IJAS Iranian Journal of Applied Animal Science

Estimation of Genetic Parameters for Lactation Curve Traits in Holstein Dairy Cows in Iran

Research Article

F. Saghanezhad[1], H. Atashi[1*], M. Dadpasand[1], M.J. Zamiri[1] and F. Shokri-Sangari[1]

[1] Department of Animal Science, Shiraz University, Shiraz, Iran

Received on: 15 Dec 2016
Revised on: 18 Apr 2017
Accepted on: 30 Apr 2017
Online Published on: Dec 2017

*Correspondence E-mail: atashi@shirazu.ac.ir

Online version is available on: www.ijas.ir

ABSTRACT

The objectives were to estimate (co)variance components and genetic parameters for lactation curve traits in Holstein dairy cows in Iran. The used data were records on Holstein cows collected during January 2003 to December 2012 by the Animal Breeding Center of Iran (Karaj, Iran). In order to describe the lactation curve, an incomplete gamma function was fitted to 691200 test-day records on 96263 lactations, 377696 test-day records on 52168 lactations, and 182143 test-day records on 24951 lactations for the first three parities, respectively. Lactation curve traits that were analyzed included a scaling factor associated with initial yield, the inclining and declining slopes of the curve, peak time, peak yield, 305-d milk yield and a lactation persistency measure derived from the incomplete gamma function. The estimated heritability of lactation curve traits for the first, second and third lactation ranged from 0.012 to 0.29, 0.017 to 0.15, and 0.02 to 0.13, respectively. Genetic correlations among lactation curve traits for the first, second and third lactation ranged from -0.68 to 0.99, -0.84 to 0.98 and -0.90 to 0.94, respectively. The estimated repeatability of lactation curve traits ranged from 0.07 to 0.40. The moderate to large positive genetic correlations of 305-d milk yield with initial yield, peak yield and lactation persistency suggest that one of these traits could be used as a selection criterion to improve all four traits. However, the peak yield and 305-d milk yield were more heritable than lactation were persistency and initial yield.

KEY WORDS Holstein dairy cow, incomplete gamma function, lactation curve.

INTRODUCTION

The graphical representation of milk yield during lactating period is lactation curve. Typical lactation curve of a dairy cow shows a peak or maximum daily yield occurring during first weeks after calving, followed by a daily decrease in milk yield until the cow is dried-off (Keown *et al.* 1986; Macciotta *et al.* 2005; Angeles-Hernandez *et al.* 2013). The lactation curve shape differs from individual to individual and is affected by genetic and environmental factors such as body weight, age, gestation, dry period, ration, season, temperature and humidity (Schmidt and Van Vleck, 1974; Macciotta *et al.* 2005). The lactation curve shape which is characterized by yield at the beginning of lactation, the inclining and declining slopes of the lactation curve, days in milk (DIM) at peak yield, peak yield, lactation persistency and lactation length, determines the total milk yield during a lactation. Genetic or phenotypic selection to improve 305-d milk yield would result in alteration of the lactation curve shape. Accurate knowledge of genetic relationships among lactation curve traits and 305-d milk yield is essential to investigate how the lactation curve shape has been changed due to ingoing genetic selection for increasing milk yield during past years (Atashi *et al.* 2012). However, only a few studies, using a very few records, have been conducted to investigate genetic aspects of lactation curve in Holstein dairy cows (Shanks *et al.* 1981; Ferris *et al.* 1985; Togashiand Lin, 2003). The objectives of this study were to estimate (co)variance components, genetic parameters, and phenotypic and genetic trends for lactation curve traits in Holstein dairy cows in Iran.

