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Phenotypic Relationship between Lactation Persistency and Change in Body Condition Score in First-lactation Holstein Cows

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ABSTRACT : We examined the correlations between lactation curve shape, including persistency and changes in body condition score (BCS) during early-stage (0 to 30 days in milk (DIM)), nadir-stage (31 to 90 DIM), and late-stage (91 to 240 DIM) lactation in 191 first-lactation cows. Data used were first-parity BCS records, scored twice every month after calving, and daily milk yields. Individual lactation curves were depicted by the Wilmink function. Lactation persistency was defined as the difference in estimated milk yields between 240 DIM and 60 DIM. Changes in BCSs in the early and late stages were defined as linear regression coefficients. There were no significant correlations between traits for lactation curve shape and change in BCS in early-stage lactation. Peak yield and total milk yield were negatively correlated with BCSs in nadir- and late-stage lactation and with BCS change in late-stage lactation, suggesting that cows with high lactation yields had low body reserves and health status in mid- to late lactation and had delayed recovery of body reserves. Lactation persistency was positively correlated with change in BCS in late-stage lactation, suggesting that cows with high lactation persistency tended to be healthy and to recover their body reserves well in late lactation. (**Key Words :** Body Condition Score, Cow, Lactation Persistency)

INTRODUCTION

Selection for total milk yield markedly increases milk production in early lactation, but this increase places metabolic stress on cows and increases disease susceptibility (Uribe et al., 1995; Jakobsen et al., 2003). To improve health and redress the negative energy balance in early lactation while maintaining total milk yield, it has been suggested that the lactation curve could be modified to reduce milk yield in early lactation and thus to give higher lactation persistency after the lactation peak (Dekkers et al., 1998; Jakobsen et al., 2003; Togashi and Lin, 2003, 2004, 2007).

Body condition score (BCS) and its changes have been widely used to indicate body reserves and energy balance in cows (Coffey et al., 2001; Berry et al., 2006). BCS is easy to measure on a large scale and is sufficiently accurate to indicate variations in body reserves among cows (Roche et al., 2009). BCS and its changes are also related to health status. BCS has negative genetic correlations with somatic cell score in milk (Banos et al., 2006) and with clinical mastitis (Lassen et al., 2003) in first-parity cows. Wells et al. (1993) reported a positive association between the prevalence of clinical lameness and low BCS.

Total milk yield has negative genetic correlations with BCS throughout lactation (Veerkamp et al., 2001) and with BCS change in early lactation (Dechow et al., 2002). However, there have been few studies of the relationship between lactation curve shape -especially lactation persistency- and BCS. Berry et al. (2007) and Roche et al. (2007) reported that increased BCS at calving and days to BCS nadir (i.e., the lowest point) were associated with reduced lactation persistency. However, there have been no reports of the relationship between lactation persistency and BCS changes in mid to late lactation, although Berry et al. (2002) reported positive genetic correlations between milk yield in mid to late lactation and BCS change at the same lactation stage.

We hypothesized that lactation persistency is related to energy balance and health, not in early lactation but in mid

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to late lactation. Our objective was therefore to examine the relationships between the shape of the first-parity lactation curve -mainly in terms of persistency- and changes in BCS at different stages of lactation.

MATERIALS AND METHODS

Body conditions of first-lactation Holstein cows were scored twice every month from June 2006 to October 2007 at the National Livestock Breeding Center Niikappu Station (Hokkaido, Japan). Condition scores were based on the scoring system proposed by Edmonson et al. (1989), with units ranging from 1 (lean) to 5 (fat) in increments of 0.25. We used daily milk records at 5 to 305 days-in-milk (DIM) from 191 cows with 72 sires, calving in 2006 and 2007, and having BCS records. Each cow had at least 200 milk records and the DIM at the time of the first record was 10 or less. The lactation periods were at least 250 days, and the ages at calving ranged from 22 to 35 months. The numbers of cows by month of calving are shown in Figure 1. Details of the management and feeding systems used on this farm were reported by Yamazaki et al. (2009).

