GENETICS AND BREEDING

Standardization of Lactation Means of Somatic Cell Scores for Calculation of Genetic Evaluations

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ABSTRACT

Sample day records of means of somatic cell scores were analyzed to develop adjustments to standardize records for length of lactation. Estimates for effect of DIM were from a model that included random lactation and cow effects for lactations to date of 753,929 Holsteins and 21,842 Jerseys calving in Pennsylvania or Wisconsin from 1987 to 1991. Lactation, cow, and residual variances were estimated using REML. Lactation and cow variances relative to a phenotypic variance of 1.00 were .57 and .31, respectively, for Holsteins and .52 and .35, respectively, for Jerseys. Estimates of effect of DIM were used to compute additive adjustments. Final lactation mean of somatic cell score at ≤305 DIM for 1,857,532 Holsteins and 113,998 Jerseys from all participating states were standardized for lactation length and analyzed to determine the national effects of calving age and the regional effects of calving month. Multiplicative adjustments were developed for calving age and additive adjustments for calving month. Sample day records of lactation means of somatic cell scores were used to estimate weights based on number of somatic cell sample days to account for the lower accuracy of short records for genetic evaluation.

(**Key words**: somatic cell, standardization, genetic evaluation, age adjustment)

Abbreviation key: **DIMLS** = DIM on last SCC sample day, **LSCS** = lactation mean of SCS, **SCS** = somatic cell score.

INTRODUCTION

Genetic evaluation for somatic cell score (SCS) for US dairy cattle (15, 21) requires methods to account for environmental influences so that additive genetic differences in lactation means of SCS (LSCS) may be predicted accurately. In a recent review, Harmon (7) indicated that the major factor influencing SCC is infection status of the mammary gland. In the absence of infection, SCC changes little with environmental factors, but incidence of mastitis and associated effects on SCC may correspond to systematic environmental differences.

Numerous studies (3, 4, 5, 6, 8, 16, 27, 28) have examined the effects of stage of lactation on SCC and SCS (the sample day SCC transformed to $\log_2$). Sample day SCC and SCS tended to be high at the beginning of lactation, decline until 5 to 6 wk into lactation, and then either remain nearly constant (first parity) or rise linearly (later parities) until dry-off. Schutz et al. (16) found the highest SCS from milk at the beginning of lactation for first parity but at the end of lactation for later parities. Lactation curves followed the inverse of curves for milk yield, and a negative correlation between sample day SCC and sample day milk yield has been documented (9). Miller et al. (10) concluded that this negative relationship reflected both the true biological effects of udder inflammation and a dilution of SCC by milk volume. Ali and Shook (1) recommended expressing SCC on a log scale to obtain a Gaussian frequency distribution and homogeneous error variances, and National Cooperative DHI required that SCC be reported as SCS by January 1, 1984 (20).

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Emanuelson and Persson (6) proposed adjustment of sample day SCS for either milk volume or stage of lactation but pointed out that adjustment for milk volume may not be appropriate if a genetic correlation exists between milk yield and SCC. Because the genetic correlation between milk yield and LSCS is .12 (15), accounting for differences in milk yield may remove the true genetic variation of LSCS. However, any dilution of SCC by milk volume may be partially offset by correction for effect of stage of lactation to the extent that dilution corresponds to the lactation curve for milk yield; i.e., adjustment for stage of lactation may account for some variance of milk yield (and, hence, SCS) for individual cows but should not remove differences between cows.

Wiggans and Shook (27) detailed a procedure to adjust sample day SCS for stage of lactation and to combine adjusted SCS into a single lactation measure with different weights for individual sample days based on stage of lactation during which the sample was taken. However, such adjustment is not possible when only the mean of sample day SCS is reported as a lactation measure as is currently done by most dairy records processing centers for LSCS (15). Schutz et al. (17) found that adjustment of sample day SCS before calculation of LSCS had little effect on mean, standard deviation, or tests of significance relative to LSCS without adjustment when sample day information was complete for lactations. Boettcher et al. (4) found differences in LSCS corresponding to classes assigned for DIM on last SCC sample day (**DIMLS**), which served as a measure for the effect of lactation length on LSCS.

