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The effect of milking frequency on milk yield and milk composition in ewes

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Abstract: Milking frequency is the main factor regulating milk yield and milk quality if feeding, welfare, health, and environmental conditions are adequate. Milk yield and composition are substantially influenced by breed, and consequently the breed has an impact on both factors at a different frequency of milking. Further, the size of cisternal compartment plays an important role in accommodating secreted milk between milkings. Thus, ewes with large cisterns (i.e. large cisternal area, high cisternal milk percentage, and delayed tight junction opening during milk stasis) adapt themselves better to longer milking intervals than ewes with a small cistern. The increase of milking frequency from two to three times a day can lead to an increase of milk yield in the range of 3 to 36%. On the other hand, the reduction of milking frequency from twice to once a day can decrease milk yield from 9 to 67%. Two milkings per week could be omitted with no negative effects on milk yield, milk composition, and somatic cell count in ewes with large cisterns. However, besides the breed and cistern storage capacity, the results in literature show that the effects of milking frequency on milk yield and milk composition can vary according to the stage of lactation, individual animal, production level, practice of stripping, and duration of changed frequency. The right use of different milking frequency strategies can result in increased milk yield or in significant savings in labour and time spent in the milking parlour with negligible or no negative effects on milk yield and composition.

Keywords: sheep; milking interval; somatic cell count

Introduction

Milking routine is a major component of the total daily labour of dairy sheep farmers (Prieto et al. 2013). The reduction of daily milking frequency in dairy sheep may be a suitable strategy to decrease milk production costs and to improve the quality of the farmer's life (Kinght and Gosling 1995). However, some authors have suggested that a reduction in the number of milkings can negatively affect the udder health (O'Brien et al. 2002). Not all sheep breeds respond to different milking frequencies identically. One of the main factors responsible for different response to different frequency of milking or omitting some milkings is the variability between breeds, i.e. milk production potential, mammary morphology, cisternal storage capacity (Labussiere 1988).

Efforts to improve milking efficiency in dairy ruminants have been focused on increasing the amount of secreted milk or reducing labour required to remove milk from the mammary gland, e.g. by

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reducing the number of daily milkings (Labussiere 1988; Castillo et al. 2008, 2009), appropriate udder morphology (Rovai et al. 1999; Gelasakis et al. 2012), and adjustment of machine milking parameters (vacuum level, pulsation rate, and pulsator ratio) (Peris 2003a, b; Sinapis et al. 2007). This is especially important for small dairy ruminant operations, which typically maintain large flocks, and as a result, the labour during milking represents about 55% of the total labour input (Marnet and McKusick 2001). The influence of milking frequency on milk yield and composition in dairy animals was studied by many researchers (Knight and Gosling 1995; Castillo et al. 2005, 2008, 2009; Prieto et al. 2013, Torres et al. 2013; Bortacki et al. 2017). Thereby, different results were obtained (Table 1, Table 2). The response of ewes to different frequency of machine milking or extended milking interval deserves continuous attention of science and dissemination of results to practical use. In this article, the effects of milking frequency of dairy sheep are discussed from different aspects, such as morphology of the udder, physiology and adaptability to machine milking, management, etc.

The importance of udder anatomy and milk ejection

Secreted milk in dairy ruminants is stored in two anatomical udder compartments: alveolar (alveolar lumen and small ducts) and cisternal (large ducts and gland and teat cisterns). Milk partitioning between both compartments varies according to species, breed, stage of lactation, and milking interval (Bruckmaier et al. 1997; Caja et al. 2004; Salama et al. 2004; Castillo et al. 2008; Ayadi et al. 2014). Udder cisterns play an important role in the storage of secreted milk between milkings and maintaining high milk secretion rates in dairy sheep (Rovai et al. 2008). The relationship between morphological udder measurements and milk production in dairy sheep has been studied by many researchers (Rovai et al. 1999, 2008; Margetin et al. 2005; Milerski et al. 2006; Castillo et al. 2008; Macuhova et al. 2008a). They showed a positive correlation between the depth or size of the cistern and total milk yield. Many studies have shown differences in the ability of dairy ewes to tolerate extended milking intervals according to the size of their cisternal udder compartment (Labussiere 1988; Castillo et al. 2008). The physical capacity of the udder cistern is limited, and prolonged milking intervals increase the inframammary pressure, consequently decreasing the milk synthesis effectiveness by the alveolar cells (Negrao et al. 2001). Ewes with large mammary cisterns might be capable of storing most of the secreted milk in cisterns and thereby favouring longer free drainage of alveolar milk to the cistern also during extended milking intervals (Davis et al. 1998), thus avoiding the negative effects on milk secretion. Therefore, longer milking intervals could be a recommended strategy for large-cisterned dairy sheep (Labussiere 1988; Castillo et al. 2008) which adapt better to longer milking intervals than small-cisterned ewes.

