Machine milking ability in goats: genetic variability and physiological basis of milk flow rate

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Summary

This review presents the results of 4 years of studies on machine milking ability in French Alpine and Saanen goats. This research aimed : 1- to validate measurements of milking ability; Milk flow parameters measured by automatic electronic jar and teat end characteristics measured by vacuometer and cutimeter seemed very convenient for that, 2- to describe inter-animal variability on the basis of milk flow rates and other characteristics of milk emission kinetics; The variability is very important and correlated between peak and mean milk flow rate an teat sphincter resistance. A high number of high yielding goats of the two breeds presented too long milking duration due to low milk flow rate suggesting a big capability of improvement of total milking rate of milking for breeders, and 3- to investigate the physiological basis for this variability; The teat characteristics and especially the teat sphincter resistance and tonus before milking explained the main part of the variability of milk flow rate. The milk ejection reflex, attested by oxytocin release around milking, was never correlated to milk flow parameter suggesting that oxytocin discharge is non essential for milk ejection in dairy goats.

Keywords : *Milking ability, goats, milk flow, teat, oxytocin*

Introduction

Because of increase in herd size and productivity per goats, compliance with new requirements about milk quality, and the lack of specialised workforce, we notice an increase in workload on the goat family-run farms. Thus, despite advances in automation, milking remains the heaviest commitment on farms, requiring about 55% of the daily working time of farmers. It is necessary to increase the hourly productivity of milking personnel (more than 200 to 250 goats/ hour/ milker), while respecting milk quality and the health status of udders. However, this work is difficult because of the considerable heterogeneity of milking times observed between animals and between farms.

This heterogeneity between animals has a genetic component. The existence of a major gene influencing the „first minute" milking flow was first postulated by Ricordeau et al. (1990), and this is now possible to measure this parameter by use of automatic milking jar on a larger scale. Different anatomical and physiological parameters concerning these variations in milking times may be the source of these inter-individual variations: 1)- The existence or not of a milk ejection reflex, which can be measured objectively based on oxytocin release (Marnet and McKusick, 2001) could suggest that some animals may be not enough stimulated. 2)- The considerable heterogeneity of udder morphology, renders difficult any adaptation to modern milking machines. 3)- Teat characteristics may be of a major importance. Indeed, Le Du and Benmederbel (1984) showed that the teat canal in goats seems to be more difficult to open than that of cows, and the vacuum necessary to achieve a flow of milk is correlated negatively with the milk flow and positively with the milking time. In addition, the milk flow seems to be easier from teats with a narrow, supple and compressible extremity.
This work thus describes the variability and genetic determinism of the milking rate in goats, while attempting to find explanatory factors through the study of some of its anatomical and physiological foundations.

Material and methods

Measurement of milk emission characteristics during milking

The measurement of milk emission kinetics (Labussière and Martinet, 1964), used different automatic control devices designed by INRA. These devices, connected in the same way as standard milking control jar, all contained a probe equipped at 0.5 cm intervals with electromagnetic switches with flexible blades and a sliding flotation device which ensured contact with these switches (Le Du et al, 1983).

Measurements on commercial farms

The measurements of variability in performance were made on 27 commercial farms, and during more than 1000 milking sessions on different goats from Alpine (n=806) and Saanen (n=217) breeds, chosen at random throughout the different lactations from 1996-1997 until 1998-1999. Machine adjustments were homogeneous (38 to 40 kPa of vacuum, 80 to 90 pulsations per min. and a ratio of 50 to 60%), and a single type of milking cluster was used (Caprilac from Gascoigne-Melotte) for measurements.

Measurements on experimental farms

Measurements on experimental farms aimed to clarify the most relevant factors for genetic variability and zootechnical data to be taken into account when measuring performance. They were repeated several times in each goat. We chose electronic jar and the same machine adjustments as in commercial farms, but the milking clusters differed (Almatic from DeLaval). Thus 1596 milking sessions on 133 Alpine goats, checked six times under standard conditions, made it possible to validate the criteria chosen and establish the factors for variations in milking characteristics. At the Moissac goat farm, 2493 milk flow measurements, performed between 1985 and 1997 on 1421 Alpine goats, the offspring of 93 fathers, made it possible to carry out a genetic study. As from 1998, these measurements were supplemented by recordings of milk emission kinetics and all other productive and anatomical data were collected by Caprigène on all goats on the farm. 80 goats with a comparable level of milk production were pre-selected and 20 goats amongst them, selected for their different lag times and milk flow rates, were chosen to study the physiological determinism of variations in milk flow and milking time.

