Check for updates

Lactation performances in primiparous Holstein cows following short and normal gestation lengths

Monica Probo[1]*, Hadi Atashi[2,3] and Miel Hostens[4,5]

[1]Department of Veterinary Medicine and Animal Sciences, Università degli Studi di Milano, Lodi, Italy, [2]Department of Animal Science, Shiraz University, Shiraz, Iran, [3]TERRA Teaching and Research Center, Gembloux Agro-Bio Tech, University of Liège, Gembloux, Belgium, [4]Department Population Health Science, University of Utrecht, Utrecht, Netherlands, [5]Department of Animal Science, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY, United States

Despite decades of research, little is known regarding physiologic temporal limits for initiation of lactation in pregnant non-lactating cattle the aim of this study was to compare the lactation performances in primiparous Holstein cows after a short gestation length (GL) or abortion to those after a normal GL. The data were collected using an automated data collection system. The 94 herds evaluated were located in Belgium, France, Italy, the Netherlands and Germany. Data from a wide range of physiological cow-life events including birth and calving events, reproduction events (insemination, pregnancy checks, and abortions), and milking events were collected. The GL was defined as the interval between the last insemination and the subsequent calving (or abortion) within a range of 150−297 days. Animals were categorized into one of five categories based on GL quantiles (C-I to C-V). Lactation curve parameters including the scale, ramp, and decay were estimated using the Milkbot model. Then, the derived 305-day milk yield (M305-d), peak yield, and time to peak were compared between different GL categories. Of 13,732 lactations, 15 (0.11%) were found with a GL shorter than 210 days (ranging from 158 to 208 days). The 305-day milk yield was significantly lower in the C-I (7,566 ± 186) and C-II groups (7,802 ± 136 kg), compared to the C-III (8,254 ± 116 kg), C-IV (8,148 ± 119 kg), and C-V (8,255 ± 117 kg) groups. The same trends were found for the scale and peak yield of the lactation; the lowest scale were found for the C-I (31.5 ± 0.73) and C-II (32.8 ± 0.53) groups, and the highest were found for the C-III (34.5 ± 0.46), C-IV (34.9 ± 0.45), and C-V (35.0 ± 0.45) groups. Peak yield increased significantly from C-I (27.8 ± 0.66 kg) and C-II group (28.8 ± 0.48 kg) to the C-III (30.2 ± 0.42 kg) and further to the C-IV (30.6 ± 0.40 kg) and C-V (30.6 ± 0.41 kg) groups. Moreover, primiparous cows in the C-II GL category showed a higher milk yield persistency (decay of 1.30E−4 ± 3.55E−5) compared to those belonging to the C-IV (decay of 1.38E−4 ± 2.51E-5) and C-V (decay of 1.38E−4 ± 2.58E-5) group. In conclusion, results showed that primiparous cows with a shorter GL produced significantly less 305-day milk and peak yields, had a higher lactation persistency, and showed a lower upward slope of the lactation curve compared to those with a normal GL.

1 Introduction

In many countries, milk yield per cow has more than doubled in the last 40 years, mainly due to the rapid progress in management and genetics selection (1). According to the literature, it appears that many of the fundamentals of milking process for a successful lactation have been understood (2); however, some of the principles that had been identified when cows produced markedly less milk may not be still valid for the high-producing cows of today (2), and some mechanisms regarding physiology of lactation are still unexplored. The initiation of milk secretion in cattle is usually thought to follow the termination of pregnancy; still, it has long been known that cows may begin to secrete milk previous to the time of parturition (3), so that the practice of pre-partum milking in dairy cows has been investigated as a means to shorten calving intervals and enhance milk production (4–8). For decades, researchers also focused on the hormonal induction of lactation, from the first successful induction in goat (9) until the development of a short-term protocol that ensures induction of lactation in most treated cows and heifers (10–13). Nevertheless, the average milk yield per lactation hormonally-induced is about 90% in multiparous cows (14), and 60–70% in primiparous cows (15) of an equivalent post calving lactation, and the use of hormones for lactation induction is legally forbidden in most of the countries (16).

Rearing heifers represents about 20% of the total milk production costs (17, 18), and the return on the investment allocated from the birth to the first lactation is commonly not fully recovered until at least the end of the first lactation (19). As a consequence, productive life of heifers is an important factor in determining economic profits of dairy farms (19). Pregnancy losses would still allow heifers to start their first lactation if they are sufficiently far advanced in pregnancy, but the exact time point when this is possible is unknown. Scattered through the earlier literature on the milk secretion are reports on lactation in suckled virgin heifers (3) and in heifers milked as early as 120 days of first pregnancy (20).