MATERIALS AND METHODS

Data

The used data were records on Holstein cows collected from January 2003 to December 2012 by the Animal Breeding Center of Iran (Karaj, Iran). The evaluated herds (n=261) were purebred Holsteins, managed under conditions similar to those used in most developed countries, and were under official performance and pedigree recording. The diet, fed as a total mixed ration (TMR), mainly consisted of corn silage, alfalfa hay, barley grain, fat powder, beet pulp, soybean meal and feed additives. Monthly milk yield was recorded by trained technicians of the Animal Breeding Center of Iran, according to the guidelines of the International Committee for Animal Recording (2011). Cows with unknown birth date, calving date, birth number, and parity number were omitted. First calving ages was calculated as the difference between the birth and first calving dates and was restricted to the range of 540 to 1200 d. Test-day records before 6 d or after 320 d of calving were excluded, and cows were required to have a minimum of five test-day records per lactation. Therefore, the final data set consisted of 691200 test-day records on 96263 lactations on first parity cows, 377696 test-day records of 52168 lactations on second parity cows, and 182143 test-day records on 24951 lactations on third parity cows distributed in 261 herds.

Trait definition

To describe the lactation curve, the incomplete gamma function proposed by Wood (1967) was used. The function was as follows:

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

Where:
y_t: daily milk yield in DIM t.
t: length of time since calving.
e: Neper number.
a: parameter to represent initial yield.
b and c: factors associated with the upward and downward slopes of the curve, respectively.

In this study, the incomplete gamma function was transformed logarithmically into a linear form as: $\ln(y_t) = \ln(a) + b\ln(t) - ct$, and fitted to monthly lactation yield records using a simple program written in Visual Basic (Microsoft Corp., Redmond, WA). The lactation persistency measure derived from the incomplete gamma function and was calculated as: $s = -(b+1)\ln(c)$ (Wood, 1967). The DIM at peak production (T_{max}) was defined as $T_{max} = (b.c)$, expected maximum yield (y_{max}) was calculated as $y_{max} = a(b.c)^b e^{-b}$, and 305-d milk yield was estimated as:

$$y_{305} = a\int_{1}^{305} t^b e^{-ct} dt$$

Typical lactation curves have positive *a*, *b*, and *c*, while curves with negative a, b, or c were considered atypical. The proportions of atypical lactation curve were 21.48, 20.71 and 19.91%, for cows in the first, second and third parity, respectively. The cows with atypical lactation curve were excluded from future analysis. The final data set consisted of 532081 test-day records on 75583 lactations on first parity cows, 297548 test-day records on 41364 lactations on second parity cows, and 142888 test-day records on 19984 lactations on third parity.

Statistical analysis

(Co)variance components for lactation curve traits (initial yield, upward and downward slopes of the curve, peak time, peak yield, lactation persistency, and 305- d milk yield were estimated using single and multiple-trait animal model. The linear model included fixed effects of herd-year-season (HYS), covariate effects of age at first calving (FCA) and total days in milk (DIM) in both linear and quadratic forms, as well as animal and residual random effects. The following repeatability animal model was used to estimate the repeatability of lactation curve traits:

$$y_{ijkl} = HYS_i + lac_j + a_k + pe_k + e_{ijkl}$$

Where:
y_{ijk}: record of animal k in j^{th} parity and belonged to i^{th} class of HYS effect.
HYS_i: fixed effect of herd-year-season of calving i.
lac: fixed effect of j^{th} parity.
a_k: random effect of animal k.
pe_k: random permanent environmental effect of animal k.
e_{ijk}: random residual error.

The genetic analyses were carried out through restricted maximum likelihood (REML) method using WOMBAT software (Meyer, 2006).

RESULTS AND DISCUSSION

General

A typical lactation curve has positive a, b, and c parameters, characterized by an initial phase that increases to a maximum and is followed by a declining phase. Lactation curve with negative values for a, b or c parameters is considered atypical. In this study, 21.48% of 96263 lactations in first parity, 20.71% of 52168 lactations in second parity and 19.91% of 24951 lactations in third parity were atypical. Rekik *et al.* (2003) reported 15 to 42% atypical curves in dairy herds of Tunisia. Ferris *et al.* (1985) reported 15% (of 5927 lactations) atypical curves in Holstein dairy cows of Michigan Dairy Herd Improvement. Atashi *et al.* (2006) and Tekerli *et al.* (2000) reported 17.7% (of 36487 lactations) and 26.3% (of 1278 lactations) atypical curves in Holstein dairy cows of Iran and Turkey, respectively. The time from parturition to the first recorded test was reported as the most important factor affecting the incidence of atypical lactation curves (Ferris *et al.* 1985; Macciotta *et al.* 2006). Variability in the quantity and quality of ration as well as physiological and health problems related to harsh environmental conditions (heat in summer) may lead to atypical lactation curves (Rekik and Gara, 2004).