Traits for lactation curve shape

The following statistical model was used to estimate individual lactation curves by the MIXED procedure of the SAS software package (SAS Institute Inc., 2008):

$$y_{ijkl} = TYS_i + \sum_{m=0}^{2} AGE_{jm} \cdot w_{klm} + \sum_{m=0}^{2} u_{km} \cdot w_{klm} + e_{ijkl}$$

where, y_{ijkl} is daily milk record l in the ith year-season of cow k calved in the jth age class in months, TYS_i is the fixed effect of the year-season of the test day (2006 or 2007 and January-March, April-June, July-September, or October-December), AGE_{jm} is the mth coefficient in a fixed regression of the age class in months at calving (≤23, 24, 25, 26, 27-28, or ≥29 months), w_{klm} is the mth covariate of the Wilmink function (Wilmink, 1987) associated with DIM, u_{km} is a random regression coefficient of individuals, and e_{ijkl} is a random residual effect associated with y_{ijkl}.

Hagiya et al. (2004) compared three methods of predicting whole lactation records from records of test days in Japanese Holstein cows. They suggested that multiple trait prediction method with Wilmink function was successful in attaining high accuracy through the whole lactation period. This method was used to estimate individual lactation curves for dairy sire and cow evaluation in Japan (National Livestock Breeding Center, 2009) until February 2010, when the evaluation model of lactation yields was changed from a lactation model to a test day model. Therefore, we selected the Wilmink function for this study.

Days in peak (peak-DIM), peak yield, lactation persistency, and cumulative milk yield from 5 to 305 DIM (305-milk) were calculated from individual lactation curves. The Wilmink function is:

$$Y_t = a + be^{-0.05t} + ct,$$

where Y_t is daily milk yield at t DIM, and a, b, and c are coefficients. The coefficients of the individual lactation curve, a_k, b_k, and c_k, were defined as a_0+u_{k0}, b_0+u_{k1}, and c_0+u_{k2}, where a_0, b_0, and c_0 were the coefficients of the Wilmink function fitted to all data in this herd, and u_{k0}, u_{k1}, and u_{k2} were random regression coefficients of individuals, as shown in the above model. DIM at peak can be estimated from $-20\log(20c/b)$ when $b<0$ and $c<0$ (Macciotta et al., 2005). Persistency was defined as the difference in estimated milk yields between 240 DIM and 60 DIM, as used in dairy sire and cow evaluation in Japan (National Livestock Breeding Center, 2009).

Traits for change in BCS

Average BCSs every 2 weeks during lactation in this herd are shown in Figure 2. BCS declined linearly in the first month after calving, reached a nadir at about 2 to 3 months, and then gradually recovered. Early stage was defined as the period from 0 to 30 DIM, nadir stage as 31 to 90 DIM, and late stage as 91 to 240 DIM. The numbers of BCS records in each year-season subclass by stage of lactation are shown in Table 1. The aim of our study was to examine the relationships between the shape of the lactation curve (lactation persistency) and changes in BCS at different stages of lactation. Coefficients of mathematical functions fitted to whole records of the lactation period cannot explain the change in each stage adequately, because these coefficients are affected by changes over the lactation period, and residual errors in these functions are high in early lactation (Olori et al., 1999). Therefore, we defined the traits of changes of BCS in each lactation stage

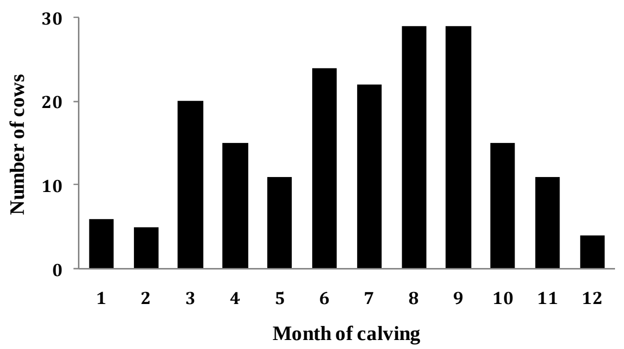

Figure 1. Numbers of cows by month of calving in 191 first-lactation cows.