The secretory activity of the mammary gland during the first pregnancy in heifers is of considerable interest, as the growth of the mammary glands during the first pregnancy is remarkable (3). Early studies on mammary development in cattle showed that the histological development of the mammary gland from early gestation to near parturition is a progressively continuous process, more nearly exponential than linear, with marked developmental changes only in late pregnancy (21, 22); most of the rapid increase in udder weight and in growth of the duct system occurs after the fifth month of pregnancy (23), particularly during the last 35 days pre-partum (24). The key roles of estrogen and growth hormone in mammary ductal development, progesterone and estrogen in lobulo-alveolar formation, and prolactin in lactogenesis are well known (2), while insulin-like growth factor-I (IGF-I) and other growth factors increase mammary growth through a direct or a paracrine regulation (25). In pregnant heifers, serum concentrations of α-lactalbumin (i.e., a whey protein that plays a central role in milk production) become detectable only in the last trimester of the gestation, with modest increases until just before calving, when concentrations markedly increase after prolactin stimulation (2). This pattern mirrors a two-stage onset of lactogenesis, with a modest increase in milk component biosynthesis in the last month before calving followed by a marked increase just before and after calving (26). Despite decades of research, little is known regarding physiologic temporal limits for initiation of lactation in pregnant

non-lactating cattle. Shorter mean GL (27) or abortion (28) were found to reduce the milk yield up even 68 or 80.6% of the normal mature-equivalent lactations, respectively. Atashi and Asaadi (29) found that primiparous cow with a short GL (250 days as minimum duration) had less lactation performances compared to those with a longer GL. To the best of our knowledge, the effect of a very short GL on lactation curve parameters in primiparous cows is unknown. Therefore, the objective of this study was to evaluate the lactation performances in primiparous cows following a short GL or an abortion, by comparison with lactation in primiparous cows after a normal GL.

2 Materials and methods

2.1 Observational dataset

The observational data were collected using an automated data collection system using a wide variety of herd management software programs as described by Hermans et al. (30). The herds included were located in Belgium, France, Italy, the Netherlands, and Germany. The dataset consisted of 8,175,067 milkings on 100 herds on which data were collected from 26,448 animals calving between January 2013 until December 2018. An average of 192 calvings per year was recorded. Data from a wide range of physiological cow-life events including birth and calving events, reproduction events (insemination, pregnancy checks, and abortions), milking events were collected and combined into a single dataset. Using the MmmooOgle system, no information on the milking system, number of milkings, or type of grazing system was available. Pregnancy diagnoses were available and used in the manuscript. Calving management was available for part of the herds but not all, hence ignored. Records from days in milk (DIM) greater than 305 days were eliminated. Daily milk yield (MY) was restricted to the range from 1.0 to 70.0 kg. The final dataset consisted of 2,124,486 milkings on 13,735 animals distributed in 94 farms.

2.2 Definition of gestation length

The GL was defined as the interval between the last insemination and the subsequent calving (or abortion) within a range of 150–297 days. Next, a minimum of 10 days in milk was required for the individual lactation curve exploration. Due to an observed lack and inconsistencies in the recording of abortion events across herd management software, the abortion codes were ignored in the final dataset and the animals were categorized to five categories strictly based on their GL length: ($150 \leq GL \leq 243$ days, C-I), ($243 < GL \leq 267$ days, C-II), ($267 < GL \leq 275$ days, C-III), ($275 < GL \leq 283$ days, C-IV), and ($283 < GL \leq 297$ days, C-V). These five GL categories were based on quantiles 0–1, 1–5, 5–25, 25–75, and 75–100%. Then, lactation curve parameters including the scale, ramp, and decay were estimated using the Milkbot model (31). The MilkBot function is as follows:

$$y_t = a \left(1 - \frac{\exp\left(\frac{c - t}{b}\right)}{2} \right) \exp(-dt)$$

in which, a is the scale parameter, representing the theoretical maximum daily yield; b is the ramp parameter, controlling the rate of rise in milk production in early lactation; c is the offset parameter, describing the offset in time between parturition and the start of lactation; and d is the decay parameter, representing the rate of senescence of production capacity. The time at which peak lactation occurred (t_{peak}) was defined as: $t_{peak} = -b \ln\left(\frac{2db}{db+1}\right) + c$ and peak yield was calculated by substitution t_{peak} in the MilkBot equation. The 305-day milk, the cumulative milk yield between calving and day 305 of the lactation, was calculated as:

$$M_{305} = \left(a - a\exp(-305\,d)\right)/d + \left(ab\exp(c/b)\left(-1 + \exp\left(-305(1/b+d)\right)\right)\right)/(2+2bd)$$

