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Lactation curves of Sarda breed goats estimated with test day models

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Test day records of milk yield (38 765), fat and protein contents (11 357) of Sarda goats (the most numerous Italian goat breed) were analysed with mixed linear models in order to estimate the effects of test date (month and year of kidding for fat and protein contents) parity, number of kids born, altitude of location of flocks (<200 m asl, 200–500 m asl, >500 m asl), flocks within altitude and lactation stage (eight days-in-milk intervals of 30 d each) on milk production. All factors considered in the models affected milk traits significantly. Milk yield was lower in first parity goats than in higher parities whereas fat and protein contents showed an opposite trend. Goats with two kids at parturition had a higher milk yield than goats with one kid and tended to have lower fat and protein percentages. Repeatability between test days within lactation was 0·34, 0·17 and 0·45 for milk yield, fat content and protein content, respectively. Lactation curves of goats farmed at different altitudes were clearly separated, especially for milk yield. Results of the present study highlight differences in milk production traits among the three subpopulations that have been previously identified within the Sarda breed on the basis of the morphological structure of animals and altitude of location of flocks.

Keywords: Goat, milk production traits, environmental effects, lactation curve.

Local breeds of small ruminants are widely recognized as a key resource within the frame of future international agricultural policies. Their great adaptation to specific environments allows for the exploitation of low-potential rural areas and wastelands providing rural societies with typical products of animal origin (Boyazoglu & Morand-Fehr, 2001; Haenlein, 2001). Moreover, they offer a potential reservoir for the genetic biodiversity that has been reduced or lost in selected breeds. In spite of these positive aspects, the development and safeguarding of these breeds is strongly constrained by their low profitability. The Sarda goat is a typical example of such a contradictory situation. Autocthonous of the Isle of Sardegna (Italy) where is exclusively farmed, it is the most numerous Italian goat breed (about 212 000 head). Sarda goats are farmed mainly for milk production: average milk yield is about 213 l (for a lactation length of around 180 d) with 5·4% fat and 4·4% protein (Associazione Italiana Allevatori, 2001). The milk is almost all processed into typical cheeses with a small (but increasing) quota destined for direct consumption. The kid slaughtered at the end of the suckling period (about one month) represents a not insignificant by-product. The farming system is the typical semi-extensive of Mediterranean areas, characterized by seasonal reproduction with kiddings concentrated in November–February. All animals are dried off at the beginning of summer. Milk of the first month of lactation is sucked by the kid.

Some authors have proposed a subdivision of the Sarda goat into three subpopulations on the basis of the altitude of location of flocks (Brandano & Piras, 1978a; Macciotta et al. 2002). Actually this criterion includes differences in the morphological structure of animals, climate conditions and feeding. Goats farmed in flocks on the plain are of larger size than goats of the mountains, whereas hill goats are intermediate between the two; also differences in udder conformation have been highlighted (Macciotta et al. 2002). Reasons for this morphological heterogeneity can be found in an independent selection in different environments and, mainly, in the effect of crosses with other breeds, especially Malta goats: actually some farmers find it more profitable to use crossbred animals and the general tendency is to keep the average proportion of Malta genes

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at about 50% in good environmental conditions (Carta et al. 2001a). Mountain goats are farmed in small flocks, often together with other species (cattle of local breeds), feeding is mainly based on the Mediteranean scrub, and goat farming represents the only way to exploit these marginal areas. In flocks located on the plain, environmental conditions are generally better and feeding is based also on forage crops and supplementation with hay or concentrate. Farms located on the hills show features intermediate between these two extremes.

At present, there is no structured selection plan for the Sarda goat, even though a herd book has existed since 1981, with a total of 4136 lactations recorded in 2001. In any case, all the above reported characteristics of the Sarda goat and of its husbandry are to be safeguarded in order to preserve fitness to specific environments, typical production systems and animal biodiversity. As a consequence, the development of a rational strategy of improvement of the breed should take account of a possible relationship between its heterogeneity and production performances of the animals. The present work investigated the effect of the altitude of location of flocks on milk production traits and on their pattern of change with time, as described by the shape of the lactation curve.

