, and stage of lactation on the milk fat globule size and fatty acid composition in sheep's milk. *Foods* **12**(13), Article 2446. <https://doi.org/10.3390/foods12132446>
- Moorby, J.M. & Fraser, M.D. 2021. Review: New feeds and new feeding systems in intensive and semi-intensive forage-fed ruminant livestock systems. *Animal* **15**(Suppl. 1), Article 100297. <https://doi.org/10.1016/j.animal.2021.100297>
- Nguyen, V.Q. 2022. Nutritional value and factors affecting milk production and milk composition from dairy sheep: A review. *CTU Journal of Innovation and Sustainable Development* **14**(3), 53–64. <https://doi.org/10.22144/ctu.jen.2022.047>
- Pardo, G. & Del Prado, A. 2020. Guidelines for small ruminant production systems under climate emergency in Europe. *Small Ruminant Research* **193**, Article 106261. <https://doi.org/10.1016/j.smallrumres.2020.106261>
- Pulina, G., Atzori, A.S., Dimauro, C., Sechi, T. & Nudda, A. 2021. The milk fingerprint of Sardinian dairy sheep: Quality and yield of milk used for Pecorino Romano PDO cheese production on a population-based 5-year survey. *Italian Journal of Animal Science* **20**(1), 171–180. <https://doi.org/10.1080/1828051X.2021.1875896>
- Pulina, G., Milán, M.J., Lavín, M.P., Theodoridis, A., Morin, E., Capote, J., Thomas, D.L., Francesconi, A.H.D. & Caja, G. 2018. Invited review: Current production trends, farm structures, and economics of the dairy sheep and goat sectors. *Journal of Dairy Science* **101**(8), 6715–6729. <https://doi.org/10.3168/jds.2017-14015>
- R Core Team. 2023. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Riggio, V. 2012. *Genetic aspects of somatic cell count and udder health in the Italian Valle del Belice dairy sheep* (Doctoral dissertation, Wageningen University). <https://doi.org/10.18174/209978>
- Salomone-Caballero, M., Fresno, M., Álvarez, S. & Torres, A. 2024. Effects of parity and somatic cell count threshold on udder morphology, milkability traits, and milk quality in Canarian goats. *Animals* **14**(9), 1262. <https://doi.org/10.3390/ani14091262>
- Scano, P. & Caboni, P. 2021. Innovation meets tradition in the sheep and goat dairy industry. *Dairy* **2**(3), 422–424. <https://doi.org/10.3390/dairy2030033>
- Selvaggi, M., D'Alessandro, A.G. & Dario, C. 2017. Environmental and genetic factors affecting milk yield and quality in three Italian sheep breeds. *Journal of Dairy Research* **84**(1), 27–31. <https://doi.org/10.1017/S0022029916000765>

- Sossidou, E.N., Ligda, C., Mastranestasis, I., Tsiokos, D. & Samartzi, F. 2013. Sheep and goat farming in Greece: Implications and challenges for the sustainable development of less favoured areas. *Animal Science and Biotechnologies* **46**(2), 446–449.
- Souza, F.N., Blagitz, M.G., Penna, C., Della Libera, A.M.M.P., Heinemann, M.B. & Cerqueira, M.M.O.P. 2012. Somatic cell count in small ruminants: Friend or foe? *Small Ruminant Research* **107**(2–3), 65–75. <https://doi.org/10.1016/j.smallrumres.2012.04.005>
- Vacca, G.M. & Dettori, M.L. 2020. Dairy sheep breeding and genetics in the Mediterranean basin. *Animals* **10**(4), Article **726**. <https://doi.org/10.3390/ani10040726>
- Wendorff, W.L. & Haenlein, G.F.W. 2017. Sheep milk: Composition and nutrition. In Y. W. Park & G.F.W. Haenlein (Eds.), *Handbook of milk of non-bovine mammals* (2nd ed., Chapter 3.2). Wiley-Blackwell. <https://doi.org/10.1002/9781119110316.ch3.2>
- Zhelyazkova, P., Dimov, D. & Andonov, S. 2023. Genetic parameter estimation of milk yield in White Maritza sheep breed using different test-day models. *Archives of Animal Breeding* **66**(3), 253–263. <https://doi.org/10.5194/aab-66-253-2023>
- Zongo, K., Krishnamoorthy, S., Moses, J.A., Yazici, F., Çon, A.H. & Anandharamakrishnan, C. 2021. Total conjugated linoleic acid content of ruminant milk: The world status insights. *Food Chemistry* **334**, Article 127555. <https://doi.org/10.1016/j.foodchem.2020.127555>