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Effect of Milking Frequency on the Lactation Performance and Lactation Curve of Holstein Dairy Cows in Iran

Research Article

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ABSTRACT

The aim of this study was to investigate the effect of milking frequency (three times daily *vs.* two times daily) on the lactation curve shape, partial and 305-d lactation performance in Holstein dairy cows in Iran. Data from February 2000 to December 2012 comprising 217345 lactations on 141364 cows distributed in 324 herds collected by the Animal Breeding Center of Iran were used. The mean milking frequency was 2.88 (0.32) times and increased from 2.72 (0.004) times in 2000 to 2.97 (0.002) times in 2012. The shape of the lactation curve for cows milked thrice daily tended to be higher and flatter than that for those milked twice. The first parity cows milked twice daily had a significant lower days in milk (DIM) until peak (79.52 (0.49) days) than those milked thrice (88.66 (0.28) days). In all parities except for parity ≥ 4, lactation persistency was higher in the cows milked thrice daily than in those milked twice. The percentages of increase in 305-d milk yield due to increasing milking frequency from two times to three times daily, were 12.34, 14.02, 12.79 and 14.76% for cows in parity 1 to parity ≥ 4, respectively. The 305-d milk yield was higher by 959 (28.89), 1175 (32.7), 1099 (38.6) and 1271 (45.0) kg for cows milked thrice daily than those milked twice in parity 1 to parity ≥ 4, respectively. The corresponding values for the 305-d fat yield were 4.35 (0.98), 16.68 (1.11), 17.19 (1.28) and 18.76 (1.51) kg. Based on the results of this study, it can be concluded that increasing milking frequency not only increased milk yield but also improved the initial yield, peak yield and lactation persistency.

KEY WORDS dairy cow, lactation curve, lactation performance, milking frequency.

INTRODUCTION

Milk yield in dairy cows can be increased by a variety of tools including improvements in genetics, environment, hormone treatment and other factors. Although, in most dairy farms, cows are milked twice daily, increasing milking frequency (three times or more) is an effective management tool to increase milk yield (Erdman and Varner, 1995; Smith *et al.* 2002; Wall and McFadden, 2008; Czerniawska-Pi atkowska *et al.* 2012). There are many studies demonstrated the effect of increased milking frequency on milk yield in dairy cows (Barnes *et al.* 1990; Smith *et al.* 2002; Hale *et al.* 2003; VanBaale *et al.* 2005; Patton *et al.* 2006; Eslamizad *et al.* 2010; Soberon *et al.* 2011). Despite considerable variation in the magnitude of the milk yield response, it was recognized that thrice daily milking increased milk production relative to twice daily (Soberon *et al.* 2011; Hart *et al.* 2013). Many studies reported that increased milking frequency caused a larger increasing in milk yield or milk composition in first parity cows than that in older cows (Amos *et al.* 1985; Allen *et al.* 1986; Gisi *et al.* 1986; Hart *et al.* 2013). Barnes *et al.* (1990) reported that milking three times daily increased milk yield by 14 and 6% during first and second lactation,

respectively. Wall and McFadden (2008) reported that there is no relationship between parity and the magnitude of the milk yield response to frequent milking. Many researchers reported that older cows respond better to frequent milking than heifers (Poole, 1982; DePeters *et al*. 1985).

The use of mathematical models describing the lactation curve will enable researchers to reveal the patterns of milk yield in response to increasing milking frequency more accurately and in much more detail. Although, many studies have considered the potential effect of milking frequency on milk yield, but there is no scientific reports detail its effect on the parameters describing the lactation curve in dairy cows. The objective of this study was to investigate the effect of milking frequency (two times daily *vs.* three times daily) on the lactation curve shape, partial and 305-d lactation performance in Holstein dairy cows in Iran.

MATERIALS AND METHODS

Data used in this study were records on Holstein cows collected from February 2000 to December 2012 by the Animal Breeding Center of Iran (Karaj, Iran). The herds evaluated were purebred Holsteins, managed under conditions similar to those used in most developed countries, and were under official performance and pedigree recording. The diet was fed as a total mixed ration (TMR) and consisted of corn silage, alfalfa hay, barley grain, fat powder, beet pulp and feed additives. Monthly milk recording was performed by trained technicians of the Iranian Animal Breeding Center. Cows with missed birth date, calving date, breeding date, drying date, and parity number were deleted. Edits were on the number of test-day records per cow per lactation (>7), lactation length (<320 d), days in milk (DIM) at which the first test-day was recorded (>5), and age at first calving (540 to 1200 d). Data on parity number were classified into four categories: parity 1, 2, 3 and ≥ 4. Ultimately, the data set used to describe lactation curve included 1,865,284 test-day records from 217345 lactations on 141364 cows distributed in 324 herds.

