Phenotypic Study of Lactation Curve in Iranian Holsteins

H. Farhangfar1* and H. Naeemipour1

ABSTRACT

A total of 136,250 monthly test day milk records collected from 13,625 Iranian Holstein heifers (three times a day milking) calved between 1991 and 2001 and distributed over 264 herds were used to study the effects of some environmental factors influencing lactation curve parameters as well as production characteristics. Wilmink’s function \(Y_t = W_0 + W_1t + W_2e^{-0.05t}\) was fitted to individual lactations. Least squares analysis of variance indicated that the herd, year and month of calving had a significant effect on all traits under consideration. Correlation analysis showed that the parameter \(W_0\) had a negative and significant \((p<0.05)\) relationship with parameters \(W_1\) and \(W_2\) while it was positively significantly correlated with milk at peak time and 305-day milk yield. Simple linear regression analysis of adjusted means of a 305-day milk yield, days to reach peak yield as well as peak milk yield in the first year of calving also revealed that there was a phenotypic increase of 137.152 Kg, 0.535 day and 0.434 Kg per year, respectively.

Keywords: Iranian Holsteins, Lactation curve, Wilmink’s function.

INTRODUCTION

The production of milk and its components varies during different months of milking. Moreover, milk production traits follow a curvilinear pattern over the course of lactation. Knowledge of the lactation curve can provide a worthwhile information source about the pattern of milk production traits which, in turn, could be used for herd management decisions (Perochon et al., 1996). To model the lactation curve of dairy cows, mechanistic and empirical approaches can be used (Perochon et al., 1996). In most practical situations, the empirical method is preferred over the mechanistic method due to the fact that the former is based on the shape of the lactation curve while the latter is based upon the metabolism of udder tissues. On this basis, many studies have been undertaken over the past three decades to apply different mathematical models to obtain more accurate prediction of the shape of the lactation curve.

Recently there, has been considerable interest in using test day models to analyse individual test day records for the genetic evaluation of dairy cows as a replacement for the traditional use of estimating accumulated 305-day lactation yields in a lactation model. Canada, for example, has officially adopted and implemented a random regression test day model in 1999 to replace the lactation model (Schaeffer et al., 2000). In a practical situation, as genetic evaluation of dairy cattle is undertaken using monthly test day records in a test day model, parametric models like Wilmink’s or polynomial regression functions (Jamrozik and Schaeffer, 1997; Jamrozik et al., 1997; Kaya et al., 2003) or Orthogonal Legendre Polynomials in covariance function (Meyer and Hill, 1997; Druet et al., 2003) could be used in the model (as fixed and random regressions) to take account of the shape of the lactation curve for individual cows at the genetic level. However, particular attention should

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be given to the number of monthly test day records available for each cow. This is due to the fact that the accuracy of estimation of genetic parameters and prediction of breeding values is affected to a great extent by the number of test day records available for each cow during lactation.

It has been well documented that the lactation curve is influenced by environmental factors such as the herd, year of calving, parity, age of calving and season of calving (Wood, 1976; Congleton and Everett, 1980; Danell, 1982; Grossman et al., 1986; Keown et al., 1986, Tekerli et al., 2000). Cows that are raised in higher yielding herds have higher peak production and more persistency when compared with low production herd cows (Keown et al., 1986). The lactation curve is also influenced by seasonal variations. For instance, cows calving in late Spring or at the beginning of Summer have a lactation curve which reaches a lower peak level than winter calvers (Wood, 1969; Rao and Sundaresan, 1979; Poso et al., 1996). The main objective of the present research was to analyse some environmental factors influencing lactation curve parameters for Iranian Holstein heifers as well as their production characteristics by fitting Wilmink’s function to monthly test day milk yields. Furthermore, adjusted phenotypic trends for all the traits under consideration will also be obtained.