Physiological (OT) and morphological measurements (udders and teats)

Blood was sampled (10 ml) via an intra-jugular silicone catheter implanted under aseptic conditions a few days prior to measurement. The sampling protocol was: Subject in barn, subject in the milking parlour (5 min prior to cluster attachment), at (T0) and then 0.5, 1, 1.5, 2, 3, 6 and 12 min after cluster application. Plasma was frozen until analysis of oxytocin levels using the EIA technique (Marnet et al. 1994).

The morphology was scored from 1 to 9 (Piacère et al. 1999) for teats: angle, implantation, orientation, shape (length and diameter of teats were measured in cm) and for udders: shape of udder halves, base length of udder suspension, position of attachment and profile.

Teat end thickness was measured by the same person before and after evening milking using a HAUPTNER cutimeter. It is a spring-loaded calipers which measure the thickness of tissue under a constant force (2.4 kPa). The teat canal resistance at opening was achieved using a vacuometer. This device comprises a rigid, transparent cup connected to a vacuum pump which creates a vacuum increasing by approximately 1 kPa /s . The level of vacuum (kPa) corresponding to the flow of the first drop of milk indicated the resistance of the teat canal to opening. This measurement was performed daily, at a fixed time from the normal time of milking for each goat.

Results

The results are presented by sampled population (Saanen or Alpine), the notion of population including both the breed and its environment.

Measurements on commercial farms

The quantity of milk produced by goats was 1.62 ± 0.52 l in the Alpine population and 1.74 ± 0.65 l in the Saanen population. The mean total milking time was 181 ± 76 s in the Alpine population and it was 213 ± 96 s in the Saanen population. The lag time, i.e. the time elapsing between the application of teat cups and the first recording of milk emission, was on average around 15 to 20 s in all animals in the two populations. The overmilking time, measured from the time when the milk flow fell from 200 ml/min to 0 at the end of milking, was an average of 25 to 30 s per animal in the Alpine population and 10 to 25 s per animal in the Saanen population. On average, this represented nearly 20% of machine milking time in the Alpine population. However, the variability was very marked as a function of farms and animals. Thus, it was observed overmilking time which was equal to or longer than the actual milk flow time. In contrast, incomplete milking, interrupted when the milk flow was still high (at around 0.6 l/min) were demonstrated on most farms. Analysis of the quantities of milk collected at the end of milking shows that they were very small below a flow rate of 200 ml/min for an additional period of around 10 s per animal. Thus further kinetic analysis only took account of the machine milk fraction, in order to standardise the notion of the end of milking. The real mean flow rate was 0.79 ± 0.25 l/min in the Alpine population and 0.64 ± 0.22 l/min in the Saanen population. The peak flow rate of goats in the Alpine population was 1.28 ± 0.41 l/min and it was 1.11 ± 0.43 l/min in Saanen goats. The first minute milk flow was 0.72 ± 0.33 l/min in Alpine goats and only 0.56 ± 0.33 l/min in Saanen animals. The real first minute milk flow, which corresponded to the quantity of milk produced from the first recording and not from the teat cup attachment, was 0.90 + 0.3 l/min in the Alpine population and 0.72 ± 0.31 l/min in the Saanen population. The highest first minute milk flow among Alpine goats was 1.016 l/min. It was markedly lower in the Saanen population (0.767 l/min). The maximum milk flow plateau appeared on average about 35 to 40 s after cluster application. A few difference was seen between the two populations. However, unlike the peak flow rate which was fleeting, the plateau lasted on average for approximately 1 min in Alpine goats and more than 1.5 minutes (101.5 s) in Saanen goats.

The correlations between the different milking parameters were relatively similar in the two populations studied (Table 1). It was possible to determine 3 categories of milk emission kinetics based on peak flow rates and milking times (Figure 1) and on the lag time (Figure 2). Thus, based on flow rates and milking times, 21.3%, 69.4% and 9.3% of kinetics in Alpine goats and 11.3%, 62.4% and 26.3% of kinetics in Saanen goats were found in groups 1, 2 and 3, respectively. Based on lag timess, 61.8%, 28.2% and 10% of Alpine kinetics versus 46.2%, 28% and 25.8% of Saanen goat kinetics were distributed in groups A, B and C, respectively.

