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PAPER

Lactation curve and persistency of Anatolian buffaloes

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Abstract

The aim of this study was to determine the lactation curve traits of Anatolian buffaloes raised under different conditions in farms in Tokat Province, Turkey. Wood's gamma curve parameters were employed to identify the lactation curve types, and values for the parameters beginning yield (a), coefficient of rising (b) and coefficient of decreasing (c) were used to determine the shape and type of lactation curve. All parameters in typical lactation curves were positive, and in the event of one parameter being negative, the curve was considered to be an atypical lactation curve. A total of 690 lactation curves were investigated. It was determined that 406 (58.84%) of these curves were typical, while 90 (13.04%) were concave and 194 (28.12%) of a decreasing type. For typical lactation curves, a, b, c, persistency (S), time after parturition until the peak yield occurs (T_{max}), maximum daily peak yield (Y_{max}), and coefficient of determination (R^2) were 7.14±0.008, 0.85±2.1, 0.40±0.001, 2.68, 63.6, 6.41 and 76.33, respectively. For concave lactation curves, values for a, b, c, T_{max}, Y_{max} and R^2 were 4.94±0.42, -0.73±0.016, -0.23±0.0038, 95.40, 7.41±0.004 and 71.68, respectively. For decreasing typical lactation curves, values for a, b, c, T_{max}, and R^2 were 5.31±0.0041, -0.15±0.007, 0.039±0.0023, 3.89±0.11 and 79.94, respectively. Parameters predicted by the Wood model within the scope of this study have the potential of being useful for breeding programmes. Further breeding/selection activities could be conducted by using the female Anatolian buffaloes with typical lactation curves.

Introduction

Owing to their resistance to diseases and lower feed consumption, buffaloes are a preferred livestock species in various regions of Turkey (Soysal *et al.,* 2005). In Turkey, buffaloes are bred particularly for their milk, and are later slaughtered for their meat once past their productive age (Şekerden, 2001). Buffalo milk is one of the most valuable products obtained for buffaloes; it represents an important source of protein for low-income buffalo farmers living in rural areas, as well as a significant source of income for rural economies (Borghese, 2005; Yılmaz *et al.,* 2011). Buffaloes in Turkey are referred to as the Anatolian buffaloes, which represent a subgroup of the Mediterranean buffalo. There are two main types of buffalo in Turkey, one being the swamp buffalo, and the other being the river buffalo. The latter type is more valuable in terms of milk production.

As milk production is one of the main source of income for dairy farms, records of milk yield are of significant importance for dairy herds. The proper estimation of annual total milk production, as well as the effective organization of breeding plans and management systems for dairy herds based on these estimates, depends both on the efficiency of the system used for recording milk production levels and the accuracy of methods for calculating the milk yield of herds. The term *lactation curve* refers to a graph illustrating the relationship between milk yield and the period of time after calving. The objective of modeling a lactation curve is to predict, as precisely as possible, the level of milk production after calving, and to thereby provide an understanding of the pattern of milk production under varying environmental conditions. In other words, these graphical representations, which demonstrate the relationship between milk yield and lactation, are assumed to indicate the total milk yield of a single lactation. The careful analysis of lactation curve shapes is important, as they might highlight feeding and management-related problems in a dairy herd (Epaphras *et al.,* 2004). On the other hand, *persistency* is defined as the slope of the decreasing phase of the lactation curve, referring to the duration of time for which the peak yield is maintained (Wood, 1967). Peak yield and persistency are the only variables of the lactation curves that can be influenced by a variety of factors, although the general shape of the curve remains mostly unchanged. A number of different empirical models have been developed to explain the shape of lactation curves (Gipson and Grossman, 1989; Wood, 1976). Among these, the use of analytical time functions allows the partition of the variability of daily milk yield into i) a regular and continuous component, and ii) a stochastic component (Beever *et al.,* 1991; Sherchand *et al.,* 1995; Grossman and Koops, 1998). Knowledge regarding the shape of lactation curves enables the prediction of total lactation milk yield based on data from a single test day (Wood, 1976) or several test days at the beginning of the lactation period. Therefore, such knowledge represents a valuable tool for decision-making in breeding and selection procedures.

