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Optimization of Milking Frequency in Dairy Ruminants

Moez Ayadi

Abstract

To make a decision on the number of milkings per day for each ruminant is a key factor to optimize the use of a machine milking. Currently, this decision is mainly taken from yield and stage of lactation data, but no udder capacity is taken into account. Milk is stored in the udder in the alveolar and cisternal compartments. Milk partitioning in the udder varied widely according to species, breed, lactation stage, parity, and milking interval. The increase in milking frequency has improved milk production in dairy ruminants. However, this practice reduces the milk composition, fertility, and productive life. To avoid increasing the number of milkings per day and reducing milk losses, a strategy based on the selection of ruminants with large udder cistern to store a large quantity of milk was adopted. Animals with great cisterns tolerate extended milking intervals and are milked faster with simplified routines. Ultrasonography will be a useful tool to measure udder cistern and to predict high-yielding animals. In practice, we propose to use the evaluation of udder cistern area, as helping criteria of udder milk storage capacity, establishing the optimal milking frequencies for each ruminant according to the production system.

Keywords: udder morphology, milking frequency, cisternal capacity, ultrasound, profitability

1. Introduction

The problems faced by farmers vary according to the region of production, the breed, the breeding, the feeding system, and the environmental conditions. Indeed, data in Europe show that milk production is surplus, but it is in deficit in Africa and South America [1]. The breeding programs for dairy animals have led to an increase in the quantity of milk. The reasons of this increase in milk yield include udder size, connective tissue mass, and secretory tissue. In fact, a hypertrophy of the secretory tissue of the udder is accompanied by a large milk production that can only be expressed phenotypically when the volume of the udder cistern is important to facilitate the storage of the milk produced [2–7].

In practice, because of the selection pressure exerted on the morphology of the udder, for example, cows with a high milk production must be milked at least three times a day. So, the increase in milking frequency has improved milk production in cows (15–20%, [8]). However, this practice reduces the fat matter, protein, fertility, and productive life of dairy cows [9]. It should be noted that the increase in the number of milkings per day is not accepted by farmers who are looking for farming practices to reduce the number of milkings per week and improve the quality of life on the farm [6].

To avoid increasing the number of milkings per day and reducing milk losses, a strategy based on the selection of ruminants with large udder cistern to store a large quantity of milk was adopted [2, 3]. Therefore, noninvasive in vivo imaging techniques to measure udder storage capacity have been developed [10–14, 5].

Indeed, the study of the internal morphology of the udder in ruminants will know an important development soon. Scientific advances such as embryo transplantation and cloning can contribute to increased uniformity of livestock. Therefore, with this new orientation, it is interesting to take into account, in addition to the external volume of the udder, the internal size of the udder, the capacity of distension of the cells, and the kinetics of udder filling to ensure better adaptation of the udders to the number of milkings (conventional mechanical milking and robotic) and the different milk production systems (extensive, intensive) to maximize farmer's income.

2. Morphology of the mammary gland in dairy ruminants

2.1 Udder morphology and milk production

The purpose of the use of morphological traits in a dairy breeding scheme is to improve the functional longevity of animals by reducing the frequency of reforms and facilitate the adaptation of animals to milking, mechanics, as well as the work of the breeder. In fact, the study of mammary morphometry in dairy animals permits identifying correlations between some morphological traits and milk production as well as the possibility of mechanical milking.

Several authors have studied the external morphological characteristics of the udder in ruminants for performance evaluation and mechanical milking skills [15–18]. The importance of these morphological measurements of the cow's udder has been accentuated by the interest in the application of the system of mechanical milking by robot [19]. In dairy cows, the large udders are usually the ones that give the most milk. Moreover, the correlations between the estimated volume of the udder and the milk production can vary from 0.60 to 0.82 depending on the breed [20]. According to the same authors, the teats must be implanted vertically, and the distance between them must never be less than 6 cm. Wide teats are associated with udder health risks and with the quality of produced milk [21]. In cattle, positive correlations have been confirmed between the distances of the teats and the teat diameter and milk yield of cows [15]. The same researchers have shown that some features of cows' mammary morphology may be associated with a risk of higher mastitis such as low teats and wide teats, as they may increase the risk of injury and the entry of pathogens inside the udder.

In ewes, the criteria of the size and shape of the udder and teats are positively correlated with milk production [21] and milk flow [22]. The presence of developed udder implies a good ability to withstand long intervals between milking and even the practice of single milking (one milking per day). Indeed, the removal of one milking per day indicates a greater loss of milk in breeds with smaller cistern udders [4]. In addition, the udders with rather horizontal teats and inserted high relative to the base of the cisterns are associated with the increase in the fraction of milk drip, requiring a manual intervention of massage and udder movement to collect the milk not extracted by the machine.