To describe the lactation curve and associated production characteristics, 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*, the variable *t* represents the length of time since calving.
e: neper number.
a: parameter to represent yield at the beginning of lactation.
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 was fitted to monthly lactation yield records using a simple program written in Visual Basic (Microsoft Corp., Redmond, WA). The DIM at peak production (T_{max}) was defined as: $T_{max} = (b/c)$ expected maximum yield (y_{max}) was calculated as: $y_{max} = a(b/c)^b e^{-b}$ persistency was calculated as: $s = -(b+1)\ln(c)$ and total yield from the calving up to 100, 200 and 305 DIM was calculated as:

$$y = a\int_1^n t^b e^{-ct} dt$$

Where:
n: 100, 200 and 305, respectively.

Typical lactation curves had positive *a*, *b*, and *c*, and curves with negative *a*, *b*, or *c* were considered atypical. Of 217345 lactations, 24558 (11.30%) lactations had atypical lactation curves and were excluded. Finally, 1654524 test-day milk records corresponding to 192787 lactations on 132057 cows in 324 herds were used to determine the effect of milking frequency (three times vs. two times daily) on the lactation curve traits, partial and 305-d lactation performance.

The effect of milking frequency (two times daily *vs.* three times daily) on the parameters describing the lactation curve as well as partial and 305-d lactation performance, was determined using flowing multiple regression mixed models in PROC MIXED (SAS, 1999).

$$y_{ijkl} = \mu + HYS_i + PMF_j + Sire_k + b(FCA - \overline{FCA}) + e_{ijkl}$$

Where:
y_{ijkl}: observation of l^{th} cow, k^{th} sire, j^{th} combination of parity and milking frequency (PMF).
i^{th}: combination of herd-year-season (HYS).
μ: overall mean.
HYS_i: effect of i^{th} HYS combination.
PMF_i: effect of j^{th} combination of parity and milking frequency.
$Sire_k$: random effect of k^{th} sire.
b: regression coefficient of dependent variable on the first calving age (FCA).
e_{ijkl}: residual effect.

RESULTS AND DISCUSSION

The distribution of parity by milking frequency is presented in Table 1. Of 192787 lactations, 88.64% milked thrice daily, whereas 11.36% milked twice. Factors associated with the milking frequency were parity, calving year, and herd size (P<0.05).

The mean milking frequency was 2.88 (±0.32) times, and increased from 2.72 (0.004) times in 2000 to 2.97 (0.002) times in 2012 (P<0.05). An increase in herd size was associated with a significant decrease in milking frequency (P<0.05). The milking frequency was also associated with parity (P<0.05), whereas the mean (SE in parentheses) milking frequency of cows in parity 1 and parity ≥ 4 was 2.74 (0.001) and 2.85 (0.001) times, respectively.

Table 1 Descriptive statistics of thrice milking daily by parity for 217345 lactations of 141364 Holstein cows between 2000 and 2012 in Iran

Item	Parity			
	1	2	3	≥ 4
Lactations (no.)	60210	49151	35072	48354
Thrice milking daily (no.)	50510	42891	31340	46158
Thrice milking daily (%)	83.89	87.26	89.36	95.46

A significant interaction was found between milking frequency and parity for the parameters describing the lactation curve, partial and 305-d lactation performance (P<0.05). The shape of the lactation curve for cows milked thrice daily tended to be higher and flatter than that for those milked twice daily (Figure 1).

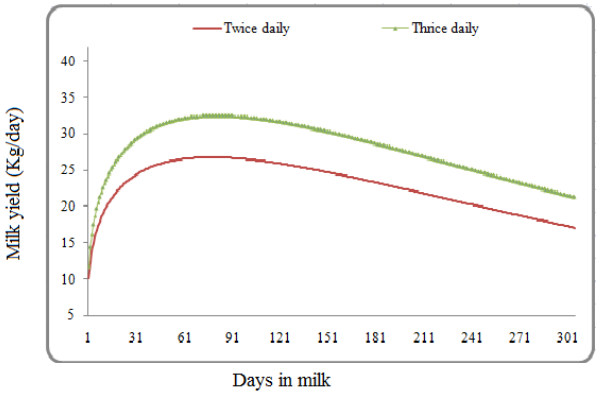

Figure 1 Lactation curves for cows milked twice (twice daily) and for those milked thrice daily at parity 1