However, milk yield and milk composition change for each compartment at different milking intervals in dairy ewes (McKusick et al. 2002a). Fat percentage in alveolar milk of sheep is greater than in cisternal milk (Antonic et al. 2013a; Ayadi et al. 2014). The main part of synthesised milk fat is collected in the alveoli and can be removed only after milk ejection in response to the udder stimulation by milking equipment or pre-milking stimulation (McKusick et al. 2002a). The difference in fat content between milk fractions can be explained by viscosity and large size of fat globules, which are accumulated in the alveolar compartment (Ayadi et al. 2014). Extended milking intervals in dairy sheep contribute to fat accumulation in the alveolar compartment (McKusick et al. 2002a; Castillo et al. 2008) causing an increase of fat content in residual milk (Castillo et al. 2009). Thus the occurrence of milk ejection during milking has a positive effect on fat content in milk. Antonic et al. (2013b, c) also observed an increasing fat content after oxytocin application. The milk ejection reflex has not only a high impact on fat content in milk but also on complete and fast milk removal (Macuhova et al. 2008b; 2012). On the other hand, there was no effect of oxytocin treatments on the content of other milk components (protein and lactose) and somatic cell count (SCC) in milk of ewes and cows (Tancin et al. 2007; Antonic et al. 2013b). No differences were observed between milk protein, lactose and total solids percentages of cisternal and alveolar milk during suckling and milking periods (Ayadi et al. 2014). Other factors influencing the milk composition are breed, health status of mammary glands, hoof health, lactation stage, and the size of the cisternal compartment in dairy animals (Ayadi et al. 2014; Baranovic et al. 2018; Krpalkova et al. 2019; Roca et al. 2019). Tsigai sheep had a higher

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content of fat than Improved Valachian (Oravcova et al. 2015) and Manchega than Lacaune (Castillo et al. 2008; 2009). According to Castillo et al. (2008), medium-yielding Manchega ewes had a higher fat content than high-yielding Lacaune ewes. Also, monthly averages of daily milk yield and milk fat and protein content during lactation differed between the early and late stage of lactation in all tested breeds (Oravcova et al. 2015).

Local factors affecting milk yield by different milking intervals

The local control of milk secretion is directly related with the physical removal of milk. The impact of this factor on the mammary function in dairy animals is evident from the well-known positive effects of milk removal frequency and the negative effects of milk stasis in the mammary cistern on milk yield (Pulina et al. 2007). Wilde et al. (1987) identified the local factor involved in the reduction of milk secretion as a peptide that was called feedback inhibitor of lactation (FIL). It is synthesised in the mammary epithelial cells and secreted with milk into the alveoli. As the time from milking increases, milk accumulates in the alveoli, similarly like does this peptide. The accumulation of milk in the mammary gland accelerates the involution process and reduces lactation persistency (Pulina et al. 2007). This causes a progressive reduction in milk synthesis and secretion. On the other hand, frequent removal of milk (and consequently of the FIL) from the mammary gland reduces local inhibitory effects on milk synthesis.

Also Silanikove et al. (2000) hypothesised that there is a proteolytic casein fragment in the mammary gland which inhibits milk synthesis. This peptide, which is made up of residues 1–28 of β-casein produced by the proteolytic activity of plasmin, reduces milk secretion in goats and cows. Politis et al. (1990) found out that the plasmin concentration in milk increased as the milk synthesis was reduced. As it was pointed out by Silanikove et al. (2010), the plasmin-derived regulatory peptide could be a more accepted mechanism. In contrast to the FIL concept, the plasmin-based concept was independently supported by another independent laboratory (Marnet and Komara 2008).