The Wood model has been used in most lactation curve model studies, for reason that it includes the basic features of lactation curves with only the three parameters beginning yield (a), coefficient of rising (b) and coefficient of decreasing (c), which allow the calculation of average yield, peak yield and peak time, respectively. This feature has allowed the Wood model to become the most widely used function for describing lactation curves (Wood, 1967; Papajcsik and Bodero, 1988). Most alternative models are also based on the Wood model (Wilmink, 1987; Papajcsik and Bodero, 1988). The model is appreciated for its simplicity and accuracy in describing the lactation curve. The Wood model is used worldwide by animal scientists to describe the lactation curves of cattle, buffalo and other farm animals (Kawata, 2011). The parameters of Wood's function define the shape of the lactation curve, and thus enable the estimation of milk yield in a particular stage of lactation as well as the persistency index of lactation.

Most lactation curve studies focus on evalu-

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ating average patterns among homogeneous groups of animals, even when individual curves are of greater interest for many practical purposes (*e.g.*, health monitoring, individual feeding, genetic evaluations). While there is considerable variation in the lactation curve shapes of different animals, the individual curve fitting in dairy animals allows a better and wider goodness of fit to be obtained (Perochon *et al.,* 1996; Olori *et al.,* 1999; Macciotta *et al.,* 2005). Atypical lactation curve shapes are characterized by an absence of a lactation peak, and occur in approximately 20 to 30 percent of cases (Olori *et al.,* 1999; Rekik and Ben Gara, 2004; Macciotta *et al.,* 2005). Lactation curves can be used to predict lactation yield by using either the entire curve, or only part of the curve's length, and also depending on the method used to describe the underlying curve. Based on the information they provide, lactation curves can be used as tools for the selection of breeding herds, and for evaluating the current level of lactation in herds. Until now, there have been only a limited number of studies in Turkey regarding the characteristics of different breeds of buffalo.

In this context, this study intends to determine the lactation curve characteristics of Anatolian buffaloes by using the Wood model.

Materials and methods

Location of experiment

This study was performed in the Tokat province of the Central Black Sea Region of Turkey. The province of Tokat is located between the 35° 27' and 37° 39' East longitudes, and the 39° 52' and 40° 55' North latitudes. The province has a transitional climate between the Black Sea marine climate and the Anatolian continental climate. The long-term mean annual temperature varies between 8.1 to 14.2°C, while the mean relative moisture varies between 56 and 73% (MARA, 2013).

Buffalo management

The lactating buffaloes grazed outside between the months of April to December, while being kept and fed indoors through the winter. During the grazing period, the buffaloes were allowed to graze between eight to seventeen hours (without any concentrates being fed), and kept indoors at night. The buffaloes were fed a total mixed ration all year round. The buffaloes were mated naturally, and hand milked twice a day. Buffalo calves were fed on milk in the morning and evening, and weaned at approximately 120 days of age.

Data collection

Data collected during the study included the 4340 test days of milk yield records obtained for the lactation of 690 Anatolian buffaloes. These records were held by the Association of Animal Breeders in Tokat between 2011 and 2014. The data obtained from Anatolian buffaloes at their 1st, 2nd, 3rd, 4th and 5th parity, with age at calving ranging from 30 to 48, 36 to 60 and 48 to 72 months. Number of test-day records per lactation varied from 5 to 10. The test-day milk records were obtained from monthly milk yield samples, collected on the morning and evening of every fifteenth day of each month. The test-day milk records were recorded using kilogram as units. Information about pedigree, date of birth, date of calving, type of birth and sex of the born calves were obtained from registers maintained for management purposes. Lactations were grouped according to lactation number, with a total of five groups being formed. Further edits involved the removal of records of milk yield sampled earlier than the 5th postpartum day, in which case the subsequent milk sample was considered as the first test day sample. The study data was obtained from the buffaloes in their first, second, third, fourth and fifth parity. All buffaloes were milked twice a day. To define the lactation curves, the daily milk yield data was obtained for buffaloes whose first five or more control yields were known. Records involving a lactation length of <150 days, a calving interval <300 or >700 days, abortion, and other pathological causes known to affect lactation yield were considered as abnormal, and hence excluded from the study (Tekerli *et al.,* 2001; Cruz *et al.,* 2009; Torshizi *et al.*, 2011). The editing of the records resulted in a considerable loss of data. The record for a buffalo was excluded in case i) the lactation number is missing, ii) a buffalo was controlled less than five consecutive times during the whole lactation length of 275 days, iii) the interval from the date of freshening to the first test-day date is less than 5 days, and iv) the test-day production is unreasonable (a test-day yield less than 1 kg or greater than 20 kg). Following the editing process, 3830 records remained. The data comprised 899 first, 777 second, 736 third, 718 fourth and 700 fifth lactations of 690 Anatolian buffaloes.