The cows milked twice daily had lower initial yield than those milked thrice (Table 2). First parity cows milked twice daily had a significant lower DIM until peak (79.52 (0.49) days) than those milked thrice daily (88.66 (0.28) days). Peak yield (SE in parentheses) was higher by 3.29 (0.10), 4.93 (0.12), 4.76 (0.14) and 5.16 (0.17) kg for cows milked thrice daily than those milked twice in parity 1 to ≥ 4, respectively (Table 2). In all parities except for parity ≥ 4, lactation persistency was higher in cows milked thrice daily than that in those milked twice (Table 2).

The milking frequency showed great influence on the partial and 305-d lactation performance in all parities (Table 3). The 305-d milk yield (SE in parentheses) was higher by 959 (28.89), 1175 (32.7), 1099 (38.6) and 1271 (45.0) kg for cows milked thrice daily than those milked twice in parity 1 to ≥ 4, respectively (Table 3). The 100-d milk yield (SE in parentheses) was higher by 268 (10.30), 461 (11.67), 438 (13.81) and 484 (16.1) kg for cows milked thrice daily than those milked twice in parity 1 to ≥ 4, respectively (Table 3). The corresponding values for the 101-200-d milk yield were 333 (10.34), 405 (11.70), 385 (13.83) and 446 (16.10) kg (Table 3). The 201-305-d milk yield (SE in parentheses) was higher by 374 (12.21), 327 (13.83), 296 (16.4) and 360 (19.13) kg for cows milked thrice daily than those milked twice daily in parity 1 to ≥ 4, respectively (Table 3). The 305-d fat yield (SE in parentheses) was higher by 4.35 (0.98), 16.68 (1.11), 17.19 (1.28) and 18.76 (1.51) kg for cows milked thrice daily than those milked twice daily in parity 1 to ≥ 4, respectively (Table 3).

The response to increasing milking frequency (three times or more times daily) can be expressed as a percentage of twice milking daily. In this study, the percentages of increase in 305-d milk yield due to increasing milking frequency from twice daily to thrice were 12.34, 14.02, 12.79, and 14.76% for cows in parity 1 to ≥ 4, respectively. The interaction of milking frequency and parity had significant effects on the response to increasing milking frequency for partial milk yield.

The interactions were most important during early-lactation. The response to milking thrice daily, expressed as a percentage of twice daily, for 100-d, 101- to 200-d and 201- to 305-d milk yield were 9.84, 12.19 and 16.22% in first parity cows, and 14.09, 13.91 and 14.97% in second parity cows. The corresponding values were 12.82, 12.89 and 13.59% for third parity cows, and 14.50, 12.94 and 16.55% for ≥ 4 parity cows.

The obtained results can be discussed as follows: milking frequency (two times daily *vs.* three times daily) showed great influence on the parameters describing lactation curve. First parity cows milked twice daily had a significant lower DIM until peak than those milked thrice daily. In agreement with this study, Amos *et al.* (1985) reported that milk production peaked at 6 wk for cows in first lactation milked twice daily and at 9 wk for cows in first lactation milked thrice daily. Hale *et al.* (2003) reported that peak milk production occurred during wk 7 for cows milked twice daily and during wk 8 for those milked thrice daily.

Lactation persistency was higher in cows milked thrice daily than that in those milked twice. Increasing milking frequency has been shown to increase lactation persistency in Holstein dairy cows (Henshaw *et al.* 2000; Dahl *et al.* 2004; Bernier-Dodier *et al.* 2010). Bernier-Dodier *et al.* (2010) showed that milking frequency modulates milk yield and lactation persistency in mid-lactation cows. Henshaw *et al.* (2000) reported that milking cows six times per day in early lactation produced persistent improvements in milk yield.

Table 2 Least squares means (SE) of the 2-way interaction of milking frequency (two times vs. three times daily) with parity for the lactation curve traits[1] in Holstein dairy cows in Iran