Materials and methods

Data

Costs of monthly recordings in small ruminants are very high in comparison with individual outputs (Barillet et al. 1987; Gonzalo et al. 2003). As a consequence, only a reduced number of animals is involved in dairy recording programmes (about 3% of the total number of goats in Italy) and, in most of cases, only milk yield is recorded. For this reason, in the present work different data sets and different models were used to analyse milk yield and fat and protein contents. Data analysed were test day records of milk production traits (milk yield, fat and protein contents) of Sarda goats gathered by the Italian Breeder Association with the AT method, according to which only one daily milking is recorded (alternatively at the morning or evening milking) every 4 weeks and the total daily yield is calculated by doubling the recorded yield. All of the animals considered are hand milked. Edits were on the number of records per lactation (>4), parity (<9), number of kids at parturition (<3), number of goats per flock (>20), number of records per test date (>10), and year of kidding (1999–2001).

Statistical models

Mathematical modelling of the lactation curve can be developed by fitting continuous and regular functions of time, y=f(t), to milk test day data. Actually some of the mathematical functions originally proposed to model the lactation curve of dairy cattle have also been applied to goats (Gipson & Grossmann, 1990; Rota et al. 1993; Ruvuna et al. 1995; Andonov et al. 1999; Fernandez et al. 2002). In the functional approach, however, environmental effects are assumed to average out over a lactation, even though there can be effects peculiar to each test day milk yield that may not average out (Jamrozik & Schaeffer, 1997). On the contrary, the test day analysis by mixed linear models (test day models) allows for the reconstruction of the lactation curve by solving for the least squares estimates of the fixed effects of a days-in-milking (DIM) factor on milk yield, taking account at the same time of all environmental factors affecting milk production such as season of parturition, season of production and parity (Stanton et al. 1992; Pool & Meuwissen, 1999). This feature of test day models is particularly useful in the case of the goat extensive farming system where productive performances are greatly affected by environmental effects. For these reasons, in this work average lactation curves of milk yield, fat and protein contents belonging to goats farmed at different levels of altitude were estimated by mixed linear models.

For milk yield, 38 765 test days of 6712 lactations were analysed with the following test day model:

$$y_{ijklmnop} = TDATE_i + ALT_j + FLOCK(ALT)_{kj} + PAR_l + KIDS_m + DIM_n + DIM(ALT)_{nj} + L_o + E_{ijklmnop} \qquad (1)$$

where

y	=	test day milk yield (kg/d)
TDATEi	=	fixed effect of the i-th date of the test (420 levels)
ALT_j	=	fixed effect of the j-th altitude of location of flocks (3 levels: plain=<200 m above the sea level; hill=200–500 m; mountain=>500 m)
FLOCK $(ALT)_{kj}$	=	fixed effect of the k-th flock nested within the j-th level of altitude (59 levels)
PAR_l	=	fixed effect of l-th parity (8 levels)
$KIDS_m$	=	fixed effect of number of kids at parturition (m=1,2)
DIM_n	=	fixed effect of the n-th days in milk interval (8 intervals each of 30 d starting from 30 d from kidding)
L_o	=	random effect of each individual lactation (6 126 levels)
$E_{ijklmnop}$	=	random residual

Average lactation curves pertaining to goats farmed at different levels of altitude were constructed by plotting least squares means of DIM(ALT) factor against days in milk.

As previously said, average lactation curves for fat and protein contents were estimated only for plain and hill goats on a different data set, that consisted of 11 357 test day records, with the following model:

$$y_{ijklmnopq} = MONTH_i + YEAR_j + ALT_k + FLOCK_l(ALT_k) + PAR_m + KIDS_n + DIM_o + DIM_o(ALT_k) + L_p + E_{ijklmnopq} \qquad (2)$$

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Table 1. Statistical significance of factors included in model [1] for the analysis of milk yield [1]

Factor	df	*F* statistic	*P* value
Altitude of location of flock	2	59·50	0·001
Flock(altitude)	59	104·68	0·001
Test Date	420	37·65	0·001
Parity	7	27·18	0·001
Number of kids	1	62·83	0·001
DIM	7	11·92	0·001
DIM(altitude)	14	50·84	0·001

The meaning of symbols is the same for model [1] except for

$MONTH_i$ = fixed effect of the i-th month of kidding (5 levels: January, February, March, November and December;)

$YEAR_j$ = fixed effect of the j-th year of kidding (j = 1999, 2000, 2001).

