UDDER MORPHOLOGY AND MACHINE MILKING ABILITY
IN DAIRY SHEEP

Gerardo Caja, Xavier Such, and Maristela Rovai

Unitat de Producció Animal, Departament de Ciència Animal i dels Aliments, Universitat Autònoma de Barcelona, 08193 Barcelona, Spain

Summary

This paper describes the particularities of the anatomy and morphology of the dairy sheep udder and the current implications on machine milkability. The sheep mammary gland is an exocrine epithelial gland mainly constituted of tubulo-alveolar parenchyma with alveoli and well differentiated cisterns. Two anatomical compartments are used for milk storage: alveolar and cisternal, the large-cisterned animals being more efficient milk producers. New methodologies are available for the study of the mammary gland ultrastructure and for the use of non invasive or dynamic measures. A detailed description of alveolar and ductal changes in the ewe udder occurring during lactation is presented. The study of external morphology by using udder typology, objective udder measurements, and linear scores in practice is also discussed. Machine milkability is evaluated by milk fractioning and milk emission curves during milking. Both criteria are discussed and analyzed in sheep breeds of different milk yield. Relationships between morphological and productive traits in dairy sheep are analyzed as a result of anatomical and physiological characteristics. Phenotypic and genetic correlations indicate that selection for milk yield will produce a worse udder morphology, resulting in udders which are inadequate for machine milking. Teat and cistern characteristics appear to be the most limiting factors in machine milkability. Some selection pressure on udder traits in long-term breeding programs needs to be considered, and the use of linear udder traits is recommended in practice to improve udder morphology and milkability.

Introduction

The mammary gland is an exocrine epithelial gland exclusive to the mammalian species, (animals able to produce milk) which is quantitatively and qualitatively adapted to the growth requirements and behavior of each species. It shows histological similarities to other epithelial glands such as the salivary and sweat glands. Milk secretion is described as the activity of a cellular factory (the lactocyte) which transforms itself into the product (the milk). The entire process is controlled by integrated neuro-endocrine and autocrine systems. It mainly develops during pregnancy and early lactation, and regresses very quickly after dry-off.

The anatomy and morphology of the sheep udder has been well known for many years (Turner, 1952; Barone, 1978), and some examples of curious selection on udder morphology have been assayed (i.e. increasing prolificacy and number of teats). Early works on the relationship between udder characteristics and milking performance in dairy ewes were carried out in the 70’s and early 80’s (Sagi and Morag, 1974; Jatsh and Sagi, 1978; Gootwine et al., 1980; Labussière et al., 1981) as a consequence of the efforts to adapt the ewe to machine milking.
With this aim and as an initiative from Prof. Jacques Labussière an international protocol (M4 FAO project) was agreed for the evaluation of the dairy sheep udder in the Mediterranean breeds (Labussière, 1983, 1988). Based on this standardized protocol, the udder of many dairy sheep breeds was systematically studied in relation to machine milking in the 3rd International Symposium on Machine Milking of Small Ruminants held in Spain (Casu et al., 1983; Fernández et al., 1983a; Gallego et al., 1983a; Hatziminaoglou et al., 1983; Labussière et al., 1983; Pérez et al., 1983; Purroy and Martín, 1983) and following symposiums (Arranz et al., 1989; Kukovics and Nagy, 1989; Rovai et al., 1999) in Europe, and also in America (Fernández et al., 1999; McKusick et al., 1999).

The interest in the dairy sheep udder has increased in the last few years in which anatomy has been explored in depth (Ruberte et al., 1994b; Caja et al., 1999; Carretero et al., 1999), linear evaluation of udder traits has been proposed (de la Fuente et al., 1996; 1999; Carta et al., 1999) and the genetic parameters evaluated (Gootwine et al., 1980; Mavrogenis et al., 1988; Fernández et al., 1995; 1997; Carta et al., 1999). Moreover, given the negative effects observed in udder morphology as a result of the increase in milk yield, main udder traits of breeds of different production levels (Rovai et al., 1999) or of genetically isolated lines of the same breed (Marie et al., 1999) are under comparison. This paper describes the particularities of the dairy sheep udder and summarizes the current implications of udder morphology on machine milkability.

**Structure and development of the mammary gland in the dairy ewe**

**Origin and development of the mammary gland:** The mammary gland is formed by two main structures: the parenchyma and the stroma. The partitioning between both structures defines the anatomical and functional characteristics of each mammary gland. The parenchyma is the secretory part of the gland and it is made up of tubulo-alveolar epithelial tissue, coming from the ectoderm layer of the embryo, and it consists of the tubular (ductal) and alveolar systems. The stroma is formed by other complementary tissues of mesodermic origin such as: blood and lymph vessels, and adipose, connective and nervous tissues. Both structures develop very early from the ventral skin of the embryo and half-way through the pregnancy a total of eight pairs of isolated mammary buds are present in all mammalian embryos (Delouis and Richard, 1991).

Well developed mammary buds are clearly observed in 2 cm long sheep embryos (near 30 days old) as reported by Turner (1952). An important differentiation in mammogenesis occurs at this stage in the ruminants, in which the mammary parenchyma develops the cisterns. An involution process according to the species then begins, and only the 7th mammary pair located in an inguinal position is maintained in sheep (Delouis and Richard, 1991). Occasionally the 6th pair can also be maintained giving as a result the supernumerary teats. Another particularity of sheep is the presence of skin inguinal bags in the groin behind each teat. They have sebaceous glands and produce a yellow and fatty secretion useful for the care of the udder skin (Ruberte et al., 1994b).

