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Genetic and environmental factors that affect gestation length in dairy cattle

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ABSTRACT

Genetic and environmental factors that might affect gestation length (GL) were investigated. Data included information from >11 million parturitions from 1999 through 2006 for 7 US dairy breeds. Effects examined were year, herd-year, month, and age within parity of conception; parturition code (sex and multiple-birth status); lactation length and standardized milk yield of cow; service sire; cow sire; and cow. All effects were fixed except for service sire, cow sire, and cow. Mean GL for heifers and cows, respectively, were 277.8 and 279.4 d for Holsteins, 278.4 and 280.0 d for Jerseys, 279.3 and 281.1 d for Milking Shorthorns, 281.6 and 281.7 d for Ayrshires, 284.8 and 285.7 d for Guernseys, and 287.2 and 287.5 d for Brown Swiss. Estimated standard deviations of GL were greatly affected by data restrictions but generally were approximately 5 to 6 d. Year effects on GL were extremely small, but month effects were moderate. For Holstein cows, GL was 2.0 d shorter for October conceptions than for January and February conceptions; 4.7 and 5.6 d shorter for multiple births of the same sex than for single-birth females and males, respectively; 0.8 d longer for lactations of ≤250 d than for lactations of ≥501 d; and 0.6 d shorter for standardized yield of ≤8,000 kg than for yield of ≥14,001 kg. Estimates for GL heritability from parities 2 to 5 were 33 to 36% for service sire and 7 to 12% for cow sire; corresponding estimates from parity 1 were 46 to 47% and 10 to 12%. Estimates of genetic correlations between effects of service sire and cow sire on GL were 0.70 to 0.85 for Brown Swiss, Holsteins, and Jerseys, which indicates that those traits likely are controlled by many of the same genes and can be used to evaluate each other. More accurate prediction of calving dates can help dairy producers to meet management requirements of pregnant animals and to administer better health care during high-risk phases of animals' lives. However, intentional selection for either shorter or longer GL is not recommended without consideration of its possible effect on other dependent traits (e.g., calving ease and stillbirth).

Key words: gestation length, breed, twinning, heritability

INTRODUCTION

Gestation length (**GL**) is the interval from conception to subsequent parturition. Silva et al. (1992) studied Guernsey, Holstein, and Jersey parturitions on 7 Florida dairy farms and found that GL had increased over time. They reported a linear regression of 0.08 d/yr, which was equivalent to 4 d over 50 yr.

Many environmental factors affect GL. A review of international dairy and beef research on GL by Andersen and Plum (1965) indicated that most studies found that calving age of the dam affected GL. In addition, about half of the studies that examined dam parity reported an effect on GL. When dam age and parity effects were reported, older cows carried calves longer (≤1 d) than did younger cows. King et al. (1985) cited 5 studies that indicated shorter GL for heifers than for cows; their own summary of embryo-transfer pregnancies in beef cattle showed that GL of young (<4 yr old) recipients was 2.7 d shorter than for older recipients.

McClintock et al. (2003) reported that shorter GL were associated with high summer temperature, which agrees with review findings (Andersen and Plum, 1965). McGuirk et al. (1998) also found shorter GL for summer calvings of beef cattle in the United Kingdom. In contrast, Silva et al. (1992) found no difference in GL between warm and cool seasons in Florida.

Calf sex affects GL. Andersen and Plum (1965) cited about twice as many studies that showed an effect of calf sex on GL as those that found no effect. For those studies that reported an effect, male calves were carried 1 to 2 d longer than females. King et al. (1985) cited 10 studies since 1965 that showed male calves are carried 1 to 2 d longer than females; their own study with embryo-transfer calves also showed a corresponding 1.4-d difference.

Gestation length was 1 d longer for cows in the high genetic milk line of the University of Wisconsin-Madison research herd than for the average line (Hageman et al., 1991). A positive genetic correlation between milk yield and GL could account for the increase in GL over 50 yr reported by Silva et al. (1992).

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Differences in GL have been reported among cattle breeds. Most dairy breeds generally average around 280 d. Brown Swiss GL has been reported to be around 10 d longer (Brakel et al., 1952; Andersen and Plum, 1965); however, despite longer GL, calving difficulty for first-parity Brown Swiss (5%; Cole et al., 2005) is less than for Holsteins (8%; Van Tassell et al., 2003). Although GL averaged 280 d in 7 Florida herds (Silva et al., 1992), GL was shorter for Jerseys (278 d) than for Holsteins (280 d) and Guernseys (282 d). Strain difference in mean GL has even been noted within breed based on the percentage of Holstein-Friesian versus Dutch Friesian genes (Oldenbroek, 1980). King et al. (1985) demonstrated with embryo-transfer pregnancies that calf breed was more influential than recipient breed in determining GL. Several beef breeds have longer GL than most dairy breeds (Andersen and Plum, 1965; King et al., 1985).

Twin and triplet births were associated with shorter GL (6.8 d and 12.7 d, respectively) compared with single births in the USDA high-twinning herd (Echternkamp et al., 2007). Knott (1932) reported that mean GL for twin births was 4 d less than GL for single births. Azzam and Nielsen (1987) reported that twins of beef breeds arrived 4 to 5 d earlier than single females and 5 to 8 d earlier than single males. Several researchers who studied GL and its relationship to other traits (e.g., Meyer et al., 2000; McClintock et al., 2003) eliminated animals with multiple-birth incidents from their examination.