Several studies (3, 4, 6, 8, 17, 19) have considered the effects of calving age or parity on lactation measures of SCC. Others (2, 10, 12, 28) have included age directly in statistical models used for genetic evaluation. Schutz et al. (19) found a nearly linear increase in LSCS with calving age for Holsteins, but LSCS for Jerseys was affected little by calving age until 42 mo and then increased linearly with age thereafter. Older cows likely have more clinical and subclinical mastitis that is attributable to prolonged exposure to mastitis-causing pathogens in the environment and milking systems, weaker teat end sphincters, and greater stress because of higher milk yield at maturity. Possible dilution of LSCS by greater milk volume with increasing age of cows would tend to slow the increase in LSCS that is associated with such effects.

Sampling month is known to affect sample day SCS (6, 8, 28). In the absence of sample day records, seasonality has been approximated by calving month (4, 17, 19). Seasonal effects were smaller than age effects (15, 19) and differed among years (3). Kennedy et al. (8) reported the lowest sample day SCS during May and the highest SCS during December for cows in Quebec. For US dairy cows, LSCS was lowest for cows calving from October to January and highest for cows calving from June to September (4, 19). Geographic region influenced the effect of calving season; the largest impact occurred in southeastern states. Seasonal influences on sample day SCS or LSCS probably are not caused directly by changes in temperature or humidity but by increased exposure of teat ends to pathogens that are more widespread in the environment under these conditions (7). The animal model used for USDA genetic evaluation of LSCS (15) includes a management group effect that considers herd, year-season of calving (2-mo seasons), parity (first and later), and registration status (only for Holsteins); therefore, seasonal effects of SCS already are considered. An exception occurs when seasons are combined across several months because of too few mates for management group (26). In that case, prior adjustment for calving month is warranted.

For USDA-DHIA genetic evaluations for yield, short records are given less weight than records of cows still milking at 305 d (26). Such adjustment is appropriate if short records have error variances greater than complete records, but incomplete milk yield records have less variation than complete 305-d records (24). Expansion of short records results in equal genetic variation but also more error variance for the expanded records; this increased variance is offset by weighting the expanded records less during evaluation procedures. Intuitively, LSCS based on short records has higher variance than LSCS based on complete lactations (305 d) because fewer sample day SCS are used to calculate LSCS. Placing less weight on shorter records is necessary for SCS.

Because somatic cell testing often is optional for dairy producers, the LSCS records provided for genetic evaluations may have few sample days. Those sample days may be early in lactation, late in lactation, or sporadic throughout lactation (relative to samples every month). The error variance for any LSCS record may be more a function of the number of SCS sample days than the lactation length. Therefore, weights should be determined by number of SCS sample days rather than by lactation length.

The primary objective of this study was to develop adjustments to standardize LSCS for lactation length, calving age, and calving season. A secondary objective was to obtain adjustments to allow less weight to be given to LSCS based on fewer sample day SCS.

MATERIALS AND METHODS

Data that were available for this study included LSCS records provided to USDA prior to December 1991 by seven of nine regional US dairy records processing centers. Records were contributed from 1987 to 1991 by Agri Tech Analytics (Tulare, CA), Pennsylvania DHIA Service Center (University Park), North Carolina Dairy Records Processing Center (Raleigh, NC), and Wisconsin DHI Cooperative (Madison); from 1987 to 1988 by Cornell Dairy Records Processing Laboratory (Ithaca, NY); from 1990 to 1991 by Minnesota Dairy Records Processing Center (St. Paul); and during 1991 by DHI Computing Service, Inc. (Provo, UT). Records also included supporting information for the number of SCS samples on which LSCS was based, DIM, and the most recent sample day SCS. Sample day records of LSCS for lactations to date were averaged through the most recent sample date and provided for cows calving in Pennsylvania and Wisconsin.

Initial data requirements were sire identification for cows with records, LSCS from 0 to 9.99, and reported number of sample days >0. The LSCS records were compared with milk records currently included for genetic evaluation to ensure the consistency of identification, parentage, birth date, and calving date.

Lactation Length

Only monthly records of LSCS from Pennsylvania and Wisconsin were used to estimate the effect of lactation length on LSCS. The first five parities of cows were included; cows with records for later parities were not required to have LSCS reported for first parity because many cows lacked first parity records. Only 1 sample d was required per lactation, but ≤60, ≤100, ≤140, ≤180, ≤220, or ≤260 DIM was required for 1, 2, 3, 4, 5, or 6 sample d, respectively, to ensure that the number of sample days was representative of the corresponding lactation length. Sample days with DIM from 7 to 305 were included. Following edits, data included 246,257 sample day records of 21,842 Jersey cows and 8,719,893 records of 753,929 Holstein cows. The remaining number of records for other breeds was insufficient for reliable analyses.