In Murciano-Granadina goats, positive correlations between teat length and milk flow ($r = 0.55$) and between teat surface ($r = 0.47$ – 0.58) and residual milk were reported [23]. In the Saanen goats, a positive correlation ($r = 0.65$) was found between the circumference of the udder and daily milk production.

Unlike other dairy animals, there has been little work on the study of mammary morphology in camels [24–29]. A good udder in camels is characterized by well-developed and symmetrical neighborhoods with vertically implanted, uniform, and well-spaced teats [30]. In the same context, [28] reported that the length and depth of the udder in camels are of the same order of magnitude as those indicated for cows [6] and for buffalos [31]. In camels, the teats placed very close to each other and sometimes fused are frequent. Juhasz and Nagy [32] showed a great heterogeneity in the morphology of the udder and teats in camels. They defined at least five different forms of teats. Ayadi et al. [28] found that daily milk production is positively correlated with teat distance ($r = 0.61$), udder depth ($r = 0.29$), and breast vein diameter ($r = 0.34$). The conformation of the udder in camels varies considerably according to the breed, the age, and the stage of lactation. Indeed, [25] reported that camels' teat length varies with parity with shorter teats in primiparous (3.40 cm) than multiparous (6.10 cm).

Recently, for the development of a dromedary selection program according to the udder and teat typology adapted to mechanical milking, [33] proposed a 5-point linear scoring template for evaluating the udder of dairy camels based on five main traits.

2.2 Storage of milk in the udder

A functional mammary gland is an exocrine gland consisting of a tubuloalveolar epithelial tissue and a stroma. In order to fulfill its production function, the udder is richly vascularized and innervated. There are two main categories of udders: the so-called udders composed without cistern (case of rodents and primates) and the so-called udder simple cistern (case of ruminants).

In the ruminant udder, it is possible to distinguish an alveolar compartment (alveoli and fine channels) from an interconnected cistern compartment (large canals and cistern). The volumes of milk accumulated in each of these anatomical compartments can be measured accurately. Milk was first evaluated by draining the milk accumulated in the cistern by insertion of a cannula into the teat canal; the alveolar milk is then recovered by milking followed or not by an injection of oxytocin [2]. The use of a cannula to drain milk has been widely used. By using this technique, the volume of milk may be overestimated (in addition to milk, a fraction of alveolar milk can be recovered by endogenous oxytocin secretion conditioned or linked to stimulation of the udder when introducing the cannula).

Intravenous injection of oxytocin receptor blocking agent (Atosiban), which inhibits milk ejection, has been developed [34, 35]. Milking after injection of Atosiban permits to collect the cistern milk; then oxytocin injection reverses the effect and the alveolar milk can be collected. The use of Atosiban is therefore recommended in ruminants [36]. Moreover, noninvasive *in vivo* imaging techniques (ultrasonography) have been used to measure cistern udder storage capacity [10, 11, 5, 13]. Certainly, whatever the measurement method, knowledge of the distribution of milk in the udder, as well as the kinetics of its filling according to the species, is particularly important to determine the appropriate intervals between milkings.

In cows, the volume of milk contained in the alveolar compartment is preponderant since it represents between 70 and 80% of the total quantity of milk 12 hours after milking [2, 3, 5]. This fraction is about 50–75% in ewes [37, 38, 4] and reaches even 80–90% in goats [39]. The cisternal milk represented 3–19% of total milk in camels [28, 12, 26] and 5% in buffaloes [40]. These proportions may vary depending on the breed of animals but also on the stage of lactation. In addition, the volume of milk stored in the cistern increases during lactation because of the decrease in secretory tissue during lactation [41]. Likewise, the volume of milk

is higher in multiparas [41]. This is due to the immaturity of the development of cisterns in primiparas [42]. Studies on milk accumulation in the udder after milking have been conducted in dairy ruminants.

Recently, [43] proposed a 6-point linear scoring template for evaluating the cisternal size of the udder of dairy cows (0 = absent cistern; 6 = very large cistern), evaluated by ultrasound according to the methodology of [5]. This classification optimizes the milking frequency according to the stage of lactation and the production system.