The relationship between GL and all health traits should be considered before making recommendations to change GL. Gestation length has been reported to be related to dystocia and stillbirth, particularly for first parturition, by Philipsson (1976), Martinez et al. (1983), Niskanen and Juga (1997), Johanson and Berger (2003), and Hansen et al. (2004). Those reports also indicated that phenotypic extremes (short or long) in GL produce more stillbirths. Genetic variation for dystocia and stillbirth are well documented (e.g., Wiggans et al., 2003; Cole et al., 2007), and those traits are included in current genetic evaluation programs. The International Bull Evaluation Service (2008) received Holstein national evaluations for calving ease and stillbirth from 11 and 7 countries, respectively, in April 2008. All participating countries except Australia provided genetic evaluations for both service sires and daughter sires. Fewer reports are available on genetic parameters for GL of dairy cattle breeds. Hansen et al. (2004), Jamrozik et al. (2005), and Azzam and Nielsen (1987) estimated direct heritabilities for GL of 0.27 to 0.45 and maternal estimates of 0.07 to 0.13 for heifers and cows.

New Zealand's Livestock Improvement Corporation (2008) recommends using a service bull that transmits a short GL to tighten calving patterns. A controlled calving season is extremely important for herds that strive to have a concentrated calving pattern (e.g., to utilize pasture forages). As an alternative for shortening GL to achieve a 365-d calving interval (Winkelman and Spelman, 2001), yak semen is even being used for some New Zealand herds (Livestock Improvement Corporation, 2007). The mean GL for yak is around 258 d with favorable reproductive rate and survival (Zhao, 2000).

The objective of this research was to document the effects of breed, cow's parity and age, conception herd-year and month, parturition code (multiple birth status and calf sex), cow's lactation length and milk yield, service sire, cow's sire, and cow on GL based on a large number of recent records. Some of those effects have been examined before. However, numbers of records generally were limited, data often were regional, and all US dairy breeds were rarely included. The benefit of including this many effects simultaneously is to determine whether some of the individual effects reported to be significant in previous studies were caused instead by the influence of a correlated trait not included in the model. Information on the effects will allow dairy producers to make more accurate predictions of expected calving date of individual animals for use in management decisions regardless of breed.

MATERIALS AND METHODS

Data

Lactation, reproductive, and dystocia records from the national dairy database at the Animal Improvement Programs Laboratory, Agricultural Research Service, USDA (Beltsville, MD), were used to determine how various genetic and environmental factors impact GL. Lactation records originated in DHI herds and were sent to USDA through 4 dairy records processing centers; dystocia records were supplied by the National Association of Animal Breeders (Columbia, MO). Breeding records originated primarily from Dairy Records Management Systems (Raleigh, NC, and Ames, IA) and AgSource Cooperative Services (Verona, WI), but breeding records from Minnesota DHIA (Buffalo, MN) were also provided through AgriTech Analytics (Visalia, CA). Pedigrees for registered animals were supplied by breed associations; pedigrees for grade animals were provided by dairy records processing centers. Any animal with <87% breed purity based on the USDA crossbred database (Cole et al., 2004) was excluded from analysis.

Table 1. Number of gestations[1] and mean gestation lengths for all animals and for animals with identified AI service sires by breed and parity[2]

	Gestations (n)		Mean gestation length (d)	
Breed	Heifer	Cow	Heifer	Cow
All animals				
Ayrshire	1,176	39,763	281.6 ± 5.1	281.7 ± 5.5
Brown Swiss	2,810	80,554	287.2 ± 6.6	287.5 ± 6.2
Guernsey	975	42,493	284.8 ± 5.9	285.7 ± 5.7
Holstein	587,295	9,692,017	277.8 ± 5.5	279.4 ± 5.7
Jersey	23,179	702,480	278.4 ± 5.4	280.0 ± 5.2
Milking Shorthorn	96	9,815	279.3 ± 6.8	281.1 ± 6.8
Red and White	566	24,015	279.5 ± 6.5	280.4 ± 6.2
Animals with identified AI service sire				
Brown Swiss	2,165	30,641	287.7 ± 6.1	287.9 ± 5.8
Holstein	508,205	6,219,560	277.7 ± 5.2	279.5 ± 5.3
Jersey	19,441	309,297	278.4 ± 5.0	279.9 ± 4.9

[1] Gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2006.

[2] Heifers (parity 1) and cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

Frequencies of GL derived from breeding and calving data were examined for each year and breed to assess data quality. Frequency distributions were inspected to determine whether mean or mode in the database appeared to be compromised historically by editing methods imposed either by the dairy records processing center or USDA. Days open might have been derived from a cow's reported calving date and an assumed GL (e.g., 290 d for Brown Swiss, 280 d for all other breeds) when breeding date was not reported, which would have indicated that breeding dates had been assigned. Days open also might have been changed to align closer to an alternate date when last breeding date and calving date were not in close agreement. The examination of yearly data revealed a single, unusual spike in GL before 1998 at exactly 280 d for each breed except Brown Swiss (which had a spike at 290 d). That spike indicated that days open had been assigned in some cases by using subsequent calving date and an assumed breed GL. Therefore, gestations were limited to those initiated by inseminations after February 1998 and ended with parturitions through December 31, 2006.

Additional edits set a minimum and maximum for GL. Gestation periods that differed from individual breed mean (282 d for Ayrshires, 288 d for Brown Swiss, 285 d for Guernseys, and 280 d for all other breeds) by more than 15 d (approximately 2.5 to 3 standard deviations) were eliminated because they were assumed to be for conceptions from an earlier or later breeding.

