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The effect of first-lactation calving season, milk production, and morphology on the survival of Simmental cows

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A B S T R A C T

Longevity in dairy and dual-purpose cattle is a complex trait which depends on many individual and managerial factors. The purpose of the present study was to investigate the survival (**SURV**) rate of Italian Simmental dual-purpose cows across different parities. Data of this study referred to 2 173 primiparous cows under official milk recording that calved between 2002 and 2020. Only cows linearly classified for type traits, including muscularity (**MU**) and body condition score (**BCS**) were kept. Survival analysis was carried out, through the Cox regression model, for different pairwise combinations of classes of milk productivity MU, BCS, and calving season. Herd-year of first calving was also considered in the model. SURV (0 = culled; 1 = survived) at each lactation up to the 6th were the dependent variables, so that, for example, $SURV_2$ equal to 1 was attributed to cows that entered the 2nd lactation. Survival rates were 98, 71, 63, 56, and 53% for 2nd, 3rd, 4th, 5th, and 6th lactation, respectively. Results revealed that $SURV_2$ was not dependent on milk yield, while in subsequent parities, low-producing cows were characterized by higher SURV compared to high-producing ones. Additionally, cows starting the lactation in autumn survived less (47.38%) than those starting in spring (53.49%), suggesting that facing the late gestation phase in summer could increase the culling risk. The present study indicates that SURV in Italian Simmental cows is influenced by various factors in addition to milk productivity. However, it is important to consider that in this study all first-calving cows culled before the linear evaluation - carried out between mid- and late lactation in this breed - were not accounted for. Finding can be transferred to other dual-purpose breeds, where the cows' body conformation and muscle development - i.e. meat-related features - are often considered as important as milk performance by farmers undertaking culling decisions.

Implications

Survival of Italian Simmental cows at various parities was analyzed through the Cox regression model for different combinations of classes of milk productivity level, body condition score, and muscularity, and first-calving season. Findings indicated that survival differed across productivity levels and that cows delivering calves in autumn have a greater culling risk. This research contributes to a better understanding of factors affecting cows' survival and culling in this dual-purpose breed. Nowadays, selling cows with good meat-related characteristics like muscularity represents an important income for the farmer, inevitably affecting survival and culling decision.

Introduction

In countries with a developed dairy industry, the average cows' lifetime as reflected by culling age has significantly decreased (Schuster et al., 2020). In particular, a substantial decrease in survival (**SURV**), an increase in mortality rates, and a sharp decline in fertility (Miller et al., 2008; Norman et al., 2009; Dallago et al., 2021) have been observed in Holstein breed. Currently, the cows' lifespan in the herd ranges from less than 3 years (Pinedo et al., 2014) to 4.5 years (Kerslake et al., 2018), while the natural lifespan would be approximately five times greater (De Vries, 2020). In

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Sweden, approximately 35–40% of the dairy cows are culled from the herd annually, typically at an average age of 60.5 months (Alvåsen et al., 2018). This raises questions about the welfare of farmed animals and the ethics of the dairy sector (De Vries and Marcondes, 2020; Infascelli et al., 2021). In commercial conditions, the length of productive life is affected by various factors and culling could be voluntary or involuntary (Hadley et al., 2006). In general, voluntary culling occurs when a fertile, free of disease and healthy cow is culled due to low milk production (Weigel et al., 2003; Chiumia et al., 2013). Instead, involuntary culling occurs regardless of productivity, i.e., when a farmer is forced to eliminate an animal due to low fertility or poor health conditions (Fetrow et al., 2006). According to Pinedo et al. (2022), culling risks may be affected by physiological state (such as parity number, lactation stage, energy balance, reproductive performance, and aging), herd size, and season. Overall, the culling rate increases progressively with age, from first lactation onwards (Tsuruta et al., 2005). It has been demonstrated that a correct mammary gland conformation, especially in terms of udder depth, fore udder attachment, front teat placement and udder support, protects cows from being culled (Caraviello et al., 2003). According to Williams et al. (2022) also the body condition score (**BCS**) recorded within the first lactation may be a suitable predictor of cow's longevity. In dual-purpose cattle, the relationship between longevity and conformation traits is even stronger than in specialized dairy breeds (Vacek et al., 2006; Strapáková et al., 2021). In fact, morphological characteristics in favor of meat yield/muscle mass like muscularity (**MU**) can encourage the farmer in favor of selling/slaughtering (Zavadilová and Stipkova, 2012; Getu and Misganaw, 2015) and are routinely evaluated in dual-purpose breeds (Cesarani et al., 2020). Several studies have been conducted to identify risk factors for survival in specialized dairy breeds (Hazel et al., 2017; Rocha et al., 2018; Grzesiak et al., 2022); however, to the best of our knowledge, only Buonaiuto et al. (2023), for the first time, attempted to explore SURV in Italian dual-purpose Simmental cattle. Through the use of Kaplan-Meier curves, it is possible to visualize time-to-event outcomes and explore variations in SURV across time, e.g., across cow's age or parities. This approach provides a comprehensive understanding of survival patterns and facilitates the identification of potential factors that influence survival outcomes in a given population. Therefore, the objective of this study was to investigate how SURV changes across parities in Simmental cows taking into account calving season, level of productivity, and morphological characteristics registered within the first lactation.