3. Milking frequency

Milk production (quantity and quality of milk) is regulated at different levels: by genetic factors, diet, various endocrines, and environmental controls. One of the levers for acting on the metabolic and secretory activity of the udder is the frequency of milking. Generally, cows are milked twice a day with milking intervals ranging from 8 to 16 hours, though studies have been conducted to determine animal milking management systems that combine maximization of quantitative and qualitative production with reduced work constraints. Research showed that for a frequency of two milkings per day, a 12–12 interval would be beneficial for high-producing cows (3–5% gain over a 10–14 interval) [37], suggesting the appearance of a brake on secretion beyond a certain time limit. To determine this limit, several studies place it between 10 and 18 hours depending on the animals [44]. These differences could be due to inter-individual variations and could also be related to anatomical features of the udder.

In fact, animals with large udder cistern produce more milk and withstand relatively longer intervals between milkings than animals with a small udder cistern, which cannot transfer their alveolar milk and in which a brake on the secretion is set up faster. Such an observation has been verified in cows [2, 5], ewes [37, 13], goats [39], and camels [45, 12]. Therefore, it has been shown that when milk can flow continuously from the udder, milk production increases [44].

3.1 Decrease in milking frequency

The consequences of reducing the number of milkings on ruminant milk production have been studied by many authors. Certainly, the passage from two milkings to a single milking per day leads to a loss of milk production from 10 to 50% in cows [42].

Short-term (1 week) trials of mid-lactation Friesian and Jersey cows from two milkings to one daily milking reported milk yield decreases ranging from 10 to 25% [2]. The responses would depend on the stage of lactation since the loss of production would be more pronounced for animals in early lactation than for animals at the end of lactation (–38 vs. –28%) [44]. This can be related to the anatomy of the gland since it is known that the proportion of milk stored in the cistern varies with relation to the stage of lactation in cows [46, 41]. In ewes, switching to one milking per day causes a decrease in production from 15 to 35% [47–49]. The lowest losses are reported in Sardi ewes, known for their high capacity for storage and high production capacity, while the largest losses are observed in pre-Alpine ewes with small tanks and low production.

In goats, one milking per day leads to production decrease from 6 to 35% compared to two milkings per day [50]. As in cows and sheep, race and stage of lactation have an effect, which can be related to the storage capacity of the udder. Undeniably, the largest losses are recorded at the beginning of lactation [39], and the lowest losses

are observed in Canary goats, with very large cisterns. Overall, a decrease in milking frequency causes production losses depending on the animal's storage capacity. Finally, it seems that this milking practice increases the concentration of somatic cells in milk [44], the increase being more marked as the number of cells in the milk at the beginning of the experiment is important. In dairy sheep, switching to one milking per day does not significantly modify the composition of milk [47], whereas in goats, an increase in fat matter and casein concentrations is reported [39].

In dairy ruminants, as time after milking increased, there is (i) an increase in alveolar distension, (ii) a decrease in udder blood flow, (iii) an increase in tight junction's permeability, and (vi) an accumulation of putative feedback inhibitor of lactation [50, 51].

3.1.1 Alveolar distension

The first signals of local regulation of mammary gland activity are probably the degree and duration of alveolar distension. Studies by [52] have shown that the amount of alveolar milk in goats is low compared to animals with a high volume of residual milk. Despite the size of the alveolar compartment of the udder of cows reaches its maximum around 16 hours after milking, the longer the interval increases beyond 16 hours, the more the cells are filled with milk. In fact, the increase in pressure following the accumulation of milk throughout the mammary ducts generally leads to an inhibition of the secretion of milk [44]. According to [53], the dilation of the mammary alveoli is accompanied by a decrease in prolactin concentrations when the milking frequency is reduced. Furthermore, the increase of the intra-alveolar pressure causes the compression of the mammary epithelial cells (CEMs) altering the activity of their cytoskeletons and thus the intracellular traffic of the constituents of milk.

3.1.2 Decrease in udder blood flow

Dairy production and mammary blood flow are positively correlated throughout lactation, with the synthesis of 1 L of milk requiring the passage of approximately 300–500 L of blood regardless of the ruminant species [54]. The increase in intra-mammary pressure (IMP) related to milk accumulation decreases the mammary blood flow (–10% after 24 hours in cows) [55] and –50% after 36 hours in goats [56]. The availability of hormones and nutrients would be reduced in the gland, thus decreasing the rate of secretion. This decrease in mammary blood flow could also be related to the activation of the sympathetic nervous system by the accumulation of milk [57]. Draining more frequently would therefore avoid a decline in blood flow, which could be a limiting factor for milk production, although the latter hypothesis has not been confirmed in goats [58].

