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Comparison of udder morphology, body weight and milk production during lactation in pasture-fed dairy sheep in Bosnia and Herzegovina

Usporedba morfologije vimena, tjelesne mase i proizvodnje mlijeka tijekom laktacije u bosanskohercegovačkih ovaca na ispaši

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ABSTRACT

Kupres, Privor and Stolac Pramenka are indigenous sheep breeds from Bosnia and Herzegovina whose milk is traditionally used for cheese production after the lambs are weaned. The main objective was to determine the udder morphology and the changes in milk production during lactation in Kupres (n=107), Privor (n=94) and Stolac (n=121) Pramenka sheep breeds kept on pasture. Milk production, udder morphology and ewe body weight were measured, samples of milk composition (milk fat, protein, lactose and total solids-not-fat content), somatic cells and total bacterial count were collected during early (day 80-100), mid (day 140-160) and late (day 200-220) lactation in Kupres, Privor and Stolac Pramenka sheep breeds. The results of this work confirm that all the breeds studied have low milk production. In addition, milk production decreases during lactation, while the proportion of milk fat, protein and non-fat components increases. The number of somatic cells in the milk increases slightly during lactation, and their concentration shows good udder health. Compared to the Privor and Stolac Pramenka breeds, the Kupres ewes had the highest milk production and the greatest udder height and width. To conclude, the udder and teat measurements in all breeds were acceptable for machine milking, which was reflected in a low teat angle and a cistern height below the teat orifice. Udder width and height show a high positive correlation with milk yield and can be used to predict milk production in all three Pramenka group sheep breeds.

Keywords: udder morphology, milk production, indigenous sheep

SAŽETAK

Kupreška, Privorska i Stolačka pramenka su izvorne pasmine ovaca u Bosni i Hercegovini, čije se mlijeko tradicionalno koristi za proizvodnju sira nakon odbića janjadi. Glavni cilj ovoga istraživanja bilo je određivanje morfologije vimena i promjena u proizvodnji mlijeka tijekom laktacije u Kupreške (n=107), Privorske (n=94) i Stolačke (n=121) pramenke, koje se uzgajaju na pašnjacima. Količina proizvedenog mlijeka, morfologija vimena, masa ovaca, kemijski sastav mlijeka (udio mliječne masti, bjelančevina, laktoze i suhe tvari bez masti), broj somatskih stanica, te ukupni broj bakterija u mlijeku određeni su u ranoj (od 80. do 100. dana laktacije), srednjoj (od 140. do 160 . dana laktacije) i kasnoj laktaciji (od 200. do 220. dana laktacije) kod Kupreških, Privorskih i Stolačkih pramenki. Rezultati ovog rada potvrđuju da sve ispitivane pasmine imaju nisku mliječnost. Osim toga, proizvodnja mlijeka se smanjuje tijekom laktacije, a povećava udio mliječne masti, bjelančevina i suhe tvari bez masti. Ukupan broj somatskih stanica u mlijeku se blago povećava tijekom laktacije, ali njihova koncentracija je upućivala na dobro zdravlje vimena. Pasmina sa najvećom proizvodnjom mlijeka, kao i visinom i širinom vimena je Kupreška u odnosu na Privorsku i Stolačku pramenku. Može se zaključiti da mjere vimena i sisa kod svih pasmina ovaca su podobne za strojnu mužnju, a što se ogleda u malom kutu kojeg sise zatvaraju s okomicom vimena, te visini cisterne ispod sisnog otvora. Širina i visina vimena pozitivno u korelirani s količinom proizvedenog mlijeka, i stoga od velikog značaja u procjeni proizvodnje mlijeka svih triju pasmina ovaca.

Ključne riječi: morfologija vimena, proizvodnja mlijeka, izvorne pasmine ovaca

INTRODUCTION

The production of sheep's milk with subsequent cheese production is an important sector of livestock farming in Bosnia and Herzegovina (Šalamon et al., 2020). However, this production is very extensive and is mainly found in the mountain regions. With a drastic reduction of vertical transhumance over the previous two decades, the sheep are mainly kept on pasture and housed in a barn in winter. The indigenous sheep breeds in Bosnia and Herzegovina are characterized by special qualities such as a strong constitution, good fertility, resistance to diseases, incredible endurance and exceptional adaptation to harsh climatic, husbandry and feeding conditions, as well as a long useful life. According to the Federal Statistical Office of FBiH (Statistical Yearbook/Calendar for the year 2023), 488901 sheep are bred and 207692 sheep are milked. Similar to Sardinian sheep (Casu et al., 2006), the main breeding goal of farmers has traditionally been to increase milk yield with a subjective evaluation of udder morphology and ease of hand milking (Salamon et al., 2019). In purebred and extensively reared Pramenka group dairy sheep breeds, hand milking is the most commonly used technique for extracting milk from the udder, but recently machine milking has been increasingly used (Šalamon and Džidić, 2014; Salamon et al., 2019), especially in crossbred herds of dairy sheep.

Udder morphology together with milk production and suitability for machine milking, used in selection programs, has been studied in Chios (Mavrogenis et al., 1988), Churra (Fernandez et al., 1995), East Friesian (McKusick et al., 1999), Manchega and Lacaune (Rovai et al., 1999; Caja et al., 2000), Bergamasca (Emediato et al., 2008) and Sardinian sheep (Casu et al., 2006). In addition, (Fernandez et al., 1995) showed a significant influence of lactation stage on all udder traits in the Churra sheep breed. The transition from hand milking to machine milking in dairy sheep requires knowledge of udder morphological measurements that are important for machine milking. Cistern height below the teat orifice, together with teat angle, is an important measure of udder adaptability to machine milking evident in values of favored udder morphology between hand and machine milking farms in Istrian sheep with no udder morphology used in the selection program (Šalamon and Džidić, 2014).

The aim of this article is to determine the udder morphology and the changes in milk production during lactation in Kupres, Privor and Stolac Pramenka sheep kept on pasture and used mainly for the production of fine cheeses. In addition, the udder morphology, the weight of the sheep and the milk production between the breeds were analyzed.

MATERIALS AND METHODS

Animals and sampling

The study was conducted on three commercial sheep farms in Bosnia and Herzegovina. Milk production, udder morphology and body weight were measured, samples of milk composition (milk fat, protein, lactose and solids non-fat content), somatic cells and total bacterial count (TBC) were collected during early (d 80-100), mid (d 140-160) and late (d 200-220) lactation in Kupres (n=107), Privor (n=94) and Stolac (n=121) Pramenka breed sheep. The sheep were in their second to fifth lactation. The sheep were kept with their lambs until day 45-60 after lambing. They were milked by hand twice a day at 6 am and 6 pm. The milk was collected in buckets.

Milk sampling and analysis

To analyze the milk composition, milk samples were taken from both halves of the udder from the bucket and placed in a sterile milk tube (100 ml were preserved with 1 tablet Bronopol Broad Spectrum Microtabs II). The milk samples from all farms were transported within 12 hours in a transport container at 4 °C to the laboratory of the Department of Veterinary Medicine in Bihać. Bacteriological analysis was performed using the BACTOSCAN FC, tip 50, Foss Electric, Hilleroed, Denmark. The somatic cell count was measured using the Fossomatic Minor device, Foss Electric, Hilleroed, Denmark. The somatic cell count and the total plate count were transformed using the base-10 logarithm. The chemical composition of the milk was measured using the Milkoscan FT 120 device, Foss Electric Denmark.

Udder morphology and body weight measurements

Morphological traits (udder height (cm), udder width (cm), cistern height (cm), teat angle (°), teat width (cm) and teat length(cm)) were measured two hours before evening milking in early, mid and late lactation according to the protocol described in Dzidic et al. (2009). After determining the morphological measurements of the udder and taking photographs, the body weight of each sheep was measured using a digital floor scale with an accuracy of ± 300 grams (Scale Depot, LP7510E-121, Chino, CA, USA).

Statistical analysis

For the statistical analysis of the variables milk composition, somatic cells, total bacterial count and udder morphology, a repeated measures model with the GLIMMIX procedure was used, with sheep as a random effect and breed, day of lactation (early, mid, late) and their interaction defined as fixed effects.

Pairwise differences between breed means were tested using the Tukey–Kramer test with adjustment for multiple comparisons.

The relationships between the traits udder morphology, milk yield and sheep weight were analyzed by estimating the correlations between the measures adjusted for the other effects in the corresponding models with best linear unbiased prediction (BLUP) for each sheep. Pearson correlation analyses were performed using the CORR procedure.

Data analysis for this article was performed using SAS/STAT software, version 9.4 of the SAS System for Windows (SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

The interaction between Pramenka-type breed of sheep and stage of lactation was significant ($P<0.05$) for all observed variables in the study (Table 1, Table 2 and Figure 1).

Milk production and composition

Milk production and lactose content in Kupres, Privor and Stolac Pramenka breeds decreased significantly ($P<0.05$) throughout lactation (Table 1). In early lactation, milk yield was significantly higher in the Kupres breed than in the Privor and Stolac breeds. In contrast, fat, protein and SNF increased significantly ($P<0.05$) throughout lactation. Somatic cell count (SCC) increased slightly throughout lactation, with only the Stolac Pramenka breed showing a significant increase in late lactation. However, all SCC values were up to 150000 cells/ml, which means that the udders were healthy. There was a significant ($P<0.05$) increase in colony-forming unit (CFU) count during lactation in all three Pramenka-type breeds, but the values were low. Furthermore, there were no differences between the breeds within the individual lactation stage. It is already known from the literature that the quantity and quality of the sheep's milk in dairy sheep depend to a large extent on seasonal climate changes and the availability of pasture grass (Sevi et al., 2004). This is even more pronounced in dairy sheep kept on pasture. The same authors concluded that the quality of sheep's milk in late lactation depends mainly on the increase in ambient temperature, involution of the mammary epithelium and the deterioration of air and surface hygiene. Kupres Pramenka breed has a higher milk production compared to Privor and Stolac Pramenka breeds, and their milk composition is very similar throughout lactation (Šalamon et al., 2020).

Milk yield, SCC and milk composition are mainly influenced by herd, stage of lactation, parity and type of parturition (Gonzalo et al., 1994). Mentioned authors found an increase in fat and protein content and logSCC from the 45th to the 150th day of lactation in the Churra breed, which corresponds to Kupres Pramenka breed of ewes values for fat and protein, while logSCC were lower. Privor and Stolac Pramenka breeds of ewes had lower values for all three variables already mentioned.

Table 1. Influence of the interaction between breed and stage of lactation on milk composition in Kupres, Privor and Stolac Pramenka sheep breeds (data are LSM ± SEM)

Parameter	Kupres			Privor			Stolac		
	Early*	Mid	Late	Early	Mid	Late	Early	Mid	Late
Milk yield (kg)	1.19 ± 0.02^{Aa}	0.59 ± 0.02^{B}	0.48 ± 0.02^{C}	0.73 ± 0.02^{Ab}	0.57 ± 0.02^{B}	0.48 ± 0.03^{C}	0.68 ± 0.02^{Ac}	0.51 ± 0.02^{B}	0.51 ± 0.03^{B}
Fat content (%)	4.26 ± 0.13^{A}	9.03 ± 0.13^{Ba}	8.76 ± 0.15^{Ba}	4.09 ± 0.14^{A}	6.57 ± 0.15^{Bb}	10.10 ± 0.20^{Cb}	3.83 ± 0.13^{A}	5.63 ± 0.14^{Bc}	7.19 ± 0.21^{Cc}
Protein content (%)	5.54 ± 0.06^{A}	6.43 ± 0.06^{Ba}	7.44 ± 0.07^{Ca}	5.54 ± 0.07^{A}	6.07 ± 0.07^{Bb}	8.22 ± 0.10^{Cb}	5.69 ± 0.06^{A}	5.81 ± 0.07^{Ac}	7.72 ± 0.10^{Ba}
Lactose content (%)	4.66 ± 0.04^{A}	4.11 ± 0.04^{Ba}	3.85 ± 0.05^{Ca}	4.61 ± 0.04^{A}	4.31 ± 0.04^{Bb}	3.49 ± 0.06^{Cb}	4.67 ± 0.04^{A}	4.40 ± 0.04^{Bb}	3.68 ± 0.07^{Cab}
SNF (%)	10.81 ± 0.06^{A}	11.20 ± 0.06^{Ba}	11.96 ± 0.06^{Ca}	10.75 ± 0.06^{A}	11.02 ± 0.06^{Bab}	12.42 ± 0.08^{Cb}	10.98 ± 0.05^{A}	10.82 ± 0.06^{Ab}	12.06 ± 0.09^{Bab}
SCC (logSCC/ml)	4.76 ± 0.05	4.91 ± 0.05^{a}	4.94 ± 0.06	4.69 ± 0.06	4.65 ± 0.06^{b}	4.92 ± 0.08	4.80 ± 0.05^{A}	4.86 ± 0.06^{Aab}	5.18 ± 0.09^{B}
TBC (logCFU/ml)	4.16 ± 0.06^{A}	4.67 ± 0.06^{B}	4.50 ± 0.07^{B}	3.98 ± 0.06^{A}	4.31 ± 0.06^{B}	4.44 ± 0.09^{B}	4.31 ± 0.06^{A}	4.27 ± 0.06^{A}	4.68 ± 0.10^{B}

Abbreviations: SNF – Solid non-fat; SCC – Somatic cell count; TBC – Total bacterial count
* Stage of lactation: Early: 80-100; Mid: 140-160; Late: 200-220 days
^{A,B,C} The mean values within the breed at different stages of lactation with different superscript differ (*P* < 0.05)
^{a,b,c} The mean values between the breeds within the individual lactation stages with different superscript numbers differ (*P* < 0.05)

Table 2. Influence of the interaction between breed and stage of lactation on udder morphology in Kupres, Privor and Stolac Pramenka dairy sheep breeds (data are LSM ± SEM)

Parameter	Kupres			Privor			Stolac		
	Early*	Mid	Late	Early	Mid	Late	Early	Mid	Late
Udder width (cm)	13.41 ± 0.13^{Aa}	11.36 ± 0.14^{Ba}	9.64 ± 0.16^{Ca}	9.72 ± 0.15^{Ab}	10.11 ± 0.16^{Ab}	8.78 ± 0.22^{Bb}	11.40 ± 0.13^{Ac}	10.47 ± 0.14^{Bb}	9.88 ± 0.22^{Ba}
Udder height (cm)	9.99 ± 0.13^{Aa}	8.43 ± 0.13^{Ba}	7.27 ± 0.15^{C}	7.50 ± 0.15^{Bb}	8.98 ± 0.15^{Aa}	6.77 ± 0.22^{B}	8.20 ± 0.12^{c}	7.77 ± 0.13^{b}	7.62 ± 0.22
Cistern height (cm)	0.76 ± 0.05	0.88 ± 0.05^{a}	0.89 ± 0.05	0.86 ± 0.0^{6A}	1.29 ± 0.06^{Bb}	1.18 ± 0.07^{B}	0.79 ± 0.05	0.88 ± 0.05^{a}	0.99 ± 0.07
Teat angle (°)	26.40 ± 1.39^{Aa}	38.74 ± 1.42^{Bab}	42.40 ± 1.52^{Bab}	32.94 ± 1.54^{Ab}	44.93 ± 1.58^{Ba}	48.89 ± 1.97^{Ba}	27.90 ± 1.32^{Aab}	33.76 ± 1.37^{Bb}	36.13 ± 1.89^{Bb}
Teat width (cm)	1.50 ± 0.03^{Aa}	1.26 ± 0.03^{Ba}	1.25 ± 0.04^{B}	1.11 ± 0.04^{b}	1.14 ± 0.04^{ab}	1.16 ± 0.05	1.27 ± 0.03^{Ac}	1.09 ± 0.03^{Bb}	1.22 ± 0.05^{A}
Teat length (cm)	2.33 ± 0.06^{Aa}	1.93 ± 0.06^{Ba}	1.87 ± 0.06^{B}	1.53 ± 0.06^{b}	1.65 ± 0.07^{b}	1.70 ± 0.09	1.91 ± 0.05^{Ac}	1.65 ± 0.06^{Bb}	1.85 ± 0.08^{AB}

* Stage of lactation: Early: 80-100; Mid: 140-160; Late: 200-220 days
^{A,B,C} The mean values within the breed at different stages of lactation with different superscript differ (*P* < 0.05)
^{a,b,c} The mean values between the breeds within the individual lactation stages with different superscript numbers differ (*P* < 0.05)

A similar decrease in milk yield in Kupres Pramenka breed of ewes during lactation was observed in the East Friesian breed in Wallachia (Kuchtík et al., 2008).

The protein and fat content increased from the 33rd to the 191st day of lactation in a similar way to all three Pramenka breeds in this study. In contrast, a significant (P<0.05) decrease in lactose content was observed in all three Pramenka breeds. All three Pramenka breeds had very similar protein, fat and SNF contents throughout lactation, similar to the Epirus mountain sheep (Simos et al., 1996).

However, their fat content in early lactation and milk yield throughout lactation were lower than Privor and Stolac Pramenka breeds, which produced less milk than the Kupres Pramenka breed. Similar values for fat, protein, lactose and SNF during lactation were found in Chios sheep, whose milk is used for the production of homemade feta cheese (Ploumi et al., 1998). Within breed, there was no significant (P<0.05) difference in logSCC during lactation. A similar situation occurred in Comisana sheep in three parities (Sevi et al., 2000). The TBC content was much lower in three Pramenka breeds than in sheep's milk produced on a farm in north-eastern Greece (Alexopoulos et al., 2011). However, there was a slight increase in TBC during lactation with the highest values at the end of lactation, i.e. in summer.

Udder morphology

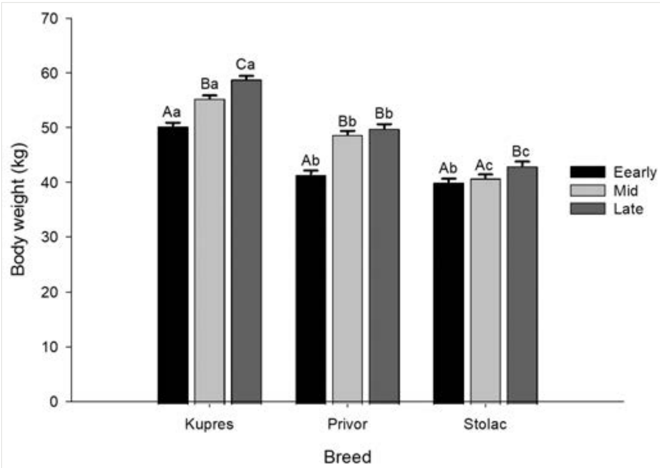
Udder width decreases significantly (P<0.05) in the Kupres, Privor and Stolac Pramenka breeds during the entire lactation (Table 2). Kupres breed has significantly higher (P<0.05) udder width values in early and in the mid of lactation than Privor and Stolac breeds. Udder height decreases significantly in the Kupres and Privor breeds during lactation (P<0.05). A decreasing trend in udder height was observed in the Stolac breed. Cistern height was numerically higher in the Privor breed in late and mid lactation than in early lactation. However, cistern height values were higher as lactation progressed. Teat angle was significantly (P<0.05) lower in early lactation than in mid and late lactation in all three Pramenka group breeds. Teat width and length were higher in the Kupres and Stolac breeds in early lactation than in mid and late lactation, while the Privor breed showed no significant changes throughout lactation.

Cistern height ranged from 0.76 cm in early lactation in the Kupres to 1.29 cm in mid-lactation in the Privor Pramenka breed. The teat angle ranged from 26° in the Kupres in early lactation to 49° in the Privor breed in late lactation. All three Pramenka type breeds had similar teat length and width to Sicilo-Sarda sheep (Ayadi et al., 2011). However, larger teats were found in Lacaune, Manchega, Bergamesca, the Istrian dairy crossbreed, Awassi, Mehraban, Ghezel, Frizarta, Spanish Assaf, Sarda and Chios dairy sheep (Labussière et al., 1981, Labussiere, 1988, Mavrogenis et al., 1988, Izadifard and Zamiri, 1997, Rovai et al., 1999, Dzidic et al., 2004, Emediato et al., 2008, Iñiguez et al., 2009, Kominakis et al., 2009, Legaz et al., 2011, Gelasakis et al., 2012). The teat diameter was similar in all the breeds mentioned, except for Bergamesca (Emediato et al., 2008), which had thicker teats. Teat length and width decreased significantly (P<0.05) during lactation in Kupres and Stolac Pramenka breeds and increased in Privor Pramenka breed, similar to Manchega sheep (Rovai et al., 1999). Longer teats with similar udder width were observed in non-milking purebred Wallachian sheep (Milerski et al., 2020). It is known that the teat measurements together with the cistern height are more variable than the udder measurements (Iñiguez et al., 2009). The teat angle increased during lactation in all three Pramenka type breeds. In the French Rouge de l'Ouest breed, similar results were found for teat angle in early lactation as in Pramenka-type breeds (Malher and Vraylaanesti, 1994). Lacaune, Manchega, the Istrian dairy crossbreed, Tsigai, Improved Walachian and Frizarta dairy sheep had teat angle values found in our three Pramenka breeds at the end of lactation (Labussière et al., 1981, Rovai et al., 1999, Dzidic et al., 2004, Milerski et al., 2006, Kominakis et al., 2009). A similar pattern of teat angle follows cistern height, which increases in size during lactation in all three Pramenka-type breeds. The values for cistern height are lowest in Lacaune, Manchega, Frizarta and Awassi dairy sheep (Labussière et al., 1981; Rovai et al., 1999; Iñiguez et al., 2009; Kominakis et al., 2009).

However, only the Tsigai dairy sheep (Milerski et al., 2006) had a similar cistern height to all investigated dairy sheep breeds at the end of lactation. Udder width decreased in all three Pramenka type breeds during lactation and their values were similar to Lacaune, Manchega, Awassi and Spanish Assaf (Labussière et al., 1981, Rovai et al., 1999; Iñiguez et al., 2009; Legaz et al., 2011). A similar trend of decreasing values during lactation was observed for udder height. Istrian dairy crossbreed, Awassi, and Frizata sheep breeds had a higher udder height than all Pramenka breeds (Dzidic et al., 2004; Iñiguez et al., 2009; Kominakis et al., 2009). Only the Spanish Assaf (Legaz et al., 2011) had similar values to three Pramenka-type breeds in this study at the beginning of lactation. It seems likely that udder height and udder width decrease in all three Pramenka-type breeds of sheep during lactation, similar to milk production.

Sheep body weight

All three Pramenka sheep breeds significantly (P<0.05) increased their body weight during lactation (Figure 1). The Kupres Pramenka breed was heavier than the Privor and Stolac Pramenka breeds in all three stages of lactation. Kupres Pramenka breed increased her body weight from 50 kg in early lactation to almost 60 kg in late lactation. Privor Pramenka breed increased body weight from 40 kg in early lactation to 50 kg in late lactation. The main reason for the low increase in body weight is most likely due to the conditions of the pastures, where further analyses of the nutrient supply and pasture management are required. The smallest change in body weight was observed in the Stolac Pramenka breed, which increased from 40 kg in early lactation to 43 kg in late lactation. Measuring body weight is very important at the end of gestation and at the beginning of lactation (Hernández et al., 2018). In order to estimate the mobilization of reserves during lactation, it is important to measure them within the same group and under the same management conditions. The body weights increased significantly (P<0.05) with lactation in all three Pramenka type breeds, which is probably related to the higher feed supply in the pastures. However, their weight change towards the mid-lactation is much lower than in Lacaune dairy ewes, where the undernutrition was detected by measuring body weight change (González-García et al., 2021). In addition, the body weight of East Friesian dairy sheep increased equally between early and mid-lactation regardless of body group (i.e. low, moderate, high) (Hernández et al., 2018). Similar lactation curves for milk production were found in low body weight East Friesian dairy sheep using the Pollott model (Hernández et al., 2018) and in all three Pramenka type breeds using the Guo-Swalve model (Šalamon et al., 2020). The Kupres Pramenka dairy breed had a similar body weight to the Latxa sheep (Oregui et al., 1997) of between 50 and 55 kg. The same study showed that the maximum adult weight in the Latxa breed is only reached at the age of four. This was related to malnutrition when the herds graze on mountain pastures like our three Pramenka-type breeds. Measuring body weight during lactation can help farmers determine the nutritional status and reserves of the dairy sheep in grazing animals.



Different capital letters indicate significant differences within the breed at different stages of lactation (P < 0.05). Different lower-case letters indicate significant differences within the individual lactation stages for different breeds (P < 0.05).

Figure 1. Body weight during lactation of Kupres, Privor and Stolac Pramenka sheep breeds (data are LSM ± SEM)

Correlations between sheep udder morphology, milk production and body weight

Milk yield was positively significantly (*P*<0.05) correlated with udder width (r=0.78), udder height (r=0.71), teat width (r=0.41), teat length (r=0.36), and negatively correlated with cistern height (r=-0.16) and teat angle (r=-0.35). Udder width and udder height were positively significantly (*P*<0.05) correlated (r=0.82). Teat length and teat width were significantly (*P*<0.05) positively correlated (r=0.89). Teat angle and cistern height were positively significantly (*P*<0.05) correlated (r=0.73). Sheep weight was positively correlated with all variables in Table 3, while the highest significant values were observed for teat width, teat length, udder height, teat angle and udder width. The correlations of milk production with udder width and length were positive and significant (*P*<0.05) for all Pramenka breeds in this study. This means that higher milk production is related to larger udder size (Labussière et al., 1981; Mavrogenis et al., 1988; Izadifard and Zamiri, 1997; Rovai et al., 1999; Emediato et al., 2008; Iñiguez et al., 2009; Legaz et al., 2011). In contrast to the studies on Lacaune and Manchega sheep (Rovai et al., 1999), we found a positive and significant (*P*<0.05) correlation between teat length and width and milk production in this study. Sicilo-Sarde and Nadji dairy sheep showed a significant (*P*<0.05) negative correlation between teat angle and teat width and length (Ayadi et al., 2011; Ayadi et al., 2014), which was more pronounced in the researched Pramenka breeds. These correlations should be treated with caution, as we found a negative correlation between teat angle and teat length, whereas in the Churra breed (de la Fuente et al., 1996), a positive correlation was found between teat placement and teat size. However, they used a nine-point scale for measurement, where the highest teat placement scores mean the lowest teat angle, which means that the data are similar, while the correlation is stronger in our Pramenka breeds and both were significant (*P*<0.05). A similar negative correlation between udder volume and teat angle was found in Istrian crossbreed dairy ewes (Dzidic et al., 2004). This means that all Pramenka breeds in the present study have a relatively small teat angle and a low cistern height, which means that they are potentially suitable for machine milking. As mentioned in the review article (Pourlis, 2020), likely, some differences in the comparison of udder morphology with milk production are due to measurements in different environments. However, when comparing this study with others, it is clear that for the majority of breeds, larger udders are associated with higher milk production. In addition, the low-producing Pramenka breeds from the present study are associated with udders suitable for machine milking.

Table 3. Pearson's correlation coefficients between udder morphology, milk yield and sheep weight in Kupres, Privor and Stolac sheep breeds

Trait[a]	MY	UW	UH	CH	TL	TW	TA
UW	0.78***						
UH	0.71***	0.82***					
CH	-0.16***	-0.24***	0.01				
TL	0.36***	0.49***	0.40***	-0.44***			
TW	0.41***	0.48***	0.39***	-0.47***	0.89***		
TA	-0.35***	-0.42***	-0.21***	0.73***	-0.53***	-0.54***	
SW	0.05	0.13***	0.19***	0.02	0.26***	0.28***	0.17***

[a] MY = milk yield, UW = udder width, UH = udder height, CH = cistern height, TL = teat length, TW = teat width, TA = teat angle, SW = sheep weight.
*** $P < 0.05$

CONCLUSIONS

The breed with the highest milk production and udder height and width was Kupres compared to Privor and Stolac Pramenka sheep breeds. The udder and teat measurements were in all breeds and acceptable for machine milking, which was reflected in a low teat angle and a cistern height below the teat orifice. Udder width and height show a high positive correlation with milk yield and can be used to predict milk production in all three Pramenka sheep in future national breeding programs.

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