All sample day LSCS of a lactation were assigned to 1 of 38 classes based on calving age as defined by Boettcher et al. (4). Age classes considered only calving ages from 18 to 120 mo because older calving ages would not be represented in fifth or earlier parities. In addition to age classes, sample day LSCS were assigned to 1 of 12 classes based on calving month. Calving age and month classes were considered separately for Pennsylvania and Wisconsin.

Sample day LSCS also were assigned to DIMLS classes to account for lactation length. Records of ≤20 d, 21 to 30 d, 31 to 40 d, . . . , 281 to 290 d, 291 to 300 d, and 301 to 305 d were in classes 1, 2, 3, . . . , 28, 29, and 30, respectively. Effect of DIMLS was considered separately for first and later parities but were assumed to be identical for Pennsylvania and Wisconsin.

Effects of DIMLS classes were estimated with a model similar to the sample day model for yield traits reported by Stanton et al. (22):

$$y_{ijklmno} = hy_i + as_j + ms_k + w_l + d_m + c_n + e_{ijklmno},$$

where $y_{ijklmno}$ = LSCS at sample day o in DIMLS class m in lactation l of cow n calving in herd-year i in age-state class j and month-state class k, hy = fixed effect of herd and calving year, as = fixed effect of calving age and state (76 classes), ms = fixed effect of calving month and state (24 classes), w = random effect common to all sample day LSCS of

TABLE 1. Number of records and levels of effects for estimation of variance components for sample day lactation means of somatic cell scores for six randomly selected subsets of Holstein data and for Jerseys.

	Holstein subset						
	1	2	3	4	5	6	Jersey
Records	440,846	419,756	445,183	379,465	470,888	409,811	222,263
Effect							
Herd-year	1531	1496	1516	1399	1586	1492	977
Age-state	76	76	76	76	76	76	76
Month-state	24	24	24	24	24	24	24
Lactation	63,681	62,465	63,440	54,963	68,330	58,554	32,969
DIM	60	60	60	60	60	60	60
Cow	37,633	37,184	37.373	32,366	40,069	34,997	18,916

a single lactation of a cow, d = fixed effect of DIMLS for first or later parity (60 classes), c = random effect common to all sample day LSCS of a cow (including permanent environmental and genetic effects), and e = random residual effect.

Variance ratios for random effects used with BLUP analyses were estimated by using the same model and an expectation-maximization type REML algorithm developed by Misztal (11). For variance estimation, 50 sample d (approximately five lactations) per herd year were required. All data meeting this requirement were used for Jerseys, but computational constraints required using subsets of data for variance estimation for Holsteins. Holstein data were divided into 20 subsets based on digits 7 (even or odd) and 8 (digit = 0, 1, 2, . . . , 9) of the DHI herd code. Variances from six randomly chosen subsets were averaged because the subsets were of similar sizes. The number of levels of effects in the model and the number of records for Jerseys and Holstein subsets are in Table 1.

For BLUP analyses, expectations of lactation, cow, and error effects were 0, and variance ratios were determined from the REML estimates: $\hat{\sigma}_w^2$ = estimate of lactation variance, $\hat{\sigma}_e^2$ = estimate of residual variance, and $\hat{\sigma}_c^2$ = estimate of cow variance. Relationships among cows were ignored when effects of lactation length were estimated because 1) these effects were of main interest; 2) genetic trend for LSCS would have little effect on estimates for these effects, especially for the relatively short time period covered by the data; and 3) computational constraints would limit analysis.

Covariance among sample day records within a lactation was assumed to be uniform or homogeneous. This assumption is not strictly valid because contiguous sample days are expected to be more correlated than are more distant ones, especially considering the part-whole relationship among updated means of SCS. The appropriate covariance structure is not easily determined and likely depends greatly on when first and later samples occurred during lactation. Inclusion of the random lactation effect was needed to include repeated samples within a lactation. Fixed estimates for effect of lactation length were of primary interest. Estimation of effects of lactation length with homogeneous covariances assumed among sample day records parallels estimation of age effects on repeated lactation records with models that include a permanent environmental effect, for which homogeneous variance among lactations of a cow is assumed (13, 18, 19, 28).