In model [2], year and month of kidding were included as seasonal factors instead of the date of the test, in order to avoid computational difficulties that can arise from having too many levels of the test date factor.

For both models the average correlation among test day records within lactation, i.e. the mean repeatability of test day values, was calculated as a ratio between the variance component associated with the individual lactation factor and the total phenotypic variance ($\sigma^2L/(\sigma^2L+\sigma^2e)$). Pairwise comparisons among the different levels of factors included in models [1] and [2] were performed by the Tukey test.

Results and Discussion

All factors considered in model [1] affected milk yield significantly (Table 1). As previously said, the altitude of location of flocks factor summarizes environmental effects, including especially climate (temperature, rainfall) and availability of pastures, and also morphological differences among the three subpopulations into which the Sarda breed is partitioned. A marked difference in average test day milk yields between goats farmed on the plain and hill flocks can be seen (about 0·2 l of milk/d) with hill flocks showing intermediate values (Table 2). Moreover, the relevant effect of the flock nested within altitude (Table 1) accounts for differences in management that are typical of Sarda goat farming. The test date factor reflects the effects of temporary environmental perturbations on the semi-extensive farming system used for goats, as confirmed by the value of the average correlation among test day records within lactation, 0·34, which is lower than values reported for dairy sheep and cattle (Stanton et al. 1992; Carta et al. 2001b).

Goats with two kids at parturition showed a higher average milk yield than goats with a single kid (Table 2), as observed in other goat breeds (Zygoyanis, 1994; Browning et al. 1995; Peris et al. 1997; Crepaldi et al. 1999; Kominakis et al. 2000; Fernandez et al. 2002). This effect has been detected also in non-suckled, intensively managed dairy goats, thus confirming the role of both the suckling reflex and the physiological mechanism during pregnancy that prepares the udder to produce more milk for does carrying multiple fetuses (Goonewardene et al. 1999).

Table 2. Least squares means of milk yield (l/d) for some factors included in model [1]

Effect	Level	Mean	SE
Parity	1	1·02[a]	0·01
	2	1·09[b]	0·01
	3	1·15[c]	0·01
	4	1·17[c]	0·01
	5	1·16[c]	0·01
	6	1·13[c]	0·01
	7	1·13[c]	0·02
	8	1·14[c]	0·02
Number of kids	1	1·09[a]	0·01
	2	1·15[b]	0·01
Altitude of location of flocks	Plain	1·22[a]	0·01
	Hill	1·13[b]	0·01
	Mountain	1·01[c]	0·02

[a,b,c] Means of levels of the same factor followed by different letters are different ($P<0·01$)

Average test day milk yield results were lower for first-kidding goats and increased with parity up to the fourth kidding (Table 2), in agreement with previous results obtained in Mediterranean (Rota et al. 1993; Fernandez et al. 2002), North-European and Mexican breeds (Montaldo et al. 1997; Crepaldi et al. 1999). Goats of parity higher than six did not show a marked decrease in milk production, probably owing to the effect of selection (they represent about the 9% of the animals of the data set analysed).

The significance of the DIM factor (Table 1) expresses the well known effect of stage of lactation on test day milk yield, whereas the significance of the DIM nested within altitude suggests a different behaviour of lactation curves. Actually, lactation curves for milk yield are clearly separated for all the three levels of altitude (Fig. 1), especially in the first phase (until around the 100th day in milk) where there are about 0·5 l/d of difference between goats on plain and mountain. A similar pattern has been observed in Sarda dairy sheep (Macciotta et al. 1999).

Results of mixed model analysis on fat and protein contents are reported in Tables 3 and 4. Flock within altitude, month and year of kidding, and parity affected both of the two composition traits (Table 3). Altitude of location of flocks had a more relevant effect on milk protein content than on fat, whereas number of kids at parturition had only a slight effect ($P=0·06$). Repeatabilities were 0·17 and 0·45 for fat and protein contents respectively. The value for fat content is lower than the one reported for Murciano Granadina goats, whereas values for protein content are broadly similar (Analla et al. 1996). In any case, the