MATERIALS AND METHODS

An initial data set consisting of 457,576 first lactation monthly test day milk records was obtained from the Animal Breeding Centre of Iran. The data was subsequently edited on the basis of the number of monthly test days (during the lactation period) and interval between consecutive test days for individual cows (three times a day milking). The interval between consecutive test days was set up to be a maximum of 60 days. Furthermore, from a computational point of view, only cows with a complete first lactation which had 10 monthly test day records were utilized to obtain a better estimation of the lactation curve parameters for individual cows. The final data set consisted of 136,250 monthly test day milk yields belonging to 13,625 first lactations of Iranian Holstein heifers from 264 herds that calved from 1991 to 2001. Some descriptive statistics of data are presented in Table 1.

To describe the lactation curve and associated production characteristics, Wilmink’s function (Wilmink, 1987) was applied in this study. The function is as follows:

\[
y_t = W_0 + W_1 t + W_2 (Exp)^{-W_0 t}
\]

where:

- \(t\) is days in milk,
- \(y_t\) is milk yield in Kg at day \(t\),
- \(W_0\) is associated with the level of production,
- \(W_1\) is associated with production decrease after peak yield, and
- \(W_2\) is associated with production increase towards peak yield.

The parameters of Wilmink’s function (\(W_0, W_1\) and \(W_2\)) were estimated for individual lactations by applying the REG procedure of

<table>
<thead>
<tr>
<th>Month of lactation</th>
<th>Days in milk (d)</th>
<th>Daily milk yield (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>13.68</td>
<td>6.64</td>
</tr>
<tr>
<td>2</td>
<td>44.15</td>
<td>6.53</td>
</tr>
<tr>
<td>3</td>
<td>74.41</td>
<td>6.77</td>
</tr>
<tr>
<td>4</td>
<td>104.87</td>
<td>6.55</td>
</tr>
<tr>
<td>5</td>
<td>135.18</td>
<td>6.78</td>
</tr>
<tr>
<td>6</td>
<td>165.66</td>
<td>6.58</td>
</tr>
<tr>
<td>7</td>
<td>195.95</td>
<td>6.79</td>
</tr>
<tr>
<td>8</td>
<td>226.43</td>
<td>6.60</td>
</tr>
<tr>
<td>9</td>
<td>256.72</td>
<td>6.84</td>
</tr>
<tr>
<td>10</td>
<td>287.14</td>
<td>6.67</td>
</tr>
</tbody>
</table>
Phenotypic Study of Lactation Curve in Iranian Holsteins __________________________

Based on the estimated lactation curve parameters, some production characteristics including peak time (PT), peak milk yield (PM), milk yields at days 60 (M60) and 280 (M280) and total 305-day milk yield (TM305) were also calculated for individual cows as follows:

\[
PT = -20(\ln \frac{20W_1}{W_2})
\]

\[
PM = \hat{W}_0 + \hat{W}_1(-20(\ln \frac{20W_1}{W_2}))+\hat{W}_2e^{0.05(60)}
\]

\[
M60 = \hat{W}_0 + \hat{W}_1(60)+\hat{W}_2e^{0.05(60)}
\]

\[
M280 = \hat{W}_0 + \hat{W}_1(280)+\hat{W}_2e^{0.05(280)}
\]

\[
TM305 = 305\hat{W}_0 + 46665\hat{W}_1 + 19.50416\hat{W}_2
\]

In order to analyse the effects of environmental factors including the herd, year of calving, month of calving and age at first calving a fixed linear model was fitted on estimated lactation curve parameters and production characteristics. Due to the highly unbalanced data, no attempt was made to fit all two- and three-way interactions in to the model. Least squares analyses of variance were undertaken by the use of the GLM procedure (General Linear Model) of the SAS software (SAS, 1989). The linear model was as follows:

\[
y_{ijk} = \mu + (\text{herd}_i) + (\text{year}_j) + (\text{month}_k) + \sum_{n=1}^{2} \beta_n [(\text{age}_{ijk})^n - (\bar{a}^n)] + e_{ijk}
\]

where:

\(y_{ijk}\) is the value of the considered trait \(W_0, W_1, W_2, PT, PM, M60, M280\) and \(TM305\) affected by the \(i^{th}\) herd, \(j^{th}\) year of calving, \(k^{th}\) month of calving and covariable of age at calving.