Parity	Group	a	b	c	Persistency[2]	Peak day[3]	Peak yield[4]
1	2	2.32 (0.011)^{B}	0.289 (0.003)^{B}	0.00371 (0.00005)^{A}	7.33 (0.011)^{B}	79.52 (0.49)^{B}	30.27 (0.16)^{B}
	3	2.47 (0.006)^{A}	0.298 (0.002)^{A}	0.00365(0.00003)^{A}	7.46 (0.005)^{A}	88.66 (0.28)^{A}	33.56 (0.13)^{A}
2	2	2.57 (0.014)^{B}	0.298 (0.004)^{A}	0.00525 (0.00005)^{A}	6.92 (0.012)^{B}	57.83 (0.55)^{A}	35.97 (0.17)^{B}
	3	2.75 (0.006)^{A}	0.303 (0.002)^{A}	0.00524 (0.00003)^{A}	6.96 (0.006)^{A}	58.23 (0.29)^{A}	40.90 (0.13)^{A}
3	2	2.57 (0.015)^{B}	0.318 (0.004)^{A}	0.00572 (0.00006)^{A}	6.92 (0.013)^{B}	57.09 (0.65)^{A}	37.76 (0.19)^{B}
	3	2.71 (0.006)^{A}	0.325 (0.002)^{A}	0.00574 (0.00003)^{A}	6.96 (0.006)^{A}	57.31 (0.30)^{A}	42.52 (0.13)^{A}
4	2	2.52 (0.019)^{B}	0.333 (0.005)^{A}	0.00587 (0.00007)^{A}	6.96 (0.016)^{A}	58.42 (0.77)^{A}	37.95 (0.21)^{B}
	3	2.71 (0.006)^{A}	0.331 (0.002)^{A}	0.00567 (0.00003)^{B}	6.98 (0.006)^{A}	58.24 (0.29)^{A}	43.12 (0.13)^{A}

The means within the same column with at least one common letter, do not have significant difference (P>0.05).
[1] Modeled as:
$\ln(y_t) = \ln(a) + b[\ln(t)] - c(t)$
Where:
y_t: milk yield on day t.
a: scaling factor to represent yield at the beginning of lactation.
b and *c*: factors associated with the inclining and declining slopes of the lactation curve.
[2] Persistency calculated as: s= -(b+1)ln(c).
[3] Days in milk (DIM) at peak yield calculated as: $T_{max} = (b/c)$.
[4] Peak yield calculated as: $y_{max} = a(b/c)^{b}e^{-b}$.

Table 3 Least squares means (SE) of the 2-way interaction of milking frequency (two times vs. three times daily) with parity for the partial and 305-d lactation performance in Holstein dairy cows in Iran

Parity	Group	100-d milk[1]	101-to 200-d milk[2]	200-d milk[3]	201-to 305-d milk[4]	305-d milk[5]	305-d fat[6]
1	2	2722.9 (14.8)^{B}	2731.3 (15.5)^{B}	5459.5 (29.1)^{B}	2305.1 (16.1)^{B}	7771.0 (43.1)^{B}	236.01 (1.57)^{B}
	3	2990.9 (11.7)^{A}	3064.4 (12.5)^{A}	6053.4 (23.7)^{A}	2679.1 (12.1)^{A}	8729.9 (34.7)^{A}	240.37 (1.31)^{A}
2	2	3270.0 (15.8)^{B}	2910.0 (16.4)^{B}	6185.7 (30.8)^{B}	2183.6 (17.4)^{B}	8376.4 (45.7)^{B}	251.78 (1.65)^{B}
	3	3730.6 (11.8)^{A}	3315.9 (12.6)^{A}	7044.3 (23.8)^{A}	2510.2 (12.1)^{A}	9551.5 (34.9)^{A}	268.45 (1.32)^{A}
3	2	3415.8 (17.4)^{B}	2984.7 (17.9)^{B}	6407.0 (33.5)^{B}	2177.4 (19.4)^{B}	8592.1 (49.9)^{B}	261.37 (1.77)^{B}
	3	3854.3 (11.9)^{A}	3369.7 (12.7)^{A}	7221.7 (24.1)^{A}	2472.9 (12.4)^{A}	9691.4 (35.4)^{A}	278.56 (1.33)^{A}
4	2	3420.4 (19.4)^{B}	3000.0 (19.9)^{B}	6427.1 (37.1)^{B}	2175.0 (21.9)^{B}	8609.8 (55.4)^{B}	264.25 (1.96)^{B}
	3	3903.9 (11.8)^{A}	3446.2 (12.6)^{A}	7348.6 (23.9)^{A}	2535.3 (12.2)^{A}	9880.9 (35.1)^{A}	283.01 (1.32)^{A}

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

[1] Total milk yield through 100 DIM calculated as: $y = a\int_{1}^{100} t^{b}e^{-ct}dt$

[2] Total milk yield through 200 DIM calculated as: $y = a\int_{1}^{200} t^{b}e^{-ct}dt$

[3] Total milk yield through 101 to 200 DIM calculated as: $y = a\int_{101}^{200} t^{b}e^{-ct}dt$

[4] Total milk yield from 201 to 305 DIM calculated as: $y = a\int_{201}^{305} t^{b}e^{-ct}dt$

[5] Total milk yield from 305 DIM calculated a: $y = a\int_{1}^{305} t^{b}e^{-ct}dt$
[6] n= 161403.
DIM: davs in milk.