Physiological determinism of inter-animal variations in milk flow

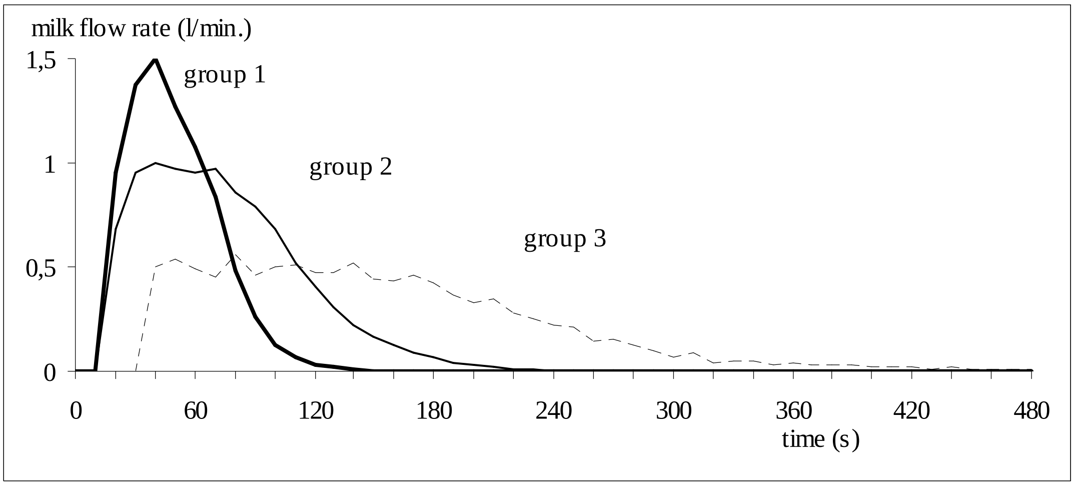
The 80 goats studied have been selected for their equivalent milk production (1.73 ± 0.27 Kg). The baseline oxytocin concentration was 12.6 ± 7.5 pg/ml and did not differ significantly between goats. It was closely correlated with the machine milk quantity and the thickness of teat tissues ($r^2 = 0.61$ and 0.5 respectively, $p < 0.01$). Peak concentrations of oxytocin, which varied considerably between and within animals at 56.2 ± 45.5 pg/ml, did not correlate with lag time categories. The total

Table 1. Phenotypic correlation between milking parameters in Alpine and Saanen goats.

		Alpine Goats (n = 710)						
		MP	TMT	LagT	MaxMF	1^{st}MF	R1^{st}MF	PlatMF
	MP	1.00	0.51 ***	-0.09 *	0.26 ***	0.26 ***	0.37 ***	0.24 ***
Saanen goats (n = 186)	TMT	0.63 ***	1.00	0.49 ***	-0.51 ***	-0.55 ***	-0.46 ***	-0.55 ***
	LagT	0.07	0.49 ***	1.00	-0.47 ***	-0.72 ***	-0.44 ***	-0.51 ***
	MaxMF	-0.11	-0.35 ***	-0.38 ***	1.00	0.86 ***	0.86 ***	0.91 ***
	1^{st}MF	-0.06	-0.57 ***	-0.75 ***	0.57 ***	1.00	0.89 ***	0.89 ***
	R1^{st}MF	0.1	-0.54 ***	-0.55 ***	0.60 ***	0.91 ***	1.00	0.88 ***
	PlatMF	-0.1	-0.55 ***	-0.54 ***	0.65 ***	0.86 ***	0.87 ***	1.00

