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Association between the lactation curve shape and calving interval in Holstein dairy cows of Iran

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Summary

This study was carried out to investigate the relationship between early lactation curve parameters and calving interval in Holstein cows of Iran. In order to describe the lactation curve, the incomplete gamma function was fitted to 5,754,428 test-day milk records corresponding to 766,108 lactations on 315,634 cows in 2,448 herds. Cows with higher milk yield during early lactation had shorter calving intervals; however, longer calving intervals increased the 305-d milk production ($P<0.01$). Cows with higher yield at the beginning of lactation, steeper ascending, and steeper descending slope had shorter calving intervals ($P<0.01$). Calving interval was increased by 2.73 (±0.12) d for every extra kg of milk at peak lactation ($P<0.01$). The calving interval was directly impacted by the persistency of milk yield, but milk yield persistency was reduced in cows with shorter calving intervals ($P<0.01$).

Key words: Reproductive performance, Lactation curve, Holstein cow

Introduction

Reproductive efficiency has a great impact on the profitability of dairy cows. Cows with poor reproductive performance have lower conception rates, require more insemination before they become pregnant, have prolonged calving intervals and have shorter lifetime (Mohammadi and Sedighi, 2009). Pregnancy rate, days to first breeding, days open, calving interval (CI) and age at first calving (FCA) can be used to evaluate reproductive performance (Ansari-Lari *et al*., 2009; Ansari-Lari and Kafi, 2010).

Lactation curve describes the pattern of milk yield throughout the lactation period. The shape of the lactation curve, characterized by an initial phase that increases to a maximum followed by a declining phase, provides valuable information for genetic evaluation and management decisions (Tekerli *et al*., 2000; Hansen *et al*., 2006). Several studies showed an association between the energy balance and lactation curve shape which is expected to be associated with calving to conception interval (Kramer *et al*., 2009; Andersen *et al*., 2011). To the best of our knowledge, there is no published study on the association between shape of the lactation curve and reproductive performance in Holstein cows. The aim of this study was to investigate the effect of early lactation curve parameters on the calving interval and the effect of calving interval on the late lactation curve traits in Holstein dairy cows of Iran.

Materials and Methods

Data from March 1992 to April 2009 comprising 766,108 lactations on 315,634 Holstein cows in 2,448 herds, collected by the Animal Breeding Center of Iran, were used. The herds were managed under conditions similar to most developed countries; and were under official performance and pedigree recording. Main ingredients of the dairy ration consisted of corn silage, alfalfa hay, cotton seed meal, barley grains, canola meal, wheat bran, fat powder, beet pulp, and feed additives.

In order to describe the lactation curve 5,754,428 test-day milk records, corresponding to 766,108 lactations, were fitted to the incomplete gamma function (Wood, 1967). The function was transformed logarithmically into a linear form as:

$$\mathrm{Ln}(y_t) = \ln a + b\ln(t) - ct$$

Where,
y_t: The daily milk yield in DIM t
t: The length of time since calving
e: The Neper number
a: A parameter representing yield at the beginning of lactation
b and c: Factors associated with the upward and downward slopes of the curve, respectively

The function was fitted to monthly lactation yield records using a program written in Visual Basic®.

The DIM at peak production was defined as:

$$T_{max} = (b/c)$$

Expected maximum yield was calculated as:

$$y_{max} = a(b/c)^b e^{-b}$$

Persistency was calculated as:

$$s = -(b+1)\ln(c)$$

Total yield from the fifth day of calving up to day 120 and 305 was calculated as:

$$y = a\int_5^n t^b e^{-ct} dt$$

Where, n = 120 and 305, respectively.

Edits were on the number of test day records per cow per lactation (>4), lactation length (<350 d), and DIM at which first test day was recorded (>5 d). The CI was calculated as the difference between calving dates from successive parities, and was restricted to 300 to 700 d. The FCA was calculated as the difference between birth date and first calving date, and was restricted to 600 to 1200 d. Data on parity number were grouped into five classes (1, 2, 3, 4 and ≥5).

Statistical analysis

Data were examined using several approaches. Several analyses were performed using CI as the dependent variable, the effects of season, herd, parity, year, FCA, lactation curve parameters and 120-d milk yield as fixed independent variables, and the sire effect as random independent variable. In order to investigate the impact of CI on the late lactation curve parameters, the effects of season, herd, parity, year, FCA, and CI were included in the model as fixed independent variables, and the sire effect as random independent effect. Data were analysed using the MIXED procedure of SAS (1999). P-values less than 0.05 were considered as significant.

