Factors Affecting the Shape of Lactation Curves of Holstein Cows from the Balikesir Province of Turkey

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ABSTRACT

The shape of the lactation curve for 475 Turkish Holsteins was estimated by fitting a gamma function to daily milk yields from monthly recording of 754 lactations. Lactation curve traits that were analyzed included a scaling factor associated with yield at the beginning of lactation, the inclining and declining slopes before and after peak yield, DIM at peak yield, and peak and lactation yields. Persistency of lactation yield was measured from 1) the gamma function, 2) the coefficient of variation for monthly test-day yields, and 3) the ratio of lactation yield to peak yield. The log-transformed gamma function explained 71% of variation in daily yield. Effects of farm operation, calving year, calving season, parity, and service period were significant for the various lactation curve traits. Peak and lactation yields were higher for cows that calved in fall and winter, and persistency was higher for cows that calved in summer and fall. Peak and lactation yields were lower, but persistency was higher during first lactation. Repeatability estimates were moderate for peak (0.26) and lactation (0.34) yields and lower (0.06 to 0.20) for other lactation curve traits.
(**Key words:** lactation curve, persistency, milk yield, Turkey)

Abbreviation key: CV = coefficient of variation, $\mathbf{R^2}$ = squared multiple correlation coefficient.

INTRODUCTION

A general goal of dairy breeding throughout the world is improved efficiency of milk production. However, in some countries (e.g., the European Union), increased milk yield is not economically desirable because of milk quotas (7). Breeders in those countries would like to reduce and to stabilize their costs relative to returns so that profit can be maximized. Regardless of the pricing system for milk yield, costs of milk production depend to a large extent on the persistency of lactation, which is an expression of the ability of the cow to continue to produce milk at peak level throughout lactation. An abrupt decline in milk yield after peak increases production costs because yield is distributed less equally over the complete lactation (7, 14).

Dairy cows with a flat lactation curve are considered to have more persistent lactations than those with the same lactation yield but a steep lactation curve. For cows with flatter lactation curves, the incidence of metabolic and reproductive disorders that originate from the physiological stress of high milk yield would be lower, and the proportion of roughage in the ration could be increased, thus reducing production costs. Knowledge of the probable shape of the lactation curve makes feeding trials more efficient because differences between treatments are more easily detected when the animals are grouped according to the expected curve shape (7, 13, 14, 15, 24). If genetic aspects of the shape of the lactation curve can be determined and then represented through a mathematical model, selection for those traits may result in improved yield efficiency.

The gamma function described by Wood (29, 30, 31, 33) is one of the most popular models used to describe the lactation curve:

$$y_n = an^b e^{-cn}$$

where y_n = milk yield on day n, a = a scaling factor to represent yield at the beginning of lactation, and b and c are factors associated with the inclining and declining slopes of the lactation curve. Typical lactation curves have positive b and c, and curves with negative b or c are considered to be from atypical lactations (22). This model can be linearized with a simple logarithmic transformation and easily solved by ordinary least squares analysis for multiple regression. Wood (31) also defined $s = -(b + 1)\ln(c)$ as a measure of persistency of lactation when using a gamma function.

Some alternative models (2, 3, 7, 8, 9, 10), most of which are more complicated than Wood's gamma function (29), have been proposed recently. Some of those alternatives require the use of nonlinear regression techniques, and computational difficulties may arise because of an increased number of parameters to be

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estimated and the greater amount of data that is needed to estimate those parameters.

Earlier research (1, 6, 9, 12, 13, 14, 15, 16, 17, 18, 20, 23, 24, 31, 32) reported that factors such as farm, calving year, calving season, calving age, parity, service period, and interval from calving to first test day significantly impact lactation traits. Genetic aspects of lactation curves and certain yield traits have been studied for different cattle breeds (2, 5, 9, 15, 16, 17, 20, 21, 28). Wood (31) reported repeatabilities of 0.10, 0.20, 0.23, and 0.18 for a, b, c, and persistency, respectively, for British Friesians.

The present study was undertaken to investigate the factors that affect the shape of lactation curves, persistency measures, and yield traits of Holstein cows in the Balikesir province of Turkey. The phenotypic relationships among those factors and their repeatabilities were examined.

MATERIALS AND METHODS

Data included observations from 1520 lactations of 724 Holstein cows that were milk recorded from 1989 through 1994 in the Balikesir province of Turkey as part of a Turk-ANAFI (Italian National Frisona Breeders Association) project. Of 1278 completed lactations with confirmed pregnancies for insemination dates, 336 were determined to have atypical lactation curves and were excluded from further analysis. Additional requirements for a lactation record to be included in the study were 1) an interval of <31 d between calving and first test day and 2) a lactation of >200 d. The final data set included information from 343 first, 225 second, 126 third, and 60 fourth lactations of 475 cows on 26 farm operations with milk recording from 1990 through 1994. At least six test-day records were available for each lactation.

Birth, calving, and service dates, daily milk yields, and identification information for cows and their parents were compiled. Calving months were grouped into four seasons: 1) winter (December through February), 2) spring (March through May), 3) summer (June through August), and 4) fall (September through November). Service period, as defined by Schneeberger (20), was the interval between calving and conception and was grouped as 1) ≤60 d, 2) 61 through 120 d, 3) 121 through 180 d, and 4) ≥181 d. Third and fourth lactations were combined to obtain a better balance among parity groups and were designated as later lactations.

The gamma model of Wood (29, 30, 31, 33) was transformed logarithmically into a linear form and was fitted to milk yields that had been recorded monthly:

$$\ln(y_n) = \ln(a) + b[\ln(n)] - cn.$$

Rowlands et al. (19) and Shimizu and Umrod (22) reported that a weighted regression method was more accurate than an unweighted regression for fitting a mathematical model to the lactation curve. Therefore, ln(a), b, and c were estimated by weighted multiple regression analysis in which integers of y_n^2 were used as weights (25).

The DIM at peak yield (y_{max}) was defined as b/c, and y_{max} was calculated as $a(b/c)^b e^{-b}$. The area under the lactation curve represents total lactation yield (y) up to and including 305 DIM:

$$y = a\int_0^n n^b e^{-cn} dn$$

where n ≤ 305 d. Total yields from lactations that were completed before 305 d were included. Persistency was computed as 1) s from the gamma function (31), 2) the coefficient of variation (**CV**) for milk yield on test day, and 3) the ratio of lactation yield to peak yield (y/y_{max}) (13, 15, 16). Higher values of s and y/y_{max} and lower values of CV indicated greater persistency.

The effects of farm operation, calving year, calving season, parity, service period, calving age, and DIM at first test day on various aspects of the lactation curve (a, b, c, b/c, y_{max}, y, s, CV, and y/y_{max}) were analyzed using the computer program of Harvey (11) and the model

$$y_{ijklmn} = \mu + FO_i + CY_j + CS_k + PA_l + SP_m + b_1CA_{ijklmn} + b_2TD_{ijklmn} + e_{ijlkmn}$$

where y_{ijklmn} = a lactation curve trait based on observation n on farm operation i (i = 1, 2, ..., 26) for calving year j (j = 1990, 1991, ... 1994), calving season k (k = winter, spring, summer, fall), parity l (l = 1, 2, later), and service period m (m = ≤60 d, 61 through 120 d, 121 through 180 d, ≥180 d); μ = overall mean; FO = effect of farm operation; CY = effect of calving year; CS = effect of calving season; PA = effect of parity; SP = effect of service period; b_1 and b_2 = linear regression coefficients; CA = calving age; TD = DIM at first test day; and e = random residual with an expected value of 0 and a variance of σ_e^2. No interaction effects were included in the model because of limited data.

After adjustment of the data for significant effects, Pearson phenotypic correlation coefficients were calculated between the different lactation curve traits. Repeatabilities were estimated from the variance components using intraclass correlation and repeated observations for the same animal (25, 26, 27, 34, 35).

Table 1. Mean squares of variables from ANOVA of lactation curve traits for Turkish Holsteins.

		Lactation curve[1] traits								
								Persistency measures		
Variable	df	a	b	c ($\times 10^{-5}$)	b/c[2]	y_{max}[3]	y[4] ($\times 10^{6}$)	s[5]	CV of y_{td}[6]	y/y_{max}
Farm operation	25	1.104**	0.0659**	2.7**	2157**	470.1**	21.22**	1.334**	862.48**	4343**
Calving year	4	0.376	0.0313	2.7**	5179**	90.7**	3.97*	1.638**	731.47**	3889**
Calving season	3	1.167	0.0239	2.3**	1404	347.8**	12.39**	1.338**	614.10**	2155*
Parity	2	0.766	0.0005	1.0	3309*	386.1**	6.47**	1.356*	508.62**	4076**
Service period	3	0.433	0.0600*	3.8**	509	30.6	26.23**	0.177	47.84	53,724**
Linear regression on:										
DIM at first test day	1	12.20**	1.0238**	4.9**	22,473**	17.4	4.00	10.388**	2.01	1746
Calving age	1	0.278	0.0003	0.0		104.6*	63.41*	0.185	3.33	385
Residual	714	0.289	0.0214	0.4	831	23.1	1.28	0.312	61.43	610
R^2	. . .	0.230	0.184	0.286	0.173	0.517	0.480	0.229	0.379	0.435

[1]Modeled as $\ln(y_n) = \ln(a) + b[\ln(n)] - cn$, where y_n = milk yield on day n, a = a scaling factor to represent yield at the beginning of lactation, and b and c are factors associated with the inclining and declining slopes of the lactation curve.

[2]DIM at peak yield.

[3]Peak yield calculated as $a(b/c)^b e^{-b}$.

[4]Total lactation yield through 305 DIM.

[5]Persistency calculated as $s = -(b + 1)\ln(c)$.

[6]Milk yield on test day.

*$P < 0.05$.

**$P < 0.01$.

RESULTS AND DISCUSSION

The squared multiple correlation coefficient ($\mathbf{R^2}$) of the log-transformed gamma function was 0.708 ± 0.08. The R^2 for parity groups were 0.609 ± 0.013 for first lactation, 0.726 ± 0.015 for second lactation, and 0.743 ± 0.015 for later lactations.

The ANOVA mean squares of model effects are in Table 1 for the lactation curve traits. The R^2 ranged from 0.173 for b/c (DIM at peak yield) to 0.517 for y_{max} (peak yield). The least squares means for group effects of calving season, parity, and service period as well as for linear regressions on DIM at first test day and on calving age for the lactation curve traits are in Table 2.

The effect of farm operation was highly significant ($P < 0.01$) for all lactation curve traits. Although calving year was not significant ($P > 0.05$) for a and b, it was significant ($P < 0.05$) for y (lactation yield) and highly significant ($P < 0.01$) for the remaining lactation curve traits. Those results are similar to the findings of Collins and Lusweti (4) and Rao and Sundaresan (17). The significant effects of both variables may be explained by the diverse feeding and management conditions as well as annual climate changes in Balikesir Province.

The effects of calving season were significant ($P < 0.05$) for y/y_{max} and highly significant ($P < 0.01$) for the other lactation curve traits except a, b, and b/c. Batra (1) reported that calving month had a highly significant effect ($P < 0.01$) on both a and b for first lactation, but only on b for second lactation, and found no significant effect on either a or b for third lactation. Differences in a, b, and b/c because of the effects of calving season may be too small to detect in these data. Similar results for the other lactation curve traits were reported in earlier research (4, 17, 20). The highest peak and lactation milk yields were reached by cows that calved during fall and winter. Ray et al. (18) also reported that maximum yield occurred during winter for 305-d fat-corrected milk yield of Arizona Holsteins. The least squares means indicated that persistency was higher for cows that calved during summer and fall. The peak yields for cows that calved in spring and summer were lower than those that calved during fall and winter. Similar results were reported by Keown et al. (12) and Schneeberger (20). The relationship between calving season and peak yield may result from increasing temperatures and decreasing fodder, especially in summer.

The lowest peak and lactation yields but the highest DIM until peak yield and persistency were found during first lactation. Similar findings were reported in earlier research (12, 15, 23). In regard to DIM until peak yield, Rao and Sundaresan (15) stated that the results indicated that the milk secretory tissue in primiparous animals takes longer to reach its peak activity than in pluriparous animals.

The differences in least squares means (Table 2) among the service period groups were too small for the persistency measures of s and CV to be statistically significant ($P < 0.05$). However, the effect of service period on y/y_{max} was highly significant ($P < 0.01$). The least squares means for y and y/y_{max} indicated that cows that conceived shortly after calving had lower lactation yield and persistency. The decline in the slope (c) of the lactation curve after peak yield also decreased with a longer service period. Similar results were reported by Schneeberger (20). The effect of service period on lactation yield and persistency may reflect the replenishment of body tissues after parturition, the varying hormone levels during pregnancy, and the increasing nutritional needs of the fetus.

Phenotypic correlations between the lactation curve traits are shown in Table 3. The negative correlation between a and b implies that higher initial yield is associated with a lower rate of increase until peak yield. The positive correlations between b and c indicate that cows that peak more rapidly also have a quicker decline after peak. Similar results have been reported in earlier research (2, 5, 15, 16, 20, 21). Correlations between DIM at peak yield and persistency measures suggested that cows that reach peak yield later during lactation would have higher persistency. The correlations of c with CV and y/y_{max} indicated that cows with a lower rate of decline (flatter lactation curve) would have higher persistency. Because of the lower but statistically significant ($P < 0.01$) correlations between y and persistency, cows with higher persistency would be expected to have higher lactation yields. Earlier research (2, 5, 15, 16, 20) has reported similar results.

Repeatability estimates for the lactation curve traits are presented in Table 4. The repeatabilities for peak and lactation yields were higher than those for other traits. The repeatabilities for a, b, c, and s were similar to those reported by Wood (31). The low and medium repeatabilities (Table 4) and the ANOVA R^2 (Table 1) indicate that lactation curve traits may be influenced by other environmental factors than those included in the model that are specific to individual lactations.

CONCLUSIONS

Significant effects ($P < 0.05$) on lactation curve traits were found for several environmental variables. The effect of DIM at first test day was highly significant (P

Table 2. Least square means for group effects and linear regression coefficients for lactation curve traits of Turkish Holsteins.

		Lactation curve[1] traits								
								Persistency measures		
Variable	Observations	a	b	c	b/c[2]	y_{max}[3]	y[4]	s[5]	CV of y_{td}[6]	y/y_{max}
	(n)				(d)	(kg)	(kg)		(%)	
Overall mean	754	2.71	0.211	0.0044	48.8	29.2	6541	6.70	26.3	219.4
Season										
Winter	178	2.74^{a}	0.226^{a}	0.0049^{b}	45.5^{a}	30.7^{a}	6697^{a}	6.58^{b}	28.4^{a}	214.3^{b}
Spring	149	2.66^{a}	0.209^{a}	0.0044^{a}	46.8^{a}	27.6^{b}	6196^{b}	6.69^{ab}	27.7^{a}	219.3^{ab}
Summer	128	2.71^{a}	0.194^{a}	0.0039^{a}	53.0^{a}	27.9^{b}	6389^{b}	6.82^{a}	24.2^{b}	224.0^{a}
Fall	299	2.74^{a}	0.217^{a}	0.0043^{a}	49.7^{a}	30.5^{a}	6882^{a}	6.72^{a}	24.8^{b}	219.9^{a}
Parity										
1	343	2.60^{a}	0.215^{a}	0.0041^{a}	55.4^{a}	26.6^{a}	6220^{b}	6.85^{a}	23.2^{b}	226.5^{a}
2	225	2.76^{a}	0.211^{a}	0.0046^{a}	45.0^{b}	30.3^{b}	6693^{a}	6.63^{b}	27.5^{a}	215.1^{b}
Later	186	2.77^{a}	0.208^{a}	0.0045^{a}	45.9^{b}	30.5^{b}	6710^{a}	6.62^{b}	28.0^{a}	216.6^{ab}
Service period										
≤60 d	107	2.62^{a}	0.242^{a}	0.0052^{c}	45.6^{a}	28.8^{a}	5845^{c}	6.65^{a}	26.8^{a}	191.6^{d}
61 through 120 d	314	2.71^{a}	0.214^{ab}	0.0044^{b}	49.4^{a}	29.4^{a}	6558^{b}	6.70^{a}	26.6^{a}	214.5^{c}
121 through 180 d	162	2.75^{a}	0.200^{b}	0.0041^{ab}	49.3^{a}	29.6^{a}	6916^{a}	6.74^{a}	26.1^{a}	232.7^{b}
≥ 180 d	171	2.76^{a}	0.190^{b}	0.0039^{a}	50.6^{a}	28.8^{a}	6845^{a}	6.72^{a}	25.5^{a}	238.7^{a}
Linear regression on										
DIM at first test day	. . .	–0.02	0.005	0.0000	0.7	0.0	9	0.01	0.0	0.2
Calving age	. . .	0.00	0.000	0.0000	0.0	0.1	17	0.00	0.0	–0.1

[a,b,c]Means with different superscripts within variable and lactation curve trait differ significantly ($P < 0.05$).

[1]Modeled as $\ln(y_n) = \ln(a) + b[\ln(n)] - cn$, where y_n = milk yield on day, n, a = a scaling factor to represent yield at the beginning of lactation, and b and c are factors associated with the inclining and declining slopes of the lactation curve.

[2]DIM at peak yield.

[3]Peak yield calculated as $a(b/c)^{b}e^{-b}$.

[4]Total lactation yield through 305 DIM.

[5]Persistency calculated as $s = -(b + 1)\ln(c)$.

[6]Milk yield on test day.

*$P < 0.05$.

**$P < 0.01$.

Table 3. Phenotypic correlations between lactation curve[1] traits of Turkish Holsteins.

						Persistency measures		
Trait	b	c	b/c[2]	y_{max}[3]	y[4]	s[5]	CV of y_{td}[6]	y/y_{max}
a	–0.902**	–0.529**	–0.596**	0.335**	0.340**	–0.693**	–0.131**	–0.003
b		0.759**	0.515**	–0.004	–0.132**	0.604**	0.310**	–0.164**
c			0.050	0.185**	–0.251**	0.057	0.725**	–0.630**
b/c				–0.196**	0.048	0.801**	–0.235**	0.392**
y_{max}					0.784**	–0.226**	0.246**	–0.220**
y						0.080*	–0.246**	0.384**
s							–0.339**	0.492**
CV								–0.339**

[1]Modeled as $\ln(y_n) = \ln(a) + b[\ln(n)] - cn$, where y_n = milk yield on day n, a = a scaling factor to represent yield at the beginning of lactation, and b and c are factors associated with the inclining and declining slopes of the lactation curve.

[2]DIM at peak yield.

[3]Peak yield calculated as $a(b/c)^b e^{-b}$.

[4]Total lactation yield through 305 DIM.

[5]Persistency calculated as $s = -(b + 1)\ln(c)$.

[6]Milk yield on test day.

*$P < 0.05$.

**$P < 0.01$.

< 0.01) for coefficients of the lactation curve. The effect of calving age was significant ($P < 0.05$) only for peak and lactation yields. The effects of farm operation, calving year, calving season, parity, and service period also must be taken into consideration when evaluating the production of cows. Highest peak and lactation yields were associated with cows that calved in fall and winter. Persistency was higher for primiparous cows and cows that calved in summer and fall. The difference in lactation yield was 713 kg between the least squares means for cows with a service period of ≤60 d and those with a service period of 61 through 120 d. If cows are bred so that they conceive from 60 to 90 d after calving, producers can attain a calving interval of 12 to 13 mo and a greater lactation yield.

Table 4. Repeatabilities and SE of lactation curve[1] traits based on 754 lactations of 475 Turkish Holsteins.

Trait	Repeatability	SE
a	0.155	0.062
b	0.198	0.062
c	0.121	0.063
b/c[2]	0.063	0.065
y_{max}[3]	0.262	0.057
y[4]	0.340	0.063
s[5]	0.182	0.061
CV of y_{td}[6]	0.120	0.063
y/y_{max}	0.150	0.062

[1]Modeled as $\ln(y_n) = \ln(a) + b[\ln(n)] - cn$, where y_n = milk yield on day n, a = a scaling factor to represent yield at the beginning of lactation, and b and c are factors associated with the inclining and declining slopes of the lactation curve.

[2]DIM at peak yield.

[3]Peak yield calculated as $a(b/c)^b e^{-b}$.

[4]Total lactation yield through 305 DIM.

[5]Persistency calculated as $s = -(b + 1)\ln(c)$.

[6]Milk yield on test day.

The moderate to large positive phenotypic correlation of lactation yield with peak yield and persistency suggest that one of those traits could be used as a selection criterion to improve all three traits. However, the moderate negative correlation between peak yield and persistency should be considered. Further analysis of the three traits, especially with regard to consumption of roughages and concentrates, would be of interest.

Among the different measures of persistency, the ratio of lactation to peak yield (y/y_{max}) may be preferred by breeders, especially for cow evaluation, because of its higher correlation with lactation yield and computational ease.

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