Material and methods

Data available

An historic overview of the SI breed is provided in the Supplementary Material S1. The data used in this study were provided by the National Association of Italian Simmental Cattle Breeders (**ANAPRI**, Udine, Italy) and included various phenotypic information of cows' lactation recorded by the Italian Breeders Association (**AIA**, Rome, Italy) such as whole lactation performance and test-day milk yield, gross composition, and somatic cell count (cells/mL).

The linear classification system used by ANAPRI for dual-purpose cows includes 26 type traits based on direct measurements or visual scores, on a scale of 1–9, except for BCS, which was scored following the method by Ferguson et al. (1994), i.e. on a scale of 1–5, with increments of 0.25 units (ranging from very thin to obese). Overall, ANAPRI refers to the international methodology of morphological evaluation "Fleckscore system" (Tanzler et al., 2015). Composite traits (e.g., MU) and total scores were presented on a scale of 68–93 points for primiparous cows, with the possibility of adjusting the scale for multiparous cows. Two traits, MU and BCS, were selected for studying their effect on survival among all the evaluated traits by breed experts (Buonaiuto et al., 2023). In Simmental cows, MU was evaluated as buttock's convexity, assigning a score to cows with thighs that had an accentuated MU and full and muscular buttocks with a clear convex profile, but with a conformation suitable to allow the udder's development (Fig. 1). The MU of these areas is essential as it provides insights into the production of prime beef cuts. This trait is scored based on the EUROP method (EC 1183/2006), with MU ranging from 68 (highly concave thigh profiles) to 93 (highly convex thigh profiles) in increments of 1 unit (ANAPRI, 2021).

The BCS was recorded through linear classifiers by evaluating the appearance of the ileal and ischial tuberosities, the thurl and tail head regions, the spinous and transverse process, the ilio-sacral and the ischial-coccygeal ligaments.

All the variables were acquired from existing databases; thus, no animal care and use committee approval was needed for this study.

Phenotypes

The initial dataset comprised 2 656 primiparous cows that underwent official milk recording between January 2003 and December 2019, and these cows were farmed in 324 dairy herds