Numbers of gestations are in Table 1 for heifers (parity 1) and cows (parity ≥2) by breed. Data for cows were abundant (>9,000 gestations) for all breeds, including more than 9 million gestations for Holsteins. Number of gestations by year (not shown) increased from 648,942 during 1999 to 924,419 during 2004 for Holstein cows. During the same period, data available from Jerseys more than doubled, and data from Brown Swiss increased even more. In contrast, heifer data were limited (<2,800 gestations) for 4 of the 7 breeds, but Holsteins had more than 580,000 gestations. The heifer-to-cow ratio for gestations differed by breed because data came from several sources. Some sources had little or no data for breeds other than Holstein, and some had no heifer data. The principal source was DHI lactation records, which provided GL only after first calving.

Methods

Means and standard deviations for GL were calculated separately for heifers and cows of 7 US dairy breeds. Because precise conception dates likely were not available for most natural services, Brown Swiss, Holstein, and Jersey means and standard deviations were also calculated using a more extensively edited data set that required an identified AI service sire (Table 1). A comparison of means and standard deviations between the 2 data sets should provide information about the accuracy of breeding dates for natural-service matings.

The model to estimate genetic and environmental effects on GL was

$$\mathrm{G_{hijkmnopqrs} = Y_h + H_{hi} + T_j + P_k + A_{mn} + L_o + M_p + SS_q + MGS_r + C_s + e_{hijkmnopqrs}},$$

where $\mathrm{G_{hijkmnopqrs}}$ is the GL for a calf conceived in year h in herd i during month j with parturition code k, cow s of parity m and age n with lactation length o and standardized milk yield p, sire q, and maternal grandsire r; Y is the fixed effect of conception year; H is the fixed effect of conception herd-year; T is the fixed effect of conception month; P is the fixed effect of calf parturition code; A is the fixed effect of dam age within parity at conception; L is the fixed effect of dam lactation length during the calf's gestation; M is the fixed effect of dam standardized milk yield during the calf's gestation; SS is the random effect of service sire; MGS is the random effect of cow sire; C is the random cow effect, and e is the random residual. Categories for dam age within parity at conception were ≤13, 14 to 15, 16 to 17, 18 to 19, or ≥20 mo for parity 1 (heifers); ≤25, 26 to 27, 28 to 29, 30 to 31, 32 to 33, 34 to 35, or ≥36 mo for parity 2; ≤41, 42 to 47, or ≥48 mo for parity 3; ≤56 or ≥57 mo for parity 4; and separate effects for parities 5, 6, 7, 8, and ≥9 regardless of age. Parturition codes (multiple birth and calf sex) were 1 = single female, 2 = single male, 3 = multiple females, 4 = multiple males, 5 = multiple births, male and female, 6 = multiple births, only a female reported; 7 = multiple births, only a male reported; or 8 = no information provided. Lactation length for cows was designated as ≤250, 251 to 300, 301 to 350, 351 to 400, 401 to 450, 451 to 500, or ≥501 d. Standardized milk yield was grouped as ≤8,000, 8,001 to 10,000, 10,001 to 12,000, 12,001 to 14,000, or ≥14,001 kg for all breeds.

Separate analyses were conducted for Brown Swiss, Holsteins, and Jerseys with an identified AI service sire. Only gestations that ended by December 31, 2005, were included to prevent an overrepresentation of shorter GL by more recent data. Heifers were analyzed with age effects for parity 1 and without effects for lactation length and standardized milk yield included in the model. Cows (parity ≥2) were analyzed separately with the full model and the remaining age-within-parity groups.

Some of the categorical variables may be correlated (e.g., age, DIM, and standardized milk yield). Therefore, the model was fit both by including and excluding DIM and standardized milk yield to determine if parity-age effects would change. Because inconsistent effect differences were noted, the full model with DIM and standardized milk yield included was used for analysis of cow data.

Variance components were estimated for GL with AIREMLF90 software (Misztal et al., 2002) from gestation data through December 2005. Heritability was estimated as

$$4\sigma^2_{\text{service sire}} \Big/ \left(\sigma^2_{\text{service sire}} + \sigma^2_{\text{cow sire}} + \sigma^2_{\text{cow}} + \sigma^2_{\text{residual}}\right)$$

for service sire and as

$$4\sigma^2_{\text{cow sire}} / (\sigma^2_{\text{service sire}} + \sigma^2_{\text{cow sire}} + \sigma^2_{\text{cow}} + \sigma^2_{\text{residual}})$$

for cow sire from gestation data through December 2006. Heritability for Holstein cows (parity ≥2) was estimated from 3 samples, each with 4% of the data. Heritability for Holstein heifers (parity 1) was estimated from 3 samples, each with one-third of the data. Heritabilities for Brown Swiss cows and Jersey cows and heifers were estimated from all available data.

Holstein service-sire and cow-sire PTA for GL were generated for heifers and cows separately based on gestations through December 2005. Means and standard deviations for service-sire and cow-sire PTA were calculated along with a frequency distribution to show the number of bulls with extreme PTA. Correlations between Holstein PTA for GL were calculated based on PTA population (heifer or cow) and sire effect (service sire or cow sire) for bulls with ≥100 or ≥500 conceptions (service sire) or daughters (cow sire). All calculations were repeated for a subset of those bulls that were designated as being in active AI service for August 2007 USDA-DHIA genetic evaluations. Genetic correlations between service-sire and cow-sire effects for GL, which were calculated as

$$\sigma_{\text{service sire, cow sire}} \Big/ \left(\sigma^2_{\text{service sire}}\sigma^2_{\text{cow sire}}\right)^{0.5},$$

were estimated with AIREMLF90 software (Misztal et al., 2002) for both cow and heifer populations using data from bulls with ≥100 conceptions (service sire) and ≥300 daughters (cow sire) for gestations through December 31, 2006. Correlation between service-sire and cow-sire effects for Holstein cows (parity ≥2) was estimated from 3 samples, each with 20% of the data. Correlations were calculated for Holstein heifers and Jersey cows from all available data that met conception and daughter requirements; those requirements were reduced to ≥50 conceptions (service sire) and ≥50 daughters (cow sire) for Jersey heifers and Brown Swiss cows.