The tight junction integrity also plays an important role in milk production. If the milking interval continues to increase, it can come to the tight junction opening (Stelwagen et al. 1995). In goats, an injection of casein hydrolysates into the udder caused a loss of the tight junction integrity, followed by rapid drying off of the gland (induction of involution) (Shamay et al. 2002). A similar effect was confirmed by Shamay et al. (2003) in dairy cows.

The response of sheep to different milking frequency

Milking frequency is the main factor regulating milk yield and quality if feeding, welfare, health, and

Table 1. Influence of milking frequency on milk yield in ewes

Breed	Milk yield	Milk yield (%) compared to 2×[1]		Reference
		1×	3×	
Lacaune	1.305 L/day	–15.4	+34.5	Negrao et al. (2001)
Sarda	0.623 kg/day	–18		Nudda et al. (2002)
Awassi	0.396 kg/day	–24		Nudda et al. (2002)
Merino	0.181 kg/day	–23		Nudda et al. (2002)
Poll Dorset	22.9 L/5 weeks/animal	–19.4		Knight and Gosling (1995)
Sardinian	1.458 L/day	–26		Labussiere (1988)
Chios	0.891 kg/day	–28		Papachristoforou et al. (1982)
Chios	1.241 L/day	–27		Koutsouli et al. (2017)
Karagouniko	0.851 L/day	–34		Koutsouli et al. (2017)
Tsigai	0.749 L/day	–67		Masar and Mikus (1985)
Tsigai, Valachian sheep	829.80 kg/102 days/25 animals		+15.35	Mikus and Masar (1978)
East Friesian	2.75 kg/day		+15.20	Thomas et al. (2014)

[1]1×, 2×, 3× = milking one, two, and three times a day, respectively

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environmental conditions are adequate (Marnet and Komara 2008). Different milking frequency can affect also the metabolic profile of dairy ewes and thereby the feed requirements (Gonzalez-Garcia et al. 2015).

This review compares different milking interval strategies with routine twice daily milkings commonly used in Slovakia on dairy farms and their impact on milk production (Table 1) and composition (Table 2). There are several milking interval strategies applied on dairy sheep farms (Marnet and Komara 2008). One strategy is an extended milking interval on some days, and thereby omitting one or two milkings per week (i.e. 13 vs 14 milkings and 12 vs 14 milkings per week). Some farmers milk the ewes only once daily and this is practiced with additional suckling (i.e. dual-purpose system of suckling and milking) or without suckling (exclusive once a day milking, i.e. 24 h between milkings) and others perform three milkings within two days (i.e. 16 h between milkings).

Omitting one or two milkings per week. Occasional milking omission impairs milk yield to a lesser extent without compromising the udder health, and could be used to reduce labour on family farms during critical days of the week (usually at the weekend) (Castillo et al. 2009). A decrease of milk yield was found out in Span-

Table 2. Summary of changes in sheep milk composition and somatic cell count (SCC) associated with milking frequency

	Breed	Effect compared to 2×[1]		Reference
		1×	3×	
Fat	Lacaune	–	–	Negrao et al. (2001)
	Lacaune	–		Castillo et al. (2005)
	Manchega	–		Castillo et al. (2005)
	Sarda	–		Nudda et al. (2002)
	Awassi	↑†		Nudda et al. (2002)
	Merino	↑†		Nudda et al. (2002)
	Poll Dorset	–		Knight and Gosling (1995)
	Karagouniko, Chios	–		Koutsouli et al. (2017)
	Tsigai	–		Masar and Mikus 1985
Protein	Lacaune	–	–	Negrao et al. (2001)
	Sarda	↑**		Nudda et al. (2002)
	Awassi	↑†		Nudda et al. (2002)
	Merino	↑**		Nudda et al. (2002)
	Poll Dorset	↑**		Knight and Gosling (1995)
	Karagouniko, Chios	–		Koutsouli et al. (2017)
Lactose	Sarda	–		Nudda et al. (2002)
	Awassi	↓†		Nudda et al. (2002)
	Merino	↓*		Nudda et al. (2002)
	Poll Dorset	↑***		Knight and Gosling (1995)
	Karagouniko, Chios	–		Koutsouli et al. (2017)
LogSCC	Manchega	–		Castillo et al. (2005)
	Lacaune	–		Castillo et al. (2005)
	Sarda	↑*		Nudda et al. (2002)
	Awassi	–		Nudda et al. (2002)
	Merino	–		Nudda et al. (2002)
	Karagouniko, Chios	↓†		Koutsouli et al. (2017)