Estimates for DIMLS classes were obtained with the same model for Jerseys and Holsteins. For Jerseys, all records were used; for Holsteins, data were divided into two subsets based on the last digit (even or odd) of the DHI herd code. To accommodate analysis with only the two subsets, the number of Holstein records was reduced further by requiring 100 sample d per herd-year subclass. The number of levels of effects and the number of records are in Table 2. According to the procedure of Emanuelson (5), additive adjustments were formed from smoothed (23) class solutions and combined for Holstein subsets. Class constants were expressed relative to the final class for first or later parities.

TABLE 2. Number of records and levels of effects for calculation of solutions for lactation length classes for two subsets[1] of Holstein data and for Jerseys.

	Holstein subset[1]		
	Odd	Even	Jersey
Records	4,223,611	4,295,260	222,263
Effect			
Herd-year	14,763	15,159	977
Age-state	76	76	76
Month-state	24	24	24
Lactation	616,824	623,089	32,969
DIM	60	60	60
Cow	361,149	366,502	18,916

[1]Subsets of data based on the last digit (even or odd) of DHIA herd code.

Correlations of sample day LSCS through 11 sample d with the lactation measure of LSCS, which was based on the latest sample day for a lactation, were computed separately for Holsteins and Jerseys. Correlations were separate for first and later parities; however, Pennsylvania and Wisconsin records were combined. Correlations were squared for use as weights based on number of SCS sample days.

Calving Age and Season

Preliminary results (not reported) and previous research (15) had shown that too few records were available for breeds other than Holstein and Jersey to develop accurate adjustments to standardize for calving age and season. For Holsteins and Jerseys, latest sample day LSCS for each lactation was preadjusted for lactation length and used as the lactation measure. Edits were similar to those used with data for analysis of lactation length except that records with <40 DIM were discarded. Data from all states that contributed LSCS records through participating dairy records processing centers were included. Preliminary research (not reported) indicated that age effects were nearly identical for all regions of the US and that effect of interaction of calving age and calving month was not important. Effects of calving month differed by geographic region, and records were assigned to month-region classes according to the calendar month of calving for four regions (Northeast, Midwest, Southeast, and West) previously defined by Schutz et al. (19). Requiring five lactations per herd-year of calving reduced the number of records only slightly. Data included 193,998 lactation records of 113,998 Jersey cows and 2,958,173 lactation records of 1,857,532 Holstein cows.

Table 3 has the number of records and levels of effects available for BLUP analyses with the following model:

$$y_{ijklmnop} = hy_{ij} + a_k + mr_{lm} + s_{in} + pe_{no} + g_{no} + e_{ijklmnop},$$

where $y_{ijklmnop}$ = LSCS record p adjusted for lactation length of a cow (daughter o of sire n) that calved at an age in class k and in region m, year j, and herd i; hy = fixed effect of herd and calving year; a = fixed effect of calving

TABLE 3. Numbers of records and levels of effects for calculation of Holstein and Jersey solutions for calving age and calving month classes.

	Holstein	Jersey
Records	2,958,173	193,998
Effect		
Herd-year	69,968	4715
Age	38	38
Month-region	48	48
Herd-sire interaction	868,733	40,171
Permanent environment	1,857,532	113,998
Animal	2,379,542	166,630
Cows with records	1,857,532	113,998
Relatives	522,003	52,625
Groups[1]	7	7

[1]Parent groups for unknown ancestors (25).

TABLE 4. Estimates of lactation variance ($\hat{\sigma}^2_w$), cow variance ($\hat{\sigma}^2_c$), and residual variance ($\hat{\sigma}^2_e$) and variance ratios for Holstein and Jersey sample day records of lactation mean of somatic cell scores.

Data	$\hat{\sigma}^2_w$	$\hat{\sigma}^2_c$	$\hat{\sigma}^2_e$	$\hat{\sigma}^2_e/\hat{\sigma}^2_w$	$\hat{\sigma}^2_e/\hat{\sigma}^2_c$
Holstein					
Subset 1	1.303	.740	.298		
Subset 2	1.282	.698	.293		
Subset 3	1.305	.674	.291		
Subset 4	1.276	.703	.291		
Subset 5	1.288	.690	.291		
Subset 6	1.298	.689	.292		
Mean	1.292	.699	.293	.226	.419
Jersey	1.131	.758	.276	.244	.363

age (38 classes); mr = fixed effect of calving month and region (48 classes); s = random effect of interaction of herd and sire; pe = random permanent environmental effect common to all LSCS of a cow; g = random additive genetic effect; and e = random residual effect. For BLUP analyses, variance ratios were assumed to be σ^2_e/σ^2_s = 13.00, σ^2_e/σ^2_{pe} = 3.10, and σ^2_e/σ^2_g = 7.22 based on σ^2_s = .05, σ^2_{pe} = .21, σ^2_g = .09, and σ^2_e = .65 relative to a phenotypic variance of 1.00 based on previous results of Schutz et al. (19).