The calculated 305-day milk (M305), peak yield, and time to peak were compared between different GL categories. For each of the outcome variables, a multi-level mixed model was built taking into account a random effect of the herd, fixed effects of month and year of calving, and age at first calving (AFC) as covariates. Least square means and contrasts were computed for each category of the GL. Significance and tendency levels were determined at $p < 0.05$ and $0.10 < p \geq 0.05$, respectively. All statistical analyses were carried out in R (32). The data analysis was made publicly available through a central code repository at https://github.com/Bovi-analytics/probo-et-al-2019.

3 Results

3.1 Descriptive data analysis

After filtering out all first lactation animals, 2,124,486 milkings from 13,735 animals on 94 farms remained for the further analysis. Of the 13,735 lactations, 15 lactations (0.11%) on 12 herds were found with a GL shorter than 210 days and with a minimum of 10 days in milk. Six (40%) out of 15 animals had a natural service, eight (53.3%) had an artificial insemination, and one heifer (6.7%) became pregnant after embryo transfer.

3.2 Lactation curves parameters

The result of the lactation curve analysis is reported in Table 1, and the individual lactation curves are reported in Figure 1. The 305-day milk yield was significantly lower in the C-I (7,566 ± 186) and C-II groups (7,802 ± 136 kg), compared to the C-III (8,254 ± 116 kg), C-IV (8,148 ± 119 kg), and C-V (8,255 ± 117 kg) groups (Table 1). The same trend was found for the scale and peak yield of the lactation, while the lowest scale and peak yield were found for C-I and C-II groups and the highest were found for C-III, C-IV, and C-V groups. The animals belonging to C-I and C-II groups showed a lower upward slope of the lactation curve, reached their peaks later, and had a higher level of lactation persistency (lower downward slope of the lactation curve) than those belonging to the C-III, C-IV, and C-V groups (Table 1). Lactation curves reconstructed from these parameters are visualized in Figure 2.

4 Discussion

The main aim of the present study was to investigate the effect of GL on lactation performances of Holstein primiparous cows. Of the 94 farms, 12.8% of the herds had one or more cases of very short GL or abortion in primiparous cows, but total incidence was low (0.11%), and the number of animals involved per farm was barely more than one. However, the requirement of a minimum of 10 days in milk for

TABLE 1 The effect of the length of the gestation on the Milkbot lactation curve parameters[1] in the first parity cows split by quantile of gestation length.

| Trait	Gestation length[2]				
	C-I	C-II	C-III	C-IV	C-V
305-day milk yield (kg)	7,566 ± 186[a]	7,802 ± 136[a]	8,254 ± 116[b]	8,148 ± 119[b]	8,255 ± 117[b]
Scale	31.5 ± 0.73[a]	32.8 ± 0.53[a]	34.5 ± 0.46[b]	34.9 ± 0.45[b]	35.0 ± 0.45[b]
Ramp	29.8 ± 0.34[ab]	29.8 ± 0.20[a]	29.5 ± 0.15[ab]	29.3 ± 0.13[b]	29.3 ± 0.14[ab]
Decay	0.00125 ± 5.74E-5[ab]	0.00130 ± 3.55E-5[a]	0.00137 ± 2.71E-5[ab]	0.00138 ± 2.51E-5[b]	0.00138 ± 2.58E-5[b]
Time to peak (d)	81.4 ± 1.94[ab]	80.7 ± 1.16[a]	77.9 ± 0.86[b]	77.4 ± 0.78[b]	77.3 ± 0.81[b]
Peak yield (kg)	27.8 ± 0.66[a]	28.8 ± 0.48[a]	30.2 ± 0.42[b]	30.6 ± 0.40[c]	30.6 ± 0.41[bc]
Lactations	129	501	8,019	2,231	3,657

