Journal of Dairy Research

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A good start: early-life risk factors associated with dairy cow longevity

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Research Article

Cite this article: Thomsen PT (2025) A good start: early-life risk factors associated with dairy cow longevity. *Journal of Dairy Research* **92**, 525–530. https://doi.org/10.1017/S0022029925101635

Received: 22 May 2025
Revised: 20 August 2025
Accepted: 20 August 2025
First published online: 7 November 2025

Keywords:
birth condition; dairy cow; length of productive life; lifetime milk yield; longevity

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Abstract

Dairy cow longevity affects production economy, climate footprint, and cow welfare. Based on data from the Danish Cattle Database, this research paper evaluates the relationship between early-life risk factors associated with the period before first calving and cow longevity, including data from all Danish dairy cows culled in 2019–2023. Explanatory variables for linear mixed models included calf size, twinning, and age at first calving. Information about the length of productive life (LPL) (mean: 1,074 days) and lifetime milk yield (mean: 32,088 kg energy-corrected milk) was available for 767,305 and 716,120 cows, respectively. Milk yield per day of life increased from 7 kg in cows culled during the first lactation to more than 20 kg in cows culled in their fifth or later lactations. For cows born as singletons, LPL was one month longer for cows born as large calves than for medium-sized calves, and 2 months longer than for small calves. Cows born as twins had 2 to 3 months shorter productive lives compared to cows born as singletons. For singletons, lifetime milk yield was 1,200 kg higher for large calves than for medium-sized calves, and 2,100 kg higher than for small calves. Lifetime milk yield was 1,500 to 3,500 kg lower in cows born as twins. Cows being among the third quartile of age at first calving had an estimated productive life 2.5 months longer, and a lifetime milk yield more than 2,600 kg higher than cows calving among the first quartile of age. The results from this study clearly demonstrate the importance of 'a good start'.

Longevity in dairy cows is very important, as it affects production economy (Grandl *et al.*, 2019; Dallago *et al.*, 2021), the environmental impact of milk production (Grandl *et al.*, 2019), and the welfare of cows (Bruijnis *et al.*, 2013). Additionally, many consumers likely expect dairy cows to live long lives (De Vries and Marcondes, 2020). Dallago *et al.* (2021) reviewed the longevity of dairy cows and concluded that dairy cow longevity has decreased in most high milk-producing countries during the last five decades.

The ability of a cow to stay in a dairy herd for a long time is influenced by many factors, some of which interact in complicated ways (Roche *et al.*, 2020; Rostellato *et al.*, 2021). These risk factors primarily relate to the life of the cow after her first calving. Very few studies have focused on risk factors for cow longevity associated with the early life of cows – the period before the cow calves for the first time. Previously, the association between longevity and season of birth (Bobadilla *et al.*, 2024), age at first calving (Froidmont *et al.*, 2013; Sherwin *et al.*, 2016), growth rates, early-life diseases, and other rearing conditions (Hultgren and Svensson, 2009; Bach, 2011; Heinrichs and Heinrichs, 2011) have been studied. Dallago *et al.* (2022) evaluated the association between longevity, measured as length of life and length of productive life (LPL), and calving ease, calf size, and twinning in a large sample of Holstein cows from Quebec, Canada. However, almost half of the cows included in their study did not complete the study but were censored before they were culled.

The present study is the first study to evaluate the association between early-life risk factors and cow longevity measured as both LPL and lifetime milk yield in a large sample of cows without censoring of animals. Additionally, this study is one of very few studies including cows of breeds other than Holstein. The objective was to evaluate the relationship between calf size, twinning, age at first calving, breed and month of birth, and LPL and lifetime milk yield, respectively, among Danish dairy cows.

