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Effects of Age and Calving Season on Lactation Curves of Milk Production Traits in Italian Water Buffaloes

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ABSTRACT

Test day (TD) records of milk production traits (milk yield, fat, and protein percentages) of 534 Italian buffalo cows were analyzed with a mixed linear model in order to estimate lactation curves pertaining to different ages at calving and different seasons of calving. Milk yield lactation curves of younger animals were lower than those of older animals until 20 wk from parturition. No effect of age at calving could be observed for fat and protein percentages. Season of calving affected milk yield only in the first phase of lactation, with the lowest production levels for summer calvings; no effect could be observed on fat and protein contents. Average correlations among TD measures within lactation were 0.59, 0.31, and 0.36 for milk yield, fat, and protein percentages, respectively. Five standard linear functions of time were able to reconstruct the average lactation curves. Goodness of fit was satisfactory for all models considered, although only the five-parameter model was flexible enough to fit all the three traits considered with excellent results.
(**Key words:** buffalo, milk production trait, lactation curve)

Abbreviation key: AS = Ali and Schaeffer model; **IQP** = inverse quadratic polynomial model; **ML** = mixed log model; **TD** = test day; **WD** = Wood model; **WIL** = Wilmink model.

INTRODUCTION

The Mediterranean water buffalo (*Bubalus bubalis*, subsp. River) was introduced in Italy from Hungary at the end of the seventh century by barbaric invasions (Maymone, 1942; Mason, 1974). In the past, buffaloes have been used in the exploitation of swamp areas of central Italy for work, milk, and meat production. Essential features of this species are a great capacity to face adverse environmental conditions and a remarkable longevity: a buffalo cow can produce up to 10 yr and more. The number of buffaloes in Italy has increased considerably in the last 10 yr, passing from 106,000 in 1989 to 200,000 in 2000 with a total milk production of about 150,000 tonne/yr (ISMEA, 1998) and a gross income of about $115 million in 1998 (De Stefano, 1998). The increasing economic relevance of the Italian buffalo lies in the absence of production quotas in the European Community and, above all, in the high market demand of mozzarella cheese, which results in a price of buffalo milk that is more than double the price of cow milk.

The average herd size is 150 cows, although a large variability exists. Animals are kept on paddocks and feeding is mainly based on TMR during lactation and on pastures for dry cows and young animals. The productive cycle is usually seasonal; most calvings (70 to 80%) are concentrated in the period July to December, as autumn is the natural mating season. Under these conditions, an Italian buffalo cow produces on average 2100 kg of milk in a standardized lactation length of 270 d with 8.37 and 4.80 of fat and protein percentages respectively, (AIA, 1999). Due to the increasing economic relevance of the dairy buffalo industry, interest is great both in improving the production level of animals and in shifting the mating season to spring and summer, a period in which the mozzarella market demand is very high (Barile et al., 1999). A selection program based on AI and progeny testing has been proposed for the 32,000 buffalo cows registered in the Italian buffalo Herd Book (AIA, 1999). However, the effectiveness of selection is constrained by both the low reproductive efficiency of this species (Seren and Parmeggiani, 1997) and the limited knowledge of the effects of main factors affecting milk production. Actually, studies on dairy buffalo are few and discontinuous (Pilla and Moioli, 1992; Metry, 1994; Jain and Sadana, 2000; Catillo et al., 2001), probably due to the great differences in the environment and in the productive level of animals in the different countries. In particular, disentangling the effect of the stage of lactation from other factors—such as management type, parity, season of calving and season of production—is difficult.

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Table 1. Least squares means of main effects included in the analysis of the three production traits.

		Milk yield (kg)		Fat percentage		Protein percentage	
Factor	Levels	Mean	SE	Mean	SE	Mean	SE
Age (yr)	Age ≤3	6.95^{A}	0.27	9.15^{A}	0.10	5.07^{A}	0.03
	3 < age ≤4	7.61^{AB}	0.25	9.08^{A}	0.10	5.11^{AB}	0.02
	4 < age ≤5	8.45^{C}	0.25	9.23^{AB}	0.10	5.07^{A}	0.03
	5 < age ≤6	8.73^{C}	0.29	9.11^{A}	0.11	5.09^{A}	0.03
	6 < age ≤7	8.63^{C}	0.31	9.06^{A}	0.12	5.01^{AC}	0.03
	>7	8.21^{BC}	0.24	8.98^{AC}	0.09	5.00^{AC}	0.02
Calving season	Winter	8.47^{A}	0.25	9.17	0.10	5.03	0.02
	Spring	8.23^{AB}	0.26	9.12	0.10	5.06	0.03
	Summer	7.66^{B}	0.22	9.09	0.08	5.09	0.02
	Autumn	8.03^{AB}	0.23	9.02	0.09	5.06	0.02

^{A,B,C}Means within columns with different superscripts differ ($P < 0.01$).