[1]The MilkBot function is as follows:

$$y_t = a\left(1 - \frac{\exp\left(\frac{c-t}{b}\right)}{2}\right)\exp(-dt)$$

In this function, a is the scale parameter, representing the theoretical maximum daily yield; b is the ramp parameter, controlling the rate of rise in milk production in early lactation; c is the offset parameter, describing the offset in time between parturition and the start of lactation; and d is the decay parameter, representing the rate of senescence of production capacity. The time at which peak lactation occurred (t_{peak}) was defined as: $t_{peak} = -b \ln\left(\frac{2db}{db+1}\right) + c$, and peak yield was calculated by substitution t_{peak} in the MilkBot equation. The 305-day milk, the cumulative milk yield between calving and day 305 of the lactation, was calculated as:
$$M_{305} = \left(a - a\exp(-305\,d)\right)/d + \left(ab\exp(c/b)\left(-1 + \exp\left(-305(1/b+d)\right)\right)\right)/(2+2bd)$$
[2]The included animals were categorized to five gestation length categories: ($150 \leq GL \leq 243$ days, C-I), ($243 < GL \leq 267$ days, C-II), ($267 < GL \leq 275$ days, C-III), ($275 < GL \leq 283$ days, C-IV), and ($283 < GL \leq 297$ days, C-V).
[a,b,c]Different superscripts indicate significant differences between gestation length categories at $p < 0.05$.
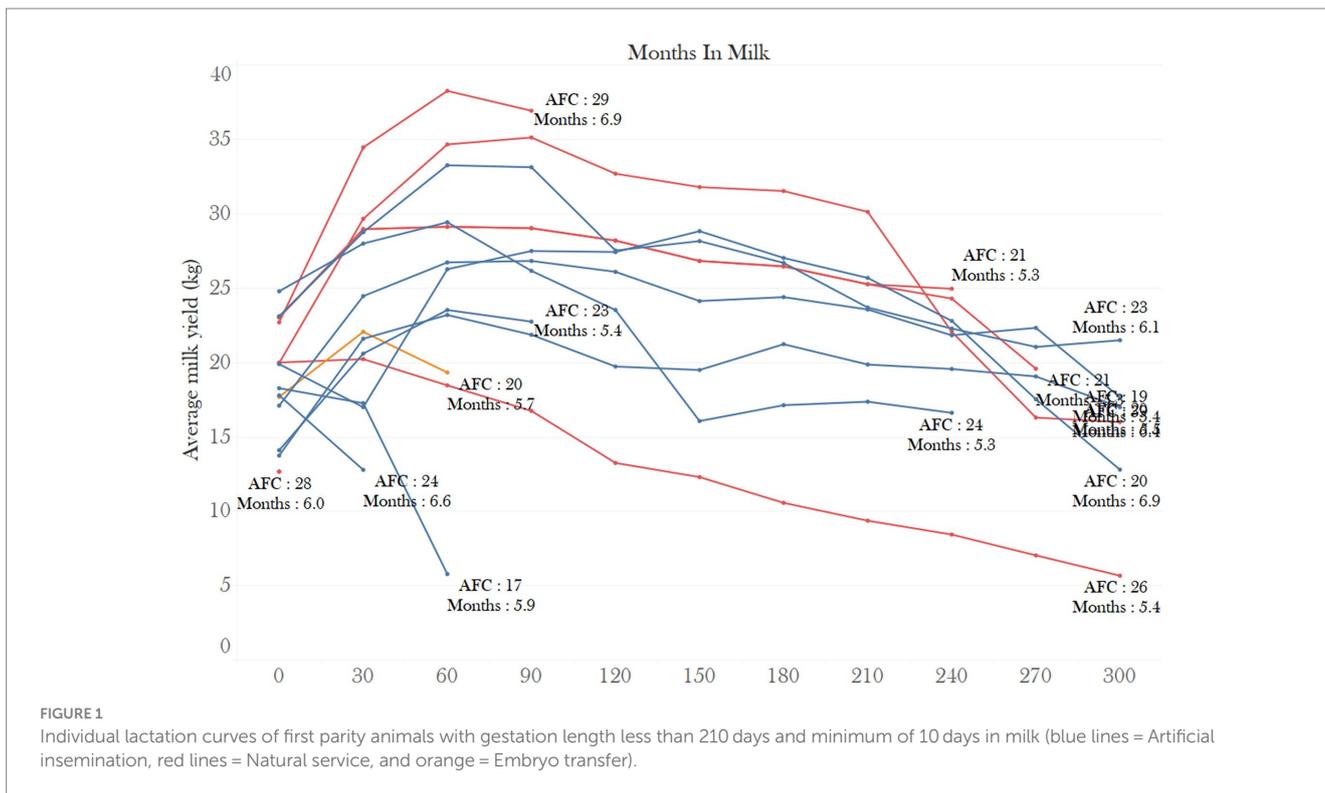
FIGURE 1
Individual lactation curves of first parity animals with gestation length less than 210 days and minimum of 10 days in milk (blue lines = Artificial insemination, red lines = Natural service, and orange = Embryo transfer).
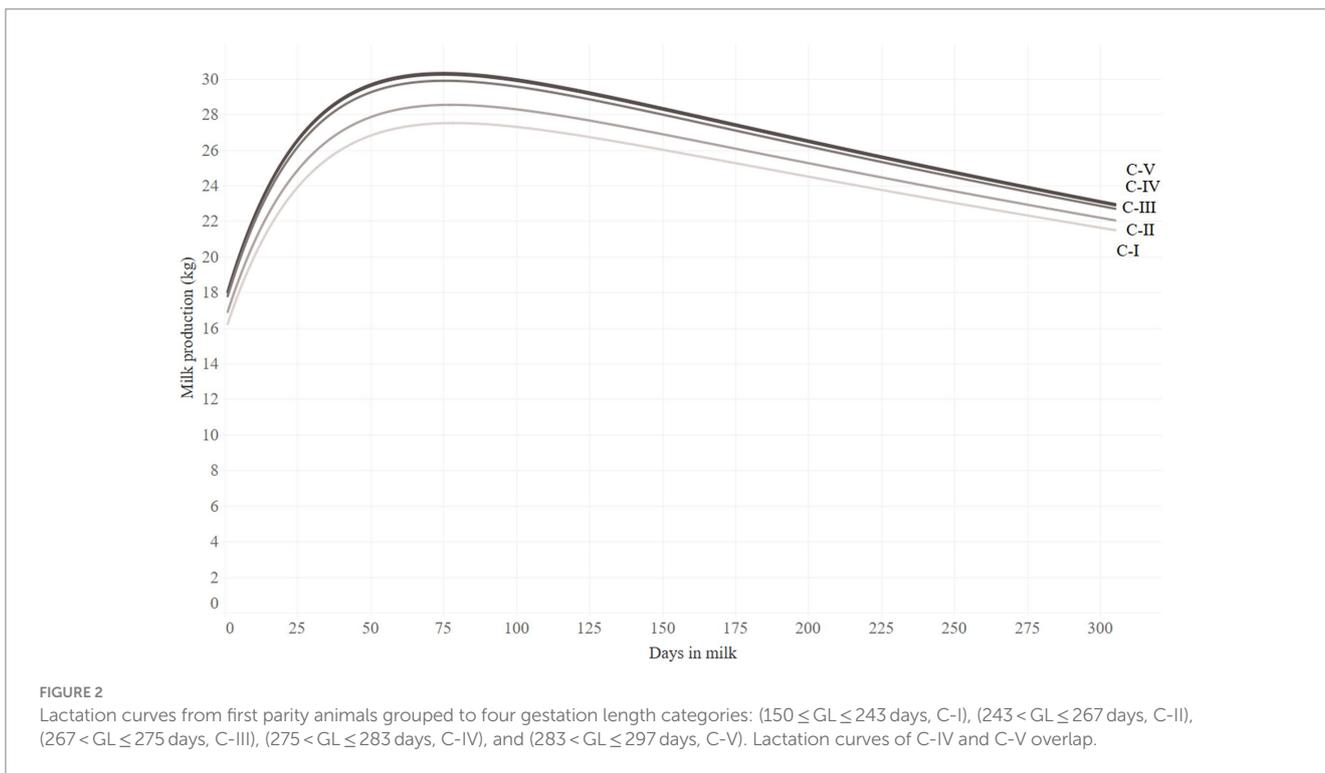
FIGURE 2
Lactation curves from first parity animals grouped to four gestation length categories: (150 ≤ GL ≤ 243 days, C-I), (243 < GL ≤ 267 days, C-II), (267 < GL ≤ 275 days, C-III), (275 < GL ≤ 283 days, C-IV), and (283 < GL ≤ 297 days, C-V). Lactation curves of C-IV and C-V overlap.