The squared multiple correlation coefficient (R^2) of the log-transformed gamma function were 62.54 (±0.09), 75.75 (±0.10) and 77.25 (±0.13) for the first, second and third parity, respectively.

Heritability and repeatability

The estimated heritability (±SE) (diagonal), genetic correlations (upper off-diagonal) and phenotypic correlations (lower off-diagonal) for lactation curve traits in the first, second and third parity are presented in Tables 1, 2, and 3, respectively. The heritability for lactation curve traits in the first, second and third parity ranged from 0.012 (downward slope of the curve) to 0.29 (peak yield), 0.017 (initial yield) to 0.15 (305-d milk yield), and 0.02 (lactation persistency) to 0.13 (305-d milk yield), respectively. Ferris *et al.* (1985) reported that heritability of lactation curve traits ranged from 0.04 (lactation persistency) to 0.16 (305-d milk yield).

Shanks *et al.* (1981) reported that heritability of lactation curve traits in the first, second and third parity ranged from 0.23 (peak yield) to 0.02 (lactation persistency and peak time), 0.19 (peak yield) to -0.03 (lactation persistency) and 0.16 (peak yield) to -0.00 (lactation persistency), respectively. The maximum estimated heritability for initial yield, upward and downward slopes of the curve was found in the third parity, while for peak time, peak yield, lactation persistency and 305-d milk yield maximum estimated heritability was found in the first parity. Shanks *et al.* (1981) reported that the heritability of initial yield and peak yield decreased, but the heritability of upward slope of the curve increased with advancing parity.

The estimated repeatability for lactation curve traits are presented in Table 4, and ranged from 0.07 (initial yield, upward slope of the curve and lactation persistency) to 0.40 (305-d milk yield). The repeatability for peak (0.33) and 305-d milk yield (0.40) were higher than those for other lactation curve traits. Tekerli *et al.* (2000) reported that repeatability for peak (0.26) and 305-d milk yield (0.34) were higher than those for other lactation curve traits.

Phenotypic and genetic correlations

The genetic correlations among lactation curve traits in the first parity ranged from -0.68 (downward slope of the curve and peak time) to 0.99 (peak time and lactation persistency), while the phenotypic correlations ranged from -0.95 (initial yield and the upward slope of the curve) to +0.83 (peak time and lactation persistency). The genetic and phenotypic correlations among lactation curve traits in the second parity ranged from -0.84 (downward slope of the curve and peak time) to 0.98 (peak time and lactation persistency), and -0.94 (initial yield and the upward slope of the curve) to +0.85 (peak time and lactation persistency), respectively. The genetic correlation among lactation curve traits in the third parity ranged from -0.90 (initial yield and upward slope of the curve) to 0.94 (upward and downward slopes of the curve), while the phenotypic correlations ranged from -0.95 (initial yield and the upward slope of the curve) to +0.84 (peak time and lactation persistency). Similar results have been reported in earlier research (Rao and Sundaresan, 1979; Shanks *et al.* 1981; Ferris *et al.* 1985; Tekerli *et al.* 2000; Boujenane and Hilal, 2012). Shanks *et al.* (1981) reported that genetic correlations among lactation curve traits ranged from -0.98 (downward slope of the curve and lactation persistency) to 0.94 (peak time and lactation persistency). Ferris *et al.* (1985) reported that genetic correlations among lactation curve traits ranged from -0.91 (initial yield and upward slope of the curve) to 0.91 (peak and 305-d milk yield). The genetic correlations between initial yield and upward slopes of the curve were -0.54, -0.83 and -0.90 for the first three lactations, while the corresponding values for phenotypic correlations were -0.95, -0.94, and -0.95, respectively. These negative strong correlation between initial yield and upward slope of the curve (-0.90 to -0.54) suggest that cow with a higher initial level of production would have a lower rate of increase until the peak. The genetic correlations between upward and downward slopes of the curve were 0.55, 0.91 and 0.94 for the first, second and third lactations, while the corresponding values for phenotypic correlations were 0.82, 0.83, and 0.84, respectively. The positive correlations between upward and downward slopes of the curve indicate that cows with a higher rate of increase until the peak would have a quicker decline after peak. Ferris *et al.* (1985) reported that genetic and phenotypic correlations between upward and downward slopes of the curve were 0.73 and 0.79, respectively.

Table 1 Heritability (±SE) (diagonal), genetic correlation (upper off-diagonal) and phenotypic correlation (lower off-diagonal) among lactation curve traits for first parity

Item	Ln (a)	b	c	Peak time	Peak yield	Persistency	305-d milk
Ln (a)[1]	0.018 (±0.003)	-0.54	-0.35	-0.12	0.64	-0.15	0.62
b[1]	-0.95	0.012 (±0.003)	0.55	0.24	0.28	0.34	0.22
c[1]	-0.68	0.82	0.022 (±0.004)	-0.68	-0.14	-0.60	-0.30
Peak time[2]	-0.38	0.24	-0.22	0.06 (±0.006)	0.45	0.99	0.60
Peak yield[3]	0.09	0.17	0.16	0.001	0.29 (±0.012)	0.50	0.98
Persistency[4]	-0.60	0.50	0.01	0.83	0.04	0.05 (±0.005)	0.63
305-d milk[5]	0.36	-0.22	-0.40	0.24	0.82	0.18	0.28 (±0.001)

[1] The a, b, and c characterize initial yield, upward slope of the curve and downward slopes of the curve, respectively.
[2] The time of peak calculated as: $T_{max} = \frac{b}{c}$.
[3] Peak yield calculated as: $y_{max} = a(\frac{b}{c})^b e^{-b}$.
[4] lactation persistency calculated as: $s = -(b+1)\ln(c)$.
[5] 305-d milk yield calculated as: $y_{305} = a\int_1^{305} t^b e^{-ct} dt$.

Table 2 Heritability (±SE) (diagonal), genetic correlation (upper off-diagonal) and phenotypic correlation (lower off-diagonal) among lactation curve traits for second parity

Item	Ln (a)	b	c	Peak time	Peak yield	Persistency	305-d milk
Ln (a)[1]	0.017 (±0.004)	-0.83	-0.74	0.48	0.45	0.38	0.76
b[1]	-0.94	0.022 (±0.005)	0.91	-0.58	0.10	-0.40	-0.44
c[1]	-0.68	0.83	0.06 (±0.007)	-0.84	-0.06	-0.73	-0.62
Peak time[2]	-0.53	0.37	-0.08	0.04 (±0.006)	0.30	0.98	0.76
Peak yield[3]	0.14	0.16	0.20	-0.89	0.10 (±0.01)	0.34	0.81
Persistency[4]	-0.75	0.66	0.20	0.85	-0.01	0.03 (±0.005)	0.75
305-d milk[5]	0.44	-0.32	-0.50	0.18	0.70	0.08	0.15 (±0.001)

[1] The a, b, and c characterize initial yield, upward slope of the curve and downward slopes of the curve, respectively.
[2] The time of peak calculated as: $T_{max} = \frac{b}{c}$.
[3] Peak yield calculated as: $y_{max} = a(\frac{b}{c})^b e^{-b}$.
[4] lactation persistency calculated as: $s = -(b+1)\ln(c)$.
[5] 305-d milk yield calculated as: $y_{305} = a\int_1^{305} t^b e^{-ct} dt$.