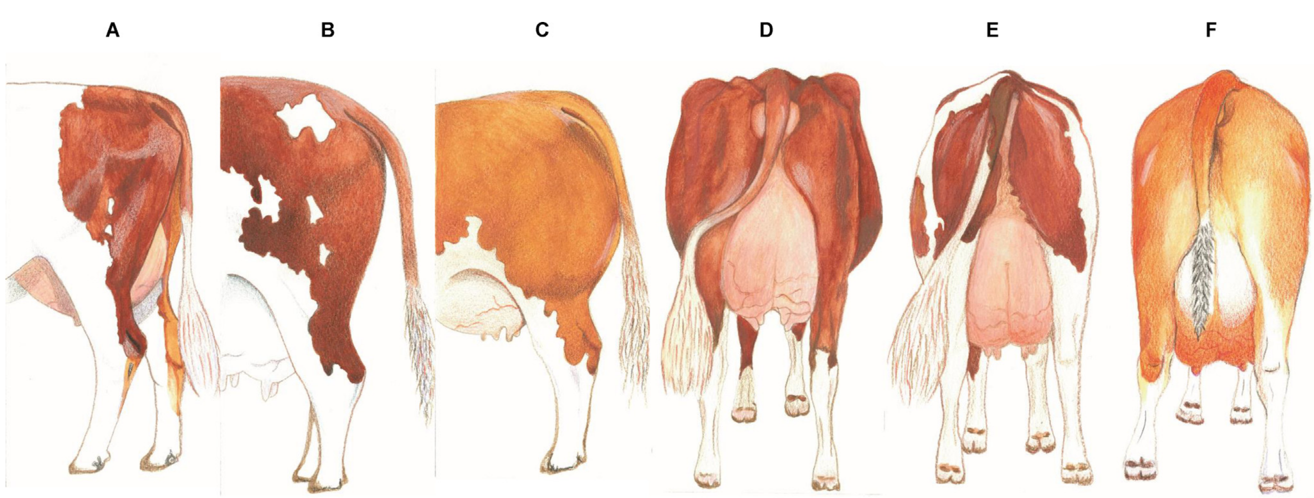

Fig. 1. Side views (A, B, C) and rear views (D, E, F) of Italian Simmental dual-purpose dairy cattle with different levels[1] of muscularity. [1]Three levels - low, medium and high - of muscularity score (MU) were considered.

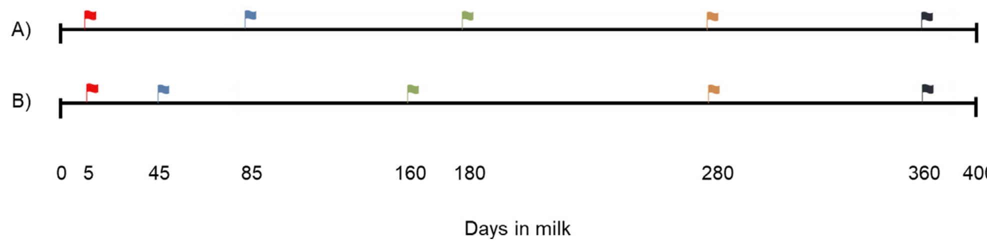

Fig. 2. Flags representing the time points[1] identified for A) muscularity and B) body condition score along the first lactation of Simmental cows. [1]Based on the random regression models proposed by Buonaiuto et al. (2022) for Simmental cows: red flag = onset of lactation; blue flag = nadir of muscle and/or fat reserves losses; green flag = maximum recovery of muscle and/or fat reserves; orange flag = start of reduction in muscle and/or fat reserves; black flag = end of the lactation.

located in the Emilia Romagna region of Italy. Prior to analysis, records with abnormal calving interval (e.g., lower than 310 days or greater than 650 days), were deleted from the dataset. Moreover, herds with fewer than five cows were not included in the final dataset. Only cows that underwent linear scoring for BCS and MU during their first lactation were included, resulting in 2 173 cows.

Four calving seasons were considered. Cows of the current research calved across all the calendar months; in particular, 30.6% calved between December and February (Winter), 25.3% calved between March and May (Spring), 20.9% calved between June and August (Summer) and 23.2% calved between September and November (Autumn).

Additionally, the dataset included linear type trait scores, which were measured by trained personnel once during the lifetime of primiparous cows. Moreover, to obtain a standardized measure of milk production, allowing for more accurate comparison and analysis across different cows and herds, official data were used to calculate the energy corrected milk (**ECM**) values using the formula from the Dairy Records Management Systems (2006), considering the daily milk produced and the solid content.

Because cows are linearly classified only once as primiparous - within the first lactation - MU and BCS difference among animals are also dependent on the stage of lactation. To overcome this issue, individual lactation curves of both MU and BCS were generated following the methodology in Buonaiuto et al. (2022). The methodology used allowed to have a prediction of MU and BCS at each DIM for each animal in order that differences in these traits, among animals, become independent from the stage of lactation (within DIM). Following Buonaiuto et al. (2022), MU and BCS predicted at a given time point (Fig. 2) were retained for comparative purposes. These time points represented specific moments of MU and BCS variation in the studied population, such as (i) the onset and end of lactation, (ii) the nadir of MU and BCS, (iii) the maximum recovery of MU and BCS, and (iv) the beginning of MU and BCS recovery in late lactation.

Survival analysis

The cow's ability to stay in the herd, i.e., to close a lactation and start the subsequent one (Hardie et al., 2021), was the definition used to define SURV traits (Fig. 3). In this study, SURV, in binary form, was calculated for each cow-lactation up to parity 6, based on the presence (1 = survived) or absence (0 = departed) of the subsequent calving date as graphically depicted in Fig. 3. Overall, the following five variables were available: $SURV_2$, $SURV_3$, $SURV_4$, $SURV_5$, and $SURV_6$.