Sire and dam information was complete for cows with records. Male pedigrees were traced back to 1950 to account for most relationships. Female pedigrees were included for dams of sires with multiple offspring. Other female pedigrees were not included because those cows contributed relatively fewer ties at a large computational cost. Unknown-parent groups were included in the additive genetic effect (25). Solutions for age at calving effects were smoothed (23) and used to develop standardization adjustments. Additive and multiplicative adjustments were compared using the method of Emanuelson (5). Calving month solutions relative to the mean of all months for a region were multiplied by −1 to form additive adjustments to standardize LSCS for seasonality.

RESULTS AND DISCUSSION

The REML variance estimates and resulting variance ratios for lactation, cow, and residual effects from analysis for lactation length are in Table 4. Empirical standard errors for Holsteins were .005 for lactation variance, .009 for cow variance, and .001 for residual variance. Lactation variance was 85% and 50% higher than cow variance for Holsteins and Jerseys, respectively. Lactation and cow variances relative to a phenotypic variance of 1.00 were .57 and .31, respectively, for Holsteins and .52 and .35, respectively, for Jerseys. Variance ratios from Table 4 were used in BLUP analyses to obtain solutions for DIMLS classes. These solutions were best linear unbiased estimates if the estimates of variances for random effects corresponded to true underlying variances. Figures 1 and 2 have smoothed constant estimates for the effect of lactation length on LSCS relative to the final class, which represented complete lactations. Constants for Holsteins (Figure 1) were the mean of

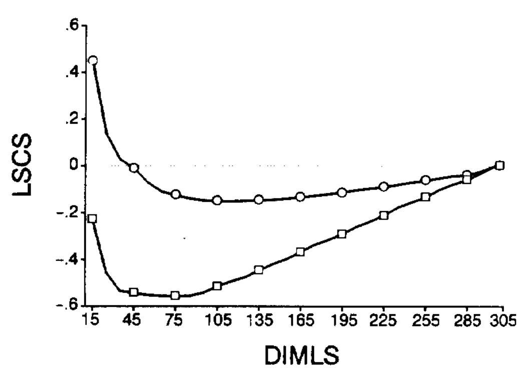

Figure 1. Smoothed estimates of effects of classes for DIM on last SCC sample day (DIMLS) on lactation mean of somatic cell score (LSCS) for first (O) and later (□) parities of Holsteins.

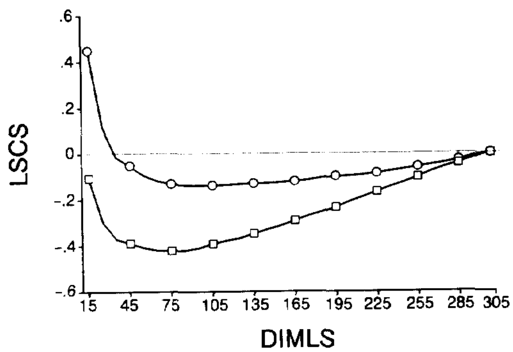

Figure 2. Smoothed estimates of effects of classes for DIM on last SCC sample day (DIMLS) on lactation mean of somatic cell score (LSCS) for first (O) and later (□) parities of Jerseys.

smoothed constant estimates from the 2 subsets of data, which never differed by >.02 for corresponding classes. Additive adjustments for standardization of LSCS to a 305-d basis are in Table 5 f or Holsteins and Jerseys.

Emanuelson (5) compared additive and multiplicative adjustments and their combinations and advocated an additive procedure to account for effect of lactation length because results did not strongly indicate a need for correction of variances (multiplicative adjustment) and because erroneously applied multiplicative correction can bias results. Relationships between mean and variances over the course of lactation are not clearly understood, especially for records of infected versus uninfected cows (5).

Smoothed solutions for calving age classes are in Table 6. Solutions were similar to previously reported results (4, 19). Although data from those studies were included in this study, current results accounted for lactation length better and were more complete. Breed differences were apparent. Solutions for Jerseys calving at <40 mo of age differed little, but solutions increased linearly with age for older Jerseys and for Holsteins of all ages. Overall mean and variance relationships, as indicated by coefficients of variation, were examined within calving age class for means and standard deviations of LSCS, standardized for calving age with differing portions of multiplicative and additive adjustment (5).