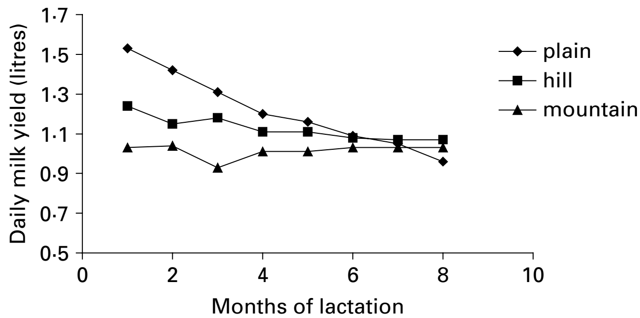

Fig. 1. Lactation curves of milk yield for Sarda goats producing at different levels of altitude (◆=plain; ■=hill; ▲=mountain).

difference between the two traits, observed to a lesser extent also in dairy sheep (Carta et al. 2001b), reflects in part the higher sensitivity of fat to short term environmental factors in comparison with protein.

Primiparous goats showed the highest milk fat content that tended to decrease in higher parities, in agreement with previous reports (Peris et al. 1997). Goats with one kid tended to have a higher milk fat content ($P=0{\cdot}054$) than goats with two kids, as observed in Greek goats (Zygoyannis, 1994).

Goats farmed in flocks on the hill tended to have a higher fat content ($P=0{\cdot}053$) than those farmed on the plain. This result can be partly explained by the negative correlation between milk yield and fat content (−0·24 in the present study), but an effect of feeding cannot be excluded: hill pastures are characterized by a higher presence of Mediterranean maquis leading to a subsequent higher content of fibre in the diet (Brandano & Piras, 1978b).

Goats kidding at the end of the winter and in early spring showed a milk fat content lower than November and December kiddings, clearly because of seasonal differences in climate and pasture availability.

Lactation curves for milk fat content of goats farmed at different levels of altitude showed quite similar shapes (Fig. 2), opposite to the pattern shown by milk yield, with a tendency to increase throughout the lactation apart from a drop between 5 and 6 months of lactation.

As previously said, the effect of the altitude of flock location on protein content was more pronounced than on fat content ($P=0{\cdot}032$ *v.* $P<0{\cdot}001$ for fat and protein contents, respectively) (Table 3). As in the case of fat, goats farmed on the hill tended to have a higher milk protein content than goats on the plain (difference of about 0·28%, $P<0{\cdot}01$) (Table 4). The difference between fat and protein in the statistical significance of the contrast, plain *v.* hill, lies in the magnitude of the SE. The higher milk protein content of goats farmed on the hill compared with those farmed on the plain can be explained by the positive correlation between protein and fat content (0·43) and the negative correlation between protein content and milk yield (−0·31).

Table 3. Statistical significance of effects included in model [2] for the analysis of fat and protein contents (%)

Effect	df	*F* statistic	*P* value
Fat content			
Altitude of location of flock	1	4·58	0·0324
Flock(altitude)	26	21·57	<0·001
Month of kidding	4	19·28	<0·001
Year of kidding	3	12·79	<0·001
Parity	7	5·75	<0·001
Number of kids	1	3·72	0·0537
DIM	7	14·74	<0·001
DIM(altitude)	7	6·40	<0·001
Protein content			
Altitude of location of flock	1	16·07	<0·001
Flock(altitude)	26	44·02	<0·001
Month of kidding	4	94·23	<0·001
Year of kidding	3	5·97	0·001
Parity	7	2·65	0·01
Number of kids	1	3·55	0·06
DIM	7	9·12	<0·001
DIM(altitude)	14	5·20	0·001

The significant effect of parity is mainly due to the contrast between fourth and fifth kiddings (Table 4); a slight effect of parity on milk protein content was reported by Diaz et al. (1999). Goats with one kid tended to have a higher protein content ($P<0{\cdot}06$) than goats with more than one kid, as evidenced in other Mediterranean breeds (Zygoyannis, 1994; Peris et al. 1997).

Goats kidding in November and December had the highest protein content (Table 3). This result partly disagrees (probably because of breed and management differences) with findings in Murciano-Granadina goats, where a slightly higher protein content for spring kiddings (Diaz et al. 1999) has been observed.

Lactation curves for protein content have a rather smooth pattern (Fig. 3), in agreement with previous results reported for Mediterranean breeds (Zygoyanis & Katsaounis, 1991; Diaz et al. 1999) with a constant slight increase or decrease for goats farmed on hill or plain respectively.