3.1.3 Increase of tight junction's permeability

A regulating mechanism involved in the practice of a single milking per day acts on the tight junctions, leading to an increase in the alveolar permeability. Really, the change in the chemical composition of milk during the practice of daily milking can be attributed to an increase in the serum in milk, as a result of changing the permeability of tight junctions. Furthermore, the increased permeability of the tight junction is achieved at around 17–18 hours of milking in cows [51], 19–20 hours in sheep [13], beyond 21 hours in goats [39], and 16 hours in camels [45]. Indeed, the change of the permeability of the mammary epithelium membrane during the practice of a single daily milking suggests a rapid increase in the concentration of lactose in the

blood plasma and increased serum protein in milk and content of milk in Cl and Na and a reduction in lactose and K [59].

3.1.4 Accumulation of the feedback inhibitor of lactation

The causes of the decrease in milk production for daily single milking are not well known. Indeed, in dairy cows, it has been shown, reduction of the milking frequency in one quarter of the mammary gland and not in the other quarters, that the quantity of milk in the treated unit only once a day decreased [60]. The same results were observed in sheep and goats [61]. In addition, incomplete emptying of the udder causes a decrease in production [62]. In order to prevent engorgement, the mammary gland has a feedback mechanism on milk synthesis; it produces a glycoprotein that inhibits its synthesis. Therefore, frequent emptying reduces the amount of this inhibiting factor in contact with the CEMs. This local chemical factor with inhibitory activity on milk secretion, called feedback inhibitor of lactation (FIL) or lactation inhibitor factor (LIF), is a low-molecular-weight protein (7.6 kDa), which has been shown in goats [63]. The FIL reduces the secretion rate of milk *in vitro* [62] and *in vivo* [63] when in contact with the alveolar epithelium. It works by inhibiting the constitutive secretion of proteins by CEMs by reversible blocking of the early stages of the biosynthesis-secretion pathway. In addition, the FIL would also inhibit lactose synthesis. Finally, FIL would regulate the number of cell tissue by triggering apoptosis [54]. Indeed, incomplete milking or milking removals would allow an accumulation of the FIL in contact with the CEMs, which would explain the reductions in milk production described above.

Recently, serotonin (5-HT) has been proposed to be an autocrine/paracrine regulator of lactation in the mouse, humans, and more recently in the bovine. The enzymatic machinery necessary for 5-HT biosynthesis has been detected in the mammary epithelium [64]. Other researches support the concept that serotonin (5-HT) is a feedback inhibitor of lactation in the bovine [65].

3.2 Increase in milking frequency

Increasing milking frequency in dairy cattle to more than two milkings per day has resulted in an increase in milk production without any negative effect on the health of the animal. There are various reasons for the practice of three milkings a day, namely, increase in the time of use of the milking machine, the size of the herd, and milk production. In fact, milking three times a day results in an increase in milk production from 3 to 39% compared to two times in dairy cows [66], 15–35% in ewes [47], 10–20% in goats [67, 62, 39], and 4–13% in camels [68, 45]. The response to increased milking frequency would be greater in high-producing, primiparous, and late-lactating cows [66, 69]. Erdman and Varner [70] in their review of 40 comparative studies of increased milking frequency reported that switching from 2 to 3 milkings per day resulted in a stable increase in milk production in terms of quantity (3.5 kg/day) and not by a proportional increase.

In studies on the milking robot, it has been shown that cows, when given free time, are milked on average between 2.7 and 3.9 times a day [71]. In addition, when a rate of four milkings per day is applied for 4 weeks, a production increase of 14% is observed [2]. However, switching to six milkings per day for 2 days only increases production by 10–15% [8]. Such observations suggest that an interval between milkings of 6–8 hours is physiologically ideal for the animal and that there would be no advantage in increasing the rate of milking above four milkings per day in cows [53], as in ewes [47]. An increase in milking frequency would therefore allow improved persistence of production in goats and cows [2, 51].

There are contradictions in the literature regarding the effects of switching to three milkings per day. For some, changes in milk composition at three milkings per day would be insignificant, while others report a decrease in milk fat compared with cows milked twice a day [8]. For some, this decrease would be greater for primiparous cows, while for others, the decrease would be greater for multiparous cows [66]. At the lactation scale, [69] noted a slight decrease in protein and casein concentrations in milk, enough to reduce cheese yield by 1.5%. Somatic cell milk content is used as an indicator of the microbiological quality of milk. Indeed, the number of somatic cells decreases when milking frequency increases [71]. On the other hand, [66] report that switching from two to three milkings per day in dairy cows increases the California mastitis test (CMT) score.