[1]1×, 2×, 3× = milking one, two, and three times a day, respectively

†$P < 0.10$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

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ish Assaf ewes from early to mid-lactation (10%) when two milkings were omitted weekly (Hervas et al. 2006). Omitting two milkings per week in early lactation tended to decrease daily milk yield in Manchega ewes (15%), whereas no effect was observed in Lacaune ewes (Castillo et al. 2009). Milking omissions in late lactation did not affect milk yield and milk composition in any of the breeds (Castillo et al. 2009). According to Castillo et al. (2005, 2009), an important role is played by the cistern size here. A weekly omission of two milkings had a greater effect on milk fat percentage than on milk protein percentage (Hervas et al. 2006; Castillo et al. 2009). On the first day of omitting one milking, values of milk fat content decreased by 13% in both Manchega and Lacaune breeds in early lactation and by 13% in Manchega ewes and 7% in Lacaune ewes in mid-lactation. On the second day of omitting one milking, milk fat content increased and recovered to normal values (Castillo et al. 2009). Similarly to milk yield, the omission of one or two evening milkings each week significantly increased fat production (32% and 41%, respectively) as well as protein (38% and 27%, respectively) and total solids production (35% and 31%, respectively) in the milk obtained on the day after the last milking omission in Spanish Assaf ewes, which can be attributed to milk accumulation in the udder cisterns (Hervas et al. 2006). However, the increase of milk yield recorded on the day immediately after milking omission could not compensate completely for the loss of milk yield in omitted milking (Hervas et al. 2006). Therefore, it can also be supposed that the observed increased production of milk components did not compensate completely for their loss in omitted milking. The 7% lower milk yields were observed after the 8th week of lactation in Pool Dorset ewes resulting from missing one milking per week (Hervas et al. 2006). In those ewes a higher concentration of protein was found, but there were no differences in the concentration of other milk components (Knight and Gosling 1995). SCC in monitoring the udder health has been described in numerous studies as a useful method for diagnosing an intramammary infection (IMI), although there is a discussion about the threshold level for diagnostic purposes (Raynal-Ljutovac et al. 2007; Albenzio et al. 2012; Rovai et al. 2015; Tvarozkova et al. 2019). The mammary bacterial infections are the major cause of an increase in SCC and loss of production, while they can negatively influence the welfare and health of affected animals. The disease has an obvious financial importance in dairy flock (Giadinis et al. 2012). Some authors found out that a reduction in the number of milkings can negatively affect the udder health in cows (O'Brien et al. 2002). In ewes, no changes of SCC have been found after omitting two milkings at the weekend (Castillo et al. 2009). Hervas et al. (2006) observed a slight increase in SCC when two milkings were omitted weekly, but SCC was always far below the levels that are considered as indicative of possible IMI.

Once a day milking. The effect of switching from twice a day to once a day milking on milk yield and milk composition can depend on the stage of lactation, breed, individual animal, production level, milking routine (e.g. milking with or without stripping), cistern storage capacity, and treatment duration (Knight and Gosling 1995; Castillo et al. 2005; Hervas et al. 2006).

Decreasing the milking frequency from twice a day to once a day reduces milk yield by 9–15.4% in Lacaune (Negrao et al. 2001; Castillo et al. 2005), 18% in Sarda, 23% in Merino, 24% in Awassi (Nudda et al. 2002), 19.4% in Poll Dorset ewes (Knight and Gosling 1995), 26% in Sardinian (Labussiere 1988); 27–28% in Chios (Papachristoforou et al. 1982; Koutsouli et al. 2017), 11–46% in Manchega (Castillo et al. 2005), 34% in Karagouniko (Koutsouli et al. 2017) and 67% in Tsigai (Masar and Mikus 1985). A high reduction of milk yield, mentioned by Masar and Mikus (1985), could be ascribed to the small volume of cisterns in the observed breed (Milerski et al. 2006).