RESULTS AND DISCUSSION

Mean GL based on gestation data through December 2006 (Table 1) were 278 d for Holstein and Jersey heifers, 279 d for Milking Shorthorn heifers and Holstein cows, 280 d for Jersey cows, 281 d for Milking Shorthorn cows, 282 d for Ayrshire heifers and cows, 285 d for Guernsey heifers, 286 d for Guernsey cows, 287 d for Brown Swiss heifers, and 288 d for Brown Swiss cows. Means confirm that cows (parity ≥2) generally have longer GL than do heifers (parity 1). Differences between heifer and cow means varied by breed from 0.3 to 1.8 d, except for Ayrshires, which had nearly the same GL for both. Brown Swiss, Holsteins, and Jerseys, which had the most heifer gestations, had cow GL that was 0.3 to 1.6 d longer than heifer GL. Longer GL

Table 2. Number of gestations[1] by parturition status and parity[2] for Brown Swiss, Holsteins, and Jerseys

	Gestations (n)			
		Holstein		
Parturition status	Brown Swiss cows	Heifers	Cows	Jersey cows
Single female calf	6,698	92,796	1,536,017	22,627
Single male calf	7,141	95,694	1,678,394	24,886
Twin female calves	195	502	27,718	189
Twin male calves	220	478	31,569	242
Twins: 1 female calf, 1 male calf	260	696	32,493	203
Twins: 1 female calf, 1 calf with unreported sex	5	23	3,950	5
Twins: 1 male calf, 1 calf with unreported sex	3	15	4,066	8
No information provided	8,302	121,374	1,931,044	191,164

[1] Gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Heifers (parity 1) and cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

for cows than for heifers supports the literature review findings of Andersen and Plum (1965) and King et al. (1985). Silva et al. (1992) reported that GL for parity 1 was 0.6 to 1.2 d shorter than for later parities. McClintock et al. (2003) found that Australian Holstein heifers had shorter GL than did mature cows (1.5 d); they estimated a high genetic correlation (0.96) between heifer and cow GL. Parity was 1 of the 2 largest effects on GL of all variables examined by Hagger and Hofer (1990) in a 3-breed (Braunvieh, Simmental, and Swiss Black and White) study. Echternkamp and Gregory (1999) found that GL was 2 d shorter for 2-yr-olds than for older cows in a USDA experimental herd (Clay Center, NE) developed primarily to increase frequency of multiple births (incidence reached nearly 50%). Jamrozik et al. (2005) reported that GL of Canadian Holsteins was 1 d shorter for heifers than for cows; however, in contrast to other studies (e.g., Simerl et al., 1991), they also found that GL decreased as age at first service increased.

Breed means generally were similar to those reported (Andersen and Plum, 1965), with GL near 280 d for Holstein and Jersey cows and longer for other breeds. Standard deviations (Table 1) were usually 5 or 6 d and were smaller after elimination of natural-service conceptions, which had less accurately recorded breeding dates. Nevertheless, mean GL for conceptions that included natural-service matings were nearly the same for Holsteins and Jerseys as those from AI services.

Numbers of gestations through December 2005 for each parturition status are in Table 2. For Holstein cows with parturition information, single-birth frequency was 46.3% for females and 50.6% for males; corresponding frequencies for Holstein heifers were 48.8 and 50.3%. Ratio of male to female calves for single births of Brown Swiss, Holstein, and Jersey cows was 1.07, 1.09, and 1.10, respectively; the male:female ratio for single births of Holstein heifers was 1.03.

Most studies (e.g., Silva Del Río et al., 2007) have reported slightly more male than female calves, which agrees with the 51 and 52% for single-birth male calves from heifers and cows, respectively, in Table 2. Echternkamp et al. (2007) reported an incidence of 51 to 55% for male calves, regardless of type of birth. Because of the need for females as herd replacements, DHI producers could have been more likely to report female rather than male births. However, the calf sex ratio in Table 2 indicates that DHI producers are providing data that are representative of most single births.

Commercialization of sexed semen began in 2003 and was recommended for use only in well-managed, highly fertile virgin heifers (DeJarnette, 2005). A higher percentage of heifers than cows may have been serviced with sexed semen, which could have contributed to the lower male:female ratio for single births from heifers. However, the majority of data for this study were from breedings before the promotion of sexed semen by major AI organizations.

Twins (Table 2) were reported for 4.7, 3.0, and 1.3% of Brown Swiss, Holstein, and Jersey cow gestations, respectively, and for 0.9% of Holstein heifer gestations. Although those breed differences are rather large, they could be partly caused by producer reporting. The male:female ratio of twins with sex reported for both calves was 1.07, 1.09, and 1.18 (i.e., 51, 52, and 54% males) for Brown Swiss, Holstein, and Jersey cow gestations; however, few observations were available for Brown Swiss and Jerseys. The corresponding male:female ratio for Holstein heifer gestations was 0.97 (49% males). Imperfect producer reporting appears to have caused only slightly more mixed-sex than same-sex twins to be observed (Table 2). Because most cattle twins are fraternal (Gowen, 1922; Echternkamp and Gregory, 2002), nearly twice as many mixed-sex as same-sex twins were expected. Echternkamp et al. (2007) reported calf sex for twin births as 47% male/female, 28% male, and 25% female in the USDA high-twinning herd, which is more in line with expectation.