At birth, the sheep udder shows clearly differentiated cisterns (Sinus lactiferus)1 and teats (Papilla mammae) and very incipient development of the ductal system, with few primary ducts surrounded by numerous stroma forming cells. After birth the udder grows at the same rate as the body (isometric growth) until puberty, with proliferation and branching of the secondary ductal system.

Puberty in most species is the quickest period of growth for ducts and stroma of the mammary gland (positive allometric growth), as a result of the action of sexual hormones. Nevertheless, the future milk capacity of the udder can be impaired at this stage by an excessive growth of the stroma (mainly adipose and connective tissues) in comparison to the parenchyma (tubulo-alveolar epithelium). This critical phase occurs earlier in sheep than in cattle, with differences between breeds. Thus, the parenchyma growth ends in sheep before puberty and, as a consequence, mammogenesis in sheep will be affected by nutrition during and after the positive allometric growth phase (Bocquier and Guillouet, 1990). The critical period for mammogenesis is from 2 to 4 months old. Moreover an early onset of puberty will bring forward the decrease in mammary development. According to Johnson and Hart (1985) and McCann et al. (1989), a relative low growth rate (50% of high rate) from weaning (wk 4) to the end of rearing period (wk 20) will increase the parenchyma growth and the milk production in the first lactation in non dairy ewe-lambs (Figure 1). No negative effects were observed at the beginning of puberty. Nevertheless a low growth rate before weaning will also negatively affect mammogenesis (McCann et al., 1989). Unfortunately there is no detailed information available on dairy sheep, but Bocquier and Guillouet (1990) reported that the restriction of concentrate in Lacaune ewe-lambs, after they reach approximately 28 to 30 kg, increases milk yield by 10% in the first lactation.

Figure 1. Effect of growth rate before puberty in ewe-lambs on milk yield at the first lactation (McCann et al., 1989).

During the first and subsequent pregnancies, the parenchyma shows an allometric growth where the placenta plays an important role. A specific ovine chorionic somatotropin hormone (oCS), dependent on prolificacy, can be obtained from the sheep placenta after day 60 of pregnancy (Martal and Chene, 1993). Mammogenesis starts clearly in sheep between day 95 and 100 of pregnancy, with detection of lactose (start of lactogenesis) after day 100 (Martal and Chene, 1993).
The presence of secretory lobes with alveolus in the extremes of the ducts can be observed in the second half of pregnancy. Delouis and Richard (1991) estimate a change from 10 to 90% in the relative weight of the parenchyma during pregnancy, where the lobulo-alveolar development of epithelial cells takes the place of the adipose tissue. The inverse process occurs during the dry period, with a complete disappearance of the alveoli in the ewe after 3 to 4 weeks, and its replacement by adipocytes (Hurley, 1989). Moreover during the involution process the mammary gland is invaded by macrophages and lymphocytes, the latter being essential for the production of immunoglobulins in the synthesis of colostrum in the next pregnancy.

**Internal structure of the mammary gland:** The study of the internal structure of the ewe udder was first carried out *in vitro* by anatomical dissection in dead animals (Turner et al., 1952; Barone, 1978; Tenev and Rusev, 1989; Ruberte et al., 1994b). This methodology reveals the presence of two independent mammary glands under a unique skin bag, each of them wrapped by a bag of fibroelastic connective tissue (*Apparatus suspensorius mammarum*) and separated by a clearly defined and intermediate wall of connective tissue (*Ligamentum suspensoris uberi*). The strength of this ligament normally produces the presence of an intermammary groove (*Sulcus intermammarius*) between each gland. This ligament plays an important role in the support of the udder, maintaining the udder tightly attached to the ventral abdominal wall. Each half udder shows internally a typical tubulo-alveolar structure with a big cistern (*Sinus lactiferus*) divided in two parts: glandular cistern (*S. l. pars glandularis*) and teat cistern (*S. l. pars papillaris*). Both cisterns are separated by a muscular sphincter of smooth muscular fibers, traditionally known as the cricoid fold, which plays an important role in milk drainage. It also helps to keep the teat and gland morphology divided during machine milking to avoid the appearance of cluster climbing. The cricoid sphincter is normally missing in goats and it is not very effective in the conic teat udders, which are not favorable for machine milking. Size and form of the gland cistern vary according to the breed and milking ability of the sheep, being greater and plurilocular in high yielding ewes (Figure 2). Another sphincter with smooth muscular fibers is present around the streaks canal (*Ductus papilaris*) in the distal part of the teat, connected to the exterior by a unique orifice (*Ostium papilare*).

The last mammary gland structures in the parenchyma are the secretory lobes, consisting of very branched intralobular ducts and alveoli. The alveolus is the secretory unit of the mammary gland and consists of a bag of a unique layer of specialized cubic epithelial cells (the lactocytes) with an inside cavity (the lumen) in which the milk is stored after secretion.

The mammary gland stores the milk extracellulary and this storage can be explained using a model of two anatomical compartments: ‘Alveolar milk’ (secreted milk stored within the lumen of alveolar tissue) and ‘Cisternal milk’ (milk drained from the alveoli and stored within the large ducts and the gland and teat cisterns). Short-term autocrine inhibition of milk secretion in the mammary gland has been related to cisternal size, the large-cisterned animals being in general more efficient producers of milk and more tolerant to long milking intervals and simplified milking routines (Wilde et al., 1996).
Partitioning between cisternal and alveolar milk is usually determined by drainage of cisternal milk, by using a teat cannula, and by milking alveolar milk after an oxytocin injection (Ruberte et al., 1994a; Wilde et al., 1996). Nevertheless cisternal milk volume can be increased in some breeds by spontaneous liberation of endogenous oxytocin as a consequence of milking conditioned behavior or as a result of teat manipulation. This effect has been shown in Lacaune but not in Manchega ewes (Table 1) by Rovai et al. (2000), in accordance with the milking ability of each breed, and the use of an oxytocin receptors blocking agent for cisternal and alveolar milk determination is recommended (Knight et al., 1994; Wilde et al., 1996). Values of cisternal milk in sheep vary from 25 to 70% according to the breed (Caja et al., 1999; Rovai et al., 2000) but they are greater than 50% in most dairy sheep breeds. Cisternal : alveolar ratio increases with lactation stage and parity in dairy cows (Wilde et al., 1996), but no references are available on sheep.