the individual lactation curve exploration probably leads to an underestimation of the real incidence within the herd.

The results showed that primiparous cows with a very short GL had less 305-day milk and peak yield, tended to reach their peaks later, had a higher lactation persistency, and showed a lower upward slope of the lactation curve compared to those with a normal GL. All results found here in first calving heifers are in the line with previous studies regarding the effect of GL on milk production (29, 33). Atashi and Asaadi (29) reported that Holstein heifers with a short GL produced less partial and 305-day lactation performance than those with an average or long GL. Norman et al. (33) found that heifers with a longer GL produced more milk, fat, and protein.

Nevertheless, in these previous studies, short gestations were defined as those with a range of 250–272 days of pregnancy (29) or with 275 days of pregnancy (33), thus considerably longer compared to the C-I category of the present study. Most of the differences in the parameters of the lactation curve in the present study can in fact be observed between the categories C-I and C-II on one side and categories C-III, C-IV, and C-V on the other sides. A difference of 687 ± 150 kg was detected in the 305-day milk yield between the categories C-I and C-III, which can, at least in part, be attributed to a lower peak yield in C-I animals [27.8 ± 0.66 kg milk/animal (C-I) vs. 30.2 ± 0.42 kg milk/animal (C-III)]. The same differences were found regarding the scale values. This can be partially explained by the fact that, since nutrients in primiparous cows are prioritized not only for lactation but also for the continued growth of the animal, milk production is generally lower but lactation persistency higher in primiparous than multiparous cows. The same trend can occur when comparing primiparous cows calving at different stage of the pregnancy and thus at different ages and body development. Compared to previous studies, a greater decrease in 305-day milk yield was found in the short GL animals of the present study. However, the present dataset was analyzed for milk production after an extremely short gestation period in primiparous cows. Nevertheless, it is well known that lactation curve in multiparous cows differs from that in primiparous, as it is characterized by a higher 305-day and peak yield. Moreover, heifers do not require a dry period (DP), and therefore the impact of a shorter gestation or an early abortion in primiparous cows is possibly lower than in multiparous cows. During the DP, mammary cells renew at a faster rate than when cows would be milked up to calving (24). This results in a large concentration of renewed mammary cells at the moment of calving which explains the high peak milk yield in the next lactation after a traditional DP (34, 35). In primiparous cows, renewal of mammary cells is not necessary, and it is known that bovine mammary gland during the first gestation follows a continuous exponential form of growth (36), but it is reported that the majority of mammary growth occurs during the latter part of gestation (37). Thus, the effect of a short gestation on lactation performances is unavoidable. Shorter DP (0–35 and 36–50 days) have been associated with a lower initial milk yield, steeper inclining, and declining slopes of the lactation curve, and a higher milk persistency compared with DP length of 51–60 days (38). Norman et al. (33) reported that the cows that performed best for milk yield and had the most favorable productive life tended to have been born following intermediate GL (274–279 days). Jenkins et al. (39) reported that reducing GL has a neutral or positive effect on future cow production. Peak lactation is achieved later in cows with 0–35- and 36–50-day DP length than in those with DP length of 51–6 days. Therefore, the effects of a short gestation in heifers and those induced by a short DP in cows are comparable, although in this study differences in time to peak were only slightly different (maximum 4 days).

Milk yield for animals of the C-II group showed a higher level of persistency compared to those in the C-IV and C-V groups. Atashi and Asaadi (29) also found that the average milk yield persistency in primiparous cows with a short GL was higher than in those with an average or long GL. The association between GL and lactation performance may be, at least in a part, explained by the fact that the greatest increase in the mass of parenchymal tissue occurs in late pregnancy (40); therefore, shorter the GL, less the mammary cells, and subsequently less the milk yield. Atashi and Asaadi (29) reported that Holstein primiparous cows with a short GL produced less milk at the beginning of lactation and at the peak than those with an average or long GL. However, inverse trends were found for milk yield persistency, upward and downward slopes of the lactation curve.

In conclusion, the effect of GL on 305-day milk yield and lactation curve parameters were investigated. The results showed that Holstein primiparous cows with a short GL produced less 305-day milk, less milk at the beginning of lactation and at the peak than those with an average or long GL. However, inverse trends were found for milk yield persistency, upward and downward slopes of the lactation curve. The present results confirm some previous literature on cows and add new details regarding the lactation curve parameters in primiparous cows, and could therefore drive farmers' decision about management of lactation in heifers with extremely short GL or abortion events.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://github.com/Bovi-analytics/probo-et-al-2019.

Ethics statement

Ethical approval was not required for the studies involving animals in accordance with the local legislation and institutional requirements because only retrospective data regarding lactation performances were used. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

MP: Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. HA: Data curation, Methodology, Writing – review & editing. MH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Writing – review & editing.

Funding

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Oltenacu PA, Broom DM. The impact of genetic selection for increased milk yield on the welfare of dairy cows. *Anim Welf*. (2010) 19:39–49. doi: 10.1017/S0962728600002220

2. Akers RM. A 100-year review: mammary development and lactation. *J Dairy Sci*. (2017) 100:10332–52. doi: 10.3168/jds.2017-12983

3. Turner CW. The development of the mammary gland as indicated by the initiation and increase in the yield of secretion. *Univ Missouri Agric Exp Stat Bull*. (1931) 1931:134–6. doi: 10.1093/ansci/1931.1.134

4. Pennington J, Malven P. Prolactin in bovine milk near the time of calving and its relationship to premature induction of lactogenesis. *J Dairy Sci*. (1985) 68:1116–22. doi: 10.3168/jds.S0022-0302(85)80937-1

5. Malven P, Head H, Collier R, Buonomo F. Periparturient changes in secretion and mammary uptake of insulin and in concentrations of insulin and insulin-like growth factors in milk of dairy cows. *J Dairy Sci*. (1987) 70:2254–65. doi: 10.3168/jds.S0022-0302(87)80285-0

6. Greene W, Galton D, Erb H. Effects of prepartum milking on milk production and health performance. *J Dairy Sci*. (1988) 71:1406–16. doi: 10.3168/jds.S0022-0302(88)79699-X

7. Grummer R, Bertics S, Hackbart R. Effects of prepartum milking on dry matter intake, liver triglyceride, and plasma constituents. *J Dairy Sci*. (2000) 83:60–1. doi: 10.3168/jds.S0022-0302(00)74855-7

8. Bowers S, Gandy S, Graves K, Eicher S, Willard S. Effects of prepartum milking on postpartum reproduction, udder health and production performance in first-calf dairy heifers. *J Dairy Res*. (2006) 73:257–63. doi: 10.1017/S0022029906001762

9. Frank RT, Rosenbloom J. Physiologically active substances contained in the placenta and in the corpus luteum. *Surg Gynecol Obstet*. (1915) 21:646.

10. Kensinger R, Bauman D, Collier R. Season and treatment effects on serum prolactin and milk yield during induced lactation. *J Dairy Sci*. (1979) 62:1880–8. doi: 10.3168/jds.S0022-0302(79)83518-3

11. Byatt J, Eppard P, Veenhuizen J, Curran T, Curran D, McGrath M, et al. Stimulation of mammogenesis and lactogenesis by recombinant bovine placental lactogen in steroid-primed dairy heifers. *J Endocrinol*. (1994) 140:33–43. doi: 10.1677/joe.0.1400033

12. Kensinger RS. Induced lactation: physiology, perception, profitability and propriety. *J Dairy Sci*. (2000) 83:23–4.

13. Magliaro A, Kensinger R, Ford S, O'connor M, Muller L, Graboski R. Induced lactation in nonpregnant cows: profitability and response to bovine somatotropin. *J Dairy Sci*. (2004) 87:3290–7. doi: 10.3168/jds.S0022-0302(04)73465-7

14. Mellado M, Antonio-Chirino E, Meza-Herrera C, Veliz F, Arevalo J, Mellado J, et al. Effect of lactation number, year, and season of initiation of lactation on milk yield of cows hormonally induced into lactation and treated with recombinant bovine somatotropin. *J Dairy Sci*. (2011) 94:4524–30. doi: 10.3168/jds.2011-4152

15. Fulkerson W. Artificial induction of lactation: a comparative study in heifers. *Aust J Biol Sci*. (1978) 31:65–72. doi: 10.1071/BI9780065

16. Jewell TM (2002). Artificial induction of lactation in nonbreeder dairy cows. Unpublished Master of Science dissertation, Virginia Polytechnic Institute and State University, Blacksburg

17. Donovan G, Badinga L, Collier R, Wilcox C, Braun R. Factors influencing passive transfer in dairy calves. *J Dairy Sci*. (1986) 69:754–9. doi: 10.3168/jds.S0022-0302(86)80464-7

18. Fetrow J. Culling dairy cows. *Am Ass Bov Pract Conf Proc*. (1987) 20:102–7. doi: 10.21423/aabppro19877465

19. Bach A. Associations between several aspects of heifer development and dairy cow survivability to second lactation. *J Dairy Sci*. (2011) 94:1052–7. doi: 10.3168/jds.2010-3633

20. Asdell S. Recent developments in the field of sex hormones. *Cornell Vet*. (1931) 21:147.

21. Kwong FJ. Histological study of the mammary gland of the cow during pregnancy. *J Am Vet Med Assoc*. (1940) 96:36–40.

22. Feldman JD. Fine structure of the cow's udder during gestation and lactation. *Lab Investig*. (1961) 10:238–55.

23. Hammond J. *The Physiology of Reproduction in the Cow*. Cambridge, UK: Cambridge University Press (2014).

24. Capuco A, Akers R, Smith J. Mammary growth in Holstein cows during the dry period: quantification of nucleic acids and histology. *J Dairy Sci*. (1997) 80:477–87. doi: 10.3168/jds.S0022-0302(97)75960-5

25. Akers RM. Major advances associated with hormone and growth factor regulation of mammary growth and lactation in dairy cows. *J Dairy Sci*. (2006) 89:1222–34. doi: 10.3168/jds.S0022-0302(06)72191-9

26. McFadden TB, Akers RM, Kazmer GW. Alpha-lactalbumin in bovine serum: relationships with udder development and function. *J Dairy Sci*. (1987) 70:259–64. doi: 10.3168/jds.S0022-0302(87)80005-X

27. Swanson E. Effect of abortions and short gestations on lactation. *J Dairy Sci*. (1970) 53:381.

28. Keshavarzi H, Sadeghi-Sefidmazgi A, Ghorbani GR, Kowsar R, Razmkabir M, Amer P. Effect of abortion on milk production, health, and reproductive performance of Holstein dairy cattle. *Anim Reprod Sci*. (2020) 217:106458. doi: 10.1016/j.anireprosci.2020.106458

29. Atashi H, Asaadi A. Association between gestation length and lactation performance, lactation curve, calf birth weight and dystocia in Holstein dairy cows in Iran. *Anim Reprod*. (2019) 16:846–52. doi: 10.21451/1984-3143-AR2019-0005

30. Hermans K, Waegeman W, Opsomer G, Van Ranst B, De Koster J, Van Eetvelde M, et al. Novel approaches to assess the quality of fertility data stored in dairy herd management software. *J Dairy Sci*. (2017) 100:4078–89. doi: 10.3168/jds.2016-11896

31. Ehrlich J. Quantifying shape of lactation curves, and benchmark curves for common dairy breeds and parities. *Bov Pract*. (2011) 45:88–95. doi: 10.21423/bovine-vol45no1p88-95

32. R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org/

33. Norman H, Wright J, Miller R. Potential consequences of selection to change gestation length on performance of Holstein cows. *J Dairy Sci*. (2011) 94:1005–10. doi: 10.3168/jds.2010-3732

34. Kuhn MT, Hutchison JL, Norman H. Minimum days dry to maximize milk yield in subsequent lactation. *Anim Res*. (2005) 54:351–67. doi: 10.1051/animres:2005031

35. van Knegsel AT, van der Drift SG, Čermáková J, Kemp B. Effects of shortening the dry period of dairy cows on milk production, energy balance, health, and fertility: a systematic review. *Vet J*. (2013) 198:707–13. doi: 10.1016/j.tvjl.2013.10.005

36. Swanson E, Poffenbarger J. Mammary gland development of dairy heifers during their first gestation. *J Dairy Sci*. (1979) 62:702–14. doi: 10.3168/jds.S0022-0302(79)83313-5

37. Delouis C, Djiane J, Houdebine L, Terqui M. Relation between hormones and mammary gland function. *J Dairy Sci*. (1980) 63:1492–513. doi: 10.3168/jds.S0022-0302(80)83110-9

38. Atashi H, Zamiri M, Dadpasand M. Association between dry period length and lactation performance, lactation curve, calf birth weight, and dystocia in Holstein dairy cows in Iran. *J Dairy Sci*. (2013) 96:3632–8. doi: 10.3168/jds.2012-5943

39. Jenkins G, Amer P, Stachowicz K, Meier S. Phenotypic associations between gestation length and production, fertility, survival, and calf traits. *J Dairy Sci*. (2016) 99:418–26. doi: 10.3168/jds.2015-9934

40. Davis S. Triennial lactation symposium/BOLFA: mammary growth during pregnancy and lactation and its relationship with milk yield. *J Anim Sci*. (2017) 95:5675–88. doi: 10.2527/jas2017.1733