In contrast, VanBaale *et al*. (2005) reported that increasing milking frequency to 6 times daily for 7 to 21 d at the start of lactation, did not increase milk yield nor improve lactation persistency. Peak yield was higher for first parity cows milked thrice daily than that in those milked twice.

Amos *et al*. (1985) reported that cows milked thrice daily reached higher peak milk production and were more persistent in milk production.

Wall and McFadden (2008) reported that three times daily milking increased peak yield and persistency of the lactation. Three times daily milking has been shown to increase milk yield in Holstein cows (Erdman and Varner, 1995; Smith *et al*. 2002; Wall and McFadden, 2008). In this study, the 305-d milk yield was higher by 959 (28.89), 1175 (32.7), 1099 (38.6) and 1271 (45.0) kg for cows milked thrice daily than those milked twice daily in parity 1 to ≥ 4, respectively. Campos *et al*. (1994) reported that milking three times daily compared with milking twice-daily increased 305-d milk yield by 1226 kg (17.3%). Erdman and Varner (1995) reported that it is better to describe milk yield responses to increasing milking frequency as fixed increases in kilograms rather than percentages. Hillerton and Winter (1992) reported that yield increases from thrice daily milking were a constant 1100 kg per lactation for both primiparous and multiparous cows.

The response to increasing milking frequency, expressed as a percentage of twice milking daily, were 12.34, 14.02, 12.79 and 14.76% for cows in parity 1 to ≥ 4, respectively. Erdman and Varner (1995) reported that increasing milking frequency to thrice daily, increased milk yield by 10 to

20%. Stelwagen (2001) reported that milking thrice daily in compared with milking twice, increased milk yield by 18%. In summaries of Dairy Herd Improvement Association records, the increase in milk production with three times per day was 12 to 16% compared with two times (Smith *et al*. 2002). Barnes *et al*. (1990) reported that milking thrice daily increased milk yield overall by 14 and 6% during first and second lactation, respectively. Erdman and Varner (1995) reported that responses of primiparous and multiparous cows were similar in magnitude for twice daily versus three time's daily milking frequency. Wall and McFadden (2008) reported that there is no relationship between parity and the magnitude of the milk yield response to frequent milking. Many researchers reported that older cows respond better to frequent milking than heifers (Poole, 1982; DePeters *et al*. 1985). The interaction of milking frequency and parity had significant effects on partial milk yield. The response to milking thrice over twice daily, for 100-d, 101- to 200-d and 201- to 305-d milk yield were 9.84, 12.19 and 16.22% in first parity cows and 14.09, 13.91 and 14.97% in second parity cows. The corresponding values were 12.82, 12.89 and 13.59% for third parity cows, and 14.50, 12.94 and 16.55% in ≥ 4 parity cows. Therefore, the results indicate that especially in primiparous heifers, thrice daily milking is more effective in late lactation than that in mid or early lactation. The 305-d fat yield was higher by for cows milked thrice daily than those milked twice daily in parity 1 to ≥ 4, respectively. Many researchers have observed no effect of frequent milking on milk composition (Poole, 1982; Rao and Ludri, 1984; Amos *et al*. 1985; DePeters *et al*. 1985; Gisi *et al*. 1986), whereas some researchers have observed a decrease in fat percentage (Allen *et al*. 1986; Smith *et al*. 2002). Due to the increase in milk production in response to frequent milking, however, there is often an increase in the total yield of fat and protein (Klei *et al*. 1997; Dahl *et al*. 2004; Soberon *et al*. 2011). Hale *et al*. (2003) determined that percentages of milk fat were decreased by increasing milking frequency, but resulting in no change in yields of fat for cows subjected to increasing milking frequency.

CONCLUSION

Thrice-daily milking compared with the more commonly practiced twice-daily, increased milk yield and milk composition ranging from 12 to 15%, depending on factors such as parity and stage of lactation. Taken together, this work demonstrated the effect of milking frequency on lactation performance as well as lactation curve. Based on the results of this study, it can be concluded that increasing milking frequency not only increased milk yield, but also improved the initial yield, peak yield and lactation persistency.

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