Table 3 Heritability (±SE) (diagonal), genetic correlation (upper off-diagonal) and phenotypic correlation (lower off-diagonal) among lactation curve traits for third parity

Item	Ln (a)	b	c	Peak time	Peak yield	Persistency	305-d milk
Ln (a)[1]	0.03 (±0.008)	-0.90	-0.77	0.38	0.40	-0.06	0.80
b[1]	-0.95	0.03 (±0.008)	0.94	-0.63	0.009	-0.17	-0.62
c[1]	-0.70	0.84	0.08 (±0.012)	-0.83	0.02	-0.48	-0.67
Peak time[2]	-0.55	0.40	-0.03	0.04 (±0.009)	0.08	0.87	0.66
Peak yield[3]	0.12	0.14	0.20	-0.08	0.09 (±0.013)	-0.01	0.72
Persistency[4]	-0.83	0.75	0.32	0.83	0.0003	0.02 (±0.007)	0.41
305-d milk[5]	0.44	-0.34	-0.50	0.17	0.70	0.17	0.13 (±0.001)

[1] The a, b, and c characterize initial yield, upward slope of the curve and downward slopes of the curve, respectively.
[2] The time of peak calculated as: $T_{max} = \frac{b}{c}$.
[3] Peak yield calculated as: $y_{max} = a(\frac{b}{c})^b e^{-b}$.
[4] lactation persistency calculated as: $s = -(b+1)\ln(c)$.
[5] 305-d milk yield calculated as: $y_{305} = a\int_1^{305} t^b e^{-ct} dt$.

Table 4 Repeatability and standard error (SE) of lactation curve traits

Item	Repeatability	SE
Ln (a)[1]	0.07	0.006
b[1]	0.07	0.006
c[1]	0.12	0.005
Peak time[2]	0.11	0.006
Peak yield[3]	0.33	0.005
Persistency[4]	0.07	0.006
305-d milk yield[5]	0.40	0.001

[1] The a, b, and c characterize initial yield, upward slope of the curve and downward slopes of the curve, respectively.
[2] The time of peak calculated as: $T_{max} = \frac{b}{c}$.
[3] Peak yield calculated as: $y_{max} = a(\frac{b}{c})^b e^{-b}$.
[4] lactation persistency calculated as: $s = -(b+1)\ln(c)$.
[5] 305-d milk yield calculated as: $y_{305} = a\int_1^{305} t^b e^{-ct} dt$.

Tekerli *et al.* (2000) reported that phenotypic correlation between upward and downward slopes of the curve in Turkish Holstein is 0.76. The genetic correlations between lactation persistency and 305-d milk yield were 0.63, 0.75, and 0.41 for first, second and third parity, respectively. The moderate genetic positive correlations between initial yield and peak yield indicate that cows with higher yield at the beginning of lactation would have higher yield at peak. The moderate positive genetic correlations between peak time and peak yield suggest that cows that reach peak yield later during lactation would have higher peak yield.

The strong positive genetic correlations between peak time and lactation persistency (ranged from 0.99 to 0.87) indicate that cows that reach peak yield later during lactation would have higher lactation persistency. The genetic correlations between 305-d milk yield and peak yield was 0.98, 0.81 and 0.72 for the first, second and third lactation, respectively.

Tekerli *et al.* (2000) reported that phenotypic correlation between 305-d milk yield and peak yield in Turkish Holstein is 0.78. Ferris *et al.* (1985) reported that genetic and phenotypic correlations between 305-d milk yield and peak yield are 0.91 and 0.85, respectively. The larger genetic correlations between peak yield and 305-d milk yield compared with those between lactation persistency and 305-d milk yield indicates that peak yield is more important in determining the 305-d milk yield than is persistency. The genetic correlation between lactation persistency and downward slope of the curve for first, second and third parity were -0.60, -0.73 and -0.48, respectively. These genetic correlations indicate that cows with larger downward slope of the curve are less persistent.

The lactation persistency depends on downward slope of the curve and increases as downward slope of the curve decreases (Ferris *et al.* 1985).

The heritability of peak yield and its genetic correlation with 305-d milk yield indicates that increasing peak yield will strongly increase 305-d milk yield as well. Ferris *et al.* (1985) reported that selecting for peak yield increased 305-d milk yield as much as direct selecting for 305-dmilk did (142 *vs.* 163 kg). Atashi *et al.* (2012) reported that the average 305-d milk yield increased by 173.5 (±0.8) kg for every extra kg of peak yield. The genetic correlations between 305-d milk yield with peak yield, upward slope and downward slope of the curve decreased with advancing parity, but correlations between 305-d milk yield and initial yield increased. However, genetic correlations between 305-d milk yield with lactation persistency and peak time showed no consistent trend across parities.

Phenotypic and genetic trends

The lactation curves for first parity cows born in 2000 and for those born in 2009 are presented in Figure 1, which explain phenotypic trend of lactation curve shape in Holstein cows in Iran.

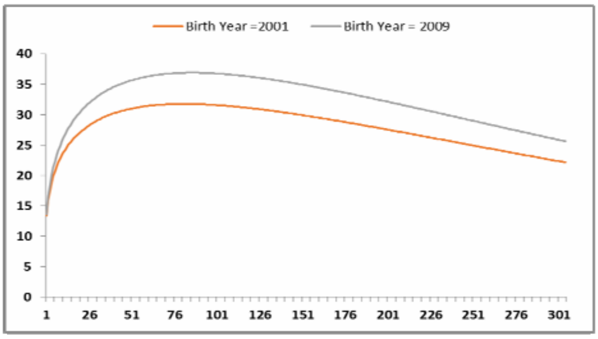

Figure 1 Lactation curves for first parity cows born in 2001 and for those born in 2009

Phenotypic trends for lactation curve traits in first parity cows are presented in Figure 2.

Figure 2 Phenotypic trends for lactation curve traits (initial yield, upward and downward slopes of the curve, peak time, peak yield, lactation persistency, and 305-d milk) for first parity cows born from 2001 to 2009

In the period from 2001 to 2009, initial yield, upward slope of the curve, lactation persistency, peak yield and 305-d milk yield significantly increased ($P<0.05$), but downward slope of the curve and peak time did not significantly changed ($P\geq0.05$). Phenotypic trends for 305-d milk yield and peak yield were more straightforward than those for initial yield, upward slope of the curve and lactation persistency.The additive genetic trends for lactation curve traits in first parity cows, given as average additive genetic solutions per birth year were presented in Figure 3.

