Genetic and non genetic effects for lactation curve traits in Holstein-Friesian cows

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Abstract

The objective of this study was to determine the genetic and non genetic effects on lactation curve traits determined by the incomplete gamma function of Wood (1967) for Holstein-Friesian cows in Morocco. Data analysed included 49 262 monthly records of the test-day milk yield from 4 888 lactations of 3 932 cows at their 1st, 2nd or 3rd parity collected during 1990 and 1999 in 232 herds enrolled in the official milk recording. In general, lactation curve traits (A, B, C, peak time [T_{max}], peak milk yield [Y_{max}], persistency and 305 day milk yield [MY305]) were affected by herd, parity, age at calving, season of calving and year of calving. Heritability estimates were low and varied from 0.01 for parameter A to 0.10 for Y_{max}. Genetic and phenotypic correlations among traits varied from -0.79 to 1.00 and from -0.80 to 0.96, respectively. Genetic correlations between MY305 and parameter C were negative, but those between MY305 and all the other lactation curve traits were positive. It was concluded that selection for high peak milk yield and persistency will result in higher 305 day milk yield.

Keywords: cows, lactation curve, incomplete gamma function, milk yield at peak , environmental effects, heritability

Introduction

The introduction of high dairy cows in Morocco started at the beginning of 1970s. More than 5 000 Holstein-Friesian heifers were introduced annually. Moreover, besides this introduction, a grading up program of local cows was adopted that increased the frequency of Holstein-Friesian genes in the Moroccan cattle population. At present, a large Holstein-Friesian population of several thousands cows was constituted. This genetic pool was subjected to some studies dealing with reproduction and production traits (Boujenane & Maty 1986, Boujenane & Aïssa 2008) and estimation of genetic parameters (Boujenane 2002), in order to improve production traits under Moroccan conditions. Furthermore, some authors have assessed the inclusion of lactation curve traits such as peak milk yield and persistency as selection criteria to improve total milk yield (Batra *et al*. 1987). However, there are no estimates available for the genetic covariances that involve lactation curve traits in Moroccan dairy cattle.

The aim of this study was to fit and estimate the traits of lactation curves of Holstein-Friesian cows in Morocco using incomplete gamma function, to investigate the environmental factors affecting lactation curve traits and to estimate their genetic and phenotypic parameters (heritabilities, repeatabilities, and genetic and phenotypic correlations).

Material and methods

Origin of data

The records initially analysed included 77 525 monthly records of the test-day milk production data from Holstein-Friesian cows collected between 1990 and 1999 in 280 farms located at different regions of the country and enrolled in the official milk recording classified as type A. These data were obtained from cows at their 1st, 2nd and 3rd parity, with age at calving ranging from 24 to 48, 36 to 60 and 48 to 72 months, respectively. They were restricted to records for which the first milk recording had occurred between 5 and 50 days (Wilmink 1987), spacing of consecutive sample days was not more than 60 days and lactation length greater than 305 days. However, when the lactation of a cow was longer than 305 days, records were truncated at 305 days in milk (DIM). Furthermore, milk yield less than 3 kg or greater than 60 kg per day was discarded. All cows were milked twice a day.

Data analyses

The mathematical model fitted was Wood incomplete gamma function (Wood 1967):

$$y_t = At^B exp^{-Ct} \tag{1}$$

where t denotes day in milking, y_t denotes daily milk yield on day t of lactation, A is a general scaling factor representing initial yield, B and C are factors associated with the inclining and declining slope of the lactation curves, respectively. Initially, parameters A, B and C were first estimated by fitting the Wood's function in form of log-linear. Atypical lactations with negative parameters B or C, as well as herds with less that two cows were discarded. Approximately, 32.7 % of the lactations analysed were excluded because of atypical shape. The remaining typical lactations with respect to Wood´s description were then analysed by the non-linear regression using the NLIN procedure and the Marquardt iterative method of SAS v. 9 (SAS Institute Inc., Cary, NC, USA). Lactation curve parameters obtained from the linearised form were used as starting grids. Moreover, individual cow lactation curve parameters obtained from the non-linear regression were used to compute peak time:

$$T_{max} = \frac{B}{C} \tag{2}$$

peak milk yield at the peak time:

$$Y_{max} = A(\frac{B}{C})^B exp^{-B} \tag{3}$$

persistency:

$$PERS = (-B+1)lnC \tag{4}$$

and 305-d milk yield calculated for each lactation by adding the daily milk yield predicted from the model from day 1 to day 305 as:

$$MY305 = \sum_{t=1}^{305} At^B exp^{-Ct} \tag{5}$$

After editing all data, final analyses were performed using a pedigree file with 8 068 animals (individuals, sires and dams) and a production file from 4 888 lactations with 49 262 test day milk yields from 3 932 cows raised in 232 farms.