Materials and methods

Danish dairy farmers are required to report certain information to the Danish Cattle Database, which is managed by the Danish Cattle Federation. This includes dates of calvings, slaughter, deaths and all movements of animals between herds. Likewise, farmers must report the sex and number of calves born. Farmers can also report the size of the calf, which is not mandatory but is done in approximately 80% of cases. Among many other additional things, the Danish

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Table 1. Descriptive statistics (distribution, lifetime milk yield (ECMlife) and length of productive life (LPL)) for each level of the explanatory variables included in an evaluation of longevity among Danish dairy cows culled during 2019 to 2023

Variable	Levels (percent of observations)	Mean ECMlife (kg energy-corrected milk)	Mean LPL (days)
Calf size	Small (4.8%)	30,845	1,051
	Medium (90.3%)	32,102	1,073
	Large (4.9%)	33,556	1,120
Twin	No (97.5%)	32,145	1,076
	Yes (2.5%)	29,823	1,005
Age at first calving	1st quartile (25.3%)	30,950	1,023
	2nd quartile (25.2%)	32,783	1,084
	3rd quartile (24.7%)	33,100	1,109
	4th quartile (24.9%)	31,509	1,083
Month of birth	January (8.3%)	32,482	1,080
	February (7.3%)	32,330	1,078
	March (7.8%)	32,229	1,081
	April (7.8%)	31,564	1,065
	May (8.1%)	31,554	1,066
	June (8.2%)	31,689	1,067
	July (8.7%)	31,841	1,069
	August (9.1%)	31,973	1,069
	September (8.4%)	32,022	1,070
	October (8.7%)	32,259	1,077
	November (8.8%)	32,451	1,082
	December (8.9%)	32,600	1,087
Breed	Holstein (68.7%)	33,195	1,077
	Jersey (11.9%)	30,538	1,139
	Crossbred (14.0%)	28,544	1,013
	Danish Red Dairy (5.5%)	29,931	1,062

Cattle Database also includes information about the cow's breed. In June 2024, a dataset from the Danish Cattle Database including information on all Danish dairy cows culled during the five-year period 2019–2023 was generated. 'Culled' included slaughtered, euthanised, and unassisted dead cows, but not cows sold to other Danish herds or exported for milk production. Only cows of the dairy breeds Holstein, Jersey, or Danish Red Dairy, or crosses between these breeds were included in the dataset. Only cows culled from milk-producing herds were included. Approximately 93% of all Danish dairy cows are part of the official milk recording scheme. For these cows, monthly milk recordings at cow level were available.

Longevity was measured in two ways: LPL and lifetime milk yield (ECMlife). LPL was defined as days from first calving to culling, and ECMlife was defined as lifetime milk yield of the cow measured in kg energy-corrected milk (Compton *et al.*, 2017; Schuster *et al.*, 2020). For each cow, milk yield per day of life was calculated as ECMlife divided by the number of days from birth to culling.

Explanatory variables included in the statistical analyses are listed in Table 1. All explanatory variables related to birth refer to the birth of the culled cow, not to her own subsequent calving(s). As an example, twinning thus refers to the culled cow being born as a twin or not, and not to whether she has had twins or not at one or more of her own calvings. Calvings with three or more calves were recorded as 'yes' for twins. Farmers recorded the size of calves as 'small', 'medium', or 'large' (compared to other calves of the same breed). Age at first calving was grouped into quartiles and differed between breeds, with median ages at first calving being 751 days (1st quartile: 714; 3rd quartile: 801) for Holstein, 714 days (677; 763) for Jersey, 761 days (724; 811) for Danish Red Dairy and 753 days (714; 806) for crossbred cows. Therefore, groups were based on quartiles within breed. Heifers calving for the first time at an age of less than 500 days or more than 1,500 days were excluded from the dataset.

The association between the outcomes LPL and ECMlife and the explanatory variables were analysed using linear mixed models (PROC MIXED, SAS 9.4). LPL and ECMlife were evaluated in separate models. To take differences between herds into account, herd was included in the models as a random effect. The approximate normal distributions of LPL and ECMlife were confirmed using Kolmogorov-Smirnov tests. Models were reduced using backward elimination with $P < 0.05$ defined as significant. To take a possible correlation between twins and calf size into account, interactions between twin and calf size were included in the models. The final models thus included the outcomes LPL and ECMlife, respectively, and the explanatory variables age at first calving, month of birth, breed, and the interaction between twin and calf size.