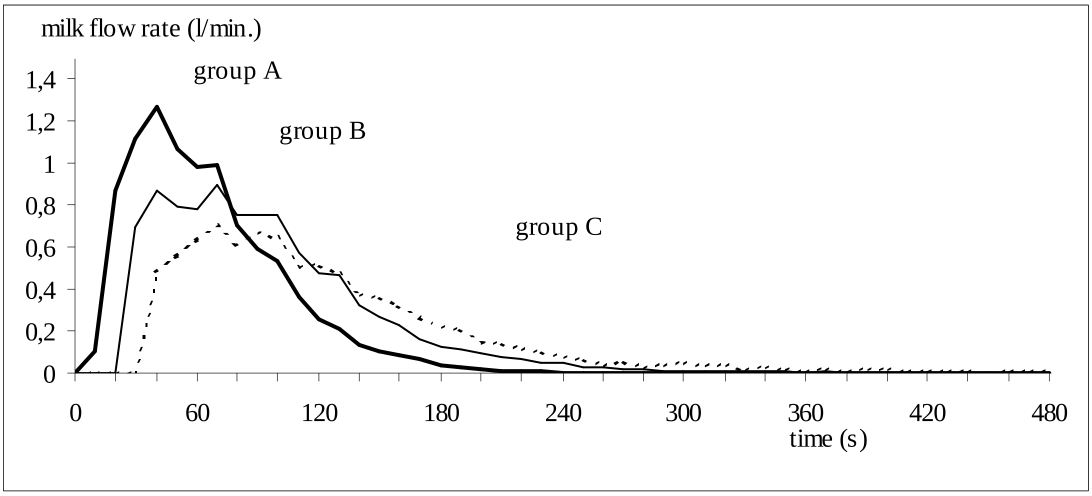
*** : significant correlations $P < 0.001$; ** : significant correlations $P < 0.01$; * : significant correlations $P < 0.05$

MP: Milk production ; TMT: Total milking time ; LagT: time between cup attachment and first recording of milk ; MaxMF : maximum or peak milk flow ; 1^{st}MF : first minute milk flow ; R1^{st}MF : Real first minute milk flow without lag time ; PlatMF : milk flow during plateau of maximum flow.



Group 1: peak flow > 1l/min and total milking time £ 2 min; Group 2: 3 min^3 total milking time^3 2 min; Group 3: peak flow < 1l/min and total milking time^3 3 min.

Figure 1. Classification of milk emission kinetics based on peak flow rates and milking times in Alpine goats (n=710).



Group A: lag time £ 10s; Group B: 20s ³ lag time ³ 10s; Group C: lag time ³ 20s.

Figure 2. Classification of milk emission kinetics based on lag time in Alpine goats (n=710).

quantities discharged and the time to reach peak oxytocin levels also exhibited considerable variability and a lack of significant relationship with categories of goats and other criteria.

The vacuum necessary to open teat sphincters was on average 26.1 ± 4.8 kPa. It was significantly higher in the two categories with the longest lag times (31.9 ± 7.4 and 41.8 ± 6.2 kPa respectively for lag times between 12.5 and 17.5 s and more than 17.5 s). This parameter was strongly correlated with lag time, with the total milking time and with the mean and peak flow rates ($r^2 = 0.61$; 0.7; -0.59 and –0.61, respectively, $p< 0.05$). For the same milk production, latency was the variable most strongly correlated with milking time, mean and peak flow rates ($r = 0.89$; -0.71 and -0.066 respectively, $p< 0.05$). Teat end thickness was 5.4 ± 0.9 mm, without difference between lag time or flow rate categories. Teat end thickness before milking was weakly but significantly correlated with lag time, milking time, milk quantity and the vacuum necessary to open teats ($r^2 = 0.3$, 0.37, 0.34 and 0.26 respectively, $p< 0.01$). No variations in thickness were measured after milking, whatever the category of goat.

Genetic determinism of inter-animal variations in milk flow

The correlations between criteria measured on experimental farm were equivalent to those measured on commercial farms.

The sources of variations in milking ability was studied. Statistical analyses (Ilahi et al., 1999), carried out on evening and morning milking sessions, and including effects of „lactation stage“, „lactation number“, their interactions and the „goat“ effect, confirmed the significant influence ($P < 0.01$) of these factors on milking characteristics. For both morning and evening milking sessions and in all age categories, the flow rate parameters (first minute flow rate and peak flow rate) diminished during lactation; in contrast, the lag time increased during lactation. The lactation number (lactations 1, 2 and 3 to 7) significantly influenced (P < 0.01) milk production (L1 < L2 and L3+), peak flow and first minute flow rate (L2 > L1 > L3+) and lag time (L3+ > L1 > L2). Inclusion of the „goat“ effect in the statistical model enabled an estimate of repeatability (correlation between successive measurements in an animal): 0.55 and 0.64 for milk quantities in the evening and morning, 0.72 and 0.74 for first minute milk flow, 0.53 and 0.63 for peak flow rate and 0.59 and 0.68 for lag time. This repeatability suggested that individual variability accounted for a high proportion of the total variability observed during lactation.