Results

In this study, 27.5% of all lactations were atypical (lactation curve with negative “a”, “b” or “c”) and were excluded from further analysis. The mean (± standard deviation) CI was 408.5 (±78.7) d (Table 1). The estimated least squares mean (±SE) of CI increased from 361.0 (±1.9) in 1992 to 426.0 (±1.1) d in 2009 (data not shown). The CI was impacted by the parity (P<0.01); whereas first parity cows had the shortest (384.7 ± 0.96 d), and cows with parity ≥5 had the longest (396.2 ± 1.07 d) CI (Table 1).

Spring and winter calvings were associated (P<0.01) with longer subsequent CI than were summer and fall calvings (Table 1). The parameters of lactation curve were influenced by the calving year, herd, FCA, calving season, CI, and parity (Table 1). The lowest peak and lactation yields but the highest DIM until peak yield and greater persistency were found in the first parity cows (Table 1, Fig. 1).

The effect of early lactation curve traits on the CI is presented in Table 2. Cows with higher yield at the beginning of lactation and steeper ascending and descending slopes had

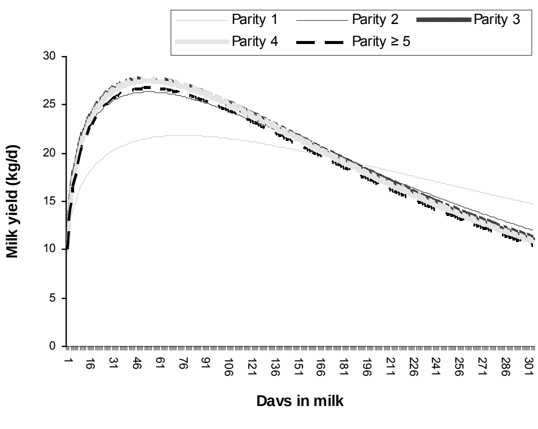

Fig. 1: Lactation curves for different parities in Holstein dairy cows of Iran (n=439,148)

Table 1: Least squares means (SE) of the lactation curve traits[1] and CI[2] within parity of Holstein dairy cows of Iran (n=439,148)

	CI	a[3]	b[4]	c[5]	s[6]	b/c[7]	Peak yield[8]	Mik-120[9]	Milk-305[10]
Parity 1	384.7 (0.96)^{d}	2.27 (0.01)^{e}	0.244 (0.002)^{e}	0.0032 (0.00003)^{e}	7.28 (0.007)^{a}	77.1 (0.3)^{a}	22.32 (0.07)^{d}	2407 (7)^{d}	5936 (16)^{e}
Parity 2	394.8 (0.96)^{b}	2.46 (0.01)^{a}	0.271 (0.002)^{d}	0.0050 (0.00003)^{d}	6.84 (0.007)^{c}	51.6 (0.3)^{b}	28.74 (0.07)^{c}	3082 (7)^{c}	6498 (16)^{c}
Parity 3	393.7 (0.99)^{c}	2.42 (0.01)^{b}	0.302 (0.002)^{c}	0.0057 (0.00003)^{c}	6.84 (0.007)^{c}	50.7 (0.3)^{c}	30.54 (0.07)^{a}	3244 (7)^{a}	6640 (17)^{a}
Parity 4	395.3 (1.06)^{b}	2.37 (0.01)^{c}	0.317 (0.002)^{b}	0.0059 (0.00003)^{b}	6.85 (0.007)^{b}	50.9 (0.3)^{c}	30.59 (0.07)^{a}	3237 (7)^{a}	6566 (17)^{b}
Parity ≥5	396.2 (1.07)^{a}	2.31 (0.01)^{d}	0.326 (0.002)^{a}	0.0060 (0.00003)^{a}	6.86 (0.007)^{b}	50.9 (0.3)^{c}	29.42 (0.07)^{b}	3107 (7)^{b}	6255 (17)^{d}
Spring	395.6 (0.98)^{b}	2.40 (0.01)^{a}	0.287 (0.002)^{c}	0.0054 (0.00003)^{b}	6.86 (0.007)^{d}	52.6 (0.3)^{d}	28.14 (0.07)^{c}	2992 (7)^{c}	6178 (16)^{c}
Summer	384.5 (0.98)^{d}	2.40 (0.01)^{a}	0273 (0.002)^{d}	0.0048 (0.00003)^{d}	6.92 (0.007)^{c}	56.7 (0.3)^{c}	28.11 (0.07)^{d}	2891 (7)^{d}	6178 (16)^{c}
Autumn	391.1 (0.98)^{c}	2.37 (0.01)^{b}	0.292 (0.002)^{b}	0.0049 (0.00003)^{c}	6.97 (0.007)^{b}	58.4 (0.3)^{a}	28.74 (0.07)^{b}	3068 (7)^{b}	6609 (16)^{a}
Winter	400.4 (0.98)^{a}	2.30 (0.01)^{c}	0.319 (0.002)^{a}	0.0054 (0.00003)^{a}	6.98 (0.007)^{a}	57.3 (0.3)^{b}	29.32 (0.07)^{a}	3111 (7)^{a}	6547 (16)^{b}
Overall	408.5 (78.7)	2.59 (0.73)	0.293 (0.20)	0.0047 (0.0029)	7.07 (0.67)	64.9 (31.1)	35.5 (8.55)	3797 (915)	8426 (2020)