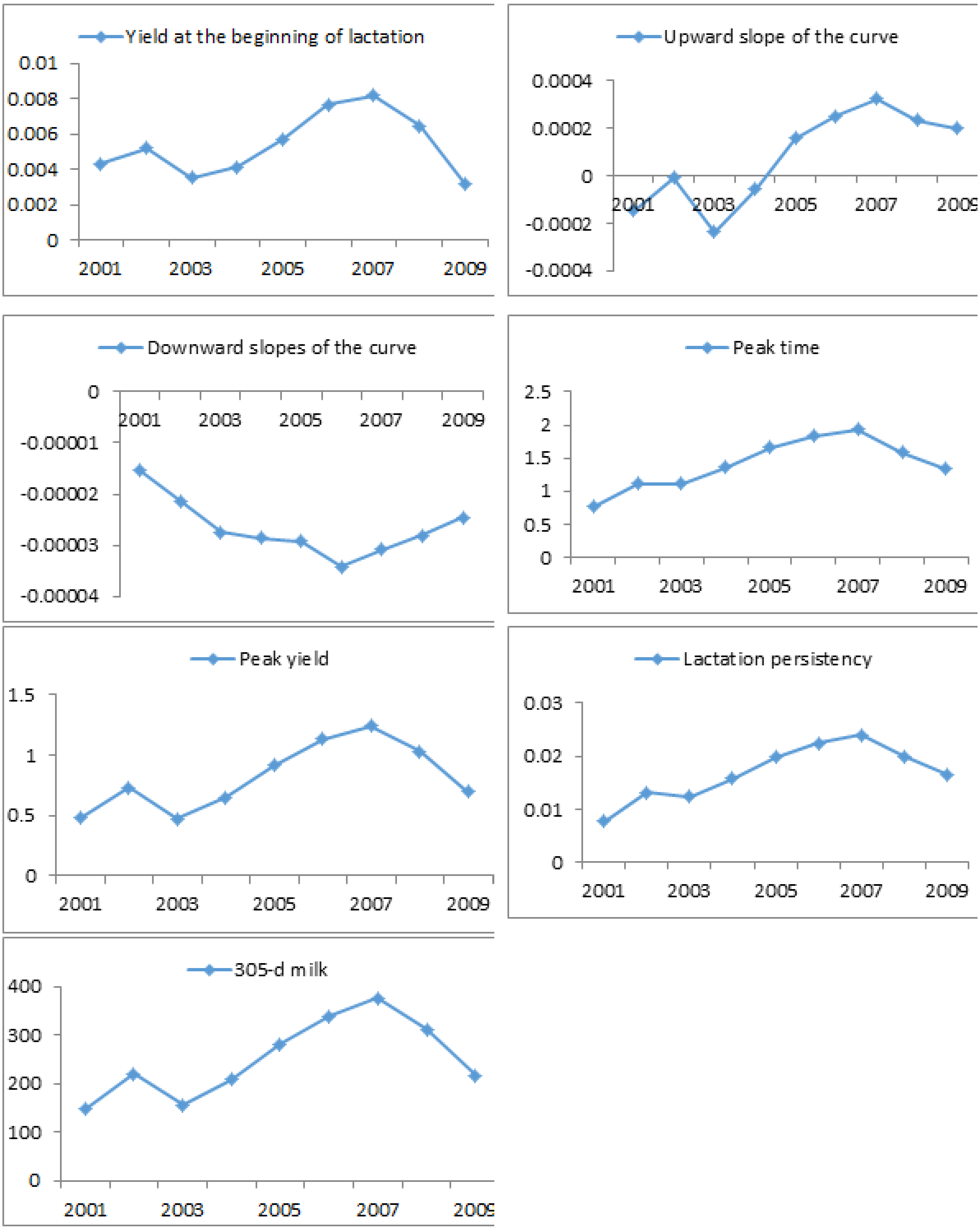

Figure 3 Genetic trends for lactation curve traits (initial yield, upward and downward slopes of the curve, peak time, peak yield, lactation persistency, and 305-d milk) for first parity cows born from 2001 to 2009

In the period from 2001 to 2009, upward slope of the curve, lactation persistency, peak time, peak yield and 305-d milk yield increased and showed significant genetic trend ($P<0.05$), but initial yield and downward slope of the curve showed no significant genetic trend ($P\geq0.05$).

Initial yield, peak yield, and 305-d milk yield showed same phenotypic and genetic trends, because there are strong phenotypic and genetic correlations among these traits. Ferris *et al.* (1985) compared the change of lactation curve characteristics after one generation of selection for

305-d milk yield and the characteristic alone. They reported that percent correlated change relative to change when selecting for initial yield, upward slope, downward slope, peak time, peak yield, and lactation persistency were -160, 52.2, 0.41, -13, 95 and 114%, respectively (Ferris *et al.* 1985).

CONCLUSION

The genetic correlations between initial yield, downward slope of the curve, lactation persistency and peak yield with 305-d milk yield indicate that cows that have a higher initial level of production, higher peak yield, higher lactation persistency and decline at a slower rate would have a higher 305-d milk yield. The moderate to large positive genetic correlations of 305-d milk yield with initial yield, peak yield and lactation persistency suggest that one of these traits could be used as a selection criterion to improve all four traits. However, the peak yield and 305-d milk yield are more heritable than lactation persistency and initial yield.

ACKNOWLEDGEMENT

The co-operation of the Animal Breeding Center (Karaj, Iran) for providing the data is greatly appreciated.

REFERENCES

Angeles-Hernandez J.C., Albarran-Portillo B., Gonzalez A.G., Salas N.P. and Gonzalez-Ronquillo M. (2013). Comparison of mathematical models applied to f1 dairy sheep lactations in organic farm and environmental factors affecting lactation curve parameter. *Asian-Australasian J. Anim. Sci.* **26,** 1119-1126.

Atashi H., Moradi-Sharbabak M. and Abdolmohammadi A. (2006). Study of some suggested measures of milk yield persistency and their relationships. *Int. J. Agric. Biol.* **8,** 387-390.

Atashi H., Zamiri M.J. and Sayyadnejad M.B. (2012). Effect of twinning and stillbirth on the shape of lactation curve in Holstein dairy cows of Iran. *Arch. Tierz.* **55,** 226-233.

Boujenane I. and Hilal B. (2012). Genetic and non genetic effects for lactation curve traits in Holstein-Friesian cows. *Arch. Tierz.* **55,** 450-457.

Ferris T.A., Mao L.L. and Anderson C.R. (1985). Selecting for lactation curve and milk yield in dairy cattle. *J. Dairy Sci.* **68,** 1438-1448.

International Committee for Animal Recording. (2011). Standards and guidelines for recording milk and milk constituents. Section 2.1, Pp. 23-56, in International Committee for Animal Recording (ICAR) Rules. Guidelines approved by the General Assembly held in Riga, Riga, Latvia.

Keown J.F., Everett R.W., Empet N.B. and Wadell L.H. (1986). Lactation curves. *J. Dairy Sci.* **69,** 769-781.

Macciotta N.P.P., Dimauro C., Catillo A., Coletta A. and Cappio-Borlino A. (2006). Factors affecting individual lactation curve shape in Italian river buffaloes. *Livest. Sci.* **104,** 33-37.

Macciotta N.P.P., Vicario D. and Cappio-Borlino A. (2005). Detection of different shapes of lactation curve for milk yield in dairy cattle by empirical mathematical models. *J. Dairy Sci.* **88,** 1178-1191.

Meyer K. (2006). WOMBAT–A Program for Mixed Model Analyses by Restricted Maximum Likelihood. User Notes. Animal Genetics and Breeding Unit, Armidale, Australia.

Rao M.K. and Sundaresan D. (1979). Influence of environment and heredity on the shape of lactation curves in Sahiwal cows. *J. Agric. Sci.* **92,** 393-401.

Rekik B. and Gara A.B. (2004). Factors affecting the occurrence of atypical lactations for Holstein-Friesian cows. *Livest. Prod. Sci.* **87,** 245-250.

Rekik B., Gara A.B., Hamouda M.B. and Hammami H. (2003). Fitting lactation curves of dairy cattle in different types of herds in Tunisia. *Livest. Prod. Sci.* **83,** 309-315.

Schmidt G.H. and Van Vleck L.D. (1974). Principles of Dairy Science. Freeman and Company, San Francisco, California.

Shanks R.D., Berger P.J., Freeman A.E. and Dickinson F.N. (1981). Genetic aspects of lactation curves. *J. Dairy Sci.* **64,** 1852-1860.

Tekerli M., Akinci Z., Dogan I. and Akcan A. (2000). Factors affecting the shape of lactation curve of Holstein cows from the Balikrsir province of Turkey. *J. Dairy Sci.* **83,** 1381-1386.

Togashi K. and Lin C.Y. (2003). Modifying the lactation curve to improve lactation milk and persistency. *J. Dairy Sci.* **86,** 1487-1493.

Wood P.D.P. (1967). Algebraic model of the lactation curve in cattle. *Nature.* **216,** 164-165.