Studies on dairy cattle have shown that the effect of DIM accounts for a substantial amount of the variation in the production of milk and in its composition. The use of mathematical functions to model the evolution over time of milk production is able to separate the effect of the lactation stage from other environmental factors only when they average out over lactation (Jamrozik and Schaeffer, 1997). To properly consider the factors whose impact can change over time, i.e., over several test-day (**TD**) measures within lactation (Swalve, 2000), the direct analysis of TD measures by mixed linear models has been proposed as an alternative to lactation curve fitting. In recent years, these approaches have been brought into one perspective in TD models that use mathematical functions as covariates to account for the curve of lactation (Ptak and Schaeffer, 1993). This methodology has proved to be particularly useful in situations in which large amounts of data are available and the effects of environmental factors have been extensively studied, as in the case with the genetic evaluation of dairy cattle.

In the present study, the same principle to combine TD modeling with lactation curve functions is developed at phenotypic level to separate the effects of main environmental factors from the variability component due to the regular evolution of milk production over time. With this aim, lactation curves of milk production traits (milk yield, fat, and protein contents) of Italian buffaloes were constructed by: disentangling the effects of the DIM from other environmental effects by the direct modeling of TD data with a mixed linear model, and fitting several linear or linearizable functions of the lactation curve to DIM effects.

MATERIALS AND METHODS

Data were 4064 TD records of milk related traits (milk yield, fat, and protein percentages) recorded on 534 Italian buffalo cows during the years 1986 to 1999 in the farm of the Istituto Sperimentale per la Zootecnia (Tor Mancina, Roma). Lactation length was fixed at 300 d and it was divided into 10 DIM intervals of 30 d each, starting from parturition. Lactations with fewer than 3 TD records were discarded.

Data were grouped according to the following factors: test date (148 levels), calving season (4 levels: 1st = January to March; 2nd = April to June; 3rd = July to September; 4th = October to December), age at calving (6 levels: 1 = age ≤ 3 yr; 2 = 3 < age ≤ 4 yr; 3 = 4 < age ≤ 5 yr; 4 = 5 < age ≤ 6; 5 = 6 < age ≤ 7 yr; 6 = 7 < age ≤ 9 yr); DIM (10 levels).

Data were analyzed by the following mixed linear model structured to highlight the effect of age and season of calving on lactation curves:

$$\begin{aligned} Y_{ijklmn} = {} & TD_i + SEA_j + AGE_k + DIM(AGE)_{lk} \\ & + DIM(SEA)_{lj} + L_m + E_{ijklmn}, \end{aligned}$$

where

TD_i = fixed effect of test date (1, 2, . . ., 148),
SEA_j = fixed effect of calving season (1, . . ., 4),
AGE_k = fixed effect of age at calving class (1, 2, . . ., 6),
$DIM(AGE)_{lk}$ = fixed effect of DIM nested within age at calving,
$DIM(SEA)_{lj}$ = fixed effect of DIM nested within season of calving,
L_m = random effect associated at each m-th individual lactation (1, 2, . . ., 534), and
E_{ijklmn} = random residual.

Fixed DIM(AGE) and DIM(SEA) estimates account for the variation of milk production traits related to the stage of lactation, considered within different ages and seasons of calving, respectively, whereas the effect of season of production is included in the TD factor. The L random factor takes account of the variability associated with each individual lactation (Stanton et al., 1992). (Co)variances among TD measures within lactation were summarized by the residual **R** matrix, which was assumed to be block diagonal with identical 10 × 10 submatrices, each corresponding to an individual lactation (Carta et al., 2001). As an alternative, the compound symmetry structure (CS), usually adopted in repeated measures design (Littel, 1988), was imposed to **R** in order to estimate the average TD variance and the mean correlation among TD pairs within lactation.

DIM(AGE) and DIM(SEA) estimates for milk yield, fat, and protein percentages were fitted with the following standard linear models of the lactation curve (Olori et al., 1999):

1) The incomplete gamma function (**WD**) of Wood (Wood, 1967)

$$y_t = at^b e^{-ct},$$

fitted in the log linear form

$$\log Y = \log a + b\log t - ct,$$

2) An inverse quadratic polynomial (**IQP**) (Nelder, 1966),

$$Y_t^{-1} = a + bt^{-1} + ct;$$

3) The exponential model (**WIL**) of Wilmink (Wilmink, 1987),

$$Y_t = a + be^{-kt} + ct;$$

4) A mixed log (**ML**) (Gou and Swalve, 1995 unpublished)

$$Y_t = a + bt^{1/2} + c\log t;$$

5) A polynomial regression (**AS**) (Ali and Schaeffer, 1987),

$$Y_t = a + bt + ct^2 + d\log t + k\,(\log t)^2.$$

According to the suggestions of Wilmink (1987), the WIL model was reduced to a three parameter linear form by setting the k exponent to the value of 0.70. In all models, Y represents the milk yield, or fat or protein percentage at week t; a, b, c, and d are parameters to be estimated. These equations have been chosen in the perspective of their inclusion as covariates in TD models applied to genetic evaluations. Actually, several studies carried out on dairy cattle have evidenced their suitability as submodels both in fixed and in random regression TD models (Ptak and Schaeffer, 1993; Jamrozk and Schaeffer, 1997; Olori et al., 1999).

Time at which peak production was attained, and the total milk, fat, and protein 300 d-yield were calculated for each model. Goodness of fit was assessed by considering the adjusted R square, which imposes a penalty according to the number of parameters to be estimated, allowing for a comparison between the three parameter model group and the AS five parameter model; the standard deviation of residuals; and the correlation between residuals and actual yields, as an index of a systematic lack of fit.

RESULTS AND DISCUSSION

The TD fixed factor absorbs a relevant amount of the whole original variability in all the traits considered. Since the test date factor accounts for the effects of the season in which a TD occurs, it can be concluded that, as already evidenced in dairy cattle (Stanton et al., 1992), the production season markedly affects Buffalo daily milk yield and composition regardless of lactation stage. Age at calving influences milk yield and protein percentage ($P < 0.001$ and $P < 0.005$), whereas the calving season has an effect only on milk yield ($P < 0.007$).

Table 1 reports estimates of milk yield, fat, and protein percentages for the different levels of age and season of calving regardless of lactation stage. Daily milk yield increases with the age of animals until 5 to 6 yr of age and then slightly decreases for buffaloes aged 7 yr and more. The effect of age on protein percentage is negligible, whereas small differences among age classes can be found for fat percentage. The calving season affects only milk yield: in particular, a relevant difference (about 1 kg of milk/day) can be observed between summer and winter calvings, whereas the other two seasons are in an intermediate position. The low productive level of buffaloes calving in summer can be explained mainly with the depressive effect of high temperatures at the debut of lactation. Actually, the inclusion of a TD effect accounts for much of the seasonal variation normally observed among buffalo cows calving in different seasons, in agreement with previous results obtained with dairy cattle (Pander et al., 1992; Stanton et al., 1992; Swalve, 1995).

Estimates of the three production traits separated for age at calving and also for lactation stages are reported in Figure 1 (a, b, and c).

Evolution over time of daily milk yield follows the typical pattern of dairy animals, with a first ascending phase to the lactation peak and a subsequent decrease toward the dry off. Lactation curves of buffaloes 2 to 3 yr of age (Figure 1a) differ from those of older animals (>4 yr), with buffaloes of 3 to 4 yr in an intermediate

Table 2. Goodness of fit statistics of the five lactation curve models for milk yield for the five age classes.

Model	AdRsq[1]	RES SD[2] (kg)	Corr[3]	Peak yield (kg/d)	Peak time (weeks)	Total milk yield (kg)
Age 3<						
Wood	0.99	0.042	0.17	9.61	6	2042
IQP	0.97	0.092	0.39	10.46	7	2004
Wilmink	0.98	0.042	0.10	9.88	6	2024
ML	0.98	0.107	0.16	9.59	6	2039
Ali Schaeffer	0.99	0.003	0.03	10.13	6	1959
3 < age < 4						
Wood	0.99	0.080	0.23	10.96	5	2240
IQP	0.98	0.076	–0.38	11.84	7	2196
Wilmink	0.97	0.117	0.14	11.12	5	2230
ML	0.97	0.124	0.14	10.96	5	2246
Ali Schaeffer	0.99	0.007	0.03	11.59	6	2141
4 < age < 5						
Wood	0.98	0.099	0.22	12.32	5	2497
IQP	0.97	0.114	–0.40	13.41	7	2440
Wilmink	0.97	0.172	0.14	12.48	5	2484
ML	0.97	0.162	0.14	12.41	4	2498
Ali Schaeffer	0.99	0.012	0.04	13.04	6	2386
5 < age < 6						
Wood	0.99	0.124	0.23	13.10	5	2577
IQP	0.98	0.177	–0.40	14.35	7	2515
Wilmink	0.97	0.232	0.15	13.15	5	2565
ML	0.97	0.211	0.15	13.15	4	2580
Ali Schaeffer	0.99	0.018	0.04	13.80	6	2449
6 < age < 7						
Wood	0.99	0.062	0.16	12.71	6	2536
IQP	0.94	0.529	–0.46	14.61	7	2502
Wilmink	0.98	0.109	0.11	13.01	5	2518
ML	0.98	0.239	0.16	12.65	5	2538
Ali Schaeffer	0.99	0.001	0.01	13.32	6	2433
Age > 7						
Wood	0.99	0.054	0.16	12.29	6	2414
IQP	0.96	0.436	–0.43	14.01	7	2373
Wilmink	0.98	0.119	0.11	12.47	5	2406
ML	0.98	0.119	0.11	12.29	5	2420
Ali Schaeffer	0.99	0.007	0.03	12.87	6	2312