\(\mu\) is the overall mean for each trait, \(\text{herd}_i\) is the fixed effect of the \(i^{th}\) herd \((i=1\ to\ 264)\), \(\text{year}_j\) is the fixed effect of the \(j^{th}\) year of calving \((j=1\ to\ 11)\), \(\text{month}_k\) is the fixed effect of the \(k^{th}\) month of calving \((k=1\ to\ 12)\), \(\beta_n\) is linear and quadratic regression coefficients of \(\text{age}_{ijk}\), \(e_{ijk}\) is the random effect of residual with expectation and variance equal to 0 and \(\sigma^2\) respectively.

Least squares means of year and month of calving for individual traits were obtained along with analysis of variance using LSMEANS option. Pearson correlation coefficients \((r)\) among eight traits were calculated using SAS software (SAS, 1989). Tests of significance were also performed under \(H_0: \rho = 0\).

RESULTS AND DISCUSSION

Overall means of \(W_0, W_1, W_2, PT, PM, M60, M280, TM305\) and PT were 31.67, -0.032, -15.880, 29.13, 28.93, 22.60, 7839 Kg and 64.94 days, respectively. The results of least squares analysis are presented in Table 2.

Table 2. Sum of squares values resulting from least squares analysis of variance of lactation curve parameters as well as production characteristics for the environmental factors fitted in the GLM.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Trait</th>
<th>Herd</th>
<th>Year</th>
<th>Month</th>
<th>Age (Linear)</th>
<th>Age (Quadratic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(W_0)</td>
<td>86670***</td>
<td>11549***</td>
<td>6098***</td>
<td>718***</td>
<td>399***</td>
<td></td>
</tr>
<tr>
<td>(W_1)</td>
<td>0.3168***</td>
<td>0.0077*</td>
<td>0.0883***</td>
<td>0.0037**</td>
<td>0.0020*</td>
<td></td>
</tr>
<tr>
<td>(W_2)</td>
<td>98164***</td>
<td>3965***</td>
<td>18715***</td>
<td>186Ns</td>
<td>77Ns</td>
<td></td>
</tr>
<tr>
<td>(PT)</td>
<td>265250***</td>
<td>20913***</td>
<td>41052***</td>
<td>2779**</td>
<td>2406*</td>
<td></td>
</tr>
<tr>
<td>(PM)</td>
<td>73928***</td>
<td>11623***</td>
<td>3984***</td>
<td>513***</td>
<td>286***</td>
<td></td>
</tr>
<tr>
<td>(M60)</td>
<td>73129***</td>
<td>11464***</td>
<td>3998***</td>
<td>505***</td>
<td>284***</td>
<td></td>
</tr>
<tr>
<td>(M280)</td>
<td>71566***</td>
<td>14463***</td>
<td>5596***</td>
<td>94**</td>
<td>55Ns</td>
<td></td>
</tr>
<tr>
<td>(TM305)</td>
<td>6085289482***</td>
<td>1133076573***</td>
<td>311008426***</td>
<td>25662663***</td>
<td>14709182***</td>
<td></td>
</tr>
</tbody>
</table>

\(a\) parameters of Wilmink’s function; \(b\) Peak time; \(c\) Peak milk; \(d\) Milk yield at day 60; \(e\) Milk yield at day 280 and \(f\) Milk yield for 305 days.

Ns: Non significant.
squares analysis of variance for all eight traits are presented in Table 2. As can be seen, all analysed traits were significantly affected by the herd, year and month of calving. However, the year of calving affected parameter \( W_1 \) only on a probability level of \( P<0.05 \). The linear effect of age at first calving significantly influenced all traits except parameter \( W_2 \) which is associated with increased production towards peak yield. The quadratic order of first calving age in the model had no significant effect on parameter \( W_2 \) and \( M_{280} \) while it was significant for the other traits.

The results also revealed that the herd effect had the greatest contribution from the total sum of squares. In contrast, the age at first calving when fitted as a quadratic effect had the lowest proportion of total variation in all traits. Hence, the herd and age at first calving are considered to be the most and the least important factors, respectively, influencing lactation curve parameters and production characteristics.

Least squares means of month of calving for individual traits are presented in Table 3. For month of calving, the lowest \( W_0 \) (level of production) occurred for cows calved between April to October. The highest levels of production were found for cows calved between November to March. These results revealed that cows calved from August to November had the lowest rate of production decrease after peak yield (\( W_1 \)). In contrast, cows calved between February to March had the highest rate of production decrease after peak yield and are considered to be more persistent. Parameter \( W_2 \), which is associated with production increase towards peak yield, was found to be lower for cows calved during May to September than that of cows calved during October to April.

The results showed that cows calved from January to August reached earlier peak yield during lactation. On the other hand, the highest number of days needed to attain peak production was found for cows calved in October where by cows had a lower rate of decrease of production after peak yield towards the end of the lactation course. Peak milk yield (PM) at each month of calving was generally greater than milk yield at 60 days of lactation (\( M_{60} \)) and both the same changes during different months of calving such that cows calved during May to September were found to have lower PM and \( M_{60} \) than that of cows calved during October to April. The results also indicated that cows calved in Spring and Summer (from April to September) produced lower total lactation milk yield (TM305) than that of cows calving during Autumn and Winter seasons.

Pearson product moment correlation coefficients among the lactation curve parameters and production characteristics are given...

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**Table 3. Least squares means for month of calving.**

<table>
<thead>
<tr>
<th>Month of calving</th>
<th>( W_0^a )</th>
<th>( W_1^a )</th>
<th>( W_2^a )</th>
<th>PT ( ^b )</th>
<th>PM ( ^c )</th>
<th>( M_{60}^d )</th>
<th>( M_{280}^e )</th>
<th>TM305 ( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>30.45</td>
<td>-0.0324</td>
<td>-14.616</td>
<td>62.20</td>
<td>27.94</td>
<td>27.78</td>
<td>21.37</td>
<td>7490</td>
</tr>
<tr>
<td>Feb</td>
<td>30.47</td>
<td>-0.0342</td>
<td>-15.086</td>
<td>61.41</td>
<td>27.84</td>
<td>27.67</td>
<td>20.90</td>
<td>7404</td>
</tr>
<tr>
<td>Mar</td>
<td>30.67</td>
<td>-0.0354</td>
<td>-14.463</td>
<td>61.02</td>
<td>28.00</td>
<td>27.83</td>
<td>20.77</td>
<td>7423</td>
</tr>
<tr>
<td>Apr</td>
<td>29.87</td>
<td>-0.0349</td>
<td>-13.585</td>
<td>59.36</td>
<td>27.25</td>
<td>27.10</td>
<td>20.10</td>
<td>7217</td>
</tr>
<tr>
<td>May</td>
<td>29.30</td>
<td>-0.0329</td>
<td>-12.895</td>
<td>59.99</td>
<td>26.84</td>
<td>26.68</td>
<td>20.09</td>
<td>7150</td>
</tr>
<tr>
<td>Jun</td>
<td>29.23</td>
<td>-0.0324</td>
<td>-11.881</td>
<td>58.99</td>
<td>26.85</td>
<td>26.70</td>
<td>20.17</td>
<td>7175</td>
</tr>
<tr>
<td>Jul</td>
<td>29.13</td>
<td>-0.0317</td>
<td>-12.025</td>
<td>60.02</td>
<td>26.82</td>
<td>26.63</td>
<td>20.25</td>
<td>7171</td>
</tr>
<tr>
<td>Sep</td>
<td>28.93</td>
<td>-0.0271</td>
<td>-11.826</td>
<td>63.27</td>
<td>26.90</td>
<td>26.72</td>
<td>21.36</td>
<td>7333</td>
</tr>
<tr>
<td>Oct</td>
<td>29.58</td>
<td>-0.0279</td>
<td>-13.060</td>
<td>64.53</td>
<td>27.43</td>
<td>27.25</td>
<td>21.76</td>
<td>7465</td>
</tr>
<tr>
<td>Nov</td>
<td>30.27</td>
<td>-0.0298</td>
<td>-13.527</td>
<td>63.61</td>
<td>27.99</td>
<td>27.81</td>
<td>21.93</td>
<td>7581</td>
</tr>
<tr>
<td>Dec</td>
<td>30.49</td>
<td>-0.0314</td>
<td>-14.636</td>
<td>63.98</td>
<td>28.04</td>
<td>27.87</td>
<td>21.70</td>
<td>7549</td>
</tr>
</tbody>
</table>