Segregation analysis (Hilahi et al., 2000), performed on the basis of 2493 first minute flow rate measurements using a father-mother model confirmed (P < 0.01) the segregation of the major gene, which had an effect of 2.3 phenotypic standard deviations on the first minute milk flow. The difference in flow between goats with HdHd and ++ genotypes was approximately 0.6 l/min. The + allele was dominant, with a 60% degree of dominance. The unknown gene explained nearly 60% of the total genetic variability, but a residual heritability of 0.30 suggested that the influence of other genes, represented in this analysis by a polygenic effect, was far from negligible.

Multi-character analysis showed that the genetic correlations between the first minute flow and milking characteristics (total lactations adjusted to 250 days of lactation) were weak: 0.10, 0.01, 0.03, -0.13, -0.07 for milk yields, protein and fat contents, amount of protein and of fat, respectively. As for Somatic Cells counts (SCC) and the morphology of teats and udders, the genealogical structure of the data only allowed an estimate of phenotypic correlations (346 goats followed in 1998). The phenotypic correlations between external morphology, physiological teat characteristics and milk flow characteristics were very weak. The shape and diameter of teats were the most strongly correlated with flow rate criteria (>0.1; P < 0.05) and with the teat sphincters resistance (>0.3; P < 0.5). Somatic cell counts (SCC) and the corresponding scores arising from logarithmic transformation (SCCS) were weakly correlated with lag time, 1st minute, maximum and mean flow rates and correlations did not differ significantly from 0 (P < 0.01; Table 2).

Table 2. Phénotypic corrélations between SCC and milk flow characteristics (n = 348 goats).

Characters	LagT	1^{st}MF	MaxMF	mMF
SCC	-0,03	0,07	0,07	0,00
SCCS	-0,03	0,11	0,11	0,02

SCC : somatic cell count ; SCCS : somatic cell count score after log transformation ; lag time : time elapsed between cup attachment and first recording of milk ; 1^{st}MF : first minute milk flow ; MaxMF : maximum or peak milk flow ; mMF : mean milk flow during milking.

Discussion

Even when they are studied under homogeneous milking situations, goats are very variable with respect to their milking ability. This variability of the goat model is of considerable value to zootechnical, genetic and physiological studies of the mammary system. Furthermore, this variability can be exploited in applied breeding, particularly since automatic devices have proved their efficiency and usefulness in the recording and quantification of different milk emission kinetic parameters on farms.

Although our protocol on commercial farms was not designed to compare different breeds (not the same environmental conditions), the characteristics measured, suggested less good mean milk flow capacities in the Saanen goats. This result needs to be confirmed because of the smaller number of farms working with this breed during our study. In general, flow rate and milking time performances lower during first lactations, thus confirming that mammogenesis is still incomplete after the first parturition.

Our results suggest the existence of common physiological mechanisms which influence the initiation of milk emission and the subsequent flow rate. The anatomical and physiological characteristics of teats (sphincter resistance) are crucial to milk emission kinetics. Indeed, the „lag time“ criterion was always negatively and strongly correlated with „flow rate“ variables. In addition, teat end thickness prior to milking was greater when milk production was higher and in animals with a longer milking time. That suggests the existence of muscle tone as a reaction to intra-mammary pressure and a limiting role for the tone of teat tissues around the straek canal on milk emission.

The 3 kinetic categories arbitrarily determined from peak flow rates and milking times or lag times confirmed the presence of difficult and lengthy milking sessions. The reason was mainly that a greater vacuum was required to open the sphincter, often at the limit of that supplied by the milking machine. The first minute flow rate, integrating the lag time, was also particularly low in animals exhibiting these kinetics. The weak phenotypic correlation between milk flow criteria and milk production means that this kinetic category corresponded to goats which did not produce significantly less than those in other categories. This could explain their late culling by breeders and thus their non-negligible percentage in herds. To reduce the total working time at milking, we feel it is a high priority to include measurement of this criterion on farms, so as to homogenise milking times down to the shortest value. In contrast, the search for a very high milk flow is questionable. Indeed, weak sphincter resistance combined with the highest flow rates may have a deleterious effect on SCC, as already reported in the dairy cow (Grindal et al, 1991). Moderate and high flow rates may however be less dependent upon teat sphincter resistance, but rather be more sensitive to intrinsic characteristics of the tissue (elasticity), diameter and length of the teat canal, or even the physiological regulation of the tone of this muscle. Indeed, the innervation and/or adrenergic reactivity of the udder and teat may partly explain some of the variations seen in flow rate, as suggested by Blum et al. (1989), Hammon et al. (1994) and Roets (1995) in the cow. The hypothesis of an important effect for oxytocin on milk flow has been refuted in the goat, because its discharge during milking did not differ as a function of flow rates or latency. These results confirm those obtained by Bruckmaier et al. (1994) (goats) and by Marnet et al. (1998) (ewes) and differ from cows more dependant for OT release for a complete udder emptying. If OT levels during milking cannot explain milking rate performance, the baseline oxytocin levels (between milking sessions), by permitting the transfer of milk from the alveoli towards the cisterns, could prevent negative feedback of milk on milk synthesis and help for milk synthesis, secretion and production.