TABLE 5. Additive adjustments for standardization of lactation mean of somatic cell scores (SCS) for DIM at last SCS sample day (DIMLS) for first and later parities of Holsteins and Jerseys.

	Holstein		Jersey	
DIMLS	Parity 1	Parities 2 to 5	Parity 1	Parities 2 to 5
≤20	−.45	+.23	−.45	+.10
21 to 30	−.14	+.45	−.12	+.29
31 to 40	−.03	+.53	+.01	+.37
41 to 50	+.01	+.54	+.05	+.39
51 to 60	+.07	+.55	+.09	+.41
61 to 70	+.11	+.56	+.12	+.42
71 to 80	+.13	+.56	+.13	+.42
81 to 90	+.14	+.56	+.14	+.42
91 to 100	+.15	+.54	+.14	+.41
101 to 110	+.15	+.51	+.14	+.39
111 to 120	+.15	+.49	+.14	+.38
121 to 130	+.15	+.47	+.13	+.36
131 to 140	+.15	+.45	+.13	+.35
141 to 150	+.14	+.42	+.13	+.33
151 to 160	+.14	+.40	+.12	+.31
161 to 170	+.13	+.37	+.12	+.29
171 to 180	+.13	+.34	+.11	+.27
181 to 190	+.12	+.32	+.10	+.25
191 to 200	+.11	+.29	+.10	+.23
201 to 210	+.10	+.26	+.10	+.21
211 to 220	+.10	+.24	+.09	+.19
221 to 230	+.09	+.21	+.08	+.16
231 to 240	+.08	+.18	+.08	+.14
241 to 250	+.07	+.15	+.07	+.12
251 to 260	+.06	+.13	+.06	+.10
261 to 270	+.05	+.10	+.05	+.08
271 to 280	+.04	+.08	+.04	+.06
281 to 290	+.04	+.06	+.03	+.04
291 to 300	+.02	+.03	+.01	+.02
301 to 305	.00	.00	.00	.00

Emanuelson (5) developed this method to determine optimal standardization procedures. Coefficients of variations for age-class means and standard deviations were minimized for all parities of Jerseys by using completely multiplicative adjustment. A higher level of multiplicative than additive adjustment was optimal for Holsteins, and the proportion was greater for later parities than for first.

Effects of parity and calving age within parity were included in genetic evaluations for the US (13) in January 1995; therefore, remaining additive differences for age effects were considered. However, some level of multiplicative correction still is warranted because both means and variances increased as calving age increased (Table 7), although coefficients of variation decreased. Homogeneous variance

TABLE 6. Estimates for calving age class relative to mean age for lactation mean of somatic cell scores standardized for lactation length for Holsteins and Jerseys.

Calving age	Holstein	Jersey	Calving age	Holstein	Jersey
(mo)			(mo)		
17 to 21	-.49	-.28	40	-.10	-.23
22	-.48	-.30	41	-.08	-.21
23	-.47	-.31	42	-.07	-.18
24	-.45	-.31	43 to 44	-.02	-.13
25	-.43	-.30	45 to 46	.02	-.05
26	-.41	-.29	47 to 48	.09	.02
27	-.39	-.27	49 to 50	.17	.07
28	-.38	-.26	51 to 52	.23	.12
29	-.37	-.25	53 to 54	.27	.16
30	-.33	-.25	55 to 57	.31	.25
31	-.31	-.25	58 to 60	.38	.37
32	-.30	-.26	61 to 63	.46	.47
33	-.28	-.25	64 to 66	.54	.55
34	-.25	-.27	67 to 71	.62	.66
35	-.22	-.27	72 to 77	.73	.79
36	-.19	-.26	78 to 83	.85	.90
37	-.15	-.25	84 to 89	.95	.98
38	-.13	-.25	90 to 95	1.06	1.07
39	-.11	-.24	96 to 120	1.17	1.18

is useful for genetic evaluation, but a higher incidence of mastitis for older cows may cause variance to increase with age. The possible need for additive adjustment should be investigated.

Multiplicative adjustments were developed for calving ages of 18 to 120 mo by assigning solutions to the mean calving age for each class. Data were standardized to the mean calving age of 46 mo for Holsteins and 49 mo for Jerseys. Multiplicative adjustments for selected calving ages are presented in Table 8. Mean LSCS adjusted for lactation length was 3.05 for Holsteins calving at 46 mo and 3.09 for Jerseys calving at 49 mo.