\( a \) parameters of Wilmink’s function; \( b \) Peak time; \( c \) Peak milk; \( d \) Milk yield at day 60; \( e \) Milk yield at day 280 and \( f \) Milk yield for 305 days.
in Table 4. The results showed that parameter $W_0$, which is associated with the level of production, was negatively correlated with $W_1$, $W_2$ and peak time while it was positively correlated with peak yield, milk yields at days 60 and 280 as well as total lactation milk yield. Negative correlations were found between the parameter related to the production increase before peak yield and PT, PM, M60, M280 and TM305. The parameter $W_1$ had negative correlations with peak yield and milk yield at day 60 while it was positively correlated with $W_2$, peak time and milk yield at day 280. No significant (P>0.05) correlation was obtained between the lactation parameter $W_1$ and total lactation milk yield. Peak time had positive and significant (P<0.001) correlations with milk yield at day 280 and total lactation milk yield. The correlation analysis revealed that milk yield at peak time had a positive correlation with M280 and very high positive correlations with M60 and TM305. Milk yields at days 60 and 280 were also strongly positively correlated with total lactation milk yield.

On the basis of adjusted means for the year of calving, phenotypic trends for each trait were calculated using simple linear regression analysis. The results obtained from the regression analysis showed that total lactation milk yield had an annual increase of 137.152 Kg (P<0.001) during 1991-2001. At the same time, the number of days needed to reach peak yield also showed a significant (P<0.001) annual increase of 0.535 days.

**Table 4.** Pearson product moment correlations (r) between lactation curve parameters and production characteristics.

<table>
<thead>
<tr>
<th>Trait</th>
<th>$W_0^a$</th>
<th>$W_1^a$</th>
<th>$W_2^a$</th>
<th>PT $^b$</th>
<th>PM $^c$</th>
<th>M60 $^d$</th>
<th>M280 $^e$</th>
<th>TM305 $^f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_0^a$</td>
<td>1.000</td>
<td>-0.556***</td>
<td>-0.465***</td>
<td>-0.070***</td>
<td>0.975***</td>
<td>0.976***</td>
<td>0.519***</td>
<td>0.830***</td>
</tr>
<tr>
<td>$W_1^a$</td>
<td>1.000</td>
<td>0.318***</td>
<td>0.525***</td>
<td>-0.371***</td>
<td>-0.376***</td>
<td>0.422***</td>
<td>-0.008ns</td>
<td></td>
</tr>
<tr>
<td>$W_2^a$</td>
<td>1.000</td>
<td>-0.430***</td>
<td>-0.375***</td>
<td>-0.365***</td>
<td>-0.179***</td>
<td>-0.242***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT $^b$</td>
<td>1.000</td>
<td>0.011ns</td>
<td>0.001ns</td>
<td>0.464***</td>
<td>0.194***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM $^c$</td>
<td>1.000</td>
<td>0.999***</td>
<td>0.682***</td>
<td>0.930***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M60 $^d$</td>
<td>Symmetric</td>
<td>1.000</td>
<td>0.678***</td>
<td>0.929***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M280 $^e$</td>
<td></td>
<td>1.000</td>
<td>0.897***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TM305 $^f$</td>
<td></td>
<td></td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$parameters of Wilmink’s function; $^b$Peak time; $^c$Peak milk; $^d$Milk yield at day 60; $^e$Milk yield at day 280 and $^f$Milk yield for 305 days.