The first minute flow rate, like the lag time now estimated using automatic recording devices, thus appear to constitute valuable parameters to characterise animals with a view to possible selection.

The variability of goats regarding milking characteristics is very great, according to intra- and inter-lactation repeatability and our estimates of total and residual heritability. The major locus, with two alleles (Hd and +) explains more than half of the total genetic variability, Hd being partially recessive. Future research for identification of this unknown gene must include the determination of molecular markers in a backcross breeding programme („QTL" approach), and the analysis of transcriptional profiles of teat cells from goats with extreme milking characteristics („Genomic" approach).

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References

Blum, J. W., Schams, D., Bruckmaïer, R., 1989: Catecholamines, oxytocin and milk removal in dairy cows. J. Dairy Res, 56, 167-177.

Grindal, R. J., Walton, A. W., Hillerton, J. E., 1991: Influence of milk flow rate and streak canal length on new intramammary infection in dairy cows. J. Dairy Res., 58, 383-388.

Hammon, H. M., Bruckmaïer, R. M., Honegger, U. E., Blum, J. W., 1994: Distribution and density of alpha- and beta-adrenergic receptor binding sites in the bovine mammary gland. J. Dairy Res., 61, 47-57.

Ilahi H., Chastin, P., Bouvier, F., Arhainx, J., Ricard, E., Manfredi, E., 1999: Milking characteristics of dairy goats. Small Ruminant Research, 34, 97-102.

Ilahi H., E. Manfredi , P. Chastin, F. Monod , J.M. Elsen P. Le Roy P., 2000; Genetical Research Cambridge, 75, 315-319.

Labussière, J., Martinet, J., 1964: description de deux appareils permettant le contrôle automatique des débits du lait aucours de la traite à la machine. Premiers résulats obtenis chez la brebis, Ann. Zootech., 13 (2), 199-212.

Le Du, J., Benmederbel, B., 1984: Aptitudes des chèvres de race Saanen à la traite mécanique. Relation avec les caractérisiques des trayons, Ann. Zootech, 33, 375-384.

Le Du, J., Dano, Y., 1990: Capteur pour l'enregistrement de la cinétique d'écoulement du lait pendant la traite. Cahiers des techniques de l'INRA, 25, 17-26.

Marnet P. G., McKusick, B. C., 2001: Regulation of milk ejection and milkability in small ruminants. Livest. Prod. Sci., 70, 125-133.

Marnet P. G., Volland, H., Pradelles, P., Grassi, J., Beaufils, M., 1994: Subpicogram determination of oxytocin by an enzyme immunoassay using acetylcholinesterase as label. J. Immunoassay, 15 (1), 35-53.

Piacère, E., Manfredi, E., Lahaye, P., 1999: Analyse génétique de la morphologie des chèvres Saanen et alpines française. In Barillet F. et Zervas N.P. (edts), Milking and milk production of dairy sheep and goats. EAAP publication N°95, Wageningen Pers, Pays–Bas. 375-380.

Ricard, E., Arhainx, J., Guillouet, P., Bouvier, F., Jacquin, M., Chastin, P., Astruc, J. M., Lagrifoul, G., Manfredi, E., Barillet, F., 1994: On farm test of INRA portable electronic jars for automatised milk recording of sheep and goats. Proceeding of 29th session of ICAR Ottawa, Canada. EAAP Publication N°75, 47-51.

Ricordeau, G., Bouillon, J., Le Roy, P., Elsen, J. M., 1990: Déterminisme génétique du débit de lait au cours de la traite des chèvres. INRA Prod. Anim., 3 (2), 121-126.

Roets, E., Burvenich, C., Hamann, J., 1995: Relationship between numbers of alpha 2- and beta 2-adrenoceptors on blood cells of bulls and milkability of their daughters. J. Dairy Res. 62, 4, 567-575.