Table 1. Cisternal and alveolar distribution in dairy sheep at mid lactation according to the breed and the method used (Rovai et al., 2000).

<table>
<thead>
<tr>
<th>Item</th>
<th>Manchega</th>
<th>Lacaune</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Atosiban(^1)</td>
<td>Control</td>
</tr>
<tr>
<td>Number of ewes</td>
<td>10</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Milk yield (l/d)</td>
<td>0.935(^b)</td>
<td>1.871(^a)</td>
<td>0.313</td>
</tr>
<tr>
<td>Alveolar milk (ml)</td>
<td>86.2(^b)</td>
<td>104.0(^a)</td>
<td>88.8(^b)</td>
</tr>
<tr>
<td>Cisternal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk (ml)</td>
<td>121.8(^c)</td>
<td>118.3(^c)</td>
<td>299.2(^a)</td>
</tr>
<tr>
<td>Area (cm(^2))</td>
<td>12.38(^b)</td>
<td>13.06(^b)</td>
<td>24.02(^a)</td>
</tr>
<tr>
<td>Cisternal : Alveolar (%)</td>
<td>59 : 41</td>
<td>53 : 47</td>
<td>77 : 23</td>
</tr>
</tbody>
</table>

\(^1\): Oxytocin receptors blocking agent injected in jugular
\(^a, b, c\): Different letters in the same line indicate significant differences at \(P<0.05\)
The results in Table 1 also indicate that cistern size plays an important role in the milk yield of the ewe. Thus, despite the differences in milk production (100%) at the same stage of lactation (90 d), alveolar milk was very similar in the two breeds, the difference being only 10% greater in Lacaune. On the contrary, the difference in true cisternal milk was 102% according to the difference observed in yield. This seems to indicate that cisternal size is a direct limiting factor for milk secretion in dairy sheep and its importance is greater than the amount of secretory tissue in the current situation (Rovai et al., 2000). A ratio of approximately 7.5 between daily milk yield and cisternal milk was obtained in both breeds.

*In vitro* anatomical studies are in some cases limited because the organ loses the tonus and becomes flaccid, which is important in the case of the udder. An *in vivo* image of the mammary gland structures can be obtained by the non invasive technique of ultrasound scans. A specific method for sheep mammography was proposed by Ruberte et al. (1994a) and its validity in cisternal measurements tested by Caja et al. (1999). The method has been used to make evident the milk ejection reflex in sheep (Caja and Such, 1999), to measure the cistern size and to compare the internal morphology of the udder in different breeds of dairy sheep (Rovai et al., 2000). Using this method it can be demonstrated that the gland cistern is flat when empty after milking as a consequence of the pressure of the mammary suspensor system (Figure 3). The method can also be used to estimate the distribution and movements of milk between the udder compartments and for non invasive dynamic studies on cisternal milk.

**Figure 3.** Scans of dairy sheep udders showing the gland and teat cisterns full of milk before milking (left) and empty after milking (right).

A different approach in the study of the cisterns and the lobulo-alveolar system in the mammary gland can be obtained by using the corrosion plastic cast method, normally used for the anatomical study of soft tissues (Ditrich and Splechtna, 1989; Ruberte et al., 1994b; Carretero et al., 1999). This method consists of obtaining a cast of the canalicular system of the mammary gland in euthanasied animals, after drainage of the milk from the udder. An epoxy resin is immediately injected through the teat sphincter to obtain the complete repletion of all the tubulo-alveolar system (cisterns, ducts and alveoli). Udders are removed after hardening of the epoxy resin and the organic tissue corroded using a KOH solution. The resulting casts (Figure 4) are used for macroscopic and microscopic studies, where anatomical details can be studied in depth.
Figure 4. Cast of a dairy sheep udder obtained by the epoxy injection and corrosion method (left) and detail of the ductal system with ducts and alveoli (right).

The study of the ultrastructure of the mammary gland is normally done by using the scanning electron microscopy method used by Williams and Daniel (1983), Caruolo (1980) and Carretero et al. (1999), which showed clear images of mammary alveoli in sheep (Figure 4). The method uses the corrosion casts previously described, after conditioning for scanning electron microscopy. Different degrees of development of the canalicular system are identified in the parenchyma of sheep mammary glands during lactation.

Tubulogenic structures found by Carretero et al. (1999) in dairy sheep varied in frequency and type according to stage of lactation but in all cases the sheep casts had the typical appearance of a bunch of grapes as described in the bibliography (Figure 5.1). All the alveoli seen in this work showed a unique and independent lobular duct without fusion between adjacent alveoli. The development of the mammary gland ducts showed a similar morphology to that previously reported in the development of the vascular system (mesodermic origin) in embryos of different species (Ditrich and Splechtna, 1989; Carretero et al., 1995). Structures indicating an extensive proliferation of the canalicular system were found by Carretero et al. (1999) in Manchega and Lacaune dairy ewes between week 1 (suckling) and 5 (start of milking) of lactation at the same time that a large number of alveolar sprouts were observed (Figure 5.2).

Both dairy breeds showed the same mammary structures and followed the same pattern of development during lactation despite the differences in reported milk yield. The development of the mammary canalicular system after parturition has already been described in primiparous sheep (Brooker, 1984) and goat (Knight and Wilde, 1993), but Carretero et al. (1999) used ewes that were in the third lactation. The finding of cellular proliferation at the time of maximum milk production, is also in accordance with the observations of Knight and Wilde (1993). Franke and Keenan (1979) demonstrated that both situations can be found even in a lactocyte.

The identification of concave valve-like structures as previously described by Caruolo (1980) was also common to all stages studied by Carretero et al. (1999). Nevertheless, these valve-like structures do not appear in our studies at the level of the opening of alveolus into the lobular duct, but at the point where a lobular duct drains into a larger duct (Figure 5.3).
**Figure 5.** Scanning electron microscopy images from epoxy casts obtained in ewes mammary glands at different stages of lactation: 1) Lobular duct (L) and alveoli (⁎) on wk 13 (bar = 40 μm); 2) Alveoli (→) on wk 1 (bar = 0.2 mm); 3) Valve-like structure (→) in a duct (bar = 30 μm); 4) Intussusceptive growth (✉️) in a lobular duct (L) on wk 1 (bar = 28 μm); 5) Alveolar sprouts (→) on wk 5 (bar = 60 μm); 6) Alveolus grooves (→) on wk 13 (bar = 30 μm); 7) Collapsed alveolus on week 13 (bar = 20 μm).
This may indicate the existence of a kind of cellular reinforcement to prevent milk leakage when the alveoli and ducts are full of milk.

At week 1 of lactation Carretero et al. (1999) reported the occurrence of ‘intussusceptive growth’ at the level of the lobular ducts in sheep during the suckling period. This new type of growth leads to an increase in the number of tubules from preexisting ones (Figure 5.4). Intussusceptive growth has only been reported in some areas of the vascular system (i.e. lung vessels and widely during embryo development) and it is characterized by the formation of pillars of endothelial tissue in the lumen of the duct (Burri and Tarek, 1990; Patan et al., 1992). The pillars appear as transversal holes in the plastic casts. This convergence in the model of development of two different cellular lines, mammary gland ductal and vascular system cells, is produced despite their different embryonic origin (ectoderm and mesoderm origin, respectively).

At week 5 after parturition, corresponding to the first week of the milking period after weaning, duct development by intussusceptive growth seemed to be complete and only changes in mammary alveoli were observed. In this way, fully developed alveoli together with others in the first phases of development were observed at the same time and in the same lobular duct. Nevertheless, structures like angiogenic buds were frequently identified in the tubules at this time. These buds appeared as semispherical enlargements that grow from the ducts and become almost spherical by the narrowing of their connection with the duct. Then, the bud surface loses its smoothness and develops small sockets giving a golf ball like image identified as alveoli. Moreover frequently developing alveoli with sprouting shape were observed on the surface of lobular ducts at this lactation stage (Figure 5.5) as previously described in the mammary gland of ewes by Alvarez-Morujo and Alvarez-Morujo (1982). Alveolar sprouts described by Carretero et al. (1999) are not comparable to the sprouts found in the extremes of lobular ducts producing the longitudinal growth of lobular ducts during puberty by Williams and Daniel (1983).

In mid lactation (week 13) the mammogenic structures were not observed by Carretero et al. (1999) in the canalicular system of the mammary gland and the most relevant observation was the alveoli morphology. They were unilocular, spherical and with their external surface smoothed or grooved (Figure 5.6). The images are in accordance with those obtained by Caruolo (1980) and suggest that grooves may be a consequence of capillary vessels surrounding the alveolus. We also observed, in a few cases, some flattened alveoli (Figure 5.7) that may be considered as collapsed (empty) alveoli, but no fused alveoli were found.

**External morphology of the mammary gland**

*Udder typology:* The first practical utilization of udder morphology on dairy sheep was made by using tables of udder typology in Awassi and Assaf (Sagi and Morag, 1974; Jatsch and Sagi, 1978), Sarda (Casu et al., 1983) and Manchega ewes (Gallego et al., 1983a, 1985), all of them based on four main udder types. A comparative table of these typologies can be observed in Gallego et al. (1985). These typologies were later adapted to the Latxa breed (Arranz et al., 1989) and Hungarian Merino and Pleven (Kukovics and Nagy, 1989). The typology used in Sarda was evaluated in field conditions (Casu et al., 1989) and extended to seven udder types mainly based on teat position and cistern size (Carta et al., 1999) with the aim of improving the small discriminating capacity of the previous typologies. Nevertheless, the evaluation of sheep udders by morphological types is easy, quick and repeatable with trained operators (Carta et al.,
Typology is recommended as a useful tool for the screening of animals, i.e. in the standardization of machine milking groups or in the choice of ewes at the constitution or acquisition of a flock, and for culling of breeding animals (Gallego et al., 1985; Carta et al., 1999).

A well shaped and healthy udder of dairy sheep for machine milking should have:
- Great volume, with globose shape and clearly defined teats
- Soft and elastic tissues, with palpable gland cisterns inside
- Moderate height, not surpassing the hock
- Marked intermammary ligament
- Teats of medium size (length and width), implanted near to vertical.

**Udder measurements:** The use of objective measurements for the characterization of the dairy sheep udder and for the study of the relations with milk yield or other productive traits has been undertaken by different authors since the development of machine milking. The continuous nature of the measurements increases the discriminating capacity of each variable and the significance of correlation with the productive traits. The methodology generally used corresponds to the standardized protocol of Labussière (1983) with small variations incorporated in some cases (Gallego et al., 1983a; Fernández et al., 1983, 1995). The repeatability of udder measurements made according to this methodology is low for udder dimensions ($r=0.17$ to $0.18$), medium for teat dimensions and teat position ($r=0.45$ to $0.52$), and high for teat angle ($r=0.65$) and cistern height ($r=0.77$), as calculated by Fernández et al. (1995) in the Churra dairy breed.

Table 2 summarizes the comparison of main objective udder measurements carried out by Rovai et al. (1999) in Manchega and Lacaune dairy sheep throughout lactation, with the aim of identifying the most significant udder traits in extreme yield conditions. The stage of lactation produced significant effects on all udder traits in accordance with Gallego et al. (1983a) and Fernández et al. (1983, 1995). Nevertheless, despite the differences in milk yield, breed effects on udder length and distance between teats were non significant, and only showed a tendency in teat angle. Similar results were observed in regard to parity, where differences in teat angle and udder length were non significant. On the contrary, differences in teat dimensions (width and length) and udder height (depth and cistern height) were significant for breed and parity. These results agree with those obtained previously in different breeds (Labussière, 1988; Fernández et al., 1983, 1995) although teat angle was affected by stage of lactation in other references (Casu et al., 1983; Gallego et al., 1983a; Labussière et al., 1983; Fernández et al., 1989a, 1995). Other authors indicate that udder length was not affected by the variation factors analyzed.

In regard to the correlation coefficients between udder traits, three natural groups can be distinguished as indicated by Fernández et al. (1995): 1) udder size (height and width), which are high and positive; 2) teat size (width and length), which are medium and positive; and 3) cistern morphology (height) and teat placement (position and angle) which are medium and positive but show low and negative correlation with teat and udder sizes. As udder width increases, cistern height and teat angle and position decrease; and, as udder height increases, cistern height and teat angle and position also increase.
When morphological traits are related to milk yield the greatest effects are observed for udder width and height and commonly tendencies are only observed for the remaining traits (Gallego et al., 1983a; Labussière et al., 1983; Fernández et al., 1989a, 1995; McKusick et al., 1999). Big volume and cisterned udders produce more milk. Main effects of teat traits are related to milk fat (McKusick et al., 1999) and milk emission during milking (Fernández et al., 1989a; Marie et al., 1999).

Table 2. Mean values of udder traits and effects of breed, parity and stage of lactation in Manchega and Lacaune dairy sheep (Rovai et al., 1999)

<table>
<thead>
<tr>
<th>Item</th>
<th>Breed</th>
<th>Effect ($P &lt;$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manchega</td>
<td>Lacaune</td>
</tr>
<tr>
<td>Number of ewes</td>
<td>63</td>
<td>24</td>
</tr>
<tr>
<td>Milk yield (wk 4 to 20) :</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total, l/ewe</td>
<td>84.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>153.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Daily, l/d</td>
<td>0.82&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.36&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Teat:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length, mm</td>
<td>33.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.1&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Width, mm</td>
<td>15.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Angle, °</td>
<td>42.5</td>
<td>44.1</td>
</tr>
<tr>
<td>Udder:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth, cm</td>
<td>17.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Length, cm</td>
<td>11.4</td>
<td>11.3</td>
</tr>
<tr>
<td>Teat distance, cm</td>
<td>12.6</td>
<td>12.0</td>
</tr>
<tr>
<td>Cistern height, mm</td>
<td>15.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a, b</sup>: Values with different letters in the same line differ ($P < 0.05$)

As a conclusion, the most significant and repeatable udder traits agreed by different authors for a wide sample of sheep dairy breeds are:

- Teat dimensions (length) and position (angle)
- Udder height (also called depth) and width
- Cisterns height

**Linear scores:** The main drawback of the udder typologies is their use for the estimation of the genetic value of breeding animals and when genetic and environment effects need to be broken down for selection. This problem has been solved in dairy sheep, as in dairy cows and goats, by using a breakdown system in which independent udder traits are evaluated according to a linear scale of 9 points (De la Fuente et al., 1996).

The four udder traits considered by De la Fuente et al. (1996; 1999) to be significant for machine milking are: udder depth or height (from the perineal insertion to the bottom of the udder cistern), udder attachment (insertion perimeter to the abdominal wall), teat angle (teat insertion angle with the vertical), and teat length (from the gland insertion to the tip). The system also includes an expanded typology to evaluate the whole udder shape, in accordance with the previously described optimal criteria and udder types, but uses the same linear scale of 9 points. Each udder trait is evaluated independently by using extreme biological standards (Table 3).
<table>
<thead>
<tr>
<th>Trait</th>
<th>Score (1 to 9)</th>
<th>1 (Low)</th>
<th>5 (Average)</th>
<th>9 (High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Udder height</td>
<td></td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>Teat angle</td>
<td></td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
<tr>
<td>Teat length</td>
<td></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
<td><img src="image9" alt="Image" /></td>
</tr>
<tr>
<td>Udder shape</td>
<td></td>
<td><img src="image10" alt="Image" /></td>
<td><img src="image11" alt="Image" /></td>
<td><img src="image12" alt="Image" /></td>
</tr>
</tbody>
</table>

The desirable value is in some cases the highest score (i.e. teat angle: vertical teats that scored 9 will reduce cluster drops and will make easier the milk drainage) or the average score in others (i.e. teat length: medium size teats scored 5 and agree with a uniform cluster length). In udder height, given its positive relationship with milk production an average score will also be preferable.