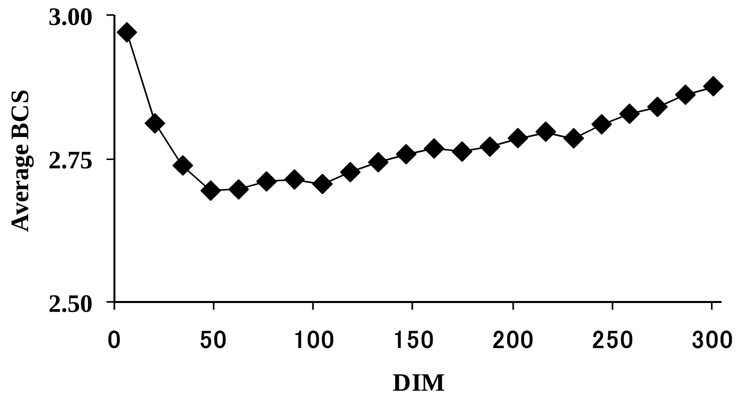

Figure 2. Average body condition scores (BCSs) measured every 2 weeks during lactation in 191 first-lactation cows. DIM, days in milk.

Table 1. Numbers of BCS records in each year-season subclass, by stage of lactation

	Early stage	Nadir stage	Late stage
Jun.-Sep. 2006	41	100	132
Oct.-Dec. 2006	43	131	278
Jan.-Mar. 2007	38	70	332
Apr.-Jun. 2007	50	84	225
Jul.-Sep. 2007	76	118	145
Oct. 2007	26	31	25

Early stage: lactation period from 0 to 30 days in milk (DIM).
Nadir stage: lactation period from 31 to 90 DIM.
Late stage: lactation period from 91 to 240 DIM.
Records of cows that had fewer than two records in the early stage, three records in the nadir stage or nine records in the late stage were eliminated in each stage.

separately. Changes in BCS in the early and late stages were defined as linear regression coefficients (early-RBCS and late-RBCS, respectively). The model described above was used to estimate each coefficient, except that linear regression was used instead of the Wilmink function. Mean BCS in the early stage was defined as BCS at 15 DIM (15d-BCS), and that in the late stage as 165 DIM (165d-BCS), as estimated by the respective linear regressions. Mean BCS in the nadir stage (nadir-BCS) was estimated by the above model, without the regression term.

Only the records in each stage were used to estimate traits in that stage. Individual coefficients in each stage, or nadir-BCSs, were defined from the combinations of linear regressions (or average BCS) of all data in each stage and random estimates for individuals, in the same way as for individual lactation curves. Records of cows that had fewer than two records in the early stage, three records in the nadir stage, or nine records in the late stage were eliminated for the estimation in each stage.

The numbers of lactation records and summary statistics for each trait are shown in Table 2. The lactation level in the herd was very high (an average of nearly 10,000 kg for 305-milk), because Niikappu Station is a breeding farm and a progeny testing station. The average nadir-BCS was not lower than that in previous reports (Coffey et al., 2002; Berry et al., 2006), although negative relationships between milk production and nadir BCS have been reported (Roche et al., 2006; McCarthy et al., 2007). To optimize the results of progeny testing, good management of this herd was practiced by feeding a total mixed ration *ad libitum*, designed for a body weight of 603 kg and a daily milk yield of 38 kg, and by providing concentrates at feeding stations in accordance with U.S. National Research Council guidelines (National Research Council, 2001) for protein and energy.

We examined correlations among traits for lactation curve shape and traits for change in BCS, and between the two sets of traits.