As data accumulate, the effect of calving age on LSCS can be determined from later parities of only those cows for which first parity LSCS were reported. However, the short time span of current data did not allow such a requirement. The adjustments used to standardize for calving age may be partly biased downward if a higher proportion of older cows, specifically those without a first parity record, have already been selected for low SCC or for mastitis resistance.

Constant estimates for effects of calving month, expressed relative to the mean of all monthly solutions in a region, are shown for first and later parities of Holsteins in Figure 3 and for Jerseys in Figure 4. The resulting additive adjustments were constants multiplied by –1 (Table 9). Solutions were similar to values reported for previous studies (4, 19) and were smaller in magnitude than those for calving age. Regional differences for effect of calving month have been discussed previously (4, 19). Differences between December and January were noticeable but smaller than between some summer months. Because herd and year effects were removed, remaining differences might be related to genetic trends for yield traits (18), which are not accounted for. Within year, cows that calved during December were younger and genetically superior for milk yield, which is correlated genetically with elevated LSCS (15).

The adjustments for standardization of LSCS records for calving age and calving month resulted from analyses of LSCS records standardized for lactation length with calving age and calving month considered simultaneously in the model, and the proposed age adjustments are multiplicative. Therefore, the order of standardization of LSCS records should be lactation length, calving month within region, and calving age.

TABLE 7. Means, standard deviations, and coefficients of variation for lactation means of somatic cell scores standardized for lactation length for Holsteins and Jerseys.

Calving age	Holstein			Jersey		
	$\overline{X}$	SD	CV	$\overline{X}$	SD	CV
(mo)						
17 to 21	2.67	1.37	.51	2.77	1.26	.45
24	2.54	1.30	.51	2.72	1.21	.44
27	2.57	1.30	.51	2.80	1.24	.44
30	2.67	1.33	.50	2.82	1.24	.44
33	2.75	1.37	.50	2.83	1.24	.44
36	2.80	1.37	.49	2.81	1.31	.47
39	2.85	1.37	.48	2.79	1.36	.49
42	2.93	1.40	.48	2.93	1.34	.46
47 to 48	3.10	1.45	.47	3.11	1.44	.46
53 to 54	3.25	1.49	.46	3.25	1.47	.45
61 to 63	3.43	1.56	.45	3.50	1.56	.45
71 to 77	3.68	1.64	.45	3.82	1.64	.43
90 to 95	4.02	1.71	.43	4.29	1.59	.37
96 to 120	4.22	1.78	.42	4.38	1.63	.36

Lactation length weights, based on number of SCS sample days, are in Table 10 for Holsteins and Jerseys. The weights are the squared correlations between LSCS, based on the number of sample days and LSCS for the complete lactation. These weights were slightly lower than those reported by Pagnacco et al. (14), who adjusted sample day SCS for stage of lactation before the lactation mean was calculated. The weights in this study corresponded reasonably well with lactation length weights used for yield records from standard test plans and based on 10 30-d segments for DIM (26). For milk yield, lactation length weights for short (<136 DIM) records were higher for first parity than for later parities (26). The opposite was true for lactation length weights for LSCS records. Presumably, the elevated risk of clinical or subclinical mastitis infection at first calving contributed to greater variation of LSCS during early first lactation, but milk yield during first lactations tended to vary less than during later lactations. Increased variability would have reduced correlation of sample day LSCS records with records for the entire lactation and would have accounted for decreased weights for lactation length.

TABLE 8. Multiplicative adjustments for standardization of lactation mean of somatic cell scores for selected calving ages for Holsteins and Jerseys.

Calving age	Holstein	Jersey
(mo)		
20	1.21	1.12
30	1.14	1.11
40	1.05	1.10
50	.96	.99
60	.89	.89
70	.84	.83
80	.79	.78
90	.76	.76
100	.74	.74
110	.73	.73
120	.71	.71

CONCLUSIONS

Based on sample day records of LSCS (LSCS calculated from all SCS through the current sample day for a lactation) from Pennsylvania and Wisconsin, lactation variance of sample day LSCS was 50 to 85% higher than cow variance. These variance ratios were used in mixed model analyses to estimate effects of lactation length. Additive adjustments for length of lactation were appropriate when only a single mean of sample day SCS was available per lactation. If individual sample day SCS were available nationally, effects of lactation length could be corrected for each sample day prior to calculation of the lactation mean (27).