Table 3. Least squares solutions[1] for effects of conception month and parturition status on gestation length by parity[2] for Brown Swiss, Holsteins, and Jerseys

Model effect	Gestations (n)				Gestation length (d)			
	Brown Swiss cows	Holstein Heifers	Holstein Cows	Jersey cows	Brown Swiss cows	Holstein Heifers	Holstein Cows	Jersey cows
Conception month								
January	2,108	29,795	526,493	23,825	0.3	0.6	0.8	0.5
February	1,944	30,951	470,538	20,582	0.9	1.0	0.8	0.5
March	1,768	36,309	473,664	19,820	0.5	0.6	0.6	0.5
April	1,395	22,539	409,937	17,566	0.7	0.6	0.5	0.5
May	1,631	22,716	392,396	18,403	1.1	0.4	0.4	0.4
June	1,619	22,475	329,388	16,564	0.2	−0.2	0.3	0.2
July	1,580	21,975	303,352	15,336	0.0	−0.6	−0.2	−0.2
August	1,810	22,098	349,498	16,607	0.1	−0.8	−0.5	−0.4
September	2,096	22,669	424,462	18,782	−0.8	−0.8	−0.8	−0.6
October	2,245	24,856	511,255	22,529	−1.5	−0.9	−1.2	−0.8
November	2,285	24,900	520,009	23,883	−0.5	−0.5	−0.8	−0.6
December	2,343	30,268	534,259	25,427	−0.1	−0.2	0.1	0.0
Parturition status								
Single female calf	6,698	92,769	1,536,017	22,627	−0.6	−0.6	−0.1	−0.7
Single male calf	7,141	95,694	1,678,394	24,886	0.7	0.6	1.0	0.7
Twin female calves	195	502	27,718	189	−5.0	−4.4	−4.8	−4.7
Twin male calves	220	478	31,569	242	−5.2	−4.4	−4.6	−4.6
Twins: 1 female calf, 1 male calf	260	696	32,493	203	−5.4	−4.6	−4.9	−4.7
Twins: 1 female calf, 1 calf with unreported sex	5	23	3,950	5	−5.3	−1.8	−4.3	−4.5
Twins: 1 male calf, 1 calf with unreported sex	3	15	4,066	8	−4.9	−4.7	−4.3	−2.6
No information provided	8,302	121,374	1,931,044	191,164	0.3	0.0	−0.5	0.0

[1] Difference from weighted mean solution for heifers or cows based on gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Heifers (parity 1) and cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

Table 3 shows GL solutions for conception month and parturition status independent of other categories. To show consistency across breeds, a constant was added to all effects within each environmental category in Tables 3, 4, 5, and 6 to make the weighted mean within the category equal zero.

Most conceptions for Holstein cows occurred from October through March, with 76% more during December (highest conception frequency) than during July (lowest conception frequency). Holstein heifers had the greatest number of conceptions during March and the fewest during July. Jersey cow conceptions followed a pattern similar to Holstein cows, with 66% more conceptions during December than during July. For Brown Swiss, December also had the most conceptions, with 68% more than during April.

Conception-year effects on GL for Holstein heifers and cows (not shown) were nearly identical and varied by only 0.3 and 0.2 d, respectively, between the years with the shortest and longest GL. Brown Swiss and Jersey cows varied by only 0.5 and 0.1 d based on small numbers of gestations. In contrast, conception month had a moderate effect on GL, with the longest GL in January or February and the shortest GL in October for Holstein and Jersey cows and Holstein heifers (differences of 2.0, 1.3, and 1.9 d, respectively). Brown Swiss cows also had the shortest GL in October (difference of 2.6 d), but the longest GL was in May with the next longest in February. The smallest difference between the longest and shortest GL was for Jerseys (1.3 d), which might indicate that climatic changes affect them less than Brown Swiss (2.6 d) or Holsteins (2.0 d). Other researchers (Andersen and Plum, 1965; McGuirk et al., 1998; McClintock et al., 2003) had reported that GL were shorter with summer parturitions (i.e., fall conceptions produce summer calvings). Because breeds are not uniformly distributed by region, some breed effects may partially reflect geographic differences.

To determine if high temperature and humidity were contributing to earlier parturition, regional subsets of Holstein data were analyzed. Regions included the Southeast (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma, Puerto Rico, South Carolina, and Texas), the Southwest (Arizona, California, and New Mexico), and states that border Canada (Idaho, Maine, Michigan, Minnesota, Montana, New Hampshire, New York, North Dakota, Vermont, Washington, and Wisconsin). Least squares solutions for effect of conception month by region (Table 4) support the theory that temperature and humidity affect GL. The GL differences between months with the largest estimated effects generally were smaller for Canadian

Table 4. Least squares solutions[1] for effects of conception month on gestation length by region for Holstein cows and heifers[2]