RESULTS AND DISCUSSION

Correlations among traits for lactation curve shape

There was a significant positive correlation between peak-DIM and 305-milk (Table 3), indicating that cows with high total milk yield tended to peak late. Phenotypic correlations between these traits ranging from 0.08 to 0.40 have been reported previously (Rekaya et al., 2000; Tekerli et al., 2000; Muir et al., 2004); some of these values therefore supported our result.

Persistency had a high positive correlation with peak-DIM and a moderate negative correlation with peak yield. This is consistent with reports that the shape of the lactation curve with high lactation persistency tends to have a low peak yield and to peak late (Rekaya et al., 2000; Tekerli et al., 2000). There was no correlation between persistency and 305-milk. It is considered that cows with high lactation persistency can maintain their milk yields in mid to late lactation, and this can tend to boost the overall milk yield. However, the negative correlation of persistency with peak yield lowered the total milk yield. This antagonistic relationship led to the lack of correlation between persistency and 305-milk. Consistent with our result,

Table 2. Numbers of lactation records and summary statistics of traits for lactation curve shape and change in body condition score (BCS)

	Trait	No. of lactation records	Mean	SD
Lactation curve shape	Peak-DIM (d)	165	77	22
	Peak yield (kg)	165	35.8	3.8
	Persistency (kg)	191	-2.9	4.0
	305-milk (kg)	191	9,843	1,071
Change in BCS	Early-RBCS (unit/d)	132	-0.010	0.003
	15d-BCS (unit)	132	2.89	0.12
	Nadir-BCS (unit)	144	2.71	0.14
	Late-RBCS (unit/d)	117	0.0006	0.0006
	165d-BCS (unit)	117	2.76	0.16

Peak-DIM = Days in peak milk yield. Peak yield = Peak milk yield.
Persistency = The difference in estimated milk yields between 240 DIM and 60 DIM.
305-milk = Cumulative milk yield from 5 to 305 DIM.
Early-RBCS = Linear regression coefficient of BCS on DIM in early lactation (from 0 to 30 DIM).
15d-BCS = BCS at 15 DIM, as estimated by linear regression in early lactation.
Nadir-BCS = Average BCS in the nadir stage (from 31 to 90 DIM).
Late-RBCS = Linear regression coefficient of BCS on DIM in late lactation (from 91 to 240 DIM).
165d-BCS = BCS at 165 DIM ,as estimated by linear regression in late lactation.

Table 3. Correlation coefficients among traits for lactation curve shape

Trait	Peak yield	Persistency	305-milk
Peak-DIM	0.02	0.61**	0.25**
Peak yield		-0.38**	0.89**
Persistency			0.00

All traits are the same as those defined in the footnote to Table 2.
** p<0.01.

Tekerli et al. (2000) reported a phenotypic correlation between persistency and 305-milk of 0.08.

Correlations among traits for change in BCS

Early-RBCS had significant negative correlations with 15d-BCS, nadir-BCS, and 165d-BCS, whereas late-RBCS had significant positive correlations with these traits (Table 4). There was a moderate negative correlation between early-RBCS and late-RBCS, indicating that cows with small BCS changes up to the nadir had small changes from the nadir onward. These results suggest that cows with low BCSs tended to have small changes in BCS over the whole lactation period. Ruegg and Milton (1995) reported that cows with higher BCSs at calving lost more condition and had higher nadir-BCSs. Unlike in our results, negative genetic correlations between gains in BCS in mid- to late lactation and nadir-BCS have been reported (Berry et al., 2002; Dechow et al., 2002). However, the lactation level in our study herd was much higher than those in these other studies. Studies have suggested that a high total milk yield increases the risk of lameness (Green et al., 2002) and claw disorders (Bielfeldt et al., 2005), and that these disorders reduce BCS (Wells et al., 1993; Espejo et al., 2006). Green et al. (2002) also reported that the incidence of first episodes of lameness peaks 3 months after calving. We therefore consider that these relationships between lactation level and health status affected the results in our study.

