**Original Paper**

# Factors Influencing the Production and Quality of Sheep's Milk

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To maintain adequate dairy productivity in sheep, it is important to focus on establishing appropriate husbandry conditions. Currently, breeders are increasingly confronted with extreme weather fluctuations during the grazing season, which significantly impact pasture quality and the milk produced. Therefore, it is crucial to seek suitable breeding systems with breed representation tailored to various climatic and geographical conditions in order to exploit their productive potential fully. This study compares the dairy productivity and milk quality of three sheep farms in the vicinity of Banská Bystrica, Slovakia, which employ different farming systems and feature different breed compositions under changing climatic conditions with increased heat stress during the summer months. Farm 1, located at 1,200 m above sea level (ASL), follows an extensive grazing system with 350 Tsigai ewes. Farm 2, situated at 500 m ASL, houses 456 Lacaune ewes in a semi-intensive system. Farm 3, at 400 m ASL, manages 470 mixed dairy and combined-breed ewes under a semi-extensive system. The results indicate that Farm 2, employing a semi-intensive system, recorded the highest milk yield (246.7 kg·ewe$^{-1}$); however, it also exhibited the most pronounced decline in the lactation curve, with lower average milk production and qualitative parameters (fat, not fat solids) for the Lacaune breed during the warm months (June – August) compared to Farms 1 and 3, which focus on raising combined breeds. In conclusion, the most suitable breeding method for the climatic and geographical conditions of the observed region appears to be a semi-extensive system with combined sheep breeds, as the variability in dairy productivity parameters during the hottest months with reduced pasture quality is not as marked as it is in specialized dairy breeds.

**Keywords:** ewes, sheepfold, milk yield, heat stress, climatic conditions

## 1 Introduction

Sheep are naturally grazing animals and are typically raised under extensive and semi-intensive production systems in Bystrica's region. Extensive sheep farming, or the Carpathian production system – traditional sheep farming is most commonly practiced in submountain and mountainous regions, primarily for combined breeds of sheep such as the Improved Valachian and Tsigai (Vršková et al., 2015). The significance of extensive sheep farming lies primarily in the grazing of inaccessible pastures for landscape management while simultaneously selecting breeds that are resilient to specific conditions. Due to seasonal grazing, sheep lactation extends throughout the entire grazing period, lasting from mid-April until the end of October. Ewes graze on permanent mountain pastures with no supplementary feeding near the shepherd's hut, which is often several kilometers from the nearest village. During the night, the sheep are housed in a sheepfold, and manual milking is carried out twice daily, in the morning and evening. In recent years, mobile milking parlors equipped with machine milking have been introduced to streamline the milking process, reduce labor intensity, and improve milk hygiene. After milking, the milk is most often processed into cheese products directly at the shepherd's hut (Margetín et al., 2021).

For dairy breeds (Lacaune, East Friesian and Slovak dairy sheep) and their crossbreeds, a semi-intensive farming system is predominantly used. Ewes achieve a milk production of at least 150 to 240 L per lactation period, which requires not only a productive breed type but also appropriate nutrition.

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Grazing is carried out near farms on intensive or semi-intensive pastures, which are regularly fertilized. The use of pastureland may involve shepherd supervision or fenced enclosures. After grazing, the sheep are gathered back to the farm, where they are housed until the next day and machine-milked in established milking parlor or using mobile milking parlor. In addition to modern milking technology, advanced feeding systems are used, including feeding wagons and feeding belts, with watering systems and supplemental feeding of sheep with silage enriched with grain concentrates (Makovický et al., 2016). Particular attention in semi-intensive farming system is given to selection (performance and utility control), breeding (estrus synchronization is often used), and maintaining good animal health through effective prevention measures (Wolfová et al., 2009).

In both farming systems, nutrition has the most significant impact on milk production. Proper nutrition is crucial not only during lactation but also throughout pregnancy. A deficiency of digestible nutrients in feed and insufficient rumen microflora, especially after lambing, can lead to a reduction in the ewe's body weight as nutrients are drawn from its own reserves, potentially resulting in complete drying (Mohapatra et al., 2019). In ewes, the postpartum period is characterized by negative energy balance and loss of body weight. The body condition after lambing is one of the key factors influencing milk production at the beginning of lactation, as most nutrients are utilized through the mobilization of fat reserves. During seasonal lambing, the first months of lactation occur in cold weather, requiring animals to use more energy for thermoregulation. During this period, the basic feed ration consists mainly of dry roughage, supplemented with silage or preserved feed and grain additives to support energy balance (Selmi et al., 2020). Proper nutrition influences the composition of sheep's milk, which differs significantly from cow's and goat's milk, not only in the content of individual components but also in the production system that affects its composition. Sheep's milk contains approximately 20% dry matter, an average of 5% protein, and around 8% fat. The fat in sheep's milk is dispersed in the form of small globules, which are about half the size of those in cow's milk. This characteristic makes it easier to digest and more suitable for consumers with allergies and intolerances. For dairy product manufacturers, the composition of sheep's milk is particularly important due to its impact on cheese yield and the overall efficiency of milk processing (Kalyankar et al., 2016).