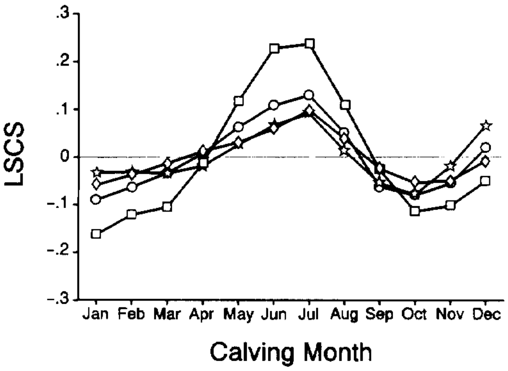

Figure 3. Estimates of effects of calving month on lactation mean of somatic cell scores (LSCS) for Holsteins in the Northeast (○), Midwest (☆), Southeast (□), and West (◇).

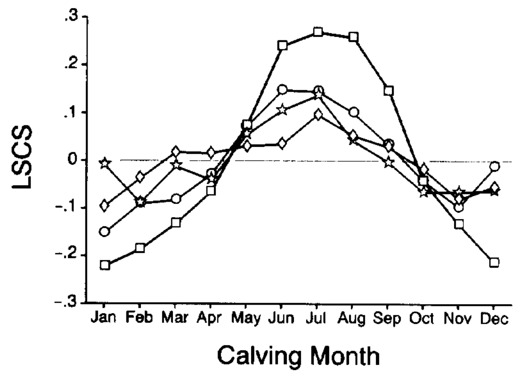

Figure 4. Estimates of effects of calving month on lactation mean of somatic cell scores (LSCS) for Jerseys in the Northeast (○), Midwest (☆), Southeast (□), and West (◇).

Similarly, effects of sample month could be considered in place of effects of calving month and might better represent the underlying biology of seasonal differences. If differences among years are larger for sample month than for calving month, inclusion of an effect for sample month rather than calving month would be indicated.

Adjustment for calving age was more crucial than adjustment for seasonality, and age

TABLE 9. Additive adjustments for standardization of lactation mean of somatic cell scores for calving month within four geographic regions of the US for Holsteins and Jerseys.

	Region			
Breed and month	Northeast	Midwest	Southeast	West
Holstein				
January	.09	.03	.16	.06
February	.06	.03	.12	.04
March	.03	.03	.11	.01
April	–.01	.02	.01	–.01
May	–.06	–.03	–.12	–.03
June	–.11	–.07	–.23	–.06
July	–.13	–.09	–.24	–.10
August	–.05	–.01	–.11	–.04
September	.06	.05	.03	.02
October	.08	.08	.11	.05
November	.06	.02	.10	.05
December	–.02	–.07	.05	.01
Jersey				
January	.15	.01	.22	.10
February	.09	.09	.19	.04
March	.08	.01	.13	–.02
April	.03	.04	.07	–.02
May	–.07	–.06	–.07	–.03
June	–.15	–.11	–.24	–.04
July	–.15	–.14	–.27	–.10
August	–.10	–.04	–.26	–.05
September	–.04	.00	–.15	–.03
October	.04	.07	.04	.02
November	.10	.07	.13	.08
December	.01	.06	.21	.05

TABLE 10. Lactation length weights based on number of somatic cell score (SCS) sample days included in the lactation mean of SCS for first and later parities of Holsteins and Jerseys.

Number of SCS sample days	Holstein		Jersey	
	Parity 1	Parities 2 to 5	Parity 1	Parities 2 to 5
1	.46	.52	.43	.56
2	.61	.67	.61	.72
3	.72	.77	.73	.81
4	.81	.84	.82	.87
5	.87	.89	.87	.91
6	.91	.93	.92	.94
7	.94	.96	.95	.97
8	.97	.98	.97	.98
9	.99	.99	.99	.99
≥10	1.00	1.00	1.00	1.00

adjustments should be updated periodically. Previously, Schutz et al. (19) reported that solutions for calving age and month for Guernseys were similar to those for Jerseys and that solutions for other breeds were more similar to those for Holsteins. As more data accumulate over time and from additional processing centers, further research will be able to calibrate further these adjustments for standardization of Holstein and Jersey LSCS and to define requirements for standardization of records for breeds with fewer cows. The importance of accounting for age within parity has recently been demonstrated for production traits (13, 18) and for SCS (14). Future research should consider the interaction of age and parity.

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