Results

The dataset included information from 931,437 cows. Of these, 767,305 cows had recordings of calf size, and 716,120 additionally were from herds participating in the official milk recording scheme, and thus also had information on ECMlife. Overall, mean LPL was 1,074 days (minimum: 0; first quartile: 582; median: 997; third quartile: 1,483; maximum: 6,787). Mean LPL was highest in Jersey cows (1,139 days), 2 months longer than Holstein cows, and more than 4 months longer than crossbred cows (Table 1). Mean ECMlife was 32,088 kg energy-corrected milk (minimum: 0; first quartile: 16,007; median: 28,925; third quartile: 44,782; maximum: 214,775). ECMlife was highest for Holstein cows (33,195 kg), followed by Jersey, Danish Red Dairy, and crossbred cows (Table 1). Fig. 1 presents the distribution of LPL and ECMlife. Of the culled cows, 83.65% were slaughtered, 10.10% died unassisted, and 6.25% were euthanised. Differences in LPL and ECMlife between slaughtered, dead, and euthanised cows were minor, with mean LPL of 1077, 1075, and 1034, and mean ECMlife of 32,027, 32,620, and 32,056, respectively. Descriptive statistics of LPL and ECMlife stratified by the explanatory variables are given in Table 1. Fig. 2 presents the mean energy-corrected milk yield per day of life for cows culled during different lactations, showing increasing milk yields per day of life from approximately 7 kg milk per day of life in cows culled during the first lactation to more than 20 kg per day in cows culled in their fifth or later lactations. Table 2 presents results from the two analyses of the association between LPL and ECMlife and the explanatory variables. For both LPL and ECMlife, type III tests of fixed effects were significant ($P < 0.0001$) for all explanatory variables, and the interactions between twin and calf size were

https://doi.org/10.1017/S0022029925101635 Published online by Cambridge University Press

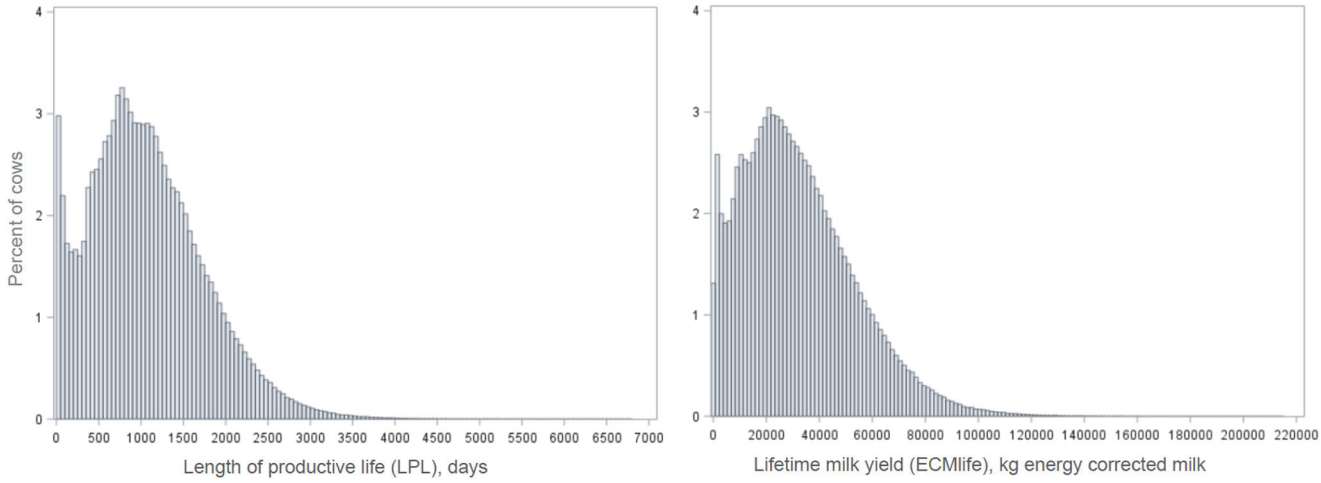


Figure 1. Distribution of length of productive life (LPL, days) and lifetime milk yield (ECMlife, kg energy corrected milk) for 767,305 and 716,120 Danish dairy cows, respectively, culled during 2019–2023.