The Pearson correlation coefficients among continuous variables (ECM, MU, and BCS) were calculated using the PROC CORR (SAS Institute Inc.). Point-biserial correlation was used to estimate correlations between binary and continuous variables, and the Jaccard-Needham correlation (Zhang and Srihari, 2003) was employed to calculate correlations between binary variables.

Traits with a continuous distribution (ECM, MU and BCS) were transformed into categorical variables, with three classes based on tertile distribution (low third, medium third and high third). The Cox regression model (Cox, 1972) was used to assess the effect of the independent variables on dairy cows' survival, accounting for censored cases (i.e, animals starting their sixth lactation) using the PROC PHREG procedure of SAS v.9.4 (SAS Institute Inc., Cary, NC). Pairwise combinations of different effects were created to obtain estimates for all the levels; e.g., for the interaction between

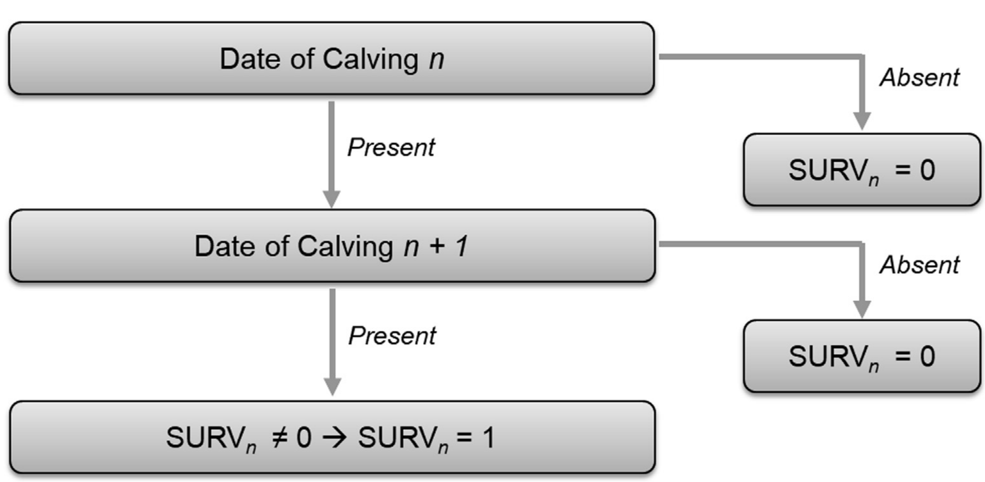

Fig. 3. Flow for the definition of the cows' survival rate (SURV) at each parity (n).

calving season and ECM class, the following 12 combinations were created: autumn – low ECM, autumn – medium ECM, autumn – high ECM, winter – low ECM, winter – medium ECM, winter – high ECM, spring – low ECM, spring – medium ECM, spring – high ECM, summer – low ECM, summer – medium ECM, and summer – high ECM. Similarly, combinations of ECM classes and BCS classes as well as ECM classes and MU classes were created to be included in the model as follows:

$$h(t)_{ij} = h_0(t) \times e^{b_1 * COMBINATION_i + b_2 * HY_j}$$

where $h(t)$ represents the hazard rate depending on time (t), hereby the cows' parity; b_1 is the logistic regression coefficient to measure the effect of one of the following i^{th} combinations: ECM-BCS class, ECM-MU class, or ECM-season; and b_2 is the logistic regression coefficient to measure the effect of the j^{th} herd-year (HY) in which the cow had the first calving.

The proportional hazard assumption of time dependency was assessed by visual examination of the scaled Schoenfeld residuals plotted against time to event (Schoenfeld, 1982). In a model adhering to the hazards assumption, the Schoenfeld residuals should exhibit dispersion around 0.

The survival functions were obtained by mean of the PLOT option available in the PROC PHREG and were used to generate Kaplan-Meier survival curves (Kaplan and Meier, 1958) to display the amount of culled animals at each parity under different conditions (calving season, ECM level, etc.). Survival functions were developed separately for BCS and MU of cows in five specific moments of their first lactation; more details about these time points can be retrieved in Buonaiuto et al. (2022).

Results

Survival rates overview

The descriptive statistics of the cows involved in the present research are reported in Table 1. The milk yield and ECM averaged 6 907.58 ± 2 148.50 kg and 7 546.26 ± 2 272.39 kg, respectively, and fat percentage ranged from 2.58 to 5.30%, with an average of 3.84% and SD of 0.40. For protein percentage, mean and SD were 3.53 and 0.22%. The average MU predicted at different time points ranged from 79.60 at 85 DIM to 80.94 at 280 DIM. The average BCS of the cows, instead, had a minimum (3.44) at 45 DIM and a maximum (3.58) at 280 DIM.