The increase of milking frequency could lead to an increased release of lactogenic hormones which will stimulate the synthetic activities of the CEMs and allow a better persistence of the lactation. These hormones may, in addition to their metabolic effects, increase the number of secretory cells and thus increase the volume of milk secreted [72]. Indeed, even if it is admitted in ruminants that the CEMs deteriorate and that their number decreases progressively with the advancement of lactation, by triggering apoptosis [54], the activity of synthesis of remaining cells is unchanged [72]. This decrease in the number of cells would be modulated by the frequency of milking. The increase of milking frequency causes cellular hypertrophy followed by an increase in the number of CEMs by proliferation of new cells. In addition, an increase in enzyme activities, reflecting their potential for synthesis, is observed in response to an increase in milking frequency in goats [62], cows [2], and camels [45].

4. Conclusions

Deciding about the number of milkings per day for each ruminant is a key factor in optimizing the use of mechanical milking. Currently, this decision is primarily based on the production level and stage of lactation data, but no udder capacity is taken into account. Therefore, it is recommended to use ruminants with large cisterns in order to minimize the effect of hydrostatic pressure on the cells and consequently reduce production losses. In practice, we propose to use the evaluation of udder cistern area by ultrasonography as a criterion to estimate milk storage capacity in the udder in order to establish the appropriate milking frequency for each ruminant according to the production system.

Research opportunities are open to broaden and consolidate this study. Indeed, the work on the heritability and the repeatability of this character “glandular cistern” is essential in order to incorporate it into the breeding programs for dairy ruminants.

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References

- [1] FAOSTAT. Production. Live Animals. Food and Agriculture Organization of the United Nations. 2016. Available from <http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QA/E> [Accessed: July 15, 2017]
- [2] Knight CH, Hirst D, Dewhurst RJ. Milk accumulation and distribution in the bovine udder during the interval between milkings. *The Journal of Dairy Research*. 1994;**61**:167-177
- [3] Davis SR, Farr VC, Copeman PJA, Carruthers VR, Knight CH, Stelwagen K. Partitioning of milk accumulation between cisternal and alveolar compartments of the bovine udder: Relationship to production loss during once daily milking. *The Journal of Dairy Research*. 1998;**65**:1-8
- [4] Castillo V, Such X, Caja G, Casals R, Salama AAK, Albanell E. Long- and short-term effects of omitting two weekend milkings on the lactational performance and mammary tight junction permeability of dairy ewes. *Journal of Dairy Science*. 2009;**92**:3684-3695
- [5] Ayadi M, Caja G, Such X, Knight CH. Use of ultrasonography to estimate cistern size and milk storage at different milking intervals in the udder of dairy cows. *The Journal of Dairy Research*. 2003;**70**:1-7
- [6] Ayadi M, Caja G, Such X, Knight CH. Effect of omitting one milking weekly on lactational performances and morphological udder changes in dairy cows. *Journal of Dairy Science*. 2003;**86**:2352-2358
- [7] Marnet PG. Milking procedures and facilities. In: Park YW, Haenlein GFW, editors. *Milk and Dairy Products in Human Nutrition: Production, Composition and Health*. 1st ed. Nowega: John Wiley and Sons Ltd.; 2013. pp. 46-64
- [8] Eslamizad M, Dehghan-Banadaky M, Rezayazdi K, Moradi-Shahrabak M. Effects of 6 times daily milking during early versus full lactation of Holstein cows on milk production and blood metabolites. *Journal of Dairy Science*. 2010;**93**(9):4054-4061
- [9] Smith JW, Ely LO, Graves WM, Gilson WM. Effect of milking interval in DHI performance measures. *Journal of Dairy Science*. 2002;**85**:3526-3533
- [10] Ruberte J, Carretero A, Fernandez M, Navarro M, Caja G, Kirchner F, et al. Ultrasound mammography in the lactating ewe and its correspondence to anatomical section. *Small Ruminant Research*. 1994;**13**:199-204
- [11] Caja G, Such X, Ruberte J, Carretero A, Navarro M. The use of ultrasonography in the study of mammary gland cisterns during lactation in sheep. In: *Proceedings of the International Symposium on Milking and Milk Production of Dairy Sheep and Goats*. Wageningen, The Netherlands: Wageningen Pers; 1999. pp. 91-93
- [12] Caja G, Salama OA, Fathy A, El-Sayed H, Salama AAK. Milk partitioning and accumulation in the camel udder according to time elapsed after milking. In: *Proceedings of the 62nd Annual Meeting of EAAP*. Stavanger; 2011. p. 363
- [13] Castillo V, Such X, Caja G, Salama AA, Albanell E, Casals R. Changes in alveolar and cisternal compartments induced by milking interval in the udder of dairy ewes. *Journal of Dairy Science*. 2008;**91**:3403-3411
- [14] Rovai M, Caja G, Such X. Evaluation of udder cisterns and effects on milk yield of dairy ewes. *Journal of Dairy Science*. 2008;**91**:4622-4629