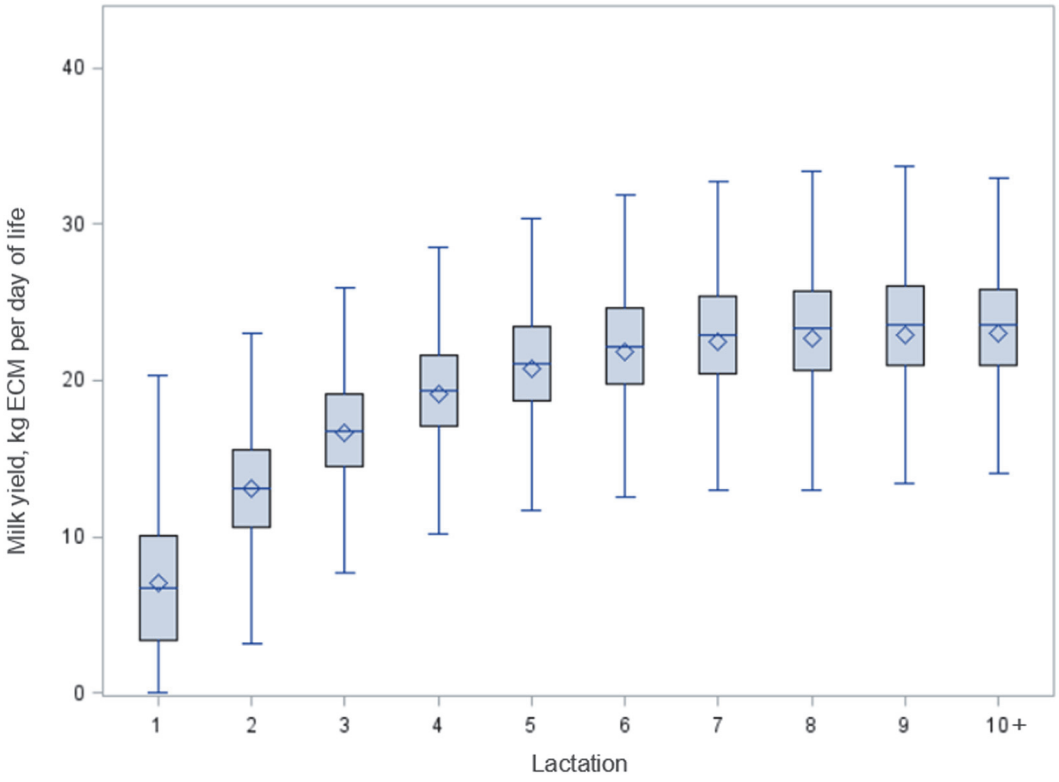


Figure 2. Box plot illustrating mean milk yield (kg energy-corrected milk) per day of life for 716,120 Danish dairy cows culled during different lactations.

significant ($P < 0.0001$). The combination of twins and large calves was uncommon: only 0.6% of all twins (116 calves) were recorded as 'large'. For singletons, the estimated LPL was almost 2 months longer for cows born as large calves than for small calves, and more than 1 month longer than for medium-sized calves. Cows born as twins had 2-to-3-month shorter estimated LPL compared to cows born as singletons. For cows born as twins the effect of calf size was small with less than one month difference in estimated LPL across calf sizes, with the highest LPL in medium-sized calves. For singletons, ECMlife was approximately 1,200 kg higher for large calves than for medium-sized calves, and 2,100 kg higher than for small calves. Compared to singletons, ECMlife was approximately 1,500 to 3,500 kg lower in cows born as twins, again with only minor differences between calf sizes within the twin group. Age at first calving was significantly associated with both LPL and ECMlife: Cows calving for the first time among the third quartile of age within breed had an estimated LPL of 2.5 months longer than cows calving among the first quartile of age. ECMlife was more than 2,600 kg higher in cows calving for the first time in the third quartile compared to the first quartile. The month of birth was distributed approximately equally throughout the year with 7.3 to 9.1 percent of cows born each month. Longevity, measured as both