Correlations between traits for lactation curve shape and change in BCS

There were no significant correlations between traits for lactation curve shape and early-RBCS, an indicator of the degree of negative energy balance in early lactation (Table 5). Both Berry et al. (2007) and Roche et al. (2007) found that increased BCS loss was associated with increased peak milk yield and reduced lactation persistency, as calculated by the Wilmink function. (Both of these study groups evaluated lactation persistency by the *c* parameter of the Wilmink function.) Our results showed the same tendency, although the relationships were not significant.

Peak yield and 305-milk had significant negative

Table 4. Correlation coefficients among traits for change in BCS

Trait	15d-BCS	Nadir-BCS	Late-RBCS	165d-BCS
Early-RBCS	-0.77**	-0.30**	-0.39**	-0.34**
15d-BCS		0.68**	0.44**	0.62**
Nadir-BCS			0.34**	0.86**
Late-RBCS				0.51**

All traits are the same as those defined in the footnote to Table 2. ** p<0.01.

Table 5. Correlation coefficients between traits for lactation curve and change in BCS

Traits	Peak-DIM	Peak yield	Persistency	305-milk
Early-RBCS	-0.01	-0.11	0.10	-0.04
15d-BCS	-0.06	-0.06	-0.05	-0.10
Nadir-BCS	-0.18*	-0.36**	-0.09	-0.33**
Late-RBCS	0.19	-0.28**	0.24**	-0.29**
165d-BCS	-0.04	-0.33**	-0.08	-0.34**

All traits are the same as those defined in the footnote to Table 2. * p<0.05; ** p<0.01.

correlations with nadir-BCS, late-RBCS, and 165d-BCS, suggesting that cows with high peak yield and total milk yield had low BCSs in mid- to late lactation and delayed recovery of body reserves. Veerkamp et al. (2001) estimated that the genetic correlations between BCSs at different DIM and full lactation yield were about -0.3 in first-parity cows. Our results also suggest that cows with high peak yield and total milk yield were not in good health in mid- to late lactation, because BCS and its changes are related to health status throughout lactation (Wells et al., 1993; Lassen et al., 2003). Yamazaki et al. (2009) reported that cows with high rates of increase in milk yield and with high milk yields in early lactation were predisposed to udder disease afterward. There was a negative correlation between peak-DIM and nadir-BCS in our study, consistent with the findings of Roche et al. (2007). This result is likely partly associated with the positive correlation between peak-DIM and 305-milk (Table 3).

Persistency was positively correlated with late-RBCS. Peak-DIM was also positively associated with late-RBCS, although the association was not significant (p = 0.067). These results suggest that cows with high lactation persistency had good recovery of body reserves in late lactation, which indicated that cows with high lactation persistency were in good health in late lactation. We examined the partial correlation coefficient between persistency and late-RBCS adjusted on 305-milk by linear regression. The partial correlation was significantly positive (r = 0.28), suggesting that the relationships between lactation persistency and recovery of body reserves and health in late lactation are favorable, regardless of the lactation level.

In conclusion, peak yield and total milk yield were negatively correlated with BCSs and its change in mid- to late lactation in first-lactation cows, suggesting that cows with high levels of lactation have low body reserves and health status in mid- to late lactation and thus delayed recovery of body reserves. Lactation persistency was positively correlated with change in BCS in late lactation, suggesting that cows with high lactation persistency tend to be healthy and recover body reserves well in late lactation. Lactation persistency was negatively correlated with peak yield, and the relationship between lactation persistency and change in BCS in late lactation was favorable regardless of the lactation level. Therefore, modification of the lactation curve to promote an increase in lactation persistency could help to maintain the health of dairy cows in late lactation without decreasing total milk yield. We note, however, that the relationships in this study are phenotypic. Inclusion of lactation persistency in the breeding goal to improve health needs to be based on genetic relationships.

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