**Figure 1.** Phenotypic trends for 305-day milk yield (+137.152 Kg/year) and peak time (+0.535 day/year) in Iranian Holstein heifers over 11 years of calving.
(Figure 1). Phenotypic trends calculated for $W_0$, $W_1$, $W_2$, PM, M60, M280 were 0.428 Kg ($P<0.001$), 0.0002 ($P<0.05$), -0.157 ($P<0.01$), 0.434 Kg ($P<0.001$), 0.433 Kg ($P<0.001$) and 0.486 Kg ($P<0.001$) respectively.

CONCLUSION

Wilmink’s function was used to evaluate the effects of some environmental factors affecting lactation curve parameters as well as some production characteristics of Iranian Holstein cows at first lactation. Thus far, some research has been carried out to analyse phenotypic and genetic aspects of the lactation curve using Wilmink’s function. In accordance with the findings of Dedkova and Nemcova (2003), the year and month of calving had significant effects on most of the traits under consideration; the herd also affected all traits significantly. With regard to the continuous distribution of the calving, age of this environmental factor was also fitted in the GLM as a covariate (as applied by Visscher et al., 1991; Visscher and Thompson, 1992; Baffour-Awuah et al., 1996; Strabel and Szwaczkowski, 1999; Ojango and Pollott, 2001) and had a significant effect on all traits except the parameter $W_2$.

The results obtained from a correlation analysis of the traits in the present study indicated that milk yield at the peak time is strongly correlated at the phenotypic level with total lactation milk yield. However, a genetic study will have to be undertaken to see how closely these traits are genetically correlated as well as the magnitude of their heritabilities. A large positive genetic correlation between 305-day and peak milk yield was also found in most studies (Ferris et al., 1985; Rekaya et al., 2000). Peak time was also correlated with 305-day milk yield. Therefore, direct selection for total lactation yield would be expected to result in lactations with a higher peak production and later peak time in Iranian Holstein heifers.

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REFERENCES

نطاقه فنوتیپ منحنی شیردهی در گاوهای هِلسائین ایران

5. فرهنگ فرجا. نیمی‌پور

چکیده

در این تحقیق به منظور بررسی آثار برخی از عوامل محیطی مؤثر بر فرستنجه‌های منحنی شیردهی و خصوصیات تولیدی شیر، از 136250 راس گاو شیری نژاد هَلسائین (3 بار دوشه در روز) ایران توزیع شده در 264 گله که در فاصله سال‌های 1370 تا 1380 زایش داشتند استفاده شد. نتایج تحلیل حداکثر مربعات واریانس نشان داد که عوامل محیطی گله، سال و ماه زایش دارای آثار معنی‌داری بر تعداد صفات مورد توجه می‌باشند. تجربه و تحلیل همبستگی بین صفات نشان داد که فرستنجه‌های مرتب با سطح تولید دارای همبستگی منفی می‌باشند که با کاهش و افزایش تولید در بین صفات مورد نظر در سال‌های هَلسائین دانه‌ای از زمان اوج شیردهی بوده ولی همبستگی آن با زمان رسیدن به اوج شیردهی و مقدار شیر در هر روز مثبت و معنی‌دار است. تجربه و تحلیل وابستگی ساده خطی ماتریس‌هاي تصادفی شده برای صفات 305 روز، تعداد روزهای مورد نیاز برای رسیدن به اوج شیردهی و مقدار شیر در اوج تولید بر حسب سال اوایل زایش نشان داد که برای صفات فوق به ترتیب افزایش سالانه فنوتیپی 137/152، کیلوگرم 535/0 روز و 324/00 کیلوگرم وجود داشته است.