- [15] Rogers GW, Spenser SB. Relationships among udder and teat morphology and milking characteristics. *Journal of Dairy Science*. 1991;**74**:4189-4194
- [16] Le Du JF, Chevalerie A, Taverna M, Dano Y. Aptitude des vaches à la traite mécanique: Relation avec certaines caractéristiques physiques du trayon. *Annales de Zootechnie*. 1994;**43**:77-90
- [17] Such X, Caja G, Pérez L. Comparison of milking ability between Manchega and Lacaune dairy ewes. In: *Proceeding of International Symposium on Milking and Milk Production of Dairy Ewe and Goats* EAAP Publication No 95. Wageningen, The Netherlands: Wageningen Pers; 1999. pp. 45-50
- [18] Ayadi M, Such X, Ezzehizi N, Zouari M, Najar T, Ben M' Rad M, et al. Relationship between mammary morphology traits and milk yield of Sicilo-Sarde dairy sheep in Tunisia. *Small Ruminant Research*. 2011;**96**:41-45
- [19] Armstrong DV, Daugherty LS. Milking robots in large dairy farms. *Computers and Electronics in Agriculture*. 1997;**17**:123-128
- [20] Labussière J, Richard P. Machine milking. Anatomical, physiological and technological aspects. Literature development. *Annales de Zootechnie*. 1965;**14**:63-126
- [21] Labussière J. Review of physiological and anatomical factors influencing the milking ability of ewes and the organization of milking. *Livestock Production Science*. 1988;**18**:253-274
- [22] Marnet PG, Combaud JF, Dano Y. Relationships between characteristics of the teat and milkability in Lacaune ewes. In: *Proceedings of 6th International Symposium on Milking and Milk Production of Dairy Sheep and Goats*; 26 September-1 October 1999. Athens, Greece: EAAP; 1999. pp. 41-44
- [23] Peris S, Caja G, Such X. Relationships between udder and milking traits in Murciano-Granadina dairy goats. *Small Ruminant Research*. 1999;**33**:171-179
- [24] Hammadi M, Atigui M, Ayadi M, Barmat A, Belgacem A, Khaldi G, et al. Training period and short time effects of machine milking on milk yield and milk composition in Tunisian Maghrebi camels (*Camelus dromedarius*). *Journal of Camel Practice and Research*. 2010;**17**:1-7
- [25] Eisa MO, Ishag IA, Abu-Nikhaila AM. A note on the relationships between udder morphometric and milk yield of Lahween camel (*Camelus dromedarius*). *Livestock Research for Rural Development*. 2010;**22**(10):1-11. Available from <http://www.lrrd.org/lrrd22/10/eisa22188.htm> [Accessed: December 12, 2017]
- [26] Atigui M, Hammadi M, Barmat A, Farhat M, Khorchani T, Marnet PG. First description of milk flow traits in Tunisian dairy dromedary camels under intensive farming system. *The Journal of Dairy Research*. 2014;**81**:173-182
- [27] Nagy P, Juhasz J. Present knowledge and future questions regarding intensive camel milk production. In: *Proceeding of 4th International Conference of ISOCARD, "Silk Road Camel: The Camelids, Main Stakes for Sustainable Development"*; 8-12 June 2015. Almaty, Kazakhstan: ISOCARD; 2015, 2015. pp. 51-56
- [28] Ayadi M, Aljumaah RS, Musaad A, Samara EM, Abelrahman MM, Alshaikh MA, et al. Relationship between udder morphology traits, alveolar and cisternal milk compartments and machine milking performances of dairy camels (*Camelus dromedarius*). *Spanish*

Journal of Agricultural Research.
2013;**1**:790-797

[29] Ayadi M, Musaah A, Aljumaah RS, Konuspayeva G, Bengoumi M, Faye B. Machine milking parameters for an efficient and healthy milking dairy camels (*Camelus dromedarius*). Journal of Camel Practice and Research. 2018;**25**(1):1-7

[30] Dioli M. Body and udder conformation faults. In: Pictorial Guide to Traditional Management, Husbandry and Diseases of the One-Humped Camel. 2nd ed. Spain. Chapters 8 to 13. 2013. p. 125