The correlation coefficients between SURV and other traits (ECM, MU, and BCS) are presented in Table 2. There was a moderate to high association observed between MU and BCS at different time points; overall, the correlation between them was 0.50 at 5 and 85 DIM, 0.51 at 180 and 280 DIM, and 0.52 in late lactation (360 DIM). On the other hand, the correlation coefficients calculated between SURV and other traits were mostly negative, with weak or moderate magnitude. For example, the correlation with ECM varied from −0.03 (for $SURV_2$) to −0.12 for $SURV_5$.

Regarding MU and BCS, weak correlations (<0.10) were observed with ECM.

Fig. 4 provides an overview of the SURV of Simmental cows examined in this study. The percentage of primiparous cows with the morphological evaluation available that survived up to the second ($SURV_2$ = 1), third ($SURV_3$ = 1), fourth ($SURV_4$ = 1), fifth ($SURV_5$ = 1), and sixth ($SURV_6$ = 1) lactation was 98% (2 136 cows), 71% (1 512 cows), 63% (953 cows), 56% (538 cows), and 53% (285 cows), respectively. It is important to take into account that, for the specific purpose of this study, cows must have MU and BCS available. In other words, the primiparous cows had to be morphologically evaluated to be involved in the study; in Italian Simmental, this is conducted by trained experts during the first lactation, including mid- to late stages. Consequently, the survival results presented in this research, particularly for $SURV_2$, may differ from population statistics due to the exclusion of primiparous cows that were culled before being linearly classified. Whether $SURV_2$ is calculated on all primiparous cows, even those without linear type traits, the proportion of cows surviving up to the second lactation ($SURV_2$ = 1) would decrease from 98 to 86% (data not showed).

Kaplan-Meier curves

The time-dependency assumption of the Cox models was estimated, and the scaled Schoenfeld residuals were plotted (Schoenfeld, 1982). As expected, we observed no discernible association between the residuals and time to event. The Kaplan-Meier curves illustrating the survival *P* of cows are presented in Fig. 5 for MU at different time points and Fig. 6 for BCS at different time points. Having considered the correlations given in Table 2, confidence intervals are presented for MU (Table 3) and BCS (Table 4) of cows at five different time points during the first lactation (DIM5, DIM85, DIM180, DIM280 and DIM360). It is generally observed that the survival *P* at parity 1 was consistently high, surpassing 98%, regardless of the ECM level. When considering the MU trait, cows with medium MU conditions and lower milk production

Table 1
Descriptive statistics of primiparous cows' lactation-based milk performance and type traits[1] at different time points[2].

Trait	N	Mean	SD	Minimum	Maximum
Milk yield, kg	2 173	6 907.58	2 148.50	149	14 754
Fat, %	2 140	3.84	0.40	2.58	5.30
Protein, %	2 154	3.53	0.22	2.85	4.33
Energy corrected milk, kg	2 142	7 546.26	2 272.39	993.78	15 376.65
MU_5	2 173	80.45	1.28	76.12	285.19
MU_{85}	2 173	79.60	1.24	75.42	84.34
MU_{180}	2 173	80.24	1.22	76.23	85.03
MU_{280}	2 173	80.94	1.23	77.12	85.79
MU_{360}	2 173	80.14	1.26	76.31	85.03
BCS_5	2 173	3.45	0.12	2.86	3.93
BCS_{45}	2 173	3.44	0.12	2.86	3.91
BCS_{160}	2 173	3.50	0.12	2.99	4.00
BCS_{280}	2 173	3.58	0.12	3.12	4.15
BCS_{360}	2 173	3.53	0.12	3.07	4.17

[1] Muscularity (MU) and body condition score (BCS) in first lactation of each cow obtained through regression models in Buonaiuto et al. (2022) for Simmental cows; see Fig. 2.
[2] As reported in Fig. 2, time points identified by Buonaiuto et al. (2022) for MU correspond to: A = onset of lactation (5 days in milk); B = nadir of muscle reserves loss (85 days in milk); C = maximum recovery of muscle (180 days in milk); D = start of reduction in muscle (280 days in milk); E = end of lactation (360 days in milk).

Table 2
Phenotypