

Udder morphology, milk production and udder health in small ruminants

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Abstract

In recent years there has been an increasing trend in research of sheep and goat udder morphology, not only from the view of its suitability for machine milking, but also in terms of milk yield and mammary gland health. More precisely, herds consisting of high-yielding sheep and goats as a result of long-term and one-sided selection to increase milk yield, have been characterised by distortion of the udder morphology caused by increasing the pressure of udder weight on its suspensory system. Along with the deteriorated milking traits, which is negatively reflected on the udder health, some udder morphology traits are often emphasized as factor of production longevity of dairy sheep and goats. Since the intention of farmers and breeders nowadays is to increase the milk yield of sheep and goats while maintaining desirable udder morphology and udder health, the aim of this paper is to give a detailed overview of the current knowledge about the relationship of morphological udder traits with milk yield, and the health of the mammary gland of sheep and goats. External measures of udder size (circumference, width and depth of the udder) are strongly correlated with milk production in sheep and goats. The morphological udder traits determining its suitability for machine milking (such as teat position and teat angle, udder depth, teat size, cistern height) are related to the mammary gland health in sheep and goats. Thus, the incidence of mastitis is noticeably higher in the udders of unsuitable shape for machine milking (deep and hung udders, unfavourable position of teats, etc.). Consequently, the morphological udder traits that affect the milkability of sheep and goats are indirectly related to milk yield.

Key words: goat milk, sheep milk, lactation, udder traits, udder health, milk composition

Introduction

Over the last two decades, and concurrently with the more frequent machine milking of sheep and goats, there has been an increasing interest in studying udder morphology with regard to the suitability of udder to machine milking, i.e., the relationship between udder morphological traits and the milking characteristics of sheep and goats (Marnet and McKusick, 2001; Džidic et al., 2004; Makovický et al., 2019). However, nowadays there is an increasing number of studies aimed at identifying different factors of udder morphology variability (Mavrogenis et al., 1988; Fernández et al., 1995; Prpić et al., 2013; 2016; Šalamon et al., 2019) from the aspect of milk production and mammary gland health and, thus identifying those udder morphology traits suitable for inclusion in selection programs (Ugarte and Gabiña, 2004; Macciotta et al., 2005; Teissier et al., 2019). Namely, in herds of high producing dairy ewes and goats, as a result of long-lasting and, most often, unilateral selection for increasing milk yield, disturbance of udder morphology (deep and hung udder, unfavourable position of teats, etc.) is increasingly noticeable due to increasing pressure of udder weight to its suspension system (McKusick, 2000; Barillet, 2007). This, in addition to impaired milking traits, has a negative effect on udder health, so that certain udder morphology traits are used as factors of premature culling of dairy animals (Castañeda-Bustos et al., 2017).

The importance of udder health should not only be viewed through the productive longevity of animals, as mastitis is a major cause of premature culling of dairy sheep, but also from the aspect of the hygienic quality of the produced milk. The majority of sheep and goat milk produced in Croatia, as well as throughout the Mediterranean, is used for cheese production without heat treatment. Since mastitis is the most expensive and common disease in flocks of dairy sheep and goats and machine milking is more frequent, functional udder traits (udder morphology, mastitis resistance, etc.) are included in dairy sheep and goat breeding programs (Barillet, 2007), especially in countries with developed sheep and goat milk production (France, Italy, Spain, etc.). Functional udder traits increase the biological and economic efficiency of production, not necessarily by increasing the quantity of

milk produced, but by reducing production costs (Macciotta et al., 2005; Barillet, 2007).

Since the intention of farmers (and breeders) is to increase the milk yield of sheep and goats while maintaining desirable morphology and udder health, the aim of this paper is to give a detailed overview of the current knowledge about the relationship of morphological udder traits with milk yield, and the health of the mammary gland of sheep and goats.

Relationship between udder morphology and milk yield

Dairy ewes

The first udder morphology measurements were conducted by Labussiere (1988) over three decades ago on Mediterranean dairy sheep breeds. Milk production is an important factor that determines the size and the shape of the udder (Fernández et al., 1995; Lérias et al., 2014). Taking into account the fact that udder morphology is an important determinant of udder suitability to machine milking (Labussière, 1988; Bruckmaier et al., 1997; Džidic et al., 2019), the first practical classification of sheep udder was conducted precisely on the basis of its suitability for machine milking in four basic types or shapes, as shown in Figure 1 (Sagi and Morag, 1974). Kukovics et al. (2006) concluded that the relationship between udder shape and milk production, as well as its chemical composition, is highly variable and genotype dependent. While investigating udder morphological traits of Assaf sheep, Sagi and Morag (1974) were the first to identify a significant relationship between udder shape and milk yield, while; for example, Volanis et al. (2002) found no significant differences in the quantity of milk produced between hand-milked Sfakia ewes of different udder shapes.

Fernández et al. (1995) found marked differences in external udder measures of Churra ewes of different lactation milk yields. Emediato et al. (2008) reported low phenotypic correlations between the milk yield and morphological udder traits during the suckling period (first 30 days of lactation), as opposed to milking period when high and positive correlations between milk yield and udder

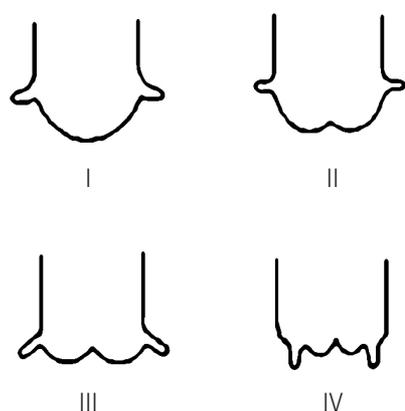


FIGURE 1. Types of sheep udder according to machine milking suitability (Sagi and Morag, 1974)

circumference (0.74), followed by milk yield and udder depth (0.75), udder width (0.63) and udder volume (0.83) were established. Similar correlation coefficients were found by Unal et al. (2008) by investigating the crosses of Chios sheep, followed by Iniquez et al. (2009) in Awassi sheep and Prpić et al. (2012; 2013) in sub Mediterranean indigenous sheep breeds. Fernández et al. (1997) pointed out low phenotypic correlations between the milk yield and analysed linear udder traits, except for udder depth whose correlation coefficient with daily milk yield was 0.40 and with quantity of proteins produced 0.38. This corresponds to the results reported by Labussière (1988), who explained that udder depth actually indicates a measure of the development of the secretory tissue of the mammary gland, and is therefore directly related to the quantity of milk produced.

Although Izadifard and Zamiri (1997) found high correlation coefficients between the milk yield and udder morphology traits in Ghezel sheep two weeks after lambing, the correlations found between these traits during the milking period were not statistically significant. However, in a more recent study Ayadi et al. (2014) reported positive correlations between sheep milk production and some measures of udder size (circumference, depth and width of the udder, and distance between teats) during the suckling period, as well as during the milking period.

McKusick et al. (1999) found that an increase in the circumference and the depth of the udder of East Friesian ewes by 1 cm results in an increase of daily milk yield in range from 0.06 to 0.11 litres,

respectively, which is consistent with the previous findings that the volume and depth of udder explain about 62 % of variations in milk production (Perez-Linares et al., 1983). Izadifard and Zamiri (1997), however, found that udder circumference is the most accurate single estimator of total lactation milk yield in sheep. Consequently, many authors have concluded that certain morphological udder traits should be used in breeding programs to improve milk production in sheep (Ugarte and Gabina, 2004; Barillet et al., 2007; Gutiérrez-Gil et al., 2008). Rovai et al. (2008) and Macuhová et al. (2008) established a positive phenotypic correlation between the cistern height (externally measured distance between the lowest udder point and the teat implantation line) and the quantity of milk produced, while Fernández et al. (1997) found no significant differences in cistern height between sheep of different milk yield.

Kominakis et al. (2009) found a correlation between the length of teats and the reduced milk yield of hand-milked Frizarta sheep in Greece, while other external teat traits (teat width and teat angle) were not related to milk yield. Negative genetic correlations (from low to moderate values) between teat dimensions and milk production have also been found in machine-milked Latxa and Churra ewes (Fernández et al., 1997; Legarra and Ugarte, 2005). However, Prpić et al. (2012; 2014) found that there was a positive and significant phenotypic correlation between teat width and daily milk yield in hand-milked sheep.

Studies on the relationship of udder morphology with the chemical composition of sheep's milk have rarely been reported in the literature. In most cases, correlations were found between measures of udder size (udder circumference, udder width and depth, and volume of the udder) and the content of some constituents in milk, as well as between teat dimensions (especially width) and the milk chemical composition (McKusick et al. 1999; Iñiquez et al., 2009; Kominakis et al., 2009). McKusick et al. (1999) clarified that the above discussed correlations result from the relationship of external measures of udder size and the quantity of milk produced, i.e. from the existence, of negative correlations between milk yield and the content (%) of milk fat and protein in milk.

Dairy goats

In high yielding dairy goats, properly developed and healthy udder is large in volume and rounded, well attached to the abdomen, of medium depth without exceeding the height of the hocks (Gall, 1980). Montaldo and Martinez-Lozano (1993) found that round-shaped udder, which corresponds with bowl-shaped udder presented in Figure 2, is the most desirable with respect to milk production as well as mammary gland health. In the same study, goats with round udder achieved the highest average daily milk production, with a significantly lower number of somatic cells in milk and a lower incidence of mastitis than found in goats of a different udder shape.

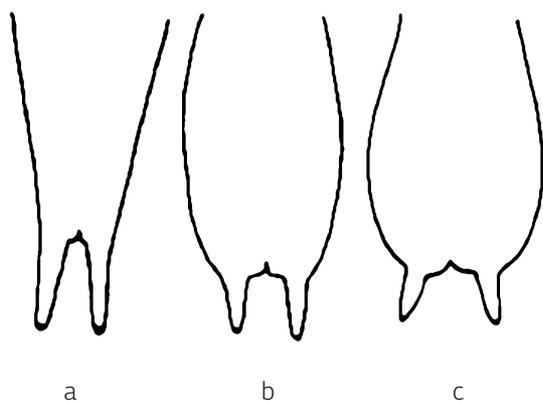


FIGURE 2. Shapes of goat udder: a, funnel; b, cylindrical; c, bowl (adapted from James et al., 2009)

As early as 1980, Gall concluded that the size of goat udder was positively correlated with the quantity of milk produced, and that milk production in goats could be estimated by visual assessment of udder (Gall, 1980). However, in an earlier study McNulty et al. (1960, cited by Gall, 1980) concluded that large udder does not necessarily mean a high milk production.

Montaldo and Martinez-Lozano (1993) and Keskin et al (2005) concluded that udder circumference was in the highest correlation with the goat milk yield compared to other external udder measures. Although they found a relatively weak relationship between most of the analysed morphological traits of udder and milk production, Capote et al. (2006) and McLaren et al. (2016) concluded that large volume udders, as well as deep and well

attached udders are significantly and positively correlated with the quantity of produced goat milk. Cedden et al. (2008) and Upadhyay et al. (2014), however, found that there were high phenotypic correlations ($r=0.6-0.8$) between external measures defining udder size (circumference, depth, and width of the udder) and milk yield.

Despite the positive correlation with the daily milk yield, Cividini et al. (2016) stated that there was a significant negative correlation between some external udder measures (udder depth and udder width) and duration of lactation of French Alpine goats since a decrease in udder depth and width was found in parallel with the advancement of lactation. Peris et al. (1999) and Pawlina et al. (2005), found that, simultaneously with the advancement of lactation, udder size decreases, while teat length and width increases, although stated is in interaction with parity. Lactation order is, in addition to the lactation stage (Lérias et al. 2014), as well as litter size (Upadhyay et al., 2014; Atay and Gokdal, 2016) and milking frequency (Capote et al., 2006), an important source of variability of goat udder morphology. Thus, Montaldo and Martinez-Lozano (1993) found that, compared to the first parity goats, those in the second and later lactations had longer teats, smaller udder circumference, and shorter distance from the teat ends to the floor. Goats milked once daily, according to Capote et al. (2006), have greater udder volume, udder circumference and udder depth, and a shorter distance from the teat end to the floor than goats milked twice daily. The same authors found higher phenotypic correlations coefficients between external udder measures (udder volume, udder circumference and distance between teats) and milk yield in goats milked once compared to those milked twice a day.

In addition to measures of udder size, according to Montaldo and Martinez-Lozano (1993), Keskin et al. (2005) and Upadhyay et al. (2014), the morphological traits of teats are positively correlated with the quantity of milk produced, with the circumference of teats being in the highest correlation with milk yield. In addition to the fact that the teat angle is one of the most important traits that determines the suitability of the udder to machine milking (Peris et al., 1999), Eyduran et al. (2013) found a positive phenotypic correlation between

teat angle and milk production, wherein the highest lactation milk yield being achieved by goats with a teat angle greater than 50°.

Some morphological udder traits are significantly associated with the chemical composition of goat milk, i.e. with an increase in udder (circumference, depth and width of udder) and teat size (teat length and width), a marked decrease in the content (%) of milk fat in milk was established (Cedden et al. 2008). However, El-Gendy et al. (2014) concluded that the correlation between the morphology of the udder with the chemical composition of goat milk is genotype depend.

Relationship between udder morphology and mammary gland health

Dairy sheep

Although mastitis, especially its subclinical form, is one of the major health problems and causes culling of dairy sheep, the relationship between the morphological traits of the udder and somatic cell count, as an indicator of udder health and milk hygiene quality, so far has been studied in only a few sheep breeds. Since the heritability of somatic cell counts in milk is low and, therefore, the reduction of somatic cell counts by selection is relatively slow and difficult to achieve, it is considered that there is a possibility of improving mastitis resistance by indirect selection of certain udder morphological traits (Legarra and Ugarte, 2005; Barillet, 2007; Crump et al., 2019). For example, Barillet (2007) found, from a breeding point of view, a desirable correlation between the number of somatic cells in milk and some morphological traits of sheep udder, such as teat position, udder depth, and prominence of the udder suspensory system.

According to Casu et al. (2006), the shape and the size of the udder are related to the productive longevity of the sheep, especially those kept on pasture. The sheep with deep (suspended) udder are more exposed to mechanical injuries of the udder and, consequently, earlier culled from breeding. Dag and Zülkadir (2004) found a significant effect of the udder type (shape) on the incidence of

mastitis in sheep, stating that Awassi sheep with high cisterns (externally measured) and horizontally placed teats (type of udder I and II, Figure 1) were more likely to develop mastitis.

Kretschmer and Peters (2002) found that the number of somatic cells in the milk of East Friesian sheep is affected by the udder depth and the position and size of the teats, while Margetín et al. (2005) conclude that sheep with horizontally oriented and longer teats have a significantly higher number of somatic cells per millilitre of milk.

On the contrary, Akdag et al. (2018) found that sheep's milk obtained from the udder of type III and type IV (Figure 1), i.e., from udder with vertically oriented teats, has the highest mean number of somatic cells. The same authors found a positive phenotypic correlation between teat length and somatic cell count in sheep's milk (Akdag et al., 2018). Accordingly, Fahr et al. (2004) reported a higher incidence of mastitis in dairy sheep with a smaller distance between the teats and the floor level. This is supported by the low, but positive, phenotypic correlations between the somatic cell count and udder depth (0.13), as well as teat dimensions (0.18) in machine-milked Churra sheep (Fernández et al., 1997), which is consistent with results established by Prpić (2011) in hand-milked Pag and Istrian sheep.

Margetín et al. (2005) found a significant effect of the breed on the incidence of mastitis in sheep. The same authors found a positive phenotypic correlation between the size of glandular udder cistern and somatic cell count ($r=0.17$) in the Lacaune breed, unlike other genotypes covered by the study.

McKusick et al. (1999) found significantly negative correlations between the somatic cell count and externally measured cistern height, as well as between SCC and udder circumference and udder width of East Friesian sheep. On the contrary, Kominakis et al. (2009) found no significant correlations between any of the studied udder morphological traits and SCC in Greek Frizarta sheep.

Also, Casu et al. (2010) estimated the likelihood of udder inflammation during the production life of Mediterranean dairy ewes based on the morphological traits of udders evaluated in their first lactation. Ewes with deep udders and teats oriented more forward had a greater likelihood of

udder inflammation than sheep with well-attached udders and less cranially oriented teats (Casu et al., 2010). This indicates the possibility of practical implementation of the early selection of sheep for better udder health based on udder morphology.

Dairy goats

According to Cedden et al. (2008), regarding the mammary gland health it is preferable for dairy goats to have a wide udder due to a negative phenotypic correlation between udder width and somatic cell counts, as well as between the distance between teat ends and the number of somatic cells in goat milk. Novotna et al. (2018) found that somatic cell count as one of udder health indicators was significantly related to udder width and udder depth. In this case, a greater number of somatic cells were found in the milk of goats of greater udder depth. On contrary, with the increase in udder width, the number of somatic cells in goat's milk was lower, with the number of somatic cells beginning to increase in udder widths greater than 17 cm. Considering the somatic cell count in milk, the udder width of 13 to 17 cm was optimal (Novotna et al., 2018).

Although Santos et al. (2015) found that the most of udder morphological traits in Saanen goats was not related to the number of somatic cells in milk, the udder circumference was negatively correlated to the number of somatic cells, with a moderately high heritability of udder circumference, suggesting the possibility of including this trait in breeding programs. Montaldo and Martinez-Lozano (1993) examined three different goat genotypes and found that milk obtained from globular udder had a lower California Mastitis test value than milk obtained from udder of a different form. Similar to these results, Rupp et al. (2011) concluded that it is desirable for the udder of dairy goats to be well attached to the abdominal wall but not too deep (hanged). That is because they have also found that with increasing the udder depth, the number of somatic cells in the milk of French Alpine and Saanen primiparous goats significantly increased. Also, the authors indicated the existence of significant phenotypic correlation between the somatic cell count in milk and teat size, with shorter

and narrower teats associated with a fewer somatic cells in milk of Saanen goat, which was not found in French Alpine goat (Rupp et al., 2011). Santos et al. (2015) found no significant association of any of the studied morphological teat traits of Saanen goats with the somatic cell count in milk, as well as with the results of the California mastitis test.

In addition to the teat size, according to the results of some studies, the shape of the teat is related to the health of the mammary gland of dairy goats (Figure 3). In a study involving several dairy goat genotypes Montaldo and Martinez-Lozano (1993) found that milk obtained from dairy goats with bottle-shaped teats had a significantly higher California Mastitis test value than the milk from goats with funnel- or cylindrical-shaped teats. Similar findings were reported by Schulz et al. (1999) in German Improved Fawn. Schultz et al. (1999) found that apart from the shape of the teats, an important trait of the udder associated with the mammary gland health are the teat distance from the floor and the udder depth. In the same study, goats with hanging udder and bottle-shaped teats that were closer to the floor had an increased somatic cell count in milk ($>1.000.000/\text{mL}$), higher number of polymorphonuclear leukocytes ($>40\%$), higher electrical conductivity of milk ($>6.8\text{ M/cm}$) and lower lactose content ($<4.6\%$). Schulz et al. (1999) found that the incidence of goats with this shape of teats increases with lactation advancement and lactation order.

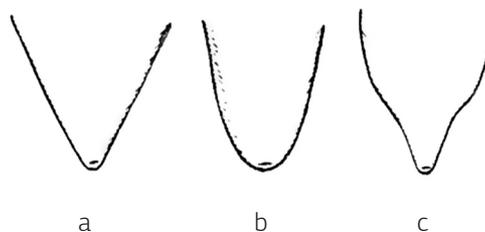


FIGURE 3. Goat teat shapes: a, funnel; b, cylindrical; c, bottle (adapted from James et al., 2009)

Pajor et al. (2014) also found a significant effect of teat shape on the hygienic quality of French Alpine goat milk, with significantly fewer somatic cells found in milk of cylindrical-shaped goats than in milk of funnel-shaped goats. Also, significantly higher prevalence of minor and major mastitis pathogens has been found in milk obtained from

goats with funnel-shaped teats (Pajor et al., 2014). Although Rupp et al. (2011) found no significant relationship between the teat shape and the somatic cell counts in French Alpine goats, concluding that Saanen goats with cylindrical-shaped teats produced milk with significantly fewer somatic cells than funnel-shaped goats. Based on the established genetic correlations, Manfredi et al. (2001), Rupp et al. (2011) and McLaren et al. (2016) concluded that further selection to increase the milk production of high-yielding goat genotypes does not necessarily have a negative impact on the health of their udders if appropriate udder morphological traits are included in breeding programs.

Conclusions

Udder morphology traits, primarily external measures of the udder size (circumference, width

and depth of the udder) are strongly associated with milk production in sheep and goats. The morphological udder traits determining its suitability for machine milking (such as teat position and teat angle, udder depth, teat size, cistern height, or udder height below the teat implantation line) are related to the mammary gland health in sheep and goats. Thus, the incidence of mastitis is noticeably higher in the udders of unsuitable shape for machine milking (deep udders with highly implanted and horizontally oriented teats). As a consequence, the morphological traits of udders that affect the milkability of sheep and goats are indirectly related to their milk yield. Correlations found between measures of udder size and the content of some constituents in milk, result from the relationship of mentioned udder traits and the quantity of milk produced, i.e. from the existence of negative correlations between milk yield and the content of milk fat and protein in milk.

Morfologija vimena, proizvodnja mlijeka i zdravlje mliječne žlijezde malih preživača

Sažetak

Posljednjih godina povećan je interes za istraživanjem morfologije ovčjeg i kozjeg vimena, ne samo sa stanovišta njegove prikladnosti strojnoj mužnji, već i u pogledu proizvodnje mlijeka i zdravlja mliječne žlijezde. Naime, u stadima visokomliječnih ovaca i koza kao rezultat dugotrajne i jednostrane selekcije na povećanje mliječnosti sve je zamjetnije narušavanje morfologije vimena prvenstveno zbog sve većeg pritiska mase vimena na njegov suspenzorni sustav ligamenata. Navedeno se, uz narušene muzne odlike, negativno odražava na zdravlje vimena, tako da se pojedine morfološke odlike vimena sve češće navode kao čimbenik proizvodne dugovječnosti mliječnih koza. Budući da je namjera uzgajivača (i selekcionara) povećanje mliječnosti ovaca i koza uz zadržavanje poželjne morfologije i zdravlja vimena, cilj je ovog rada je detaljno prikazati dosadašnje spoznaja o povezanosti pojedinih morfoloških odlika vimena s mliječnošću i zdravljem mliječne žlijezde ovaca i koza. Mjere veličine vimena (opseg, širina i dubina vimena) su snažno povezane sa proizvodnjom mlijeka ovaca i koza. Morfološke odlike koje određuju prikladnost vimena strojnoj mužnji (kao što su položaj i kut sisa, dubina vimena, veličina sisa i visina cisterne) su povezane sa zdravljem mliječne žlijezde ovaca i koza. Stoga je učestalost mastitisa zamjetno veća u vimena neprikladnog oblika za strojnu mužnju (duboka i obješena vimena s nepoželjnim položajem sisa, i dr.). Posljedično, morfološke odlike vimena koje imaju utjecaj na muznost ovaca i koza neizravno su povezane i s laktacijskom proizvodnjom mlijeka.

Ključne riječi: kozje mlijeko, ovčje mlijeko, laktacija, odlike vimena, zdravlje vimena, sastav mlijeka

References

1. Akpa, G.N., Asiboro, O.E., Oni, O.O. (2003): Relationships among udder and teat size characteristics with milk yield in Red Sokoto goats. *Tropical Agriculture* 80 (2), 114-117.
2. Atay, O., Gokdal, Ö. (2016): Some production traits and phenotypic relationships between udder and production traits of Hair goats. *Indian Journal of Animal Research* 50 (6), 983-988.
3. Ayadi, M., Matar, A.M., Aljumaah, R.S., AlshaiKh, M.A., Abouheif, M.A. (2014): Evolution of udder morphology, alveolar and cisternal milk compartment during lactation and their relationship with milk yield in Najdi sheep. *Spanish Journal of Agricultural Research* 12, 1061-1070. <http://dx.doi.org/10.5424/sjar/2014124-5545>
4. Barillet, F. (2007): Genetic improvement for dairy production in sheep and goats. *Small Ruminant Research* 70, 60-75. <https://doi.org/10.1016/j.smallrumres.2007.01.004>
5. Bruckmaier, R.M., Paul, G., Mayer, H., Schams, D. (1997): Machine milking of Ostfriesian and Lacaune dairy ewe: udder anatomy, milk ejection and milking characteristics. *Journal of Dairy Research* 64, 163-172.
6. Capote, J., Arguello, A., Castro, N., Lopez, J.L., Caja, G. (2006): Correlations between udder morphology, milk yield and milking ability with different milking frequencies in dairy goats. *Journal of Dairy Science* 89, 2076-2079. [https://doi.org/10.3168/jds.S0022-0302\(06\)72276-7](https://doi.org/10.3168/jds.S0022-0302(06)72276-7)
7. Castañeda-Bustos, V.J., Montaldo, H.H., Valencia-Posadas, M., Shepard, L., Perez-Elizalde, S., Hernandez-Mendo, O., Torres-Hernandez, G. (2017): Linear and nonlinear genetic relationships between type traits and productive life in US dairy goats. *Journal of Dairy Science* 100 (2), 1232-1245. <https://doi.org/10.3168/jds.2016-11313>
8. Casu, S., Pernazza, I., Carta, A. (2006): Feasibility of a linear scoring method of udder morphology for the selection scheme in Sardinian sheep. *Journal of Dairy Science* 89, 2200-2209. [https://doi.org/10.3168/jds.S0022-0302\(06\)72290-1](https://doi.org/10.3168/jds.S0022-0302(06)72290-1)
9. Cedden, F., Kaya, S.O., Daskiran, I. (2008): Somatic cell, udder and milk yield in goat. *Revue De Medecine Veterinaire* 159 (4), 237-242.
10. Cividini, A., Flisar, T., Kovač, M., Kompan, D. (2016): Correlations between udder traits and their relationship with milk yield during first lactation in Slovenian Alpine goats. *Acta Agriculturae Slovenica* (Suppl. 5), 113-117.
11. Crump, R.E., Cooper, S., Smith, E.M., Grant, C., Green, L.E. (2019): Heritability of phenotypic udder traits to improve resilience to mastitis in Texel ewes. *Animal* 13 (8), 1570-1575. <https://doi.org/10.1017/S1751731118002951>
12. Dag, B., Zülkadir, U. (2004): Relationships among udder traits and milk production in unimproved Awassi sheep. *Journal of Animal and Veterinary Advances* 3, 730-735.
13. Dzidic, A., Kaps, M., Bruckmaier, R.M. (2004): Machine milking of Istrian dairy crossbreed ewes: udder morphology and milking characteristics. *Small Ruminant Research* 55, 183-189. <https://doi.org/10.1016/j.smallrumres.2004.02.003>
14. Dzidic, A., Rovai, M., Poulet, J., Leclerc, M., Marnet, P. (2019): Milking routines and cluster detachment levels in small ruminants. *Animal* 13 (S1), S86-S93. <https://doi.org/10.1017/S1751731118003488>
15. El-Gendy, M.E., Hafsa, F.H.Y., Saifelnasr, E.O.H., El-Sanafawy, H.A., Saaba, F.E. (2014): Relationship between udder characteristics and each of reproductive performance and milk production and milk composition in Zaraibi and Damascus dairy goats. *Egyptian Journal of Sheep & Goat Sciences* 9 (3), 95-104.
16. Emediato, R.M.S., Siqueira, E.R., Stradiotto, M.M., Maestá, S.A., Fernandes, S. (2008): Relationship between udder measurements and milk yield in Bergamesca ewes in Brazil. *Small Ruminant Research* 75, 232-235. <https://doi.org/10.1016/j.smallrumres.2007.11.006>
17. Fahr, R.D., Schulz, J., Süß, R., Al-Hamoud, A.R. (2004): Physical examination of the mammary gland and milk indicators of udder health in East Friesian milk sheep. *Tierärztliche Praxis* 32, 133-139.
18. Fernández, G., Alvarez, P., San Primitivo F., De la Fuente, L.F. (1995): Factors affecting variation of udder traits of dairy ewes. *Journal of Dairy Science* 78, 842-849. [https://doi.org/10.3168/jds.S0022-0302\(95\)76696-6](https://doi.org/10.3168/jds.S0022-0302(95)76696-6)
19. Fernández, G., Baro, J.A., de la Fuente, L. F., San Primitivo, F. (1997): Genetic parameters for linear udder traits in dairy ewes. *Journal of Dairy Science* 80, 601-605. [https://doi.org/10.3168/jds.S0022-0302\(97\)75976-9](https://doi.org/10.3168/jds.S0022-0302(97)75976-9)
20. Gall, C. (1980): Relationship Between Body Conformation and Production in Dairy Goats. *Journal of Dairy Science* 63 (10), 1768-1781. [https://doi.org/10.3168/jds.S0022-0302\(80\)83136-5](https://doi.org/10.3168/jds.S0022-0302(80)83136-5)
21. Gutiérrez-Gil, B., El-Zarei, M.F., Alvarez, L., Bayón, Y., de la Fuente, L.F., Primitivo, F., Arranz, J.J. (2008): Quantitative trait loci underlying udder morphology traits in dairy sheep. *Journal of Dairy Science* 91 (9), 3672-3681. <https://doi.org/10.3168/jds.2008-1111>
22. Iniguez, L., Hilali, M., Thomas, D.L., Jesry, G. (2009): Udder measurements and milk production in two Awassi sheep genotypes and their crosses. *Journal of Dairy Science* 92 (9), 4613-4620. <https://doi.org/10.3168/jds.2008-1950>
23. Izadifard, J., Zamiri, M.J. (1997): Lactation performance of two Iranian fat-tailed sheep breeds. *Small Ruminant Research* 24, 69-76. [https://doi.org/10.1016/S0921-4488\(96\)00923-6](https://doi.org/10.1016/S0921-4488(96)00923-6)
24. James, I.J., Osinowo, O.A., Adegbaso, O.I. (2009): Evaluation of udder traits of West african dwarf (wad) goats and sheep in Ogun State, Nigeria. *Journal of Agricultural Science and Environment* 9 (1), 75-87.
25. Keskin, S., Kor, A., Karaca, S., Mirtağoğlu, H. (2005): A study of relationships between milk yield and some udder traits by using of path analysis in Akkeçi goats. *Journal of Animal and Veterinary Advances* 4 (5), 547-550.
26. Kominakis, A.P., Papavasiliou, D., Rogdakis, E. (2009): Relationships among udder characteristics, milk yield and non-yield traits in Frizarta dairy sheep. *Small Ruminant Research* 84 (1-3), 82-88. <https://doi.org/10.1016/j.smallrumres.2009.06.010>

27. Kukovics, S., Molnár, A., Ábrahám, M., Németh, T., Komlósi, I. (2006): Effects of udder traits on the milk yield of sheep. *Archiv für Tierzucht, Dummerstorf* 49 (2), 165-175.
28. Labussière, J. (1988): Review of physiological and anatomical factors influencing the milking ability of ewes and the organization of milking. *Livestock Production Science* 18, 253-274.
[https://doi.org/10.1016/0301-6226\(88\)90035-8](https://doi.org/10.1016/0301-6226(88)90035-8)
29. Lérias, J.R., Hernández-Castellano L.E., Suárez-Trujillo A., Castro N., Poulis A., Almeida, A.M. (2014): The mammary gland in small ruminants: major morphological and functional events underlying milk production. *Journal of Dairy Research* 81, 304-318.
<https://doi.org/10.1017/S0022029914000235>
30. Lotrič, M., Zajc, P., Simčič, M., Mulc, D., Barač, Z., Špehar, M. (2017): Analysis of milk production traits of Alpine and Saanen goat populations in Croatia and Slovenia. *Agriculturae Conspectus Scientificus* 82 (3), 307-310.
31. Macciotta, N.P.P., Mele, M., Cappio-Borlino, A., Secchiari, P. (2005): Issues and perspectives in dairy sheep breeding. *Italian Journal of Animal Science* 4, 5-23.
<https://doi.org/10.4081/ijas.2005.5>
32. Macuhová, L., Uhrinacat, M., Macuhova, J., Margetin, M., Tancin, V. (2008) The first observation of milkability of the sheep breeds Tsigai, Improved Valachian and their crosses with Lacaune. *Czech Journal of Animal Science* 53(12), 528-536.
<https://doi.org/10.17221/369-CJAS>
33. Makovický, P., Margetin, M., Makovický, P., Nagy, M. (2019) Machine milkability of East Friesian and Lacaune dairy sheep. *Indian Journal of Animal Sciences* 89 (6), 686-691.
34. Manfredi, E., Piacere, A., Lahaye, P., Ducrocq, V. (2001): Genetic parameters of type appraisal in Saanen and Alpine goats. *Livestock Production Science* 70, 183-189.
[https://doi.org/10.1016/S0301-6226\(01\)00180-4](https://doi.org/10.1016/S0301-6226(01)00180-4)
35. Margetin, M., Spanik, J., Milerski, M., Čapištrák, A., Apolen, D. (2005): Relationship between morphological and functional parameters of udder and somatic cell counts in milk of ewes. *Physiological and Technical Aspects of Machine Milking. ICAR Technical Series* 10, 255-258.
36. Marnet, P.G., McKusick, B.C. (2001): Regulation of milk ejection and milkability in small ruminants. *Livestock Production Science* 70, 125-133.
37. Mavrogenis, A.P., Papachristoforou, C., Lysandrides, P., Roushias, A. (1988): Environmental and genetic factors affecting udder characters and milk production in Chios sheep. *Genetics Selection Evolution* 20 (4), 477-488.
38. McKusick, B.C. (2000): Physiologic factors that modify the efficiency of machine milking in dairy ewes. In: Proceedings 6th Great Lakes Dairy Sheep Symposium, Guelph, Canada, pp. 86-100.
39. McLaren, A., Mucha, S., Mrode, R., Coffey, M., Conington, J. (2016): Genetic parameters of linear conformation type traits and their relationship with milk yield throughout lactation in mixed-breed dairy goats. *Journal of Dairy Science* 99 (7), 1-10.
<https://doi.org/10.3168/jds.2015-10269>
40. McNulty, R., Downing, C., Aulenbacher, A.D. (1960): Your dairy goat. Univ. California, Agric. Ext. Ser. Circ.
41. Montaldo, H., Martinez-Lozano, F.J. (1993): Phenotypic relationships between udder and milking characteristics, milk-production and California mastitis test in goats. *Small Ruminant Research* 12 (3), 329-337.
[https://doi.org/10.1016/0921-4488\(93\)90068-S](https://doi.org/10.1016/0921-4488(93)90068-S)
42. Novotna, K., Svitakova, A., Rychtarova, M., Fantova, M., Nohejlova, L. (2018): Methodology of udder description and the effect on somatic cell count in Czech White Shorthaired goat breed. *Medycyna Weterynaryjna* 74 (8), 497-500.
<https://doi.org/10.21521/mw.6108>
43. Pajor, F., Egerer, A., Sramek, A., Weidel, W., Polgar, P., Bardos, L., Poti, P. (2014): Effect of teat morphology on hygienic quality of goat milk. *Magyar Allatorvosok Lapja* 136 (9), 535-540.
44. Pawlina, E., Kruszynski, W., Zielezinski, M., Bosek, M. (2005): Relations between the goat udder dimensions in the first and second lactation. *Medycyna Weterynaryjna* 61 (2), 204-206.
45. Perez-Linares, J., Gomez Gil, J., Garcia Lopez, J. (1983): A study on udder morphology in Manchega ewes. In: Sever Cuesta, ed., III. Symposium Internacional de Ordeno Mecanico de Pequeños Rumiantes, Valladolid, Spain, pp. 583-591.
46. Peris, S., Caja, G., Such, X. (1999): Relationships between udder and milking traits in Murciano-Granadina dairy goats. *Small Ruminant Research* 35, 171-179.
[https://doi.org/10.1016/S0921-4488\(99\)00017-6](https://doi.org/10.1016/S0921-4488(99)00017-6)
47. Prpić, Z. (2011): Relationship of breed with ewe milk yield, udder morphology and udder health. Doctoral thesis. University of Zagreb, Faculty of Agriculture, Zagreb (in Croatian with English abstract).
48. Prpić, Z., Mioč, B., Vnučec, I., Vrdoljak, J., Pavić, V. (2012): Morfologija vimena i mliječnost paške ovce. In: Proceedings 47th Croatian and 7th International Symposium on Agriculture, Opatija, Croatia, 13-17 February, pp. 727-731.
49. Prpić, Z., Mioč, B., Vnučec, I., Držaić, V., Pavić, V. (2013): Non-genetic factors of udder morphology traits in Istrian ewes. *Mljekarstvo* 63 (2), 72-80.
50. Prpić, Z., Mioč, B., Vnučec, I., Pavić, V. (2014): Morfološke odlike vimena istočnofrizijskih ovaca. In: Proceedings 49th Croatian and 9th International Symposium on Agriculture, Dubrovnik, Croatia, 16-21 February, pp. 615-619.
51. Prpić, Z., Vnučec, I., Beniç, M., Mioč, B. (2016): Povezanost veličine legla s proizvodnjom mlijeka, morfologijom i zdravljem vimena istočnofrizijskih ovaca. *Journal of Central European Agriculture* 17 (4), 1331-1345.
<https://doi.org/10.5513/JCEA01/17.4.1853>
52. Rovai, M., Caja, G., Such, X. (2008): Evaluation of udder cisterns and effects on milk yield of dairy ewes. *Journal of Dairy Science* 91 (12), 4622-4629.
<https://doi.org/10.3168/jds.2008-1298>
53. Rupp, R., Clément, V., Piacere, A., Robert-Granié, C., Manfredi, E. (2011): Genetic parameters for milk somatic cell score and relationship with production and udder type traits in dairy Alpine and Saanen primiparous goats. *Journal of Dairy Science* 94, 3629-3634.
<https://doi.org/10.3168/jds.2010-3694>

54. Sagi, R., Morag, M. (1974): Udder conformation, milk fractionation in the dairy ewe. *Annales de Zootechnie* 23, 185-192.
<https://doi.org/10.1051/animres:19740207>
55. Santos, D. S., Lima, M.G.B., Noznica, C.F., Lima, D.M., Batista, C.F., Gomes, R.C., Bertagnon, H.G., Santos, B.P., Della Libera, A.M.M.P. (2015): Udder conformation of Saanen goats: aesthetic or functional parameters? *Arquivo Brasileiro de Medicina Veterinaria e Zootecnia* 67 (5), 1287-1294.
<http://dx.doi.org/10.1590/1678-4162-8246>
56. Schulz, J., Fahr, R.D., Finn, G., Naumann, I. (1999): Physical examination of the mammary gland and milk indicators of udder health in the goat. *Tierärztliche Praxis Ausgabe Grobtiere Nutztiere* 27 (2), 92-98.
57. Šalamon, D., Furdić, P., Tešija, T., Džidić, A. (2019): Genetic parameters for the external udder morphology in commercial farms of Istrian sheep from Croatia. *Journal of Central European Agriculture* 20 (1), 68-73.
<https://doi.org/10.5513/JCEA01/20.1.2462>
58. Teissier, M., Larroque H., Robert-Granie, C. (2019): Accuracy of genomic evaluation with weighted single-step genomic best linear unbiased prediction for milk production traits, udder type traits, and somatic cell scores in French dairy goats. *Journal of Dairy Science* 102 (4), 3142-3154.
<http://dx.doi.org/10.3168/jds.2018-15650>
59. Ugarte, E., Gabiña, D. (2004): Recent developments in dairy sheep breeding. *Archiv für Tierzucht* 47, 10-17.
60. Unal, N., Akcapinar, H., Atasoy, F., Yakan, A., Ugurlu, M. (2008) Milk yield and milking traits measured with different methods in Baфра sheep. *Revue de Medecine Veterinaire* 159 (10), 494-501.
61. Upadhyay, D., Patel, B.H.M., Kerketta, S., Kaswan, S., Sahu, S., Shushan, B., Dutt, T. (2014): Study on udder morphology and its relationship with production parameters in local goats of Rohilkhand region of India. *Indian Journal of Animal Research* 48 (6), 615-619.
<http://dx.doi.org/10.5958/0976-0555.2014.00042.9>
62. Volanis, M., Kominakis, A., Rogdakis, E. (2002): Genetic analysis of udder score and milk traits in test day records of Sfakia dairy ewes. *Archiv für Tierzucht* 45, 71-77.