	Gestation length (d)						
	Cows				Heifers		
Conception month	Canadian border states[3] (n = 2,435,275)	Southeast[4] (n = 227,647)	Southwest[5] (n = 950,851)	United States (n = 5,245,261)	Canadian border states[3] (n = 175,419)	Southeast[4] (n = 15,906)	United States (n = 311,551)
January	0.7	0.8	0.7	0.8	0.6	0.4	0.6
February	0.7	0.9	1.0	0.8	0.8	1.1	1.0
March	0.5	0.6	0.9	0.6	0.5	1.1	0.6
April	0.5	0.3	0.6	0.5	0.5	0.4	0.6
May	0.5	0.3	0.3	0.4	0.4	0.0	0.4
June	0.4	0.3	0.0	0.3	0.0	−0.2	−0.2
July	−0.2	0.2	−0.5	−0.2	−0.7	−0.1	−0.6
August	−0.5	−0.4	−0.7	−0.5	−0.8	−0.5	−0.8
September	−0.7	−0.9	−0.9	−0.8	−0.7	−1.5	−0.8
October	−1.1	−1.3	−1.0	−1.2	−0.7	−1.3	−0.9
November	−0.7	−1.6	−0.6	−0.8	−0.4	−1.5	−0.5
December	0.2	−0.5	0.1	0.1	−0.1	−0.6	−0.2

[1] Difference from weighted mean solutions for heifers or cows based on gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Heifers (parity 1) and cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

[3] Idaho, Maine, Michigan, Minnesota, Montana, New Hampshire, New York, North Dakota, Vermont, Washington, and Wisconsin.

[4] Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma, Puerto Rico, South Carolina, and Texas.

[5] Arizona, California, and New Mexico.

border states than for the southern United States. Results for Southwestern heifers are not shown because of limited data. A model effect of interaction of conception month with region also was examined. Results (not shown) were nearly identical to those in Table 4; cows in the Southeast had the largest GL differences between months with the largest estimated effects.

The factor producing the largest difference in GL was twinning (Table 3). For twin births of Holstein cows, GL was shorter by 4.6 d compared with single-birth females and by 5.7 d compared with single-birth males. Corresponding differences for Holstein heifers were similar but slightly smaller: 3.9 and 5.1 d. Jersey and Brown Swiss cows followed a similar pattern: twin births shorter than single-birth females by 4.0 and 4.7 d, respectively, and shorter than single-birth males by 5.4 and 5.9 d. Considerably shorter GL for twins than for single births agrees with Knott (1932) and Echternkamp et al. (2007). Shorter GL (1.1 to 1.5 d) for single-birth female calves than for single-birth male calves also agrees with several previous findings (Andersen and Plum, 1965; Hagger and Hofer, 1990; Echternkamp et al., 2007). Hagger and Hofer (1990) found that calf sex was 1 of the 2 largest effects on GL for all breeds. McClintock et al. (2003) reported that heifers carried male calves longer than female calves (0.6 d) as did milking cows (0.9 d). In the USDA high-twinning herd, male calves from single births were carried 1.5 d longer than females (Echternkamp et al., 2007).

Gestation length for first parturitions was 0.8 d shorter for Holstein heifers that conceived at ≤13 mo compared with those that conceived at ≥20 mo (Table 5), which was the largest age difference within any parity. Gestation length for Holstein second calvings increased with age by 0.5 d for conceptions at ≤25 mo compared with conceptions at ≥36 mo. However, differences in GL with age were small for subsequent Holstein parities. Jersey cows showed the same pattern as Holsteins for age within parity, and Brown Swiss differences with age were even larger, although based on limited data. That pattern across and within parity could indicate that animal size, which is correlated with age, affected GL; however, animal weights were not available for confirmation. Shorter GL for first parity or for younger ages is in agreement with other studies cited in the review of Andersen and Plum (1965) as well as with several studies since (Hagger and Hofer, 1990; McClintock et al., 2003).

Gestation length decreased as DIM increased (Table 6); Holstein cows with ≤250 DIM had GL that were 0.8 d longer than cows with ≥501 DIM. Brown Swiss and Jerseys exhibited similar tendencies with decreases of 0.6 and 0.4 d, respectively, as lactation length increased. Holstein GL increased as standardized milk yield increased (Table 6) by 0.6 d more for cows with yield of ≥14,001 kg compared with cows with yield of ≤8,000 kg. Jerseys with higher yield also had longer GL (0.8 d), but no trend was evident for Brown Swiss, which had fewer observations.

Table 5. Numbers of gestations[1] and least squares solutions[2] for effects of conception age within parity on gestation length by parity[3] for Brown Swiss, Holsteins, and Jerseys

		Gestations (n)			Gestation length (d)		
Parity	Conception age (mo)	Brown Swiss	Holstein	Jersey	Brown Swiss	Holstein	Jersey
1 (heifer)	≤13	—	35,025	—	—	−1.9	—
	14 to15	—	119,680	—	—	−1.8	—
	16 to 17	—	83,402	—	—	−1.6	—
	18 to19	—	38,606	—	—	−1.4	—
	≥20	—	34,838	—	—	−1.1	—
2	≤25	224	184,978	16,351	−1.2	−0.5	−0.5
	26 to 27	977	464,041	20,155	−0.6	−0.3	−0.5
	28 to 29	1,497	478,536	16,523	−0.4	−0.3	−0.4
	30 to 31	1,523	360,456	10,453	−0.3	−0.2	−0.3
	32 to 33	1,234	243,203	6,464	−0.1	−0.1	−0.1
	34 to 35	931	60,743	3,944	−0.4	0.0	0.0
	≥36	1,526	232,877	5,276	0.2	0.0	−0.1
3	≤41	1,427	564,356	34,859	−0.1	0.1	0.1
	42 to 47	2,662	576,354	19,459	0.3	0.1	0.2
	≥48	1,991	309,718	7,753	0.2	0.2	0.3
4	≤56	1,397	441,041	28,901	0.1	0.2	0.2
	≥57	2,495	411,376	13,450	0.1	0.2	0.3
5		2,395	447,952	26,073	0.2	0.2	0.2
6		1,275	214,318	14,754	0.1	0.1	0.1
7		673	94,039	7,870	0.2	0.1	0.2
8		327	38,496	3,955	−0.5	0.0	0.1
≥9		270	22,767	3,084	0.4	0.0	0.2

[1] Gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Difference from weighted mean solutions for cows for Brown Swiss and Jerseys; difference between phenotypic mean gestation length for cows and heifers subtracted from heifer solutions for Holsteins.