[31] Prasad RMV, Sudhakar K, Raghava Rao E, Ramesh Gupta B, Mahender M. Studies on the udder and teat morphology and their relationship with milk yield in Murrah buffaloes. Livestock Research for Rural Development. 2010;**22**(20):1-10. Available from: <http://www.lrrd.org/lrrd22/1/pras22020.htm> [Accessed: October 19, 2014]

[32] Juhasz J, Nagy P. Challenges in the development of a large-scale milking system for dromedary camels. In: Proceedings of the WBC/ICAR 2008 Satellite Meeting on Camelid Reproduction; Budapest, Hungary. 2008. pp. 84-87

[33] Ayadi M, Aljumaah RS, Samara EM, Bernard F, Gerardo C. A proposal for linear assessment scheme for the udder of dairy camels (*Camelus dromedarius*). Tropical Animal Health and Production. 2016;**48**:927-933

[34] Bruckmaier RM, Rothenanger E, Blum JW. Measurement of mammary gland cistern size and determination of the cisternal milk fraction in dairy cows. Milchwissenschaft. 1994;**49**:543-546

[35] Wellnitz O, Bruckmaier RM, Albrecht C, Blum JW. Atosiban, an oxytocin receptor blocking agent:

Pharmacokinetics and inhibition of milk ejection in dairy cows. The Journal of Dairy Research. 1999;**66**:1-8

[36] Rovai M, Such X, Caja G, Knight CH. Interbreed differences in cisternal and alveolar milk partitioning in the udder according to yield in dairy sheep. Journal of Dairy Science. 2000;**83**(Suppl.1):166 (Abstract)

[37] Marnet PG, McKusick BC. Regulation of milk ejection and milkability in small ruminants. Livestock Production Science. 2001;**70**:125-133

[38] McKusick BC, Thomas DL, Berger YM, Marnet PG. Effect of milking interval on alveolar versus cisternal milk accumulation and milk production and composition in dairy ewes. Journal of Dairy Science. 2002;**85**:2197-2206

[39] Salama AAK, Caja G, Such X, Peris S, Sorensen A, Knight CH. Changes in cisternal udder compartment induced by milking interval in dairy goats milked once or twice daily. Journal of Dairy Science. 2004;**87**:1181-1187

[40] Thomas CS, Svennersten-Sjaunja K, Bhosrekar MR, Bruckmaier RM. Mammary cisternal size, cisternal milk and milk ejection in Murrah buffaloes. The Journal of Dairy Research. 2004;**71**:162-168

[41] Caja G, Ayadi M, Knight CH. Changes in cisternal compartment based on stage of lactation and time since milk ejection in the udder of dairy cows. Journal of Dairy Science. 2004;**87**:2409-2415

[42] Davis SR, Farr VC, Stelwagen K. Regulation of yield loss and milk composition during once-daily milking: A review. Livestock Production Science. 1999;**59**:77-94

[43] Molenaar A, Leath SR, Caja G, Henderson HV, Cameron C, Challies M,

- et al. Development of ultrasound methodology to measure cow udder cistern storage capacity in the new Zealand pasture-fed context. Proceedings of the New Zealand Society of Animal Production. 2013;**73**:114-116
- [44] Stelwagen K, Knight CH, Farr VC, Davis SR, Prosser CG, McFadden TB. Continuous versus single drainage of milk from the bovine mammary gland during a 24 hour period. Experimental Physiology. 1996;**81**:141-149
- [45] Ayadi M, Hammadi M, Khorchani T, Barmat A, Atigui M, Caja G. Effects of milking interval and cisternal udder evaluation in Tunisian Maghrebi dairy dromedaries (*Camelus dromedarius* L.). Journal of Dairy Science. 2009;**92**:1452-1459
- [46] Dewhurst RJ, Knight CH. Relationship between milk storage characteristics and the short-term response of dairy cows to thrice-daily milking. Animal Production. 1994;**58**:181-187
- [47] Négrao JA, Marnet PG. Cortisol, adrenalin, noradrenalin and oxytocin release and milk yield during first milkings in primiparous ewes. Small Ruminant Research. 2003;**67**:69-75
- [48] Nudda A, Pulina G, Vallabell R, Bencini R, Enne G. Ultrasound technique for measuring mammary cistern size of dairy ewes. The Journal of Dairy Research. 2000;**67**:101-106
- [49] Salama AAK, Such X, Caja G, Rovai M, Casals R, Albanell E, et al. Effects of once versus twice daily milking throughout lactation on milk yield and milk composition in dairy goats. Journal of Dairy Science. 2003;**86**:1673-1680
- [50] Wilde CJ, Knight CH, Addey CVP, Blatchford DR, Travers M, Bennett CN, et al. Autocrine regulation of mammary cell differentiation. Protoplasma. 1990;**159**:112-117
- [51] Stelwagen K, Knight CH. Effect of unilateral once or twice daily milking of cows on milk yield and udder characteristics in early and late lactation. The Journal of Dairy Research. 1997;**64**:487-494
- [52] Peaker M, Blatchford DR. Distribution of milk in the goat mammary gland and its relation to the rate and control of milk secretion. The Journal of Dairy Research. 1988;**55**:41-48
- [53] Stelwagen K. Effect of milking frequency on mammary functioning and shape of the lactation curve. Journal of Dairy Science. 2001;**84**:E204-E211
- [54] Akers RM. Lactation and the Mammary Gland. 1st ed. USA: Iowa State Press; 2002
- [55] Guinard-Flament J, Rulquin H. Effect of one daily milking on mammary blood flow (MBF) in dairy cows. Livestock Production Science. 2001;**70**:180 (Abstract)
- [56] Stelwagen K, Davis SR, Farr VC, Eichler SJ, Politis I. Effect of once daily milking and concurrent somatotropin on mammary tight junction permeability and yield of cows. Journal of Dairy Science. 1994;**77**:2974-3001
- [57] Bruckmaier RM, Wellnitz O, Blum JW. Inhibition of milk ejection in cows by oxytocin receptor blockade, α -adrenergic receptor stimulation and in unfamiliar surroundings. The Journal of Dairy Research. 1997;**64**:315-325
- [58] Lacasse P, Prosser CG. Mammary blood flow does not limit milk yield in lactating goats. Journal of Dairy Science. 2003;**86**:2094-2097
- [59] Auldism MJ, Prosser CG. Differential effects of short-term once-daily milking