In dairy sheep breeds, milk production levels are also influenced by the duration of suckling and the weaning of lambs. The quality of forage, the transition to pasture-based nutrition, and a high intake of fresh pasture significantly enhance nutrient intake, stimulating milk synthesis. Grazing a diverse range of herbs on high-altitude pastures positively affects the quality of sheep's milk, which is among the most nutrient-rich of all bovine milk varieties (Freer and Dove, 2002). It belongs to the casein-type milk, meaning that casein is the primary protein component. Casein makes up to 80% of the total protein content and plays a crucial role in cheese production (Kovačová et al., 2021).

In Slovakia, sheep farming conditions are not uniform due to the country's diverse geography and increasingly frequent climatic variations across regions. In recent years, even in the temperate climate zone, which includes Central European countries such as Slovakia, significant changes in livestock production have begun to emerge as a result of global warming (Margetín et al., 2021). Climate changes are manifested through unusually high daily temperatures and frequent seasonal fluctuations. Climatologists predict that in the coming years, particularly during the summer months, there will be an increased occurrence of heat waves accompanied by drought. In temperate climate zone countries, summer precipitation is expected to decrease by up to 15%, and the average annual temperature is projected to rise by up to 2 °C by 2050 (Arellano et al., 2025). The number of hot days (above 30 °C) is also expected to increase. In Europe, we are witnessing not only a gradual rise in temperatures but also more pronounced year-to-year variations and greater variability in climatic factors across seasons (spring, summer, autumn, winter). The variability of average winter temperatures is decreasing, while the variability of average summer temperatures is increasing (Zucali et al., 2017). To improve the efficiency of sheep farming for milk production in foothill and mountainous areas, it is essential to select resilient breeds that can withstand adverse climatic conditions and efficiently utilize pastures. This, in turn, positively impacts milk yield (Tančin et al., 2009). This study compares milk yield and qualitative milk parameters among different sheep breeds raised in the Banská Bystrica region of Slovakia, aiming to identify the most resilient breed and optimal farming system for sustaining production under temperature fluctuations.

## 2 Material and Methods

The study was conducted on three farms specializing in sheep farming for milk production and dairy product processing. All farms are located in central Slovakia, near Banská Bystrica, but each operates under a different sheep farming system. In this study, milk production data were recorded throughout the grazing season, considering weather fluctuations. Precipitation was measured using a simple rain gauge and temperature was recorded with a thermometer. Our results were then evaluated together with the results from the Hydrometeorological Institute (Figure 1 and Figure 2).

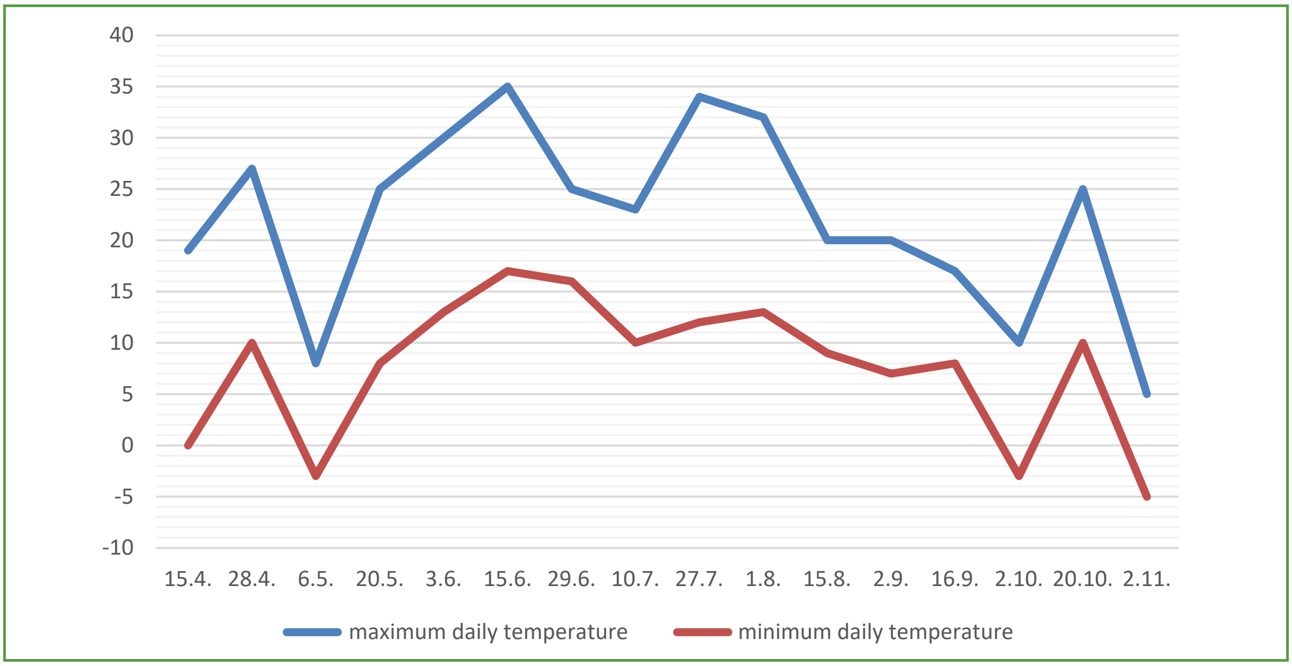


**Figure 1** Maximum and minimum temperatures in 2019 (°C)
Source: SHMU, 2019

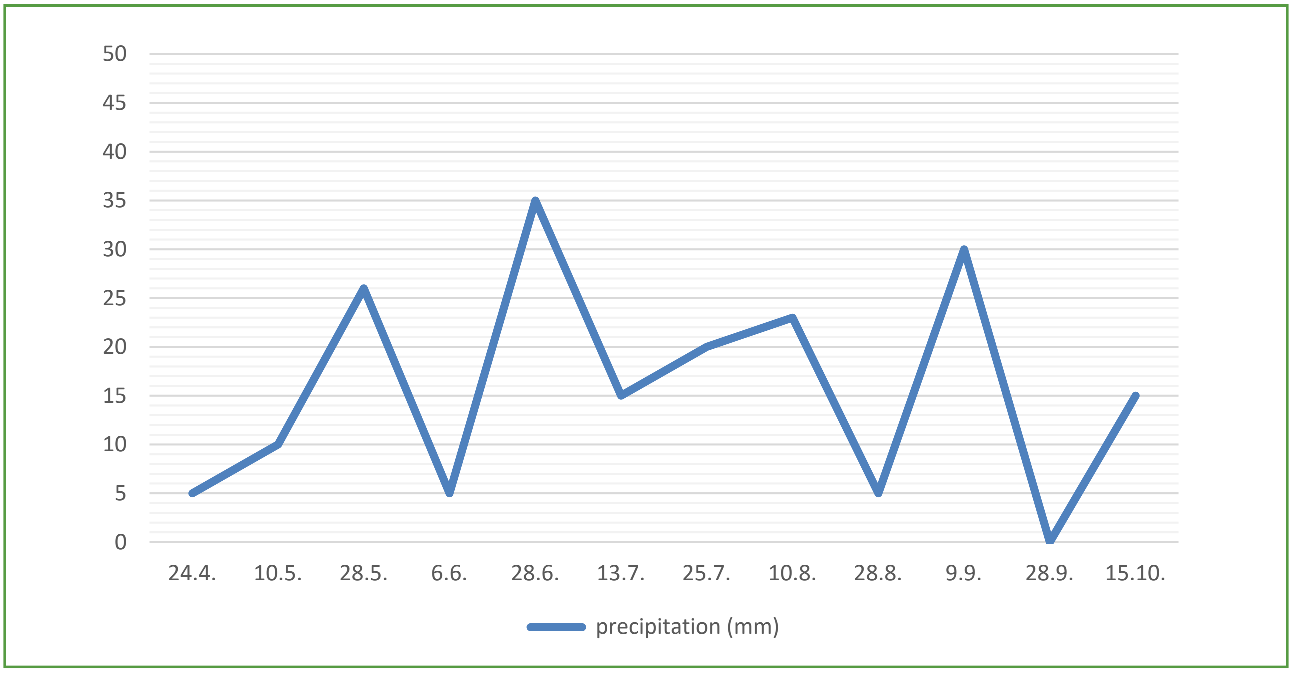


**Figure 2** Precipitation in 2019 (mm)
Source: SHMU, 2019

### *2.1 Farm 1 – Skubín*

Farm 1 is located near Banská Bystrica in the Skubín area (Figure 3). During the summer, an extensive farming system is used. The flock consists predominantly of the Tsigai breed. At the beginning of the season, lambs were weaned April 5th, marking the start of regular milking twice a day at fixed intervals. In April the ewes were fed in the barn with a mixed ration consisting of alfalfa silage, corn silage, oat straw, hay, soybean by-products, and brewery spent grains, at a rate of 5 kg·head·day$^{-1}$. The grains feed comprised a mixture of oats and barley, while 3 kg·head·day$^{-1}$ of hay and 1.5 kg·head·day$^{-1}$ of silage formed the afternoon ration. This feeding regimen continued until the first transfer to the second place April 24th. Subsequently, the ewes were housed in the stall with deep litter and grazed on mountain pastures. During this period, insufficient rainfall and unfavorable weather for new growth, including ground frosts in May, negatively affected milk production.

The second transfer took place June 5th, when the sheep were moved to the high-mountain area of Veľká Fatra National Park. Here, the mountain farm is situated at an altitude of 1,200 m ASL, while the high-altitude pastures, which the flock had to access, reach up to 1,600 m ASL (Figure 4). The sheep were housed using the traditional method of basket stabling, and their primary source of nutrition was the native high-mountain vegetation. August 15th, the flock was relocated to a lower area (715 m ASL), having traversed 42 km to reach the designated location. The sheep grazed on young and alfalfa – grass pastures, which had been mown in June for use as hay for winter feed reserves. Gradually, the animals began to dry and the number of lactating ewes decreased. This decline was due to the end of the lactation period and the onset of the rut, followed by the introduction of rams into the flock. Milking was completely discontinued October 20th.

### *2.2 Farm 2 – Ráztoka*

Farm 2 is located in the village of Ráztoka in the Brezno district. This facility focuses on the production of dairy sheep, particularly purebred Lacaune. It is situated in a foothill area with pastures and operates under a semi-intensive farming system. Throughout the season, the ewes were housed in a single facility under uniform conditions. At the beginning of the season, the flock comprised 456 ewes (Figure 5). Following the traditional weaning of lambs, milking commenced at regular intervals. The ewes were milked in a parallel milking parlor, which, together with the milk room, forms part of the housing area where the animals are kept overnight and during milking (Figure 6). At the start of the milking season, outside the grazing period, the feed ration consisted of hay and a mixture of alfalfa silage, grass silage, and corn silage. In the milking parlor, the sheep received additional feed comprising mixed barley, BAK (a feed mixture for lactating sheep), and granular corn kernels. When transitioning to pasture, the succulent feed was discontinued, and the sheep were fed solely hay and straw *ad libitum*. There were challenges due to insufficient rainfall in the spring, and during the summer, the farm experienced significant issues with foot rot in the sheep, which adversely affected milk production. In September, milk yield began to decline as lactation neared its end. In the final week of October, only morning milking was performed, and on November 10th, milking was completely discontinued.

**Figure 3** First minitored sheep herd – Skubin, Slovakia
Photo by Kubišová (2019)

**Figure 4** First monitored sheep herd in the national park Veľká Fatra, Slovakia
Photo by Kubišová (2019)

**Figure 5** Stall for sheep from Farm 2 – Ráztoka, Slovakia
Photo by Kubišová (2019)

**Figure 6** Milking parlor on the Farm 2
Photo by Kubišová (2019)

### *2.3 Farm 3 – Iliaš*

Farm 3 is located near Banská Bystrica, near the village of Hronsek. This facility employs a semi-extensive sheep farming system that combines Tsigai, improved Valachian, and their crosses with Lacaune and Slovak dairy sheep. The total number of milking ewes was 470 pcs. During winter, the ewes were housed in a barn and fed with corn silage, alfalfa silage, grass silage, hay, and a basal feed (a mixture of oats and barley). April 6$^{th}$, the lambs were weaned using the traditional weaning method, and the first milking took place that evening. The ewes are manually milked in specialized milking cage – strunga, where each milker uses their own stainless steel container. April 15$^{th}$, grazing began, and a gradual transition to pasture-based feeding was initiated. April 29$^{th}$, the sheep were moved to the second place, where they spent the summer season. The ewes were housed overnight in basket-stabling and a covered hall was available for milking (Figure 7). The feeding ratio at this site consisted solely of grazing, with no supplementation of any feeds. During the observed season at this location, there were significant issues with low precipitation and insufficient desirable pasture, which negatively affected milk yield. The number of milking ewes began to decline already in the summer, but this decrease was especially pronounced in the autumn. As temperatures dropped, milk yield also declined. October 17$^{th}$, the ewes were milked only in the morning, and they were gradually drying. The final milking was performed October 29$^{th}$.

### *2.4 Ethical statement*

For this study, the examination of the ewes and the collection of milk samples were approved by the Ethics Committee at the University of Veterinary Medicine and Pharmacy in Košice no. EKVP 2022/05 following EU legislation 2010/63/EU, article 1 : 5 (practices not likely to cause pain, suffering, distress, or lasting harm equivalent

**Figure 7** Third minitored sheep herd – Iliaš, Slovakia
Photo by Kubišová (2019)

to or higher than, that caused by the introduction of a need to follow good veterinary practice).

### 2.5 Determining the Basic Components of Milk

Determining the basic components of milk in samples from all farms as fat, protein, lactose and not fat solids (SNF) content was tested by FTIR spectroscopy using MilkoScan FT 6000 (Foss Analytical A/S, Hillerød, Denmark), according to Záhumenská et al. (2024). All examinations are accredited by SL Examinala by the Slovak National Accreditation Service according to ISO/IEC 17 025. Milk yield was calculated as the total volume of milk produced per monitoring period, divided by the number of sheep milked.

### 2.6 Statistical Analysis

Differences in milk production and qualitative parameters among the monitored farms were statistically evaluated. The results were evaluated using MS Excel (Microsoft, Redmond, Washington, USA). Basic statistical characteristics, such as mean, and standard deviation, were calculated for numerical data. A one-way analysis of variance (ANOVA) was conducted to compare differences among farms, followed by Tukey's post-hoc test for multiple comparisons of means, with a confidence level of 95% using GraphPad Prism statistical software 8.3.0.538 (GraphPad Software, San Diego, CA, USA).

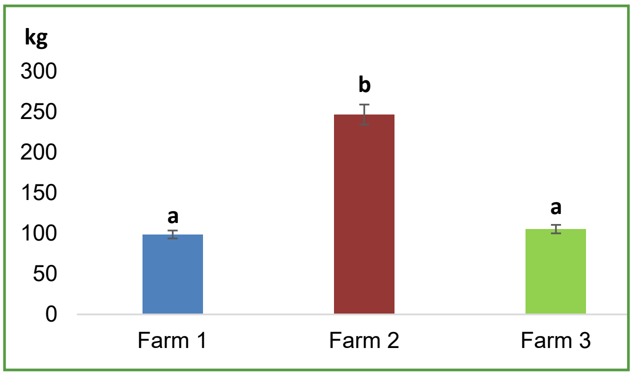


**Figure 8** Comparison of milk yield (kg/ewe) among sheep from the monitored farms.
Farm 1 – extensive farming method, Farm 2 – semi-intensive farming method, Farm 3 – semi-extensive farming method; a, b, c – different letters above a columns for statistical significance (*P* <0.05)

## 3 Results and Discussion

### 3.1 Results

The comparison of milk yield, average daily production, and milk quality parameters shows significant variability among sheep from three farms with different production systems and breed compositions. The highest milk yield was recorded on Farm 2 (246.7 kg·ewe$^{-1}$), which is characterized by a semi-intensive system and the raising of Lacaune sheep (Figure 8). On the same farm, the highest average DMP·ewe$^{-1}$ was observed, although it also showed the most pronounced decline in the lactation curve during the warm months of June to August compared to Farms 1 and 3 (Figure 9).

The farms were monitored monthly from April to October, and at the same intervals, the average amount of milk produced during morning and evening milkings was recorded. Additionally, bulk tank milk samples were collected from the monitored sheep farms for the qualitative analysis of milk components such as fat, protein, lactose, and not fat solids (SNF) content. At the same time, climatic changes during the monitoring period were recorded, particularly temperature (Figure 1) and precipitation (Figure 2). During the months of June to August, notably warm conditions were observed with

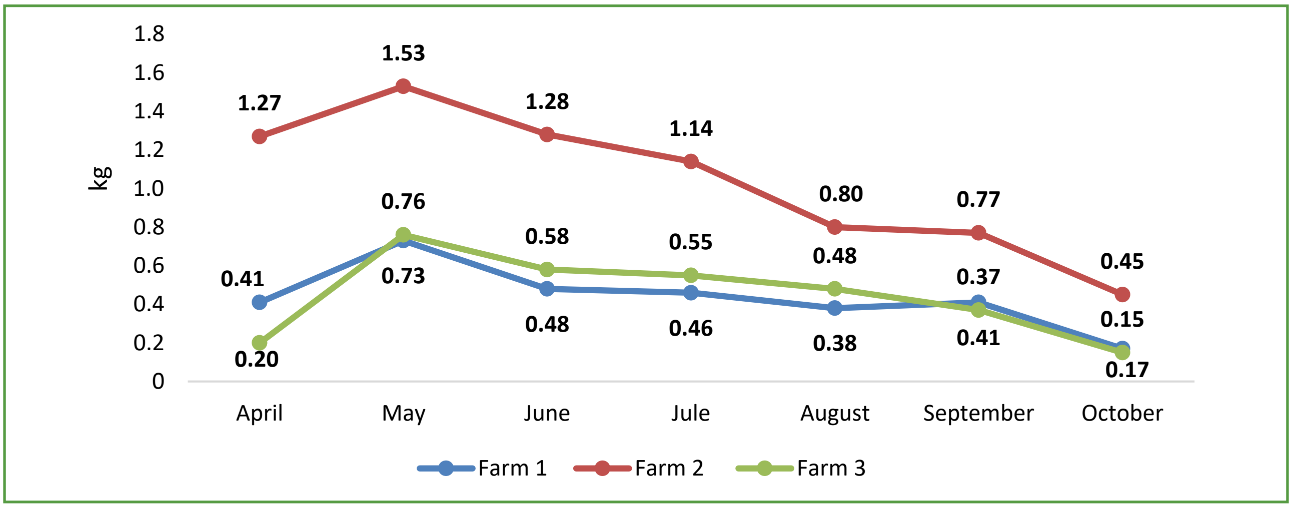


**Figure 9** Comparison of average daily milk production (DMP) among sheep from monitored farms during milking season
Farm 1 – extensive farming method, Farm 2 – semi-intensive farming method, Farm 3 – semi-extensive farming method

daily temperatures ranging from 25 to 35 °C with minimal rainfall, which was also reflected in a decrease in pasture quality in the region.

#### *3.1.1 Monitored Sheep Farms*

##### *3.1.1.1 Evaluation of Farm 1 – Skubín*

At the first farm – Skubín, with extensive farming system for Tsigai sheep, the average yield reached 98.67 kg of milk·ewe$^{-1}$. Gradually, the ewes increased milk production with peak of lactation in May. At the beginning of June, the ewes were transferred to a second place due to the transhumance of the grassy forage. Despite the transfer, a lower average yield (Figure 8) was recorded from June to August due to high daytime temperatures and reduced rainfall. Milk quality was higher at the beginning of lactation due to the superior quality of spring pastures. In May, increased rainfall enriched the pastures. The June sampling results showed a decline in milk components compared to May, which was attributed to the lower temperatures and variable weather in May that contributed to better pasture quality. Furthermore, the decline in milk production during this period was influenced by the ewes' constant movement over rugged terrain at the second place. Gradually, the milk yield of the ewes declined due to the high-mountain environment, rugged terrain, and insufficient rainfall on the pastures. The grassland did not provide enough nutrients, so the ewes did not receive adequate inputs to produce large amounts of high-quality milk. In mid-August, the ewes were relocated to a lower area where high-quality pasture was available. The pastures were mowed at the beginning of July, and by August, high-quality alfalfa and meadow herbage-rich pasture, resulting in increased milk yield. In September, the final samples were collected, and the results confirmed a higher content of milk components at the end of lactation. At the end of the milking season, the lowest milk yield was recorded, accompanied by the highest levels of fat, protein, and SNF in the milk (Table 1).

##### *3.1.1.2 Evaluation of Farm 2 – Ráztoka*

Based on the evaluation of milk production at Farm 2, with a semi-intensive farming system was recorded the highest average milk yield of 246.7 kg·ewe$^{-1}$ (Figure 8). In April and May, at the beginning of lactation, the measured values were in very good levels due to a consistent management regime with only minor weather fluctuations and minimal health issues related to foot rot. Although the milk yield and peak of lactation in May could have been even higher, insufficient rainfall in the spring and inadequate nutrient intake from pasture prevented the ewes from reaching their full potential. During the summer period, a significant decline in milk production was observed (Figure 9), primarily due to a high number of lame ewes, which are less resistant to foot rot than the crossbred sheep on the other monitored farms. The necessity to move the ewes further

**Table 1** Evaluation of the basic indicators of ewe's milk, depending on the month of milking

| Parameter | Farm | Monitored period | | | | | Mean ±SD |
|---|---|---|---|---|---|---|---|
| | | May | June | Jule | August | September | |
| Fat % | Farm 1 | 8.78 | 8.01 | 8.51 | 7.51 | 9.97 | 8.56 ±0.71$^{a}$ |
| | Farm 2 | 6.77 | 7.63 | 7.98 | 7.85 | 8.91 | 7.83 ±0.85$^{a}$ |
| | Farm 3 | 9.12 | 8.12 | 8.72 | 9.93 | 11.17 | 9.41 ±0.52$^{b}$ |
| | | | | | | | <0.05 |
| Lactose % | Farm 1 | 4.65 | 4.87 | 4.65 | 4.74 | 4.42 | 4.67 ±0.37 |
| | Farm 2 | 4.93 | 4.9 | 4.81 | 4.69 | 4.47 | 4.76 ±0.54 |
| | Farm 3 | 4.87 | 4.99 | 4.76 | 4.58 | 4.35 | 4.71 ±0.28 |
| | | | | | | | <0.05 |
| Protein % | Farm 1 | 5.66 | 5.55 | 6.01 | 6.97 | 7.43 | 6.32 ±0.55 |
| | Farm 2 | 5.45 | 5.53 | 5.77 | 6.19 | 7.15 | 6.01 ±0.64 |
| | Farm 3 | 5.52 | 5.46 | 5.72 | 6.4 | 8.07 | 6.23 ±0.78 |
| | | | | | | | <0.05 |
| SNF % | Farm 1 | 10.96 | 11.42 | 11.56 | 12.94 | 12.86 | 11.97 ±1.07 |
| | Farm 2 | 11.17 | 11.29 | 11.45 | 11.79 | 12.6 | 11.66 ±0.86 |
| | Farm 3 | 11.25 | 11.3 | 11.35 | 11.92 | 13.48 | 11.86 ±0.45 |
| | | | | | | | <0.05 |

a, b, c – different letters within a columns for statistical significance (*P* <0.05); SNF – solids not fat from the farm to access pasture also contributed to the reduced milk yield. The lower milk composition, compared to Farm 1, was mainly influenced by breed, although the values steadily increased as expected (Table 1).

##### *3.1.1.3 Evaluation of Farm 3 – Iliaš*

The average milk yield on the Farm 3, with a semi-extensive farming system was 105.3 kg·ewe$^{-1}$ (Figure 8). As a result of moving the sheep to new, high-quality pastures at the end of April, high levels of milk components, particularly proteins and fat were observed (Table 1). However, with the variable weather in May and the occurrence of cold days, the levels of these components declined. This decrease in the bulk tank milk sample may also be attributed to a lower proportion of milk from dairy breed ewes, since crossbred ewes tend to exhibit higher milk component values. In the hottest months, from June to August, a reduced DMP was recorded, similar to the observations from the other two farms, compared to the first two months. The DMP continued to gradually decline during the final two months (September–October) (Figure 9).

### *3.2 Discussion*

Not only the breed with genetic potential influences milk production, but also a number of environmental factors that change during the grazing season (Legerra et al., 2007). The aim of the study was to determine the most significant factors influencing both the quality and quantity of sheep milk and to identify the most effective farming method for the selected locality. To achieve this, the milking season was evaluated on three sheep farms located in the vicinity of Banská Bystrica, Slovakia. In the monitored farms, milk yield was regularly assessed along with the corresponding climatic conditions.

The findings indicate that the most suitable farming system under these conditions is a semi-extensive one using crossbred sheep. This is because specialized dairy breeds such as Lacaune on Farm 2, are more susceptible to long-term weather fluctuations manifested as deteriorating pasture growth and decreased production compared to traditional breeds with a combined production potential, which are better able to cope with challenging climatic conditions. During periods of adverse climatic conditions, it is advisable to supplement dairy sheep with feeds, such as alfalfa hay and clover-grass silage, to meet their higher nutritional requirements. In this context, the extensive farming system is increasingly losing its significance due to global warming which diminishes the value and quality of high-mountain pastures and a shortage of labor (Makovický and Margetín, 2017).

The study shows that the best results were achieved by Farm 2 during monitored period, which recorded the highest average milk yield·ewe$^{-1}$. The ewes were maintained under consistent conditions throughout the season and grazed year-round on the same pastures near the farm. In the lactation curves and graphs depicting the quantity and quality of milk from Farms 2 and 3, although the milk yield gradually decreased, the qualitative composition steadily improved. In contrast, Farm 1 experienced significant fluctuations in both milk quality and quantity. Among the measured components, fat was the most influenced by nutrition.

Therefore, it is advisable that the ewes be raised using a semi-intensive system throughout the year to ensure they graze under consistent climatic conditions. Additionally, regular pasture rotation is essential to minimize the degradation of forage, along with a thorough understanding of pasture composition. Relocation of sheep to areas with different altitudes, we encounter a change in climate and also a change in the composition of the grassland (Vrábliková et al., 2017).

During the pasture season, all fluctuations and milk quality were influenced by a single, most important factor: the weather. Due to global warming and insufficient rainfall, the pastures have been degraded, exhibiting low nutritional value and poor regeneration. When selecting a suitable breed for foothill and mountainous regions, dairy and dual-purpose breeds were compared based on the amount of milk produced and the proportion of its individual components.

Immediately after lambing, the mammary gland produces colostrum. The proteins primarily albumins and globulins serve as defensive agents. The rich composition of colostrum gradually diminishes as the mammary gland transitions to milk production. From weaning until drying of mammary gland, the composition of the milk changes, and by the end of lactation, the milk exhibits a richer nutrient profile. From an economic standpoint, milk produced from late summer to autumn is most advantageous for cheese production. Additionally, very old individuals are unsuitable for breeding due to their high somatic cell counts (Pal et al., 2017). The most important aspect is to habituate them to human contact from birth, so that later during milking the sheep are not subjected to stress and abuse (Margetín, 2021).

From the lactation curves we can observe the average yield·ewe$^{-1}$ after the weaning of lambs at the individual farms. Figure 9 shows that Farm 2 had a higher DMP right from the start compared to the other two farms, which is influenced by the breed of the ewes (Lacaune) forming the herd. However, the average DMP declined more rapidly from the lactation peak than at the other two farms, where milk production·ewe$^{-1}$ remained approximately constant for two months. The lactation peak was reached in May. This was due to the young pasture, but as a result of unexpectedly low temperatures and ground frosts, the high yield could not be maintained for an extended period.

Milk yield decline was recorded primarily during the months of June through August, when the highest temperatures and minimal rainfall were observed. As milk yield decreased, fat content, protein, and SNF increased, which is associated with a higher yield in cheese production. With the onset of autumn, the rut, and the end of the season, sheep milk production naturally declined. Some ewes reduced their production immediately after mating, which was reflected in the average DMP. Temperatures dropped, weather conditions worsened, pasture availability diminished, and milk yield decreased. The ewes were gradually dried. Table 1 shows that fat was the most variable qualitative parameter of milk, primarily influenced by nutrition, breed, and changing climatic conditions. At the beginning of lactation, low fat levels indicate a negative energy balance, where fatty acids are derived from the fat reserves (Kalyankar et al., 2016).

Gradually, toward the end of lactation, its level should increase (Keresteš et al., 2016). The flock from Farm 1 experienced a slight decline in milk fat in June due to replace the sheep a mountainous area. In August, a marked decrease in milk fat was observed on Farm 1, attributed to high temperatures with minimal rainfall. Later, after moving to different pastures, milk fat increased significantly toward the end of lactation. On Farms 2 and 3, milk fat increased moderately (Table 1). The other milk components gradually and steadily increased, except for lactose, which progressively decreased. In previous years, milk yield was significantly higher. This is due to climate change, which has altered pasture vegetation, and to a shift in the type of dairy sheep, which are not well adapted to mountainous conditions.

Significant differences in milk composition among the farms are also attributed to breed differences. Dairy sheep breeds that produce higher milk yields have similar milk component levels, but the increased dilution in the udder results in a lower percentage of these components (Hamann et al., 2004). Protein content is not as strongly affected by external factors; rather, it is influenced primarily by breed, nutrition, and lactation stage, as evidenced by the higher milk yield for cheese production observed in autumn (Keresteš et al., 2005). Protein levels depend on the amount of nitrogenous substances relative to energy intake in the form of starch. At the beginning of lactation, the ewes are in a negative energy balance and exhibit relatively low protein levels (Freer and Dove, 2002). Table 1 shows an increasing trend in the proportions of proteins and SNF across all three monitored farms. The highest levels of proteins and SNF were recorded on Farm 3 at the end of lactation, a result that is particularly desirable for breeders aiming to produce dairy products.

Lactose, a disaccharide composed of glucose and galactose, is the most stable component in milk, as confirmed by our results. The presence of starch in the feed for fattening promotes the production of propionic acid, which affects glucose levels through gluconeogenesis. A reduced intake of starch decreases lactose synthesis, and consequently milk production, while fat and protein levels in the milk increase (Maskaľová et al., 2024). Throughout the entire lactation period, lactose maintained an approximately constant proportion in the milk composition. We observed a decline in lactose content relative to the other components, which increased, particularly at the end of the grazing season (Table 1).

## 4 Conclusions

A comparison of the three farms suggests that a semi-extensive system with crossbred sheep is most suitable for the local climate, showing the least fluctuation in milk production and quality during heat stress and poor pasture conditions. While Farm 2 with Lacaune sheep recorded the highest milk yield, crossbred farms had richer milk composition, where lower yields translated into higher cheese production efficiency. It's crucial to determine the best sheep breeds for the area and assess whether the required conditions can be met amid increasing climate fluctuations.

Climate change demands strategies to improve adaptability at various levels, including livestock management, health, and breeding. The predicted climate shifts will increase selective pressure on breed resilience and biological traits, affecting overall production and product quality.

### Authors Contributions

Zuzana Kubišová and František Zigo investigated and wrote the manuscript. Jana Záhumenská provided methodology and software. Tomáš Mihok editing and corrected manuscript according to the reviewers' recommendations. All authors have read and agreed to the published version of the manuscript.

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