This linear methodology has been used in Spain for the evaluation of different flocks (27 flocks and 10,040 ewes) of Churra, Manchega and Latxa dairy ewes (De la Fuente et al., 1999), and it is also being partially used in the Lacaune breed for the evaluation of morphological traits in relation to machine milking ability (Marie et al., 1999). Results for Spanish breeds are shown in Figure 7 according to lactation stage and parity effects. In regard to lactation stage, all linear scores decreased as lactation progressed, udder height and udder attachment being the traits which showed the greatest decrease during lactation, while teat size was only slightly modified. This evolution agrees with the loss of udder volume and milk yield but indicates a deterioration of udder morphology for machine milking as indicated by udder shape. Only udder height was improved. Regarding lactation number, udder height increased dramatically in the first lactations, while other traits decreased and teat size was steadily constant. As a consequence, udder shape deteriorated and its score decreased rapidly from first to third lactation and stabilized thereafter.
Figure 7. Evolution of linear scores of main udder traits in Spanish dairy sheep: ▲, udder height; ■, udder attachment; Δ, teat angle; □, teat length; and, ●, udder shape (elaborated from De la Fuente et al., 1999).

The values of linear scores calculated by Fernández et al. (1997) in the Churra dairy breed (Table 4) were sufficiently repeatable (r = 0.48 to 0.64) and showed intermediate heritability values ($h^2$=0.16 to 0.24) as reported in cattle. Coefficients of variation ranged between 18 and 37%. The authors indicate that a single scoring per lactation would be sufficient in practice.

Table 4. Genetic parameters of linear udder traits in dairy sheep (Fernández et al., 1997).

<table>
<thead>
<tr>
<th>Trait</th>
<th>Heritability ($h^2$)</th>
<th>Repeatability (r)</th>
<th>Correlation with milk yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Phenotypic ($r_p$)</td>
</tr>
<tr>
<td>Udder height</td>
<td>0.16</td>
<td>0.51</td>
<td>0.40</td>
</tr>
<tr>
<td>Udder attachment</td>
<td>0.17</td>
<td>0.48</td>
<td>-0.01</td>
</tr>
<tr>
<td>Teat placement</td>
<td>0.24</td>
<td>0.64</td>
<td>-0.04</td>
</tr>
<tr>
<td>Teat size</td>
<td>0.18</td>
<td>0.54</td>
<td>0.03</td>
</tr>
<tr>
<td>Udder shape</td>
<td>0.24</td>
<td>0.62</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Udder shape, equivalent to a typology of expanded categories (nine), was highly repeatable and heritable, indicating its utility as a single trait for dairy sheep selection. Nevertheless udder shape showed high and positive genetic correlation with udder attachment ($r = 0.55$) and teat placement ($r = 0.96$), as a result of the main role of these traits in the definition of udder shape. Consequently, the use of the first four linear udder traits will be sufficient to improve programs of udder morphology. Phenotypic and genetic correlations showed that selection for milk yield will produce a worse udder morphology, mainly in udder height and teat placement, giving as a result baggy udders which are inadequate for machine milking.
Repeatabilities of udder linear scores obtained in Lacaune dairy breed (Marie et al., 1999) were also high (r= 0.59 to 0.71) and show moderate phenotypic correlation with milk yield in primiparous and multiparous ewes. Heritabilities of udder traits reported in Assaf ($h^2 = 0.23$ to 0.42; Gootwine et al., 1980), Chios ($h^2 = 0.50$ to 0.83; Mavrogenis et al., 1988), and Sarda with the seven expanded typologies ($h^2 = 0.55$; Carta et al., 1999), gave higher values but, as indicated by the last authors, probably they were overestimated. Nevertheless, taking into account the conclusions of Fernández et al. (1997), the genetic variability and heritability of the studied udder traits indicate that the efficiency of the breeding programs could be improved and some selection pressure on udder traits in long-term breeding programs needs to considered.

**Machine milking ability**

Machine milkability is normally estimated by fractional milking (i.e. machine milking, machine stripping, and extraction of residual milk after an oxytocin injection) or by analysis of milk emission curves obtained during machine milking without massage or extra stimulation of the mammary gland. The methodology proposed in the M4 FAO Project (Labussière, 1983) is normally used as the standardized method for both criteria.

**Milk fractioning:** Milk fractions were mainly used as an important indicator for the evaluation of the milkability in dairy sheep when the routines included hand stripping as in the M4 FAO project (Labussière, 1983). Reported values of milk fractioning varied according to breed (Labussière, 1988; Such et al., 1999a), milking routine (Molina et al., 1989) and machine milking parameters (Fernández et al., 1999). Values of fractioning ranged normally from 60 to 75 : 10 to 20 : 10 to 15, for machine milking : machine stripping : residual milk, respectively.

The comparison of milking ability of two groups of ewes characterized by different milk yield (Manchega, 0.6 l/d; Lacaune, 1.3 l/d), was carried out by Such et al. (1999a) in late lactation (week 16) and under the same milking conditions. Values of fractional milking (machine milk : machine stripping milk : residual milk) were 65:19:16 and 68:21:11, for Manchega and Lacaune ewes, respectively. No significant differences were observed according to breed in percentages of milk fractions, except in the case of residual milk (Figure 8). Both breeds gave on average 86% milk during machine milking, but Manchega breed retained more milk in the ductal system of the udder. This result was obtained despite the differences reported in milk yield and in absolute values of each fraction, as well as in cistern size (Table 1) and udder morphology (Table 2), of each breed as discussed previously. Differences in udder size and morphology explain the increase in machine stripping milk according to milk yield, and were also reported by effect of lactation stage (Gallego et al., 1983b; Labussière, 1988).

As a conclusion, the obtained results show the unsuitability of the milk fractions as a main indicator for the evaluation of milkability in ewes, fractioning probably being a better indicator for the study of machine or milking routine effects, which were the same in this case. Moreover, Caja et al. (1999a) in goat and Fernández et al. (1999a) in sheep, reported significant differences in the machine stripping fraction according to milking routine or machine milking parameters, respectively.
**Figure 8.** Milk fractioning obtained during machine milking of dairy sheep according to the breed at the same stage of lactation (Such et al., 1999a): MM, machine milk; MSM, machine stripping milk; RM, residual milk; m, milked; g, present in the gland.