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Table 2. Results from two linear mixed models evaluating the association between length of productive life (LPL) and lifetime milk yield (ECMlife) and early-life risk factors in Danish dairy cows culled during 2019 to 2023

Variable	Levels	Estimate LPL	p-value (Type III)	Estimate ECMlife	p-value (Type III)
Intercept	-	1,166.5	-	31,307	-
Twin*calf size	Singleton*small	75.5	<0.0001	1,454	<0.0001
	Singleton*medium	93.6		2,324	
	Singleton*large	129.7		3,542	-
	Twin*small	21.1		−180	
	Twin*medium	26.0		21	
	Twin*large	0		0	
Age at first calving	1st quartile	−47.4	<0.0001	−2,139	<0.0001
	2nd quartile	7.5		−269	
	3rd quartile	28.3		507	
	4th quartile	0		0	
Month of birth	January	−4.4	<0.0001	−88	<0.0001
	February	−6.9		−248	
	March	−0.3		−203	
	April	−18.7		−892	
	May	−20.0		−926	
	June	−22.6		−919	
	July	−17.8		−649	
	August	−20.1		−595	
	September	−18.6		−482	
	October	−9.6		−215	
	November	−4.8		−96	
	December	0		0	
Breed	Holstein	37.1	<0.0001	3,218	<0.0001
	Jersey	−134.8		−4,330	
	Crossbred	−42.0		236	
	Danish Red Dairy	0		0	

LPL and ECMlife, was significantly associated with month of birth. Cows born in April to September had an estimated LPL of approximately 10–20 days less than cows born in November to March, and ECMlife was approximately 400–800 kg lower in cows born in April to September compared to November to January.

Discussion

The results from this study clearly demonstrate the importance of 'a good start': Cows with a difficult start – born as a twin or of small size – generally had decreased longevity, irrespective of whether longevity was measured as LPL or ECMlife. Previous research has documented several problems associated with small calves, calves born at difficult calvings, or calves born as twins. These problems include an increased risk of failure of passive transfer, increased morbidity and decreased average daily weight gain (Lombard *et al.*, 2007; Waldner and Rosengren, 2009; Shivley *et al.*, 2018). Heinrichs and Heinrichs (2011) found that dystocia was negatively associated with lifetime milk yield. Bach (2011) found that calves with a higher growth rate 12 to 65 days old had a higher probability of reaching the second lactation. Dallago *et al.* (2022) studied the association between birth conditions and longevity in Holstein cows. Using conditional inference survival trees, they found the longest life in large or medium-sized calves born at an unassisted calving. Small calves born as twins had the shortest life. Large or medium-sized calves born at an unassisted or surgery calving had the longest productive life, whereas twin calves from an assisted calving had the shortest productive life. In the present study, calf size was associated with longevity only in singletons, whereas being born as a twin was associated with decreased longevity, irrespective of the size of the calf.

As illustrated in Fig. 2, longevity influenced milk yield per day of life to a very high degree. Cows culled in their fifth or later lactations had a milk yield per day of life which was approximately three times higher than cows culled during the first lactation. This clearly illustrates the benefits of cows living long lives on both

https://doi.org/10.1017/S0022029925101635 Published online by Cambridge University Press

production economy and climate impact. Overall, the explanation behind this is fewer productive days after first calving compared to unproductive days before first calving in cows culled at a younger age. Additionally, the low milk yield per day of life among cows culled during their first lactation – compared to cows culled during their second or later lactations – is likely also influenced by some first lactation cows culled after very few days in milk and the fact that culling for low milk production is more likely during the first lactation compared to later lactations (Thomsen and Houe, 2023).