The current milk recording scheme in Turkey is generally based on the monthly supervision of dairy herds. Although daily weighing is the most appropriate method for recording the quantity of milk (in order to then calculate the total lactation milk yield), this recording method is very time consuming and costly, especially when the size of the dairy herd in large (Wood, 1976; Farhangfar and Rowlinson, 2007). For this reason, in many countries, the record for each test day is taken regularly at monthly intervals.

Statistical analysis

The database was first built in Microsoft Excel and then imported into Statistica 5.0. V (1995) for the modeling, graphing and fitting of the lactation curves. Milk yield was recorded on a monthly basis, and throughout the lactation period, the lactation milk yield (LMY) was calculated using the Trapez method (Koyuncu *et al.*, 2002; Berger and Thomas, 2013). The data regarding milk production on day 5 (X_1), 35 (X_2), 65 (X_3), 95 (X_4), 125 (X_5), 155 (X_6), 185 (X_7), 215 (X_8), 245 (X_9) and 275 (X_{10}) were recorded, along with the milk production level for all lactations (ICAR, 2008). The LMY and lactation length (LL) were calculated using the equations below. To determine LL:

$$LL=[na-[(a/2-A)]$$

To determine the LMY:

$$LMY_{Trapez}=[(A_1-CD)*k_1]+\left[\sum_i^n\left[\left(\frac{k+k'}{2}\right)*(A'-A)\right]\right]+[(DD-A_n)*k_n]$$

where: CD is calving date, DD is drying date, n is the number of milk yield controls, a is the control period, A and A' are consecutive milk control dates, k and k' is milk yield in consecutive controls.

The mathematical expression of the lactation curve is called the biometry of lactation. Wood (1967) previously examined the variations in daily milk yield. In present study, lactation curve shapes were analyzed by fitting individual curves into the Wood model (Wood, 1967), which has been widely used by many researchers (Macciotta *et al.,* 2005; Farhanghfar and Rowlinson, 2007; Jeretina *et al.*, 2013). In this context, the following statistical model was employed:

$$Y_t{:}at^b\exp(-ct)$$

where t represents the day of milking, y_t represents the daily milk yield on day t of lactation, a is the general scaling factor representing initial yield, and b and c are the factors associated with the inclining and declining slope of the lactation curves, respectively. Parameters a, b and c were initially estimated by fitting the Wood's function into the log-linear form.

The gamma model of Wood (1967) was transformed logarithmically into a linear form, and was fitted to the monthly recorded milk yields:

$$\ln(Y_t)\_\ln(a)+b[\ln(n)]-cn$$

Atypical lactations with negative b or c parameters, as well as herds with less than two buffaloes were excluded from the study data. The remaining lactations that were typical according to Wood s description were then analyzed using non-linear regression in accordance with the NLIN procedure and the Levenberg Marquardt iterative method of Statistica 5.0. V (1995). In this method, the iteration algorithm was used for the solution, with a converge criterion of 1E-0.8. In order to reduce number of iterations required to reach the solution, results from the literature and previous analyses of data were used for the initial values of the parameters. Therefore, estimations were made for the a, b, c values of the gamma model. The lactation curve parameters obtained from the linearized form were used as the starting grids. In addition, the individual buffalo lactation curve parameters obtained through non-linear regression were used to calculate the peak time.

The gamma function described the lactation curve using the mean of the predicted yield, the difference between the predicted and lactation milk yield, the coefficient of determination R^2, and the respective standard errors. To evaluate the effects of such factors as parity and age, the analysis of variance for the gamma function parameters was performed using the fixed-effect multiple regression model. The data was classified into the five lactation groups, and the mean scores were compared using Duncan's multiple range test). The following statistics were calculated following the fitting of the curve: S was calculated as:

$$S{:}\text{-}(b+1)\ln(c)$$

The maximum daily milk yield (Y_{max}) was calculated as:

$$Y_{max}{:}\ a(b/c)^b\ e^{-b}$$

The time of maximum milk yield (T_{max}) was calculated as:

$$T_{max}{:}b/c$$

The correlation coefficients were obtained from the curve components, and all statistical analysis techniques were performed using the SPSS 17 software (2009). The parameters of Wood's model were estimated using non-linear regression, and by fitting the individual curves. If both the b and c parameters were negative, the lactation curve had a concave shape; on the other hand, if parameter b was negative and parameter c was positive, the lactation curve had a negative slope (decreasing type). After fitting the model, the parameters were estimated. The parameters of Wood's model were used to draw the lactation curve of Anatolian buffaloes, and to determine their shape.