on milk yield, milk composition and concentration of selected blood metabolites in cows with high or low pasture intake. Proceedings of the New Zealand Society of Animal Production. 1998;**58**:41-43

[60] Stelwagen K, van Espen DC, Verkerk GA, McFadden HA, Farr VC. Elevated plasma cortisol reduces permeability tight junctions in the lactating bovine mammary epithelium. *The Journal of Endocrinology*. 1998;**159**:173-178

[61] Wilde CJ, Knight CH. Milk yield and mammary function in goats during and after once-daily milking. *The Journal of Dairy Research*. 1990;**57**:441-447

[62] Wilde CJ, Addey CV, Knight CH. Regulation of intracellular casein degradation by secreted milk proteins. *Biochimica et Biophysica Acta*. 1989;**992**:315-319

[63] Wilde CJ, Addey CVP, Li P, Fernig DG. Programmed cell death in bovine mammary tissue during lactation and involution. *Experimental Physiology*. 1997;**82**:943-953

[64] Stull M, Pai A, Vomachka V, Marshall AJ, Jacob AM, Horseman ND. Mammary gland homeostasis employs serotonergic regulation of epithelial tight junctions. Proceedings of the National Academy of Sciences. 2007;**104**(42):16708-16713

[65] Hernandez L, Stiening L, Wheelock CM, Baumgard JB, Parkhurst LH, Collier RJ. Evaluation of serotonin as a feedback inhibitor of lactation in the bovine. *Journal of Dairy Science*. 2008;**91**(5):1834-1844

[66] Allen DB, DePeters EJ, Laben RC. Three times a day milking: Effects on milk production, reproductive efficiency and udder health. *Journal of Dairy Science*. 1986;**69**:1441-1446

[67] Knight CH, Foran D, Wilde CJ. Interactions between autocrine and endocrine control of milk yield; thrice-daily milking of bromocriptine-treated goats. *Journal of Reproduction and Fertility*. 1990;**5**. Abstract. no. 30

[68] Alshaikh MA, Salah MS. Effect of milking interval on secretion rate and composition of camel milk in late lactation. *The Journal of Dairy Research*. 1994;**61**:451-456

[69] Klei LR, Lynch JM, Barbano DM, Oltenacu PA, Lednor AJ, Bandler DK. Influence of milking three times a day on milk quality. *Journal of Dairy Science*. 1997;**80**:427-436

[70] Erdman RA, Varner M. Fixed yield responses to increased milking frequency. *Journal of Dairy Science*. 1995;**78**:1199-1203

[71] Ipema AH. Integration of robotic milking in dairy housing systems review of cow traffic and milking capacity aspects. *Computers and Electronics in Agriculture*. 1997;**17**:79-94

[72] Knight CH, Wilde CJ. Mammary cell changes during pregnancy and lactation. *Livestock Production Science*. 1993;**35**:3-19