Conclusions

Results of the present study give useful indications of main milk production features of Sarda goats. The average milk yield is undoubtedly low if compared with highly productive dairy breeds such as Alpine or Saanen, but it can be considered good if the unfavourable conditions of production are taken into account. Moreover, the high fat and protein contents confirm the suitability of the Sarda Goat milk for cheesemaking.

The results of mixed linear model analysis highlight the relevant effects of management and environmental factors on milk production performances of goats farmed in semi-extensive conditions. For these reasons, the replacement of

Table 4. Least squares means of milk fat and protein contents (%) for some factors included in model [2]

		Fat content, %		Protein content, %	
Effect	Level	Mean	SE	Mean	SE
Parity	1	5·30[d]	0·08	4·16	0·04
	2	5·17[c]	0·08	4·16	0·04
	3	5·18[c]	0·08	4·17	0·04
	4	5·02[a]	0·08	4·14[a]	0·05
	5	5·04[a]	0·08	4·20[b]	0·05
	6	4·96[b]	0·09	4·20	0·06
	7	5·05[a]	0·09	4·19	0·04
	8	5·05[a]	0·10	4·24	0·05
Number of kids	1	5·12	0·08	4·19	0·05
	2	5·07	0·08	4·17	0·05
Altitude of location of flocks	Plain	4·94	0·04	4·04[a]	0·04
	Hill	5·25	0·14	4·32[b]	0·08
Month of kidding	January	5·07[a]	0·08	4·13[a]	0·04
	February	4·94[a]	0·08	4·08[a]	0·04
	March	4·91[a]	0·12	4·03[a]	0·05
	November	5·30[b]	0·07	4·36[b]	0·03
	December	5·27[b]	0·08	4·31[c]	0·04

[a,b,c] Means of levels of the same factor followed by different letters are different ($P<0·01$)

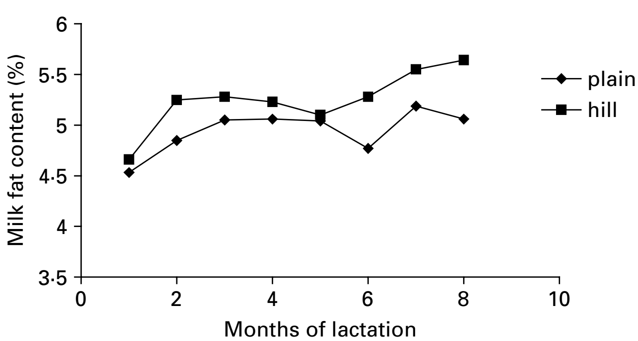

Fig. 2. Lactation curves of milk fat content of Sarda goats producing at different levels of altitude (◆ = plain; ■ = hill).

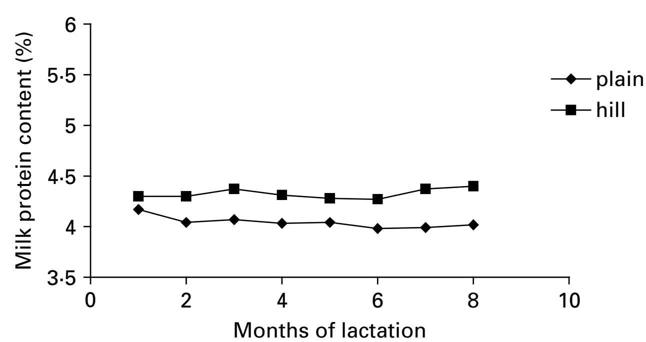

Fig. 3. Lactation curves of milk protein content for Sarda goats producing at different levels of altitude (◆ = plain; ■ = hill).

this population by high-yielding exotic dairy breeds, following programmes carried out in several countries, does not seem to be a valid option (Serradilla et al. 2001).

Of particular interest are differences in average milk production performance of goats farmed at different levels of altitude. These results are not sufficient to confirm the existence of three different genetic subpopulations within the Sarda breed because the effect of the geographical altitude of location of flocks includes effects of feeding, environment and morphological differences. However, such a marked heterogeneity of the breed, also in milk production traits, suggests a need for particular care in the development of rational genetic and management strategies.

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