![Graph showing milk fractioning](image)

**Milk emission:** Milk emission is one of the most interesting criteria for studying milkability in the machine milking of dairy sheep and its main traits are considered to be relevant for the design of milking machines and to adopt the optimal milking routine in each breed. As milk yield strongly influences intramammary pressure, a strong effect of milk production on all milk flow parameters is also expected, as indicated by Marnet et al. (1999) and observed clearly in dairy goats (Bruckmaier et al., 1994; Caja et al., 1999a). Moreover, milk emission will be different for a.m. and p.m. milkings, and its curves should be analyzed separately. Morning milking will increase milk flow and milking time, but emission of alveolar milk will be observed easily and separately in the afternoon.

Milk emission curves are obtained by manual (Labussière, 1983; Fernández et al., 1989b; Peris et al., 1996) or automatic methods (Labussière and Martinet, 1964; Mayer et al., 1989b; Bruckmaier et al., 1992; Marie et al., 1999). The flow from the right and left mammary glands can be recorded separately (Labussière and Martinet, 1964; Labussière, 1983) or as a whole (Fernández et al., 1989b; Peris et al., 1996; Bruckmaier et al., 1992; 1996; Marie et al., 1999; Marnet et al., 1999), but results and conclusions of flow may be different in consequence (Rovai, 2000).

A good milk emission curve should mean a quick and complete milking, with a high milk flow rate and an effective ejection of alveolar milk under the action of the oxytocin. The milk emission pattern is related to the structure of the udder (cistern size), to the teat traits (size and position) and to the neuro-hormonal behavior of the ewe (Labussière et al., 1969; Bruckmaier et al., 1994, 1997; Marnet et al., 1998, 1999). Globose and big cisterned udders with medium size, vertical and sensitive teats, that are able to open the sphincter rapidly and widely at low vacuums, are preferable.
An early typology of milk emission curves was proposed by Labussière and Martinet (1964), and widely adopted for the study of sheep dairy breeds (Labussière, 1983, 1988). The milk emission typology considers curves of different shape: ‘1 peak’ (single), ‘2 peaks’ (bimodal) and others, the last corresponding to animals with irregular or multiple milk emission curves (≥ 3 peaks). In some cases an ewe changes the milk emission typology on consecutive days, and more than two recordings are recommended in practice. The first peak occurs very early after cluster attachment and it is identified as cisternal milk, which is drained after the opening of the teat sphincter. The second peak corresponds to alveolar milk and occurs as a consequence of liberation of alveolar milk during the appearance of the milk ejection reflex by effect of released oxytocin (Labussière and Martinet, 1964; Labussière et al., 1969; Fernández et al., 1989b; Marnet et al., 1998). Milking-related release of oxytocin has been measured in dairy sheep by Mayer et al. (1989a) and Marnet et al. (1998). The machine milk fraction is normally greater and milk flow maintained high during a longer time in the bimodal ewes, which are considered favorable for machine milking in dairy ewes. Milking of ewes showing a single milk emission curve can be completed by using a milking routine with machine or manual stripping (‘repasse’) after cessation of the machine milk flow, which is unfavorable and increases dramatically the total milking time per ewe. Moreover, simplified milking routines (without hand or machine stripping) are well accepted by bimodal ewes as indicated by Molina et al. (1989) in Manchega dairy sheep.

Distribution of animals in a flock according to number of peaks has also been used as an index of machine milkability in dairy breeds as indicated by Labussière (1988). Sheep breeds with a greater percentage of ewes showing 2 peaks being the most appropriate for machine milking. Nevertheless peak distribution in a flock changes according to the stage of lactation as observed by Rovai (2000) in a flock with breeds of different yield and milkability (Table 5). Number of ewes in the 1 peak typology increased at the end of lactation and on the contrary the ≥ 3 peaks decreased compensating the losses in the 2 peaks group.

Table 5. Distribution (%) of milk emission curves obtained in dairy ewes during machine milking according to breed and stage of lactation (Rovai, 2000).

<table>
<thead>
<tr>
<th>Stage of lactation (d)</th>
<th>Manchega</th>
<th>Lacaune</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 peak</td>
<td>2 peaks</td>
</tr>
<tr>
<td>42&lt;sup&gt;1&lt;/sup&gt;</td>
<td>28.6</td>
<td>56.7</td>
</tr>
<tr>
<td></td>
<td>(62)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>(123)</td>
</tr>
<tr>
<td>70</td>
<td>29.6</td>
<td>64.2</td>
</tr>
<tr>
<td></td>
<td>(67)</td>
<td>(145)</td>
</tr>
<tr>
<td>98</td>
<td>39.4</td>
<td>54.8</td>
</tr>
<tr>
<td></td>
<td>(74)</td>
<td>(103)</td>
</tr>
</tbody>
</table>

<sup>1</sup>: First week after weaning at day 35.
<sup>2</sup>: Number of emission curves analyzed.
Machine milking parameters can also modify the milk flow characteristics in dairy sheep, mainly the volume of the second peak and the milking time, as reported by Fernández et al. (1999) in Manchega dairy ewes milked at different vacuum levels (36 and 42 kPa) and pulsation rates (120 and 180 P/min).

Clear differences in milk emission curves during the p.m. milking were observed by Such et al. (1999b) according to breed, when Manchega and Lacaune dairy ewes at the same stage of lactation were compared (Figure 9) indicating the importance of this criterion on the evaluation of milkability. Daily milk yield at comparison and percentage of bimodal ewes during the comparison period were 0.6 l/d and 38%, and 1.3 l/d and 83%, for Manchega and Lacaune ewes respectively.