However, the results of milking frequency effects on milk yield could be influenced by ongoing measurements at different stages of lactation. Thereby, the reduction of milk yield was between 10 and 33% in early lactation, between 18 and 24% in mid-lactation, and between 9 and 13.3% in late lactation (Papachristoforou et al. 1982; Labussiere 1988; Knight and Gosling 1995; Negrao et al. 2001; Nudda et al. 2002; Castillo et al. 2005). However, also the duration of lactation appears to be affected by reduced milking frequency. According to Papachristoforou et al. (1982), in the Chios breed low-yielding ewes had not only a greater reduction in milk production but also a significantly shorter lactation than high-yielding ewes when milked once a day.

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In contrast to no or only a slight effect of omitting one milking a week, reducing the milking frequency from twice to once daily significantly lowered the total milk yield and also the daily yield of all components in Pool Dorset ewes (Knight and Gosling 1995). Thereby, increased protein and reduced lactose concentrations were observed, while fat and total solids concentrations did not differ. Also in Sarda, Merino, and Lacaune ewes, the protein percentage in milk was higher when they were milked only once a day (Negrao et al. 2001; Nuda et al. 2002). However, the milking frequency did not affect the percentages of milk components in Manchega and Lacaune ewes during early and late lactation (Castillo et al. 2005; Santibanez et al. 2009). SCC was influenced by milking frequency only in Sarda ewes, and the same trend was observed in Awassi, Merino, Chios and Karagouniko breeds, but the differences were not significant (Nuda et al. 2002; Koutsouli et al. 2017). Castillo et al. (2005) did not observe any differences in SCC in Manchega breed and Lacaune breed according to the milking frequency throughout the milking period.

According to Knight and Gosling (1995), switching from twice a day to once a day milking would be useful only when all the ewes were at a similar stage of lactation, and possibly in late lactation. The volume of milk fractions changed with the advancement of lactation weeks following the same trend of daily milk yield changes (McKusick et al. 2002a; Castillo et al. 2008; Ayadi et al. 2014). Thereby, not only the amount of cisternal but also of alveolar milk decreased with the increasing stage of lactation. Therefore, it can be supposed that more milk can be stored in both compartments by extending the milking interval. Definitely, once a day instead of twice a day machine milking reduces the farmer's working time. However, whereas no negative impacts on the udder health in dairy sheep were observed in most studies, the impact on milk yield and milk composition varies in the studies (Nudda et al. 2002; Castillo et al. 2005; Koutsouli et al. 2017). Some authors (e.g. Marnet and Komara 2008) do not consider once a day milking a good system for dairy sheep breeders because of its greater impact on mammary gland physiology and udder health that limits the use of this system to only short periods, to the end of lactation.

At present, the dual-purpose system of suckling and milking (mixed system) is used for the first 30 days of lactation in some countries. However, during this system, there likely occurs not only a failure of milk ejection during machine milking, but also the additional inhibition of the transfer of milk fat (but not milk protein) from the alveoli to the cistern from the evening to the morning when ewes are separated from their lambs (McKusick et al. 2001; 2002b). And this could potentially be a disadvantage for cheese making (McKusick et al. 2001; 2002b). The low fat content was also observed at milking after lamb weaning; it was likely caused by a failure of milk fat transfer from the alveoli to the cistern due to possible stress from lamb weaning (McKusick et al. 2001; Antonic et al. 2013a). SCC was not influenced if the mixed system or only twice a day milking was applied (McKusick et al. 2001). Whereas most lactation traits differed during the first 30 days of lactation in dependence on the weaning system, the weaning system did not influence their performance in the next stages of lactation. During the 6th week when finally all ewes were milked only twice daily, the milk fat percentage and milk yield were similar in all weaning systems (McKusick et al. 2002b). The mixed system has been shown to be economically superior in terms of lamb and milk production to both the traditional system of exclusive lamb suckling (without any machine milking) during the first 30 days of lactation (a tradition in Slovakia) and the system where lambs are weaned 24 h postpartum and the ewe is machine milked twice daily (McKusick et al. 2001).