[3] Heifers (parity 1) and cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

Heritability estimates are shown in Table 7. Heritability of service sire based on cow parturitions was 33% for Holsteins and Jerseys and 36% for Brown Swiss. Estimates of heritability for heifer parturitions were considerably larger at 46% for Jerseys and 47% for Holsteins. Brown Swiss had too few records to calculate a reliable estimate. Heritability estimates for cow sire ranged from 7 to 12%. Heritability estimates for GL were 0.24 from the Florida Agricultural Experiment Station herd (Simerl et al., 1991) and 0.22 from 7 Florida herds (Silva et al., 1992). Zhang and Shook (2001) estimated a maternal grandsire heritability for GL of 0.14 to 0.20 from Wisconsin Holstein DHI records from 1992 through 2000; VanRaden et al.

Table 6. Numbers of gestations[1] and least squares solutions[2] for effects of lactation length and standardized[3] milk yield on gestation length for Brown Swiss, Holsteins, and Jerseys

	Gestations (n)			Gestation length (d)		
Production variable	Brown Swiss	Holstein	Jersey	Brown Swiss	Holstein	Jersey
Lactation length (d)						
≤250 d	526	94,105	6,699	0.2	0.3	0.0
251 to 300	4,109	1,318,414	77,897	0.1	0.2	0.2
301 to 350	7,980	1,824,307	87,750	0.1	0.1	0.0
351 to 400	4,635	991,912	36,111	0.0	−0.1	−0.1
401 to 450	2,601	504,155	16,159	0.0	−0.2	−0.3
451 to 500	1,338	257,338	7,529	−0.2	−0.4	−0.4
≥501	1,635	255,020	7,179	−0.4	−0.5	−0.4
Standardized milk yield (kg)						
≤8000	5,725	237,922	126,794	0.0	−0.3	−0.1
8,001 to 10,000	8,546	1,013,991	89,924	0.0	−0.2	0.1
10,001 to 12,000	6,134	1,988,749	20,911	0.0	0.0	0.4
12,001 to 14,000	2,038	1,498,352	1,589	−0.1	0.1	0.6
≥14,001	381	506,237	106	0.1	0.3	0.7

[1] Gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Difference from weighted mean solutions for heifers or cows.

[3] Yield standardized for calving age, calving month, previous days open, and daily milking frequency.

Table 7. Heritability estimates[1] for gestation length by breed, sire effect, and parity[2]

	Heritability (%)			
	Service sire		Cow sire	
Breed	Heifers	Cows	Heifers	Cows
Brown Swiss	—	36	—	7
Holstein	47	33	12	12
Jersey	46	33	10	12

[1] Based on gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2006.

[2] Heifers (parity 1) and cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

(2004) estimated a maternal grandsire heritability of 0.10 from Holstein cows born from 1992 through 1994. Hansen et al. (2004), Jamrozik et al. (2005), and Azzam and Nielsen (1987) estimated direct heritabilities for GL of 0.27 to 0.45 and maternal estimates of 0.07 to 0.13 for heifers and cows, which are similar to current estimates. The heritability estimate for cow sire might be expected to be only half as large as the heritability estimate for service sire simply because the cow sire is 1 generation before service sire. Suggestions that the sire breed of a crossbred calf has a larger influence on GL than does the sire breed of a crossbred cow likely are based on that generational difference; that is, the more distant the generation, the smaller the influence. The heritability estimates in Table 7 were used in calculating bull PTA.

Means and standard deviations of Holstein PTA for GL are shown in Table 8. For all bulls, mean service-sire PTA for GL was −0.24 d based on heifer gestations and −0.02 d based on cow gestations; corresponding means for bulls in active AI service were −0.47 and −0.43 d. Mean cow-sire PTA was 0.14 d based on heifer gestations and 0.06 d based on cow gestations; corresponding means for bulls in active AI service were 0.12 and 0.04 d. Standard deviations ranged from 1.41 to 1.46 d for service sire and from 0.71 to 0.75 d for cow sire. The larger standard deviations for service-sire PTA than for cow-sire PTA were expected based on the heritability estimates (Table 7). The PTA extremes for GL were −5.4 and 5.3 d for service sire and −2.8 and 3.1 d for cow sire. Both service-sire and cow-sire PTA had relatively normal distributions (Figure 1). Some bulls were included as sires for both heifer and cow data sets; therefore, the estimated PTA are not completely independent. However, standard errors are expected to be extremely small because of the large number of records used to estimate PTA for GL based on heifer and cow gestations.