[1] AdRsq = Adjusted r-square.

[2] RES SD = Standard deviation of residuals.

[3] Corr = Correlation between actual yields and residuals.

position; such a separation is evident in the first phase of lactation ($P < 0.01$) and gradually decreases until the 20th wk from calving. Peak yield occurs at around the 6th wk of lactation in all age classes; the rate of decline following peak tends to increase with the age of animals. Thus, if persistency is defined as the extent to which peak yield is maintained (Grossman et al., 1999), lactation curves of buffalo cows aged 2 to 3 yr are characterized by the highest persistency. This behavior, common in dairy species, can be explained by the maturation process which is still in progress in young animals and that counteracts the normal decline in milk yield. However, it must be underlined that lactation persistency of buffaloes is, in all age classes, about three times lower than in dairy cattle. Such a relevant limitation of the productive ability of buffaloes can be ascribed to the absence of selection in this species. Actually, the state of pregnancy results in a markedly reduced milk yield for lactating buffalo cows, as happened in dairy cattle before the development of selection programs for the improvement of milk yield (Oltenacu et al., 1980; Coulon et al., 1995).

Estimates of fat and protein percentages for different stages of lactation (Figure 1b and c) do not show differences among age classes, in agreement with previous results in dairy cattle, in which fat and protein percentage lactation curves did not change substantially with parity. The general shape of lactation curve, however, differs between fat and protein percentages in each age class. Time evolution of protein content has an opposite trend in comparison with milk yield, reaching its lowest point at approximately the same time as peak milk yield occurs. On the other hand, the pattern of fat content lacks the minimum that in dairy cattle usually

Table 3. Goodness of fit statistics of the five lactation curve models for fat percentage for the five age classes.

Model	AdRsq[1]	RES SD[2] (%)	Corr[3]	Total fat yield (kg)
Age < 3				
Wood	0.97	0.017	0.13	182
IQP	0.96	0.038	0.12	180
Wilmink	0.94	0.047	0.21	181
ML	0.97	0.014	0.11	182
Ali Schaeffer	0.99	0.005	0.07	179
3 < Age < 4				
Wood	0.95	0.042	0.23	197
IQP	0.92	0.074	0.24	194
Wilmink	0.87	0.099	0.32	196
ML	0.94	0.046	0.21	197
Ali Schaeffer	0.98	0.009	0.10	193
4 < Age < 5				
Wood	0.92	0.054	0.25	223
IQP	0.89	0.089	0.26	220
Wilmink	0.85	0.108	0.34	222
ML	0.92	0.056	0.24	223
Ali Schaeffer	0.98	0.006	0.08	220
5 < Age < 6				
Wood	0.89	0.090	0.32	220
IQP	0.84	0.143	0.34	223
Wilmink	0.77	0.189	0.42	222
ML	0.87	0.102	0.31	225
Ali Schaeffer	0.96	0.023	0.15	221
6 < Age < 7				
Wood	0.92	0.060	0.28	222
IQP	0.89	0.103	0.30	221
Wilmink	0.82	0.142	0.29	218
ML	0.91	0.048	0.22	221
Ali Schaeffer	0.99	0.004	0.06	218
Age > 7				
Wood	0.93	0.047	0.26	209
IQP	0.89	0.078	0.28	208
Wilmink	0.84	0.104	0.35	206
ML	0.92	0.051	0.25	209
Ali Schaeffer	0.98	0.009	0.10	205

[1] AdRsq = Adjusted r-square.

[2] RES SD = Standard deviation of residuals.

[3] Corr = Correlation between actual yields and residuals.

occurs with a lag of about 3 wk following peak milk yield; moreover, at around the 10th week of lactation, the curve shows an inflection point which distinguishes between a first phase of rapid increase and a second asymptotic increasing phase.

Main results of fitting the different linear functions of time to DIM(AGE) estimates for the three traits considered are reported in Tables 2, 3, and 4. Milk yield (Table 2) is predicted with high accuracy by all models (adjusted $R^2 > 0.96$). The best fit is obtained with the AS function, that is also the only model able to give a good fit with fat and protein percentages (adjusted $R^2 = 0.96$) (Tables 3 and 4). Predicted peak time ranges from 4 (ML) to 7 wk (IQP), whereas predicted 300-d milk yield differs very little among all models. In comparison with the AS, the three parameter models (WD, WIL, and ML) under predict milk yield around peak production, whereas they overpredict it in the decreasing phase of lactation; the contrary happens with the IQP model. Moreover, all these models overpredict the negative peak of protein percentage. Therefore, the pattern of residuals of observed against predicted values is characterized by the same sign for successive weeks, indicating a nonsatisfactory description of the lactation curves. As a consequence, estimated correlations between residuals and observations are positive (except for IQP in the case of milk yield) and relatively high for all three parameter models, further indicating the tendency of residuals to increase with observed yields.

On the contrary, in the AS model, both residual variance and correlations between residuals and observed values are negligible for all traits and all age classes. These results confirm that, among all linear functions

Table 4. Goodness of fit statistics of the five lactation curve models for protein percentage for the five age classes.

Model	AdRsq[1]	RES SD[2] (%)	Corr[3]	Peak protein content (%)	Peak time (weeks)	Protein yield (kg)
Age <3						
Wood	0.72	0.013	0.43	4.84	8	104
IQP	0.77	0.011	0.34	4.81	8	102
Wilmink	0.87	0.006	0.32	4.73	7	103
ML	0.79	0.013	0.48	4.82	8	104
Ali Schaeffer	0.98	0.001	0.09	4.69	8	101
3 < Age < 4						
Wood	0.77	0.012	0.38	4.83	6	115
IQP	0.80	0.012	0.31	4.82	6	113
Wilmink	0.87	0.007	0.32	4.74	6	114
ML	0.83	0.009	0.37	4.81	7	115
Ali Schaeffer	0.99	0.001	0.06	4.68	7	110
4 < Age < 5						
Wood	0.74	0.012	0.40	4.83	8	127
IQP	0.80	0.010	0.31	4.80	8	125
Wilmink	0.89	0.005	0.29	4.71	7	127
ML	0.81	0.009	0.39	4.81	8	127
Ali Schaeffer	0.97	0.001	0.13	4.63	7	123
5 < Age < 6						
Wood	0.83	0.010	0.32	4.80	5	127
IQP	0.84	0.009	0.24	4.78	6	128
Wilmink	0.92	0.005	0.25	4.70	6	129
ML	0.88	0.007	0.31	4.77	7	131
Ali Schaeffer	0.99	0.001	0.07	4.59	7	126
6 < Age < 7						
Wood	0.76	0.013	0.39	4.76	8	127
IQP	0.82	0.010	0.30	4.72	9	126
Wilmink	0.90	0.005	0.28	4.63	7	125
ML	0.83	0.013	0.45	4.73	8	127
Ali Schaeffer	0.98	0.001	0.10	4.59	7	123
Age >7						
Wood	0.72	0.012	0.42	4.78	8	121
IQP	0.78	0.009	0.33	4.75	8	119
Wilmink	0.88	0.005	0.30	4.66	7	120
ML	0.79	0.008	0.40	4.76	8	121
Ali Schaeffer	0.99	0.001	0.08	4.62	8	116

[1] AdRsq = Adjusted r-square.

[2] RES SD = Standard deviation of residuals.

[3] Corr = Correlation between actual yields and residuals.

considered in the present work, only this model is flexible enough to analytically represent lactation curves of Buffalo milk production traits. As an example, Figure 2 reports the regular and continuous patterns of lactation curves obtained by fitting the AS model to DIM(AGE) estimates for milk yield (Figure 2a), fat (Figure 2b), and protein (Figure 2c) contents for the first four age classes. The last column of Tables 2, 3, and 4 reports estimates of milk, fat, and protein 300-d yields obtained by integrating the different functions for a standardized lactation length of 43 wk. Considering values obtained by the AS model as a reference, it can be observed that results of all three parameter models differ very slightly from AS values. Fitting of DIM(SEA) estimates yields similar (not reported) results.