Milking three times in two days (every 16 hours). The use of different strategies of reduced milking frequency can result in significant savings in labour and time spent in the milking parlour. McKusick et al. (2002a) reported a reduction of the total milking time by approximately 27% in comparison with twice a day milking when ewes were milked three times in two days (i.e. every 16 h). Thereby, no differences were observed between a 12-h and a 16-h milking interval in the total amount of milk produced, milk composition and quality (McKusick et al. 2002a; Thomas et al. 2014) or lactation length (McKusick et al. 2002a) in East Friesian crossbred ewes. The percentage of fat and protein and SCC did not differ, too (Thomas et al. 2014).

According to Marnet and Komara (2008), the use of a 16-h interval between milkings is not deleterious to the health of the mammary gland of ewes. Therefore, it seems to be a viable and

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simple approach with no negative impact on milk quality, milk quantity, or net income, but with a positive impact on the quality of life for the dairy producer due to a substantial reduction in time needed to milk the ewes. Marnet and Komara (2008) reported that one of the disadvantages of this frequency of milking is the adaptation of the farmers to this unfamiliar routine.

Milking three times a day. Another possibility to increase the profitability of dairy sheep farms is to increase the milk production. One strategy used for this purpose is to increase the milking frequency. By increasing the milking frequency from twice to three times a day, Mikus and Masar (1978) found out a milk yield gain of 15% and 3% (with or without hand stripping) in Tsigai and Valachian sheep. Negrao et al. (2001) reported that the increase of milking frequency from twice to three times a day caused a milk yield gain of 34.5% in Lacaune ewes. Thereby no statistical differences were observed in the content of fat and protein in milk between ewes milked three or two times a day in the latter study. However, in the study of Mikus and Masar (1978) a higher content of fat and total solids in ewes milked three times a day with or without hand stripping was reported.

If the East Friesian crossbred ewes were milked in the first 30 days of lactation three times daily, they produced in total 12.6 kg (15.2%) more milk than the ewes milked twice a day (De Bie et al. 2000; Thomas et al. 2014) probably as a consequence of "lactation imprinting" of mammary functions described by Wall and McFadden (2012). In general, more milk was obtained by milking three times a day, but the response was variable according to the genotype of the ewes and the storage capacity of their udders. For example, the 25% East Friesian crossbred ewes did not show any response at all to three times a day milking, while the 50% East Friesian crossbred ewes showed a significant response (12.8% more milk in 30 days), and the response of the 37.5% East Friesian crossbred ewes was even greater (36% more milk in 30 days). A possible explanation is that the 25% East Friesian crossbred ewes reached their maximum genetic potential production and an increasing demand through the third milking did not result in the increasing supply. On the other hand, 37.5% East Friesian crossbred and 50% East Friesian crossbred ewes have a genetic potential to produce more milk, but they are limited by their udder storage capacity. By emptying the udder more often, they produce more milk (De Bie et al. 2000). Different response of breeds to three times a day milking might be related to the efficient or inefficient autocrine control of milk secretion according to the degree of selection for dairy production (Bencini and Pulina 1997).

Conclusion

Dairy trait variations between breeds (e.g. production potential, mammary morphology, and cisternal capacity) could be among the main factors responsible for the variable and contradictory results reported in the literature where the effects of milking omission or different milking frequency in dairy ruminants are examined. Other factors are the evaluation at different stages of lactation and different duration of the tested milking frequency application. The cistern size plays an important role in accommodating secreted milk during extended milking intervals. Thus, long milking intervals or omission of one milking could be a recommended strategy for large-cisterned dairy sheep. In general, milking three times a day is most suitable at the beginning of lactation, twice a day in mid-lactation and once a day for a short time at the end of lactation. However, the effects of different milking frequency per day should be studied separately in each breed more in detail to make correct decisions in practical dairy management. Then there is an economic aspect. The advantages and disadvantages of individual milking frequency treatments must also be evaluated from an economic point of view which takes into account the duration of milking, labour costs, feed costs, sanitising the milking system, milk yield of ewes, milk cost and its composition.

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