[1]Modeled as $\ln(yt) = \ln(a) + b[\ln(t)] - ct$, [2]Calving interval, [3]A scaling factor to represent yield at the beginning of lactation, [4]Factors associated with the inclining slope of the lactation curve, [5]Factors associated with the declining slopes of the lactation curve, [6]Persistency calculated as $s = -(b + 1)\ln(t)$, [7]DIM at peak yield calculated as b/c, [8]Peak yield calculated as $a(b/c)^{b}e^{-b}$, [9]Total yield from the fifth day of calving up to DIM of 120 calculated as $y = a\int_{5}^{120} t^{b}e^{-ct}dt$, [10]Total yield from the fifth day of calving up to DIM of 305 calculated as $y = a\int_{5}^{305} t^{b}e^{-ct}dt$

Table 2: Estimated regression coefficients of CI[1] on lactation curve parameters[2] in Holstein dairy cows of Iran (n =439,148)

	Regression coefficient	SE	P-value
a[3]	-6.96	2.60	<0.01
b[4]	-122.9	10.59	<0.01
c[5]	-1251.68	214	<0.01
s[6]	24.42	0.56	<0.01
b/c[7]	0.05	0.008	<0.01
Peak yield[8]	2.73	0.12	<0.01
Milk-120[9]	-0.021	0.001	<0.01

[1]Calving interval, [2]Modeled as $\ln(yt) = \ln(a) + b[\ln(t)] - ct$, [3]A scaling factor to represent yield at the beginning of lactation, [4]Factors associated with the inclining slope of the lactation curve, [5]Factors associated with the declining slopes of the lactation curve, [6]Persistency calculated as $s = -(b + 1)\ln(t)$, [7]DIM at peak yield calculated as b/c, [8]Peak yield calculated as $a(b/c)^{b}e^{-b}$, [9]Total yield from the fifth day of calving up to DIM of 120 calculated as $y = a\int_{5}^{120} t^{b}e^{-ct}dt$

a significantly (P<0.01) shorter CI (Table 2). The DIM at peak production and peak yield significantly increased (P<0.01) CI (Table 2). The CI was increased (P<0.01) by 2.73 (±0.12) d as milk yield at peak lactation increased by one kg (Table 2). Cows with greater yield persistency had longer (P<0.01) CI (Table 2), but cows with higher milk yield during the first 120 DIM had shorter (P<0.01) CI. The late lactation curve characteristics such as persistency, descending slope, and 305-d milk yield were influenced by the CI (P<0.01). Cows with shorter CI (i.e., conceiving earlier during lactation) had steeper descending slope after peak, were less persistent and produced less 305-d milk (P<0.01).

Discussion

The mean (standard deviation) CI was 408.5 (78.7) d. Ansari-Lari and Kafi (2010) using 8,204 calving records in five herds, reported that mean number of days to first service, days open and CI in Holstein cows in Fars province was 67, 134 and 403 d, respectively. The mean CI increased steadily by 1.02 (±0.03) d per year from 1992 to 2009. Specific causes of such decline in reproductive performance are not clear, but the widespread use of the sperm from North American bulls could be an important cause. Artificial insemination is used in almost all Holstein dairy herds in Iran, and 60 to 80% of the semen is usually imported from North America. Sorensen *et al*. (2007) reported that use of sires, in countries that used American Holsteins has led to a documented decline in the reproduction performance. Harris and Kolver (2001) reported that rapid adoption of North American genetics into New Zealand herds played a role in their reproductive decline. McNaughton (2003) reported that New Zealand Holstein cows reached puberty earlier, had shorter estrous cycles and luteal phase length, and had higher milk progesterone concentration until 16 d after insemination than did North American and Dutch Holstein cows.

The decrease in reproductive performance over time has been reported in dairy populations in many countries (Washburn *et al*., 2002; Lopez-Gatius, 2003; Mee, 2004). In Holstein dairy herds of the United States, Washburn *et al*. (2002) found an increase in days to first service from 84 to 100 d between 1985 and 1999 in 10 Southeastern states. de Vries and Risco (2005) reported that mean CI was increased by 1.1 ± 0.1 d per year from 399 ± 2 d in 1976 to 429 ± 2 d in 2000 in Florida and Georgia dairy herds. Several researchers found no trend in CI, and some reported that mean CI was decreased over time. Refsdal (2007) reported that most fertility measures in Norwegian cattle showed a positive trend (sixty days non-return rates after single inseminations and mean number of inseminations per cow inseminated) or relatively constant trend (CI) during 1989-2005. Ansari-Lari *et al*. (2009) reported that mean CI decreased from 435 d in 2000 to 389 d in 2005 of Holstein dairy cows in Fars province.