Results and discussion

Lactation milk yield and lactation length

The mean LMY was determined as 695 kg, with the LMY values ranging between 509 and 825 kg for the 1st, 2nd, 3rd, 4th, 5th and all lactations. This result is lower than the ones reported by İzgi and Asker (1988), Afzal *et al.* (2007), Özenc *et al.* (2008), Şekerden (2011), and higher than the ones reported by Sahin and Ulutas (2014). The mean LL was 152 days. The findings of our study were in agreement with the results of Sahin and Ulutas (2014). Our LL value was lower than the one determined by Afzal *et al.* (2007), who had reported an LL of 273 days. The differences between our results and those of other researchers could be associated with differences in climate and management, and/or to genetic differences between the herds.

Type of lactation curves

The shapes of the obtained lactation curves are shown in Figure 1. As shown in the Figure 1, the average TDMY increased from the beginning of lactation towards the peak time, and then decreased gradually towards the end of lactation. This indicates that the milk yield of an Anatolian buffalo changes during the course of the lactation. In this study, parameters relating to the lactation curves were calculated using the Gamma model developed by Wood (1967). Among the 690 different lactation records that were evaluated, 406 (58.84%) were typical curves, while 90 (13.04%) were concave curves and 194 (28.12%) were decreasing type curves. In the current study, the ratio of atypical lactation curves was 41.16% for Anatolian buffaloes reared under varying conditions in the province of Tokat. Of the atypical lactation curves, 68.30% were decreasing type curves, while 31.69% were concave types curves. This observation is inconsistent with the results reported by Kaygısız (1999b) for Holstein cattle (42%). On the other hand, Kaygısız (1999a) had reported that 60% of atypical lactation curves were of the decreasing type, while 40% were of the concave type. These values were higher than those previously determined for Anatolian buffalo by Kaygısız (1999a) and for Holstein cattle by Rekik and Ben Gara (2004). On the other hand, Tekerli *et al.* (2000) reported that atypical curves represented 26.3% of a total of 1278 completed lactations. The fact that the ratio of buffaloes with typical lactation curves is higher than the ratio of buffaloes with atypical lactation curves can be considered as a positive sign for dairy farms, since such ratios indicate higher milk yields. However, different studies on buffaloes have report different percentages of atypical lactation. Mansour *et al.* (1992) reported that 3.5% of Egyptian buffaloes had atypical lactation curves, while the ratio of atypical lactation for Pakistan Nili Ravi buffaloes was reported as 4.6% (Khan and Gondal, 1996).

Atypical curves were assumed to be associated with buffaloes that exhibited various data-related problems, such as the lack of information, erroneous data or management problems. The occurrence of atypical shapes,

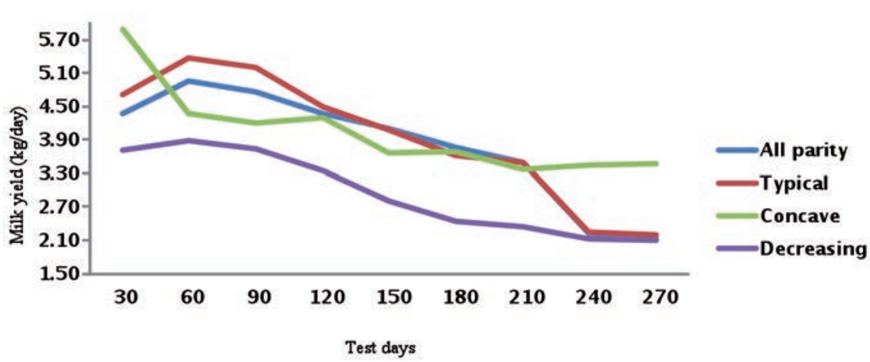

Figure 1. Type of lactation curves.

characterized by the absence of a lactation peak, is reported to occur in about 15-42% of buffaloes (Rekik *et al.*, 2003; Soysal *et al.,* 2005; Atashi *et al.,* 2009; Boujenane and Hilal, 2012). However, Shanks *et al.* (1981) reported a lower proportion of 840 atypical lactations among 113,705 lactations.

In terms of values, the curve using all lactations and the typical lactation curves were very similar to one another (Figure 1), indicating that most lactations in dairy farms/businesses are typical (in other words, have typical lactation curves). Concave and descending type curves tended to decrease gradually starting from the beginning of lactation. Buffaloes with concave and descending type lactation curves produce lower quantities of milk.

Lactation curve parameters and characteristics

The values for the model parameters, which depended on the shape of the lactation curves, are provided in Table 1. The lactation curve shapes were determined by identifying the curve type based on the curve parameter values a, b and c.

The coefficients of determination R^2 indicated that the factors studied in all parities accounted for 75.98% of total variation. The coefficient of determination (R^2), which is an indication of the model's fit to the structure of the available data, was determined in our study as 76.33±0.50% for typical lactation. Thus, it is possible to state that the determination of coefficient sufficiently explained the variances of the lactation curves. The values/percentages reported by other researchers varied between 49.0 and 72.0% (Kaygısız, 1999a). A large coefficient of determination indicates the ability of the independent variable and the model to describe the dependent variable. In this study, the mean coefficient of determination values were lower than the values of 99.1%, 99.8%, 68.1%, 70.3% and 61.0% reported by Kumar *et al*. (1992).

As it can be seen in Table 1; the parameter a values (indicating the starting milk yield) for all lactation curves, typical lactation curves, concave lactation curves and decreasing lactation curves were determined as 5.80, 7.14, 4.94 and 5.31, respectively.

The a parameter values of Wood's model in the 1st, 2nd, 3rd, 4th, 5th and all lactations were estimated 7.21, 5.56, 6.55, 8.66, 7.70 and 7.14, respectively. These results were consistent with findings of Elahi Torshizi *et al.* (2011), who reported the value for this parameter as 4.98. These results are lower than the values reported in certain studies (Barbosa *et al.*, 2007; Anwar *et al.*, 2009), while other studies have reported higher values (Kaygısız, 1999; Coletta *et al.*, 2007; Jeretina *et al.*, 2013; Şahin *et al.*, 2014). Using the Wood model, Aziz *et al.* (2006) reported parameter estimates varying between 29.92 and 49.23 from the 1st to the 10th lactation. On the other hand, Orman *et al.* (2000) reported with the Wood model parameter estimates between 4.99 and 10.76 from the 1st to 5th lactation.

The b parameter values of the Wood model for five and all parities were estimated as 0.84, 0.97, 0.62, 1.09, 0.70 and 0.85, respectively.

The parameter b values (which represent the coefficient of rising in all lactations) for all lactation curves, typical lactation curves, concave lactation curves and decreasing lactation curves were determined as 0.538, 0.85, 0.73 and 0.15, respectively. This result is similar with the findings of Kaygısız (1999a) who reported b parameter estimates between 0.49 and 0.86 from the 1st to the 6th lactation by the Wood Model. Using the Wood Model, Elahi Torshizi *et al.* (2011) reported b parameter estimates between 0.184 and 0.218, while and

Table 1. Parameters and standard errors of lactation curve traits according to lactation number.

Lactations		a	S_x	b	S_x	c	S_x	T_{max}	Y_{max}	LL	LMY	S	R^2
First	Typical	7.21	0.585	0.84	0.080	0.40	0.036	62.4	6.45	160.95	670.80	2.66	79.53
	Decreasing	4.73	0.757	-0.20	0.301	0.06	0.057	-	-	155.10	463.80	3.30	74.64
	Concave	4.14	0.388	-0.70	0.104	-0.24	0.046	86.1	5.90	139.76	595.60	-	65.06
	All	5.36	0.550	0.58	-0.513	0.23	-0.137	80.7	7.33	151.94	576.73	2.45	73.07
Second	Typical	5.56	0.537	0.97	0.130	0.45	0.052	65.1	4.55	142.10	509.90	2.58	76.06
	Decreasing	5.36	0.683	-0.23	0.059	0.04	0.010	-	-	164.10	642.20	3.97	79.70
	Concave	3.81	0.189	-0.63	0.164	-0.20	0.044	93.6	6.29	133.14	515.80	-	72.20
	All	4.91	0.470	0.61	0.118	0.23	0.035	111	7.07	146.45	555.97	2.71	75.98
Third	Typical	6.55	0.508	0.62	0.097	0.26	0.034	70.8	8.27	157.47	825.10	2.16	67.95
	Decreasing	7.05	0.550	-0.11	0.032	0.03	0.022	-	-	165.30	846.00	3.72	62.50
	Concave	4.84	0.431	-0.73	0.118	-0.27	0.060	81.9	6.32	132.64	688.30	-	72.72
	All	6.14	0.496	0.49	0.082	0.19	0.039	83.4	9.73	151.80	786.47	2.716	67.72
Fourth	Typical	8.66	0.840	1.09	0.149	0.51	0.071	63.9	6.16	148.00	726.00	2.39	78.69
	Decreasing	4.81	0.762	-0.07	0.030	0.009	0.020	-	-	149.70	488.00	4.95	96.20
	Concave	6.31	0.930	-0.95	0.238	-0.30	0.092	95.1	7.73	132.90	861.00	-	91.74
	All	6.59	6.59	0.70	6.593	0.27	6.593	125.7	8.36	143.53	691.67	2.89	88.87
Fifth	Typical	7.70	0.827	0.70	0.092	0.38	0.047	54.9	6.94	155.87	743.50	2.62	79.41
	Decreasing	4.61	0.539	-0.14	0.015	0.04	0.041	-	-	170.31	583.30	3.51	86.67
	Concave	5.63	0.930	-0.62	0.238	-0.15	0.092	120.9	12.10	156.70	752.00	-	56.70
	All	5.98	0.765	0.49	0.115	0.19	0.060	89.1	9.17	160.96	692.93	2.72	74.26
General	-	5.60	0.765	0.21	0.115	0.13	0.060	48.6	7.33	231.00	953.00	2.47	95.30
All parity	Typical	7.14	0.659	0.85	0.110	0.40	0.048	63.6	6.41	152	695.00	2.68	76.33
	Decreasing	5.31	0.658	-0.15	0.087	0.03	0.030	-	-	160	604.00	3.89	79.94
	Concave	4.94	0.574	-0.73	0.172	-0.23	0.067	95.4	7.41	139	682.00	-	71.68
	All	5.80	0.630	0.57	0.123	0.22	0.048	98.1	8.32	150	660.00	2.70	75.98

a, beginning yield; S_x, standard deviation of x; b, coefficient of rising; c, coefficient of decreasing; T_{max}, time after parturition when peak yield occurs; Y_{max}, maximum daily peak yield; LL, lactation length; LMY, lactation milk yield; S, persistency; R^2, coefficient of determination.

Jeretina *et al.* (2013) reported b parameter estimates between 0.179 and 0.193. These results are higher than those reported by Anwar *et al.* (2009) and Şahin *et al.* (2014). Coletta *et al.* (2007) reported b parameter estimates to be between 0.25 and 0.36 by the Wood Model.

Based on the Wood model, the c parameter values for the 1st, 2nd, 3rd, 4th, 5th and all parities were determined as 0.40, 0.45, 0.26, 0.51, 0.38 and 0.40, respectively. The parameter c values (which represent the coefficient of decreasing) for all lactation curves, typical lactation curves, concave lactation curves and decreasing lactation curves were determined as 0.226, 0.404, 0.234 and 0.039, respectively.

This result is higher than the values reported by certain studies (Kaygısız, 1999a; Barbosa *et al.*, 2007; Coletta *et al.*, 2007; Anwar *et al.*, 2009; Jeretina *et al.,* 2013; Şahin *et al.*, 2014), while lower values have been reported in the study of Aziz *et al.* (2006). Elahi Torshizi *et al.* (2011) similarly reported a lower value of 0.002, while Patel and Vataliya (2011) reported lower values ranging from 0.023 to 0.035 for the 1st, 2nd and >3rd lactations. The c parameter estimates reported by Anwar *et al.* (2009) was 0.038. For higher milks yields, higher values for parameters a and b and lower parameter c values are desirable. Parameter a had similar values in the all curves, typical curves and decreasing curves, while parameter b was positive only in the all and typical lactation curves. These values indicated that buffalo with typical lactation curves provide higher milk yields.

In this study, the S (persistency), T_{max} (time after parturition when peak yield occurs) and Y_{max} (maximum daily peak yield) and R^2 (coefficient of determination) values for typical lactations were determined as 2.68, 63.6 and 6.41, respectively. While the persistency values in present study were lower than some of the values reported previously in the literature (Kaygısız, 1999a; Tekerli *et al.,* 2001), they were similar to the values reported by Çilek *et al.* (2008) and Keskin *et al.* (2009). While the Y_{max} value in our study was higher than the value reported by Kaygısız (1999a), it was consistent with the value determined by Tekerli *et al.* (2001). In this study, the calculated T_{max} value for typical lactations was lower than the value reported by Kaygısız (1999a), yet similar to the value determined by Tekerli *et al.* (2001).

The lactation curve parameters that were calculated in this study for buffalo herds were higher than those determined in previous studies, which may be attributed to the fact that the buffaloes in our study were raised in different environmental conditions, and/or that herd management for the studied buffaloes was being performed correctly in terms of milk production (Kaygısız, 1999a).

Correlations between parameters and characteristics

In this study, the correlations between the lactation curve parameters (a, b, c), T_{max}, Y_{max}, S, LL and LMY were evaluated and determined. The relevant results relating to these correlations are provided in Table 2. In all lactations and typical lactation curves, statistically significant correlations (P<0.01) were identified between parameter a and the parameters b, c, Y_{max}, LMY and S; between parameter b and the parameters c, Y_{max} and S; between parameter c and the parameters Y_{max} and S; between parameter T_{max} and the parameters Y_{max} and S;

Table 2. Correlations among lactation curve parameters.

Lactations		a	b	c	T_{max}	Y_{max}	LMY	LL
All lactation	b	-0.413**						
	c	0.599**	0.932**					
	T_{max}	-0.20	-0.018	-0.0338				
	Y_{max}	0.688**	0.373**	0.360**	0.148**			
	LMY	0.011**	-0.001	-0.018	-0.037	0.040		
	LL	0.037	0.075	0.063	-0.073	0.065	0.494**	
	S	-0.389**	-0.131**	-0.283**	0.379**	0.41**	0.105**	-0.012
Typical	b	0.355**						
	c	0.582**	0.915**					
	T_{max}	0.061	0.073	0.061				
	Y_{max}	0.694**	0.364**	0.355**	-0.148**			
	LMY	0.089**	-0.029	-0.053	-0.094	0.118**		
	LL	-0.039	0.070	0.024	0.092	0.011	0.514**	
	S	-0.504**	-0.170**	-0.361**	0.379**	-0.107**	0.149**	0.040
Concave	b	0.304*						
	c	0.524**	0.908**					
	T_{max}	-0.030	-0.018	-0.073				
	Y_{max}	0.579**	0.160	0.149	0.540**			
	LMY	-0.019	-0.162	-0.030	-0.153	-0.080		
	LL	0.109	-0.083	-0.167	-0.026	0.012	0.499**	
	S	-0.337**	-0.206	-0.361**	0.659**	0.363**	0.042	-0.156
Decreasing	b	0.622**						
	c	0.712**	0.970**					
	T_{max}	-0.022	-0.015	0.018				
	Ym_{max}	0.772**	0.485**	0.456**	-0.063			
	LMY	0.123	0.111	0.104	-0.031	0.157		
	LL	0.055	-0.028	-0.015	-0.096	0.079	0.446**	
	S	-0.250**	-0.026	-0.138	0.521**	0.42**	0.104	-0.034

a, beginning yield; b, coefficient of rising; c, coefficient of decreasing; T_{max}, time after parturition when peak yield occurs; Y_{max}, maximum daily peak yield; LMY, lactation milk yield; LL, lactation length; S, persistency. *P<0.05;; **P<0.01.

between parameter Y_{max} and parameter S; and between parameter LMY and the parameters LL and S. In typical lactation curves, the correlations between parameter Y_{max} and the parameters T_{max} and S were determined to be significant.

In concave lactation curves, statistically significant correlations (P<0.01) were identified between parameter a and the parameters b, c, Y_{max} and S; between parameter b and parameter c; between parameter c and parameter S; between parameter T_{max} and the parameters Y_{max} and S; between parameter Y_{max} and parameter S; and between parameter LMY and parameter LL. In the decreasing lactation curves of the current study, statistically significant correlations (P<0.01) were identified between parameter a and the parameters b, c, Y_{max} and S; between parameter b and the parameters c and Y_{max}; between parameter c and parameter Y_{max}; between parameter T_{max} and parameter S; and between parameter LMY and parameter LL.

In this study, the calculated correlations were very close to the values reported in literature (Kaygısız, 1999a). Taking into account the typical lactation curves (which are considered to be the ideal type of curve), a negative and statistically significant relationship (P<0.01) was identified between parameters a and b, while the relationship between parameters a and c was identified as being positive and statistically significant (P<0.01).

Based on the statistically significant (P<0.01) and negative correlation between parameter a and parameters T_{max}, S and b, it is possible to state that buffaloes with higher initial milk yields took longer to achieve their maximum daily milk yields, and demonstrated a lower level of persistence. Based on the high and positive correlation between parameter a and parameter Y_{max}, it is possible to state that buffaloes with higher initial milk yields achieved higher maximum daily milk yields, and consequently had high lactation milk yields. As long as the milk yields remain high, a buffalo will be kept in lactation for longer periods by the dairy farm, meaning that its lactation period will be longer. In sum, it is possible to state that buffaloes with higher initial milk yields take longer to achieve their maximum yields, and that the maximum yields of these buffaloes are comparatively lower. A negative and statistically significant (P<0.01) correlation between persistency (S) and parameters a, b and c indicated that the increase and decrease in milk yields would be slower in high persistency buffaloes. In this study, a negative correlation was identified between S and Y_{max}, while a positive correlation was identified between S and T_{max}, indicating that buffaloes with higher S values take longer to reach their maximum yields due to a slower curve. The presence of a positive and statistically significant correlation between lactation milk yield and parameters a and Y_{max} indicated that buffaloes with higher initial milk yields would have higher Y_{max} values, and hence higher milk yields. The positive correlation between the lactation period and the LMY milk yield indicated that an increase in lactation period would lead to an increase also in the LMY milk yield. A reduced typical character (or an increasing atypical character) of lactation curves may result from a combination of factors, such as the persistency values, the way in which the herd is managed and taken care of, the feeding of the buffaloes, and the buffaloes' health, and may affect the lifetime productivity of buffaloes. A preference for more persistent buffaloes with standard lactation curves during selection can be a useful and effective approach to breeding, depending on the model parameters being used. In other words, in cases where the pedigrees of buffaloes in a herd are not known, the parameters calculated by taking environmental factors into account can be used as selection criteria. The shape of the lactation curve is one such criteria (along with total or lactation milk yield) that can be considered in the assessment of buffalo milk yield. As buffaloes with typical lactation curves provide higher milk yields, they should be preferred during animal selection and elimination activities.

The mean milk yield values of Anatolian buffaloes with decreasing (604 kg) and concave type (682 kg) lactation curves were 13 and 2% lower, respectively, than the mean milk yield value of buffaloes with typical lactation curves (695 kg). It was similarly reported that the mean milk yield value of buffaloes with atypical lactation curves was 5-6% lower than the mean milk yield value of buffaloes with typical lactation curves (Kaygısız, 1999a; Yılmaz and Kaygısız, 2000).

The phenotypic correlation between parameter a and T_{max} and the correlation between parameter a and persistency were negative and medium-level, while the correlation between parameter a and Y_{max} was positive and high. Buffaloes starting lactation with higher milk yields thus exhibited higher maximum daily milk yield, although they also had lower persistency. In this study, the phenotypic correlation between Y_{max} and T_{max} was negative and low for both typical and decreasing curves.

In previous studies (Atashi *et al.*, 2009; Seangjun *et al.*, 2009), the correlation between Y_{max} and T_{max} was reported as negative, indicating that buffaloes with higher daily milk yield reached their maximum daily milk yield earlier.

Therefore, buffaloes which have a higher initial production, higher peak milk, and decline at a slower rate will also have a high LMY. On the other hand, Farhangfar and Rowlinson (2007) found it equal to zero. In our study, a positive correlation was calculated between Y_{max} and T_{max}. Y_{max} had high and positive genetic correlation with LMY, indicating that increasing Y_{max} will lead to an increase in LMY as well.

Conclusions

In conclusion, the mean values of milk yield for buffaloes with typical lactation curves (695 kg) were higher than the mean values of milk yield for buffaloes with atypical (decreasing and concave) lactation curves. Indirect selections in buffalo herds based on typical lactation curves (in which all parameters are positive) could facilitate and contribute positively to the management of the herd. In addition, the yield level of the herd can also be improved by excluding buffaloes with atypical lactations from the herd. Such a herd selection approach can be performed by using the female Anatolian buffaloes with typical lactation curves.

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