Individual cow lactation curve traits obtained were subjected to statistical analyses. They were first analysed by least-squares analysis of variance using MIXED procedure of SAS v. 9 (SAS Institute Inc., Cary, NC, USA) to determine the significance of the fixed effects to include in the model for genetic parameter estimation. The statistical model for lactation curve traits included the random effect of cow and the fixed effects of herd (232 herds), parity (1, 2 and 3), age at calving (≤30 months, >30 to ≤42 months, and >42 months), calving season (October through April and May through September), and year of calving (1990, …, 1999). First order interactions between effects were not tested and hence were assumed to be negligible.

Variance components for individual cow lactation curve traits were estimated for each trait separately with derivative-free REML procedures using the MTDFREML program of Boldman *et al.* (1995). The basic single trait repeatability model in matrix notation was:

$$y = Xb + Za + Wpe + e \qquad\qquad (6)$$

where y is a vector of observations, b is a vector of fixed effects with incidence matrix X, $a \sim N(0, A\sigma_a^2)$ is a vector of random animal effects with incidence matrix Z, $pe \sim N(0, I_c\sigma_{pe}^2)$ is a vector of random permanent environmental effects with incidence matrix W, and $e \sim N(0, I_n\sigma_e^2)$ is a vector of random residual effects. σ_a^2 is the additive genetic variance, σ_{pe}^2 is the permanent environmental variance, σ_e^2 is the residual variance, A is the additive genetic relationship matrix, and I_c and I_n are identity matrices of order equal to the number of cows and the number of records, respectively.

Convergence of the derivative-free iterative process was considered reached when the variance of simplex values (–2 log likelihood) was less than 10^{-8}. To ensure a global maximum, each analysis was restarted with previous converged values until the estimated value of the –2 log-likelihood function did not differ in its first three decimal places. Solutions for fixed and random effects were from the last round of iteration in which the global maximum was achieved.

Similar derivative-free REML procedures were used for bivariate analyses to estimate covariance components and correlations between traits. The model included the same fixed effects and the animal effects only. Estimates from single-trait analyses were used to obtain starting values for bivariate analyses. Convergence was first obtained when the simplex variance was less than 10^{-3} and then when the simplex variance was less than 10^{-6}.

Results and discussion

General

In lactation curves investigated in this study, percent of atypical lactations (parameter B or C negative) was found to be 32.7 %. Among them, 31.8 % lactations for parameter of B and 16.1 % lactations for parameter of C had negative estimates and 15.9 % lactations had both B and C negative. These curves were assumed to correspond to cows with problems because of lack of information, erroneous data or management problems. The occurrence of atypical shapes, characterised by the absence of the lactation peak, occured in about 15-42 % (Tekerli *et al.* 2000, Rekik *et al.* 2003, Soysal *et al.* 2005, Atashi *et al.* 2009). Only Shanks *et al.* (1981) reported a low proportion; 840 atypical lactations of 113 705 lactations.

The descriptive statistics for the studied traits are reported in Table 1. Milk yield increased from calving to the peak milk yield of 23.6 kg that was reached at day 41.4, and then decreased gradually until dry off with a persistency of 6.56. The proportion of milk yield produced from calving to the lactation peak represented 10.6 % of the milk yield produced during 305 day lactation. Likewise, milk yield produced from calving to day 100, from day 101 to day 200, and from day 201 to day 305 represented 28.7 %, 33.6 % and 37.7 % of the 305 lactation milk yield, respectively.

Table 1
Descriptive statistics for traits studied in Holstein-Friesian cows in Morocco

	Number	Arithmetic mean	Standard deviation	Coefficient of variation, %
Age at calving, mo.	4 888	39.1	11.5	29.4
Daily milk yield, kg	4 888	20.7	6.63	32.0
A	4 888	17.0	2.62	15.4
B	4 888	0.1039	0.0604	58.1
C	4 888	0.0029	0.0013	44.8
T_{max}, days	4 888	41.4	20.8	50.2
Y_{max}, kg	4 888	23.6	5.55	23.5
PERS	4 888	6.56	0.48	7.32
MY305, kg	4 888	8 946.4	3 142.9	35.1

Environmental effects

The least-square means for group effects of parity, age at calving and season of calving for the lactation curve traits are shown in Table 2. Parity significantly influenced all lactation curve traits studied, resulting in curves of similar shapes but different production levels. Parameters A, B, C, Y_{max} and MY305 increased with parity, whereas T_{max} and persistency decreased as parity increased. The results showed that the first lactation had the lowest A, the lowest B and the lowest C. Multiparous cows reached their peak of production earlier in the lactation than first parity cows (35.6th day of lactation). Likewise, the highest persistency was for the first parity cows.