Finally, as far as the behavior of individual lactation curves around the mean curve (for each age class or season of calving) is concerned, preliminary indications can be drawn from the (co)variances associated with the two random factors included in the TD model (the residual term and the individual lactation factor) estimated by imposing the CS structure. Such a (co)variance model requires the estimation of only two parameters, the residual variance (σ^2_e) and the variance component associated with each individual lactation (σ^2_L). Average TD constant variance and average correlation (repeatability) among all TD pairs within lactation can then be calculated as ($\sigma^2_L + \sigma^2_e$) and $\sigma^2_L/(\sigma^2_L + \sigma^2_e)$ respectively. In the present study, average variances were 5.50, 1.28, and 0.12, whereas the average correlations were 0.59, 0.31, and 0.36 for milk yield, fat, and protein percentages, respectively. Such figures are similar to those observed in dairy cattle as far as milk yield is concerned and markedly lower for milk constituents

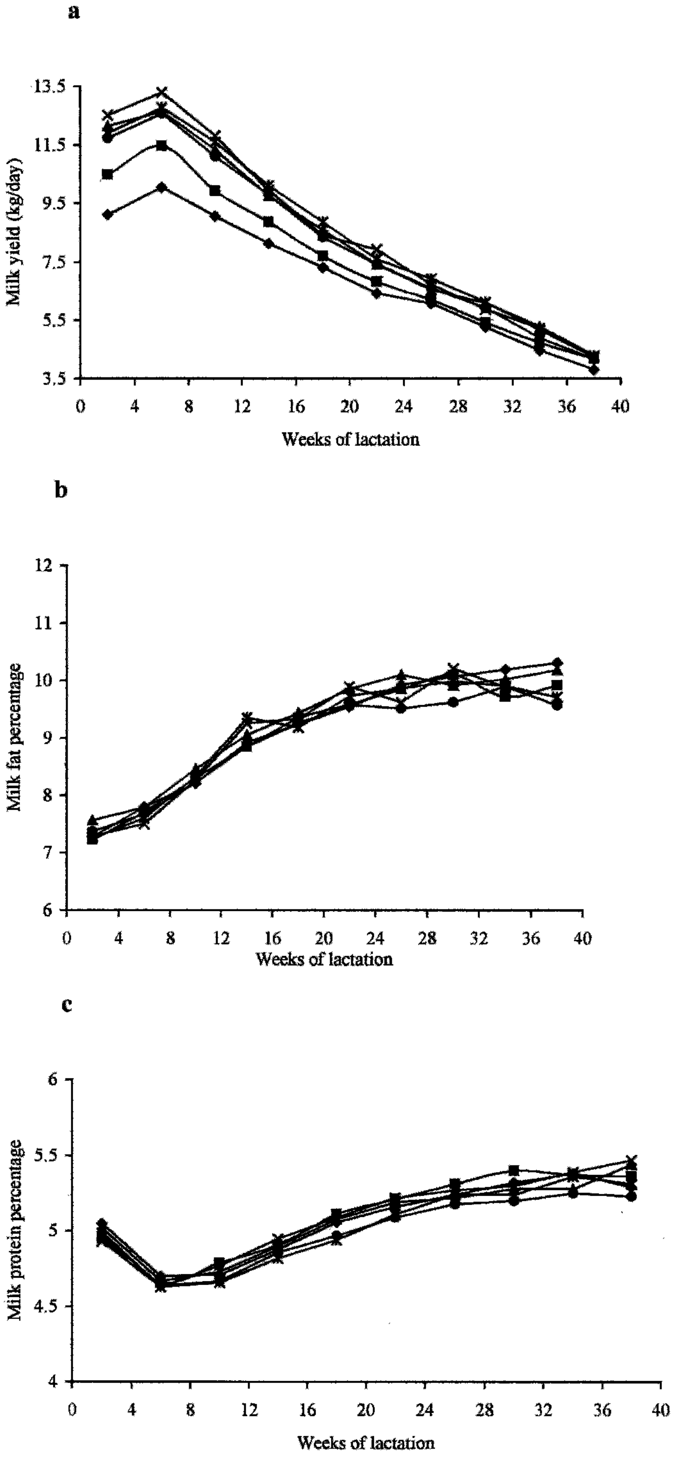

Figure 1. a. Milk yield lactation curves for different ages at calving (◆ = ≤ 3 yr; ■ = 3 < age ≤ 4; ▲ = 4 < age < 5; x = 5 < age ≤ 6; * = 6 < age ≤ 7; ● = < 7 age ≤ 9). b. Milk fat percentage lactation curves for different ages at calving (◆ = ≤ 3 yr; ■ = < age ≤ 4; ▲ = 4 < age ≤ 5; x = 5 < age ≤ 6; * = 6 < age ≤ 7; ● = < 7 age ≤ 9). c. Milk protein percentage lactation curves for different ages at calvng ◆ = ≤ 3 yr; ■ = 3 < age ≤ 4; ▲ = 4 < age ≤ 5; x = 5 < age ≤ 6; * = 6 < age ≤ 7; ● = < 7 age ≤ 9).

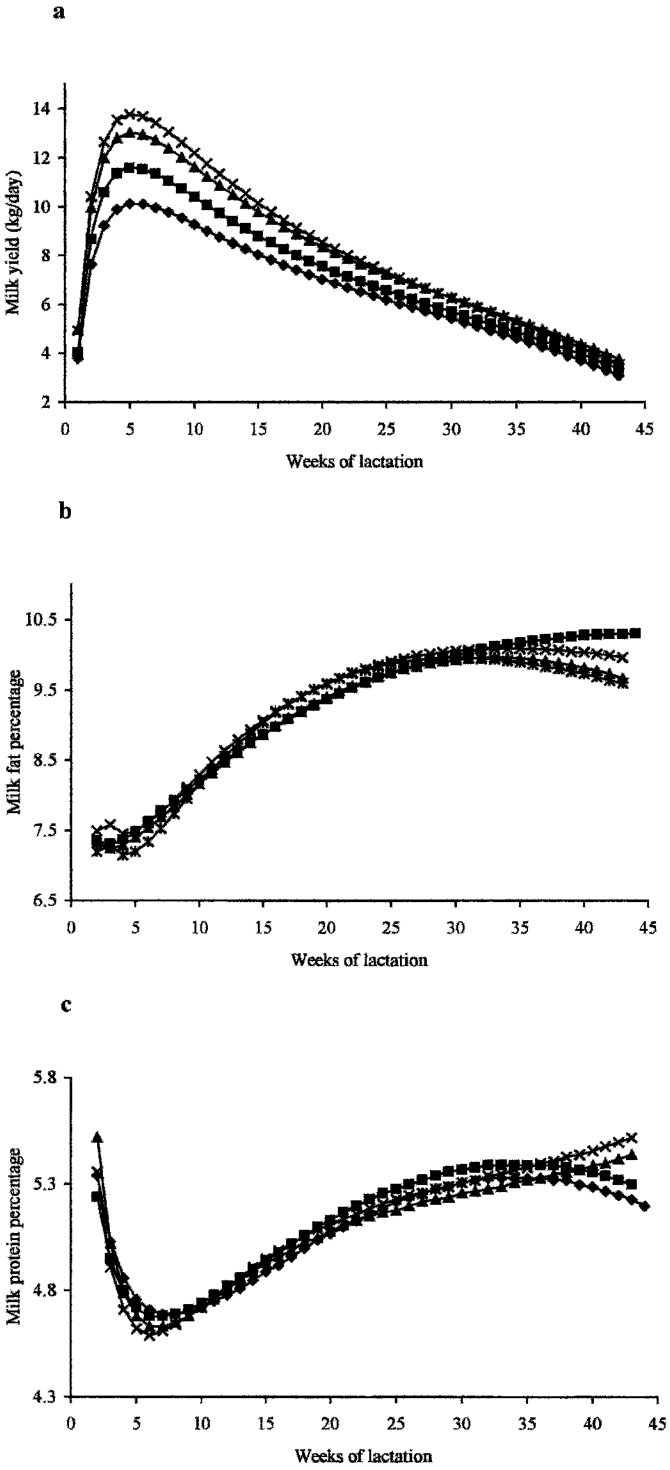

Figure 2. a. Fitting of the five parameter model to milk yield lactation curves for different ages at calving (◆ = < 3 yr; ■ = < age ≤ 4; ▲ = 4 < age ≤ 5; x = 5 < age ≤ 6). b. Fitting of the five-parameter model to milk fat percentage lactation curves for different ages at calving (◆ = ≤ 3 yr; ■ = 3 < age ≤ 4; ▲ = 4 < age ≤ 5; x = 5 < age ≤ 6). c. Fitting of the five-parameter model to milk protein percentage lactation curves for different ages at calving (◆ = ≤ 3 yr; ■ = 3 < age ≤ 4; ▲ = 4 < age ≤ 5; x = 5 < age ≤ 6).