Figure 9. Milk emission curves resulting from p.m. machine milking of dairy sheep according to breed (□, Manchega; ■, Lacaune) and number of peaks (Such et al., 1999a).

Significant differences in the values of maximum milk flow (76 vs 129 ml/5s) and milk peak volume (207 vs 586 ml) were observed for the 1 peak Manchega versus Lacaune ewes, respectively. The significant values for the 2 peaks ewes were: first peak (72 vs 94 ml/s; and, 171 vs 344 ml) and second peak (41 vs 83 ml/s; and, 78 vs 239 ml), for Manchega vs Lacaune, respectively. Total emission time until a milk flow <10ml/s were: 1 peak (25 vs 39 s) and 2 peaks (48 vs 56 s) for Manchega vs Lacaune respectively, being the difference significant in all cases. Observed differences in milk flow parameters between breeds were in accordance with their milk yield. Nevertheless, despite the differences of milk emission curves, the total volume of milk obtained in 1 peak vs 2 peaks ewes were similar in each breed: Manchega (207 vs 249 ml) and Lacaune (586 vs 583 ml) respectively for 1 vs 2 peaks. Moreover maximum milk flow was the same in both breeds for the 2 peaks ewes, despite the differences in yield. As a consequence, it can be suggested that other factors different from milk ejection reflex are mainly conditioning the milk flow during machine milking in dairy ewes.
At present, teat and cistern characteristics seem to be the most important factors in relation to milk flow curves in dairy sheep. Results of Marie et al. (1999) and Marnet et al. (1999) in Lacaune dairy sheep, and Bruckmaier et al. (1994, 1997) studying the effects of milking with or without prestimulation in Saanen dairy goat, and Friesian and Lacaune dairy sheep, are in accordance with these conclusions.

Marnet et al. (1999) indicate that lag time between teat cup attachment and arrival of the first milk jets to the recording jar can be used as an indicator of milkability. Moreover significant correlation of lag time with vacuum needed to open the teat sphincter \( r = 0.61 \), total milking time \( r = -0.86 \), and mean \( r = -0.84 \) and maximum \( r = -0.80 \) milk flow rates, were observed. A low but significant correlation between Somatic Cell Count and maximum milk flow was also obtained \( r = 0.39 \). Moreover, the vacuum value needed to open the teat sphincter seems to remain constant in each animal during lactation and is also positively related with the teat congestion observed after milking. The highest vacuum value needed to open the teat sphincter in this experiment was 36 kPa, suggesting that the use of a low milking vacuum is possible in Lacaune dairy ewes.

According with these results Marie et al. (1999) studied the main udder traits and milk flow characteristics by using an automatic milk recorder in two lines of Lacaune dairy ewes differing 60 l in genetic merit. Milk yield and milking time averaged 0.94 l/d and 2 min 44 s, respectively. Average lag time was 25 s for a minimum volume of milk of 160 ml. Maximum milk flow \( 0.87 \) l/min was observed 27 s later \( 52 \) s from cluster attachment \) in average. Lag time was negatively correlated with milk yield \( r = -0.26 \) and maximum milk flow \( r = -0.49 \). Measured repeatabilities for milk yield, lag time and maximum milk flow were high in the same lactation \( r = 0.46 \) to 0.59 \) and between lactations \( r = 0.40 \) to 0.75 \). Flow parameters varied according to milk yield as previously reported by Bruckmaier et al. (1994) in goats, but the increase in milking time was lower than in milk.

Correlation of udder traits with flow parameters obtained by Marie et al. (1999) were low \( -0.3 \) to 0.3 \) and tended to increase in multiparous ewes. An increase in teat angle was associated to a greater lag time \( r = 0.28 \) and a lower maximum milk flow \( r = -0.26 \), both unfavorable traits. On the contrary, a very marked intermammary groove was correlated to greater milk yield \( r = 0.28 \) and milk flows \( r = 0.33 \) to 0.34 \), and lower lag time \( r = -0.23 \). As a final conclusion the authors indicate that a good udder shape tends to improve milkability in dairy sheep and recommended the inclusion of this trait in genetic programs.

Bruckmaier et al. (1997) compared milk flow and udder anatomy, including ultrasound images, in Lacaune and Friesian dairy ewes. Both breeds showed similar milk yield and cisternal areas. Nevertheless, milk flow was lower and stripping milk yield higher in the Friesian ewes as a consequence of udder morphology that showed cisternal bags below the level of the teat channel. The use of a prestimulation routine failed to reduce stripping milk and total milking time but increased milk flow in both breeds. Oxytocin release was different in both breeds and a dramatic increase in blood concentration was observed in Lacaune ewes during teat stimulation and early milking, while only slight release was found in Friesian ewes. During machine milking, significant increase in oxytocin was observed in 88% of Lacaune but only in 58% of Friesian ewes. The authors also indicate the occurrence of single peak typologies in milk emission with or without increasing concentrations of oxytocin in both breeds.
Implications

Relationship between morphological and productive traits are evident in dairy sheep as a consequence of anatomical and physiological characteristics. Breed differences are also detected despite the differences in milk yield. Phenotypic and genetic correlations indicate that selection for milk yield will produce a worse udder morphology, mainly in udder height and teat placement, causing baggy udders which are inadequate for machine milking. Teat and cistern characteristics appear to be the most limiting factors in machine milkability and especially in milk flow. Genetic variability, repeatability and heritability of udder traits indicate that some selection pressure on udder traits needs to be considered. In practice the use of four linear udder traits will be sufficient to improve udder morphology in long-term breeding programs.

Literature Cited

Caja G. and Such X. 1999. Curso de actualización sobre ordeño mecánico de ovino y caprino. SEOC-UAB, Bellaterra, Barcelona. CD Rom.