In the present study, the best longevity, measured as both LPL and ECMlife, was found among cows belonging to the third quartile of age at first calving. This is in contrast with findings from some previous studies. Hultgren and Svensson (2009) found the lowest risk of culling in cows calving for the first time less than 771 days old. However, differences between this age group and older age groups were relatively minor and often not significant. Bach (2011) found a small difference in the mean age at first calving of cows completing the first lactation (724 days) or not (737 days). Froidmont *et al.* (2013) found the highest lifetime milk production and the highest number of productive days in cows calving for the first time 22–26 months old. Sherwin *et al.* (2016) found increasing odds of culling during the first lactation with increasing age at first calving. It is noteworthy that most of these studies are much smaller than the present study and typically focus on stayability during the first lactation only. Age at first calving is heavily influenced by management decisions made by the farmer. Age at first calving may thus be seen as a manageable risk factor, defined as a risk factor which a farmer can relatively easily (in terms of labour and investments) change, eliminate or mitigate (Thomsen and Houe, 2024). Risk factors related to the birth of a cow (size of calf and twinning) are not manageable in the same way. However, knowledge about the association between such risk factors and longevity may be used as a decision support tool when farmers need to make an early selection between two otherwise 'equal' replacement heifers: which one to keep and which one to sell. Age at first calving has been shown to be associated with numerous other outcomes, for example, risk of dystocia, production economy, fertility, and risk of sole ulcers (Ettema and Santos, 2004; Eastham *et al.*, 2018; Atashi *et al.*, 2021; Thomsen and Houe, 2024). The optimal age at first calving varies between these outcomes, and it is therefore important not only to focus on one outcome when deciding the target age at first calving in a herd.

The findings of lower LPL and ECMlife in cows born in April to September may be due to heat stress. Heat stress is relatively common in Denmark during the summer months. Bobadilla *et al.* (2024) studied longevity in a pasture-based milk production system in Uruguay and found that season of birth had a small impact on the longevity of dairy cows, with the longest LPL in cows born in the spring. Heat stress may affect calves both in utero and during early life. Ahmed *et al.* (2021) found that late-gestation heat stress of dairy cows reduced foetal growth and influenced postnatal performance and immune status of the offspring. Broucek *et al.* (2009) found a reduced intake of concentrates and reduced growth in pre-weaned Holstein calves subjected to heat stress. Even though the effect of season found in the present study was relatively small compared to the other risk factors identified, a reduced longevity in cows subjected to heat stress in early life adds to the existing list of negative effects of heat stress in dairy cows and calves (Cartwright *et al.*, 2023). Season of birth is often correlated with season of both first insemination and first calving. As Danish dairy cattle are typically only at pasture during the period May to November, the likelihood of calves being at pasture at a young age also differs with season of birth. These factors may also partly explain the observed association between season of birth and longevity.

This study included more than 80% of the approximately 931,000 Danish dairy cows culled during the five-year period studied and is thus considered representative of the population of dairy cows in Denmark. The retrospective study design eliminated the need for censoring of cows still alive, hereby removing uncertainty associated with the future faith of cows. The negative effects of 'a bad start' may be even bigger than estimated here, as this study only included animals calving at least once. Calves experiencing 'a bad start' are likely to have a higher risk of culling before their first calving. Thus, seen in a broader perspective, the effect of early-life risk factors for cow longevity may be even larger than estimated in the present study. Generally, the quality of the included data was considered very high. LPL was calculated based on information about dates of birth and death which farmers are required to report with 7 days after the event (EU legislation: EC 1760/2000). The risk of recall bias is thus very small, and the farmer-reported dates were double-checked, e.g., with dates of slaughter or death reported by slaughterhouses and incineration plants. ECMlife was calculated based on information about milk yield recorded by the Danish milk recording association, certified by the International Committee for Animal Recording (ICAR). Farmers' reports of twinning are also considered very reliable, whereas calf size is more subjective and might be influenced by the assessment of individual farmers.

In conclusion, the milk yield per day of life was three times higher in cows culled during their fifth or later lactations, compared to cows culled during the first lactation. This fact underlines the importance of longevity in dairy cows, both in relation to production economy and climate impact. A good start impacts cow longevity. Cows born as singletons and being large at birth generally had longer productive lives and produced more milk during their life. Age at first calving also impacted longevity, with longer productive lifespan and more milk produced by cows belonging to the third quartile of age at first calving.

Acknowledgements. This work was supported by Foreningen PlanDanmark (grant no. 23054). The study sponsor had no influence on the selection of data, analyses, presentation of results, interpretations or conclusions.

Competing interests. The author has no competing interests.

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