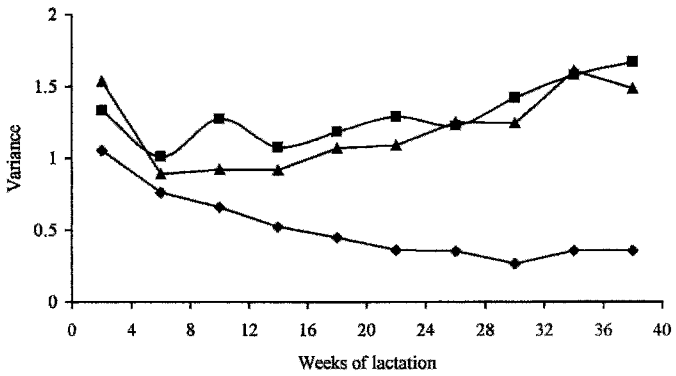

Figure 3. Pattern or residual variances for milk yield (◆) (kg^2 10^{-1}) fat (■) [(g/100 ml)^2 × 10] and protein (▲) ((g/100 ml)^2 × 10) percentages.

(Stanton et al., 1992), suggesting a great variability among shapes of individual lactation curves (Olori et al., 1995). This feature is further confirmed by the results obtained with the independent estimation of each element of the (co)variance matrix without assumptions on equal variances and constant correlations. Milk yield variance (Figure 3) tends to decrease as the lactation proceeds, with a slight increase at the end; on the contrary, fat and protein percentage variances increase along the lactation. Moreover, correlations between TD pairs within lactation at different time distance (lag) (Figure 4) show a decreasing trend already evidenced in dairy cattle (Godall and Sprevak, 1984) and sheep (Macciotta et al., 2000). The main differences among the three traits, besides the more regular behavior of milk yield and slight fluctuations for milk constituents, can be found in the maximum value of correlation (0.67, 0.38, and 0.50 for milk yield, fat, and protein percentages, respectively) and in a faster decreasing rate for protein content. All these results highlight the great range of variability in individual lactation curve shapes. A similar limitation in extending the average lactation curves to individual pattern has been found in dairy cattle where a great range of goodness of fit of mathematical functions has been evidenced when fitted to individual lactation curves (Olori et al., 1999).

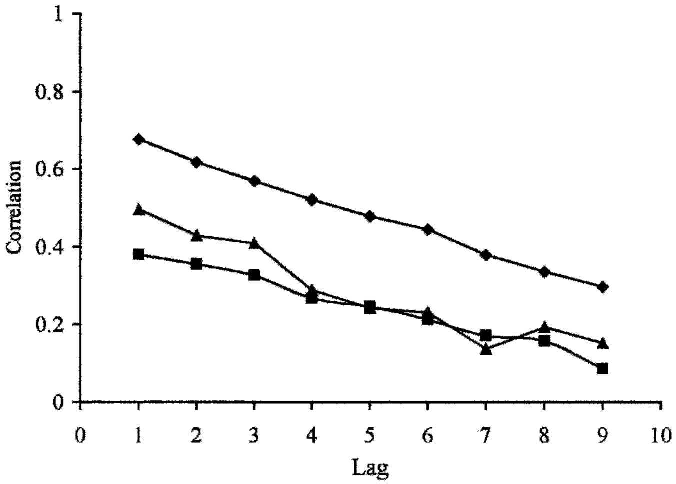

Figure 4. Pattern of correlation for milk yield (◆) fat (■) and protein (▲) (× 10) percentages.

CONCLUSIONS

The mixed linear model is effective in estimating lactation curves of milk production traits of Italian water buffaloes. The general shape of the lactation curve for the three traits considered is similar to dairy cattle, although, in the case of milk yield, a relevant difference concerning persistency has been observed. This result can be interpreted as an evidence of the low selection performed in buffalo cows. Age is an important factor in differentiating milk yield lactation curves, whereas its effect is less important on milk components. A clear separation cannot be found among lactation curves pertaining to different seasons of calving. Goodness of fit to average lactation curves is quite high for all mathematical functions. However, only the AS model is able to mathematically represent the time evolution of all the three traits considered with an appreciable accuracy, predicting yields without sensible correlations among residuals which, on the contrary, are relevant for all the three parameter models. The (co)variance structure of random effects suggests the conclusion that an accuracy of prediction of the same magnitude of that obtained in the fitting of the average curves does not seem to be achievable as far as individual lactation curves are concerned.

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