Spring and winter calvings were associated with longer CI than summer and fall calvings. de Vries and Risco (2005) also reported that cows that calved during spring had longer CI compared with the cows that calved during other seasons in Florida and Georgia dairy herds. Eicker *et al*. (1996) found that cows which calved during spring had lower conception rates compared with those calved in winter. Meadows *et al*. (2006) reported that spring and summer calvings resulted in reduced fertility compared to winter calvings. Harman *et al*. (1996) reported that winter calving was associated with lower fertility. The present study demonstrated an association between the parity number and CI. First parity cows and cows with parity ≥5 had the shortest and the longest CI, respectively. Eicker *et al*. (1996) reported that cows of parity ≥3 had lower conception rate than did first parity cows. Meadows *et al*. (2006) found that cows of parity ≥2 had lower conception rate than did first parity cows.

The parameters of lactation curve were impacted by the calving year, herd, FCA, calving season, CI, and parity. Cows with higher milk yield during early lactation had shorter CI (i.e., conceived earlier), but longer CI was associated with increased 305-d milk yield. Many studies have reported on the relationship between milk yield and fertility in dairy cattle, but the results are not consistent. There are reports showing that higher milk yield was associated with longer time to resumption of ovarian activity (Stevenson and Britt, 1979; Nebel and McGillard, 1993). Lopez-Villalobos *et al*. (2005) reported that high yielding cows tended to have longer postpartum intervals.

Earlier researchers reported lower production of progesterone (Lucy and Crocker, 2001) and irregular estrous cycles in cows selected for high milk yield (Opsomer *et al*., 1998). These physiological changes may make dairy cows more susceptible to other factors that could reduce their reproductive performance (Washburn *et al*., 2002). There are also reports of no association between milk yield and recurrence of ovarian activity (Harrison *et al*., 1990). Grosshans *et al*. (1997) reported no significant phenotypic correlations between milk production and fertility in first lactation grazing cows in New Zealand. Studies in European cattle did not find a definitive link between milk production and reproduction (Loeffler *et al*., 1999). However, it was reported that US dairy herds with the greatest milk production generally had better reproductive performance (Stevenson and Britt, 1979; Nebel and McGillard, 1993). Other factors that may explain the decline in fertility are greater negative energy balance and increased levels of inbreeding (Lucy, 2001). Changes in management practices such as intentional delayed breeding, and less effective estrous detection can affect these parameters.

Cows having higher yield at the beginning of lactation and with steeper ascending and descending slopes had a shorter CI, whereby CI was increased by 2.73 (±0.12) d as milk yield at peak lactation increased by one kg. Andersen *et al*. (2011) reported that lactation curves characterized by a low intercept, a steep ascending slope, and a steep descending slope were associated with early conception but no relationship was found between peak yield and time of conception. Lopez-Villalobos *et al*. (2005) reported that peak yield was directly associated with the interval from calving to first estrus, but the DIM at peak yield was inversely associated with the interval from calving to first estrus.

Most dairy cows conceive a few weeks after reaching their peak production; therefore, the persistency of milk yield may be affected by conception time. Results of the present study showed that cows with higher persistency had longer CI, which is in accordance with previous reports (Lean *et al*., 1989; Haile-Mariam *et al*., 2003). Brotherstone *et al*. (2004) reported that the days open was associated with the shape of lactation curve while, cows that conceived shortly after calving had lower persistency. Tekerli *et al*. (2000) reported that cows with shorter days open produced less milk through 305 DIM and had quicker decline after peak but milk yield persistency was not impacted by days open. However, Lopez-Villalobos *et al*. (2005) found a negative correlation between lactation persistency and the interval from calving to first estrus. The cows which conceived early in lactation (i.e. cows with short CI) had steeper descending slope after peak and were less persistent in milk production. Cows with higher persistency may be able to utilize cheap roughage more efficiently, suffer less stress due to high peak yield, and may be more resistant to diseases (Togashi and Lin, 2003), although they are reproductively less efficient.

In conclusion, cows with higher milk yield during early lactation had shorter CI, but longer CI was associated with increased milk yield through 305 DIM. Cows with higher yield at the beginning of lactation and steeper ascending and descending slopes had shorter CI. The CI was directly impacted by the persistency of milk yield, and milk yield persistency was reduced in cows with shorter CI. It may be concluded that cows with longer lactations, accompanied by higher persistency and lower peak yield, are less prone to the stress of lactation and metabolic disorders. This would allow consumption of more less-costly roughages and can be a strategy of choice for future dairy production.

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