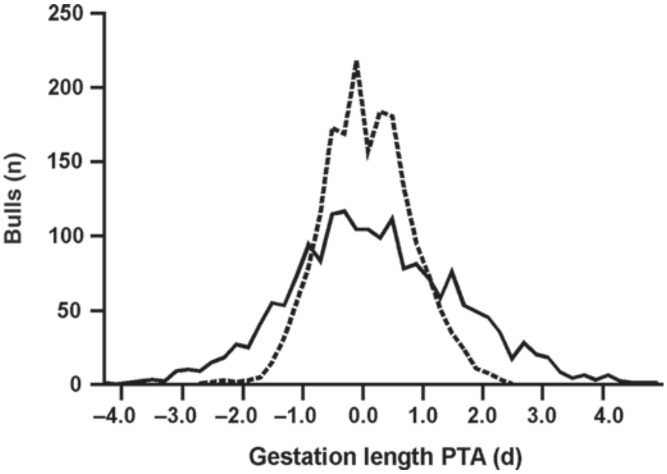

Figure 1. Frequency distributions of Holstein bull PTA for gestation length based on cows (parity ≥2) for service sires (solid line) and cow sires (dashed line) with ≥100 conceptions.

Correlations between PTA for GL based on heifers and cow breedings (Table 9) were extremely high for service sires (0.96 to 0.98). Correlations were somewhat

Table 8. Holstein means, SD, and range of PTA[1] for gestation length by bull AI status, sire effect, and parity[2] for bulls with ≥100 conceptions (service sire) or daughters (cow sire)

			PTA for gestation length (d)				
AI status	Sire effect	Parity group	Mean ± SD	Shortest[3]		Longest[3]	
All	Service sire	Heifer	−0.24 ± 1.45	−4.2	(O Man)	4.2	(Mandelin)
		Cow	−0.02 ± 1.41	−5.4	(Fire)	5.3	(Sovereign)
	Cow sire	Heifer	0.14 ± 0.75	−1.9	(Bond)	2.6	(Gibson)
		Cow	0.06 ± 0.73	−2.8	(Kevin)	3.1	(Altapermission)
Active AI	Service sire	Heifer	−0.47 ± 1.43	−4.2	(O Man)	4.2	(Mandelin)
		Cow	−0.43 ± 1.46	−5.3	(Aspiration)	5.3	(Sovereign)
	Cow sire	Heifer	0.12 ± 0.73	−1.4	(Pyrex)	2.6	(Gibson)
		Cow	0.04 ± 0.71	−2.1	(O Man)	2.3	(Shandy)

[1] Based on gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Heifers (parity 1) and cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

[3] Bull short name in parentheses.

Table 9. Correlations between Holstein bull PTA[1] for gestation length derived from heifer versus cow breedings[2] by sire effect, number of conceptions (service sire) or daughters (cow sire) per bull, and bull AI status

Sire effect	Conceptions/ daughters per bull	Correlation	
		All bulls	Active AI bulls
Service sire	≥100	0.96	0.96
	≥500	0.98	0.98
Cow sire	≥100	0.83	0.77
	≥500	0.91	0.75

[1] Based on gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Heifers (parity 1) or cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

lower for cow-sire PTA (0.75 to 0.91), which agrees well with the maternal genetic correlation of 0.91 between heifer and cow GL reported by Jamrozik et al. (2005). Correlations between service-sire and cow-sire PTA for GL (Table 10) were also rather high (0.57 to 0.76) considering that they were based on independent samples. Estimates of the genetic correlation between service-sire and cow-sire GL effects (Table 11) were 0.73 and 0.85 for Holstein and Jersey heifers and 0.70, 0.79, and 0.84 for Brown Swiss, Holstein, and Jersey cows, respectively. Those correlations indicate that the heifer and cow GL likely are controlled by many of the same genes and that service-sire and cow-sire effects on GL can be used to evaluate each other within heifer and cow populations.

CONCLUSIONS

Gestation length was moderately heritable and open to rapid change under selection. Genetic evaluations for service-sire GL based on heifer and cow breedings were highly correlated as were similar evaluations for cow-sire GL. Service-sire and cow-sire GL evaluations were moderately correlated regardless of the population (heifer or cow) on which they were based.

Several genetic and environmental factors can help improve prediction of calving date, but most improvement requires documented data on breed, parity, age, conception month, DIM, milk yield, service sire, cow sire, and evidence of impending multiple births. Intentional selection for either shorter or longer GL without consideration of other dependent traits (e.g., calving ease and stillbirth) is not recommended without additional research.

Knowledge of which environmental and genetic factors impact GL should lead to improved performance of US dairy cattle. More precise prediction of parturition date can aid dairy producers in meeting nutritional needs of pregnant cows of all breeds and in administering appropriate management actions that minimize risk from metabolic diseases. With the exception of physical trauma caused by dystocia, most periparturient diseases can be avoided with aggressive management, mineral supplementation, and so on. More accurate predictions of GL also can assist managers in meeting targeted lengths for dry periods. Future research can determine and clarify relationships of GL with dystocia, stillbirth, and other health traits as data for those traits become more available through improved recording.

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Table 10. Correlations between Holstein bull PTA[1] for gestation length for service sire versus cow sire by population from which PTA were derived, number of conceptions (service sire) or daughters (cow sire) per bull, and AI status

Population from which PTA were derived[2]	Conceptions/ daughters per bull	Correlation	
		All bulls	Active AI bulls
Heifers	≥100	0.57	0.60
	≥500	0.57	0.58
Cows	≥100	0.71	0.71
	≥500	0.76	0.72

[1] Based on gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2005.

[2] Heifers (parity 1) or cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

Table 11. Estimates[1] of genetic correlation between service-sire and cow-sire effect for gestation length by breed and parity[2]

	Genetic correlation	
Breed	Heifers	Cows
Brown Swiss	—	0.70
Holstein	0.73	0.79
Jersey	0.85	0.84

[1] Based on gestations initiated by inseminations after February 1998 and ended with parturitions through December 31, 2006.

[2] Heifers (parity 1) or cows (parity ≥2); for example, a gestation that produced a second calving is parity 2.

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