Table 2
Least-square means for lactation curve traits of Holstein-Friesian cows

Fixed effects	Number	Lactation curve traits						
		A	B	C	T_{max}	Y_{max}	PERS	MY305
Parity		***	***	***	*	***	***	***
1	2 431	15.9	0.073	0.0026	35.6	20.0	6.51	7 135.1
2	1 541	16.9	0.091	0.0031	33.1	22.6	6.40	8 529.0
3	916	17.2	0.096	0.0033	32.1	23.4	6.36	8 983.0
Age, months		*	**	ns	*	***	ns	***
Age ≤30	1 651	16.6	0.082	0.0030	32.5	21.5	6.42	7 931.1
30< Age≤42	1 510	16.6	0.086	0.0030	32.9	21.9	6.42	8 171.2
42< Age≤72	1 727	16.9	0.092	0.0031	35.3	22.6	6.44	8 544.8
Calving season		*	***	***	ns	***	***	***
Oct.-April	1 970	16.6	0.080	0.0028	34.0	21.5	6.46	7 889.0
May-Sept.	2 918	16.8	0.093	0.0032	33.2	22.5	6.39	8 542.4

*P<0.05, **P<0.01, ***P<0.001, ns: not significant, P>0.05

Age at calving had significant effects on parameters A, B, T_{max}, Y_{max} and MY305, but not on parameter C and persistency. The youngest cows had lowest A, B, Y_{max} and MY305, but the highest T_{max}.

Considering the season of calving, peak milk yield was higher in those cows calving from May to September compared with those calving from October to April, but the peak occurrence was similar for cows calving in both seasons. Likewise, persistency was higher for cows calving from October to April compared to those calving from May to September. The season effect demonstrated that the higher initial production level, the higher the peak milk yield with slower rate of decline.

Noteworthy, herd and year of calving significantly influenced lactation curve traits owing to herd management differences and yearly change of production factors. Keown *et al.* (1986) reported that the cows that are raised in higher yielding herds have higher peak production and more persistency when compared with low herd production cows.

The effects of environmental factors on lactation curve traits found in this study are in agreement with the results reported in the literature (Tekerli *et al.* 2000, Rekik *et al.* 2003, Amin 2007, Atashi *et al.* 2009). The significant environmental effects may have practical implications in determining optimal feeding management and season of breeding to maximise total lactation yield.

Genetic and phenotypic effects

Variance components, heritability and repeatability estimates for lactation curve traits are presented in Table 3. Heritability estimates for lactation curve traits were low and ranged from 0.01 for parameters A and C to 0.10 for milk yield at lactation peak. Additionally, heritabilities computed as the average values from all bivariate analyses were almost similar to those estimated from single trait analyses. The low heritability estimates for lactation curve traits suggest that such traits are mainly dependent on environmental variation. The heritability estimates for parameters A, B and C are in agreement with those reported by Batra *et al.* (1987) and Farhangfar & Rowlinson (2007). However, Farhangfar & Rowlinson (2007) and López-Ordaz *et al.* (2009) reported estimates that are greater for Y_{max} (0.28), T_{max} (0.11 and 0.17) and MY305 (0.30 and 0.28). Heritability estimate for persistency was close to those reported by Atashi *et al.* (2006) and Farhangfar & Rowlinson (2007), and slightly higher than that reported by Shanks *et al.* (1981). Muir *et al.* (2004), using first parity data in Holstein, found heritabilities of 0.45 for MY305, 0.09 for T_{max} and 0.18 for the persistency defined as the slope of the lactation curve after peak production. Rekaya *et al.* (2000), using first parity data, found heritabilities as 0.26, 0.14, 0.26, and 0.05 for MY305, persistency, Y_{max} and T_{max}, respectively.

Repeatability estimates for lactation curve traits were also low and close to heritability estimates, owing to the low permanent environmental effects. López-Ordaz *et al.* (2009) reported that repeatability for Y_{max} was 0.24, similar to the estimates by Rekaya *et al.* (2000) and Tekerli *et al.* (2000), as 0.26. The repeatability for persistency was 0.15 (López-Ordaz *et al.* 2009) and 0.18 (Tekerli *et al.* 2000).

Genetic and phenotypic correlations among lactation curve traits are presented in Table 4. Genetic correlations varied from −0.79 to 1.00 and phenotypic correlations ranged from −0.80 to 0.96. Genetic correlations between lactation curve parameters (A, B, T_{max}, Y_{max} and PERS) and 305-d milk yield were positive, but those between parameter C on one hand and A, Y_{max}, persistency and MY305 on the other hand were negative.

Table 3
Variance components, heritability and repeatability estimates for lactation curve traits

Parameter[a]	Lactation curve traits						
	A	B	C	T_{max}	Y_{max}	PERS	MY305
σ^2_a	0.04	0.11×10^{-3}	1.18×10^{-8}	18.3	1.48	0.006	414 289
σ^2_{ep}	0.04	1.19×10^{-8}	1.00×10^{-8}	0.016	0.271	6.57×10^{-8}	1.71
σ^2_e	4.69	1.84×10^{-3}	1.16×10^{-6}	285.6	12.9	0.138	4 188 923
σ^2_p	4.77	1.95×10^{-3}	1.18×10^{-6}	304.0	14.4	0.144	4 603 212
h^2	0.01	0.05	0.01	0.06	0.10	0.05	0.09
t	0.02	0.06	0.02	0.06	0.10	0.05	0.09

[a]σ^2_a: additive genetic variance, σ^2_{ep}: permanent environment variance, σ^2_e: residual variance, σ^2_p: phenotypic variance, $h^2 = \dfrac{\sigma^2_a}{\sigma^2_p} =$ heritability, $t = \dfrac{\sigma^2_a + \sigma^2_{ep}}{\sigma^2_p} =$ repeatability.

Table 4
Estimates of genetic correlations, phenotypic correlations and heritabilities among lactation curve traits in Holstein-Friesian cows from bivariate analyses[1]

	Lactation curve traits						
	A	B	C	T_{max}	Y_{max}	PERS	MY305
A	**0.02**	0.66	−0.79	1.00	0.76	1.00	0.67
B	−0.19	**0.05**	0.38	0.99	0.96	0.47	1.00
C	0.18	0.63	**0.02**	0.38	−0.19	−0.55	−0.17
T_{max}	−0.37	0.32	−0.38	**0.06**	1.00	0.75	1.00
Y_{max}	0.55	0.67	0.51	0.13	**0.10**	0.81	0.98
PERS	−0.32	−0.14	−0.80	0.77	−0.19	**0.05**	0.89
MY305	0.38	0.81	0.65	0.05	0.96	−0.25	**0.08**

[1]Heritabilities, on diagonal, are the average values from all bivariate analyses. Genetic correlations above diagonal and phenotypic correlations below diagonal.

Therefore, animals that have a higher initial level of production (A parameter) will attain the peak faster and thereafter decline at a slower rate than those with a lower initial level of production. The strong negative genetic correlation between parameters A and C suggests that cows selected for high initial milk yield may be highly persistent in milk production. This is because lactation persistency is negatively correlated with rate of decline. From the genetic point of view, MY305 and Y_{max} are practically the same variable with a genetic correlation close to 1. Farhangfar & Rowlinson (2007) and López-Ordaz et al. (2009) obtained a similar value and Rekaya et al. (2000) a value of 0.90. Additionally, the genetic correlation between persistency and MY305 was 0.89. This value is higher to the estimate by Rekaya et al. (2000), 0.33 and Farhangfar & Rowlinson (2007), 0.53 using first parity data. Thus, positive correlation of MY305 with T_{max}, Y_{max} and persistency suggest that selection for higher producing cows will lead to higher peak yield, greater persistency and later peak time. On the other hand, studies investigated the genetic aspects of persistency, found heritability estimates to be of moderate size (0.1 to 0.2) and zero to positive genetic correlation with the 305 day milk yield. Analysis of relationship between persistency and other traits shows that genetic improvement for persistency is possible.

Phenotypic correlation between A and T_{max} and correlation between A and persistency were negative and medium, while correlation between A and Y_{max} was positive and medium.

If cows started lactation with high milk yield, maximum daily milk yield will be high, however, persistency will be lower. In this study, the phenotypic correlation between Y_{max} and T_{max} was positive and low. Farhangfar & Rowlinson (2007) found it equal to zero. According to previous studies (Atashi *et al.* 2009, Seangjun *et al.* 2009), phenotypic correlation between Y_{max} and T_{max} was negative indicating that cows with high daily milk yield reach the maximum daily milk yield early. Therefore, cows that have a higher initial level of production, higher peak milk and decline at a slower rate will have a high 305 day milk yield.

In conclusion, factors influencing lactation curve traits of Moroccan Holstein-Friesian cows were herd, parity, age at calving, season of calving and year of calving. Additionally, heritabilities obtained in this study confirm that lactation curve traits have a small genetic variation. However, despite the low heritabilities, there is still potential for improvement through selective breeding. Y_{max} had the highest heritability and had high and positive genetic correlation with 305 day milk yield, which indicates that increasing Y_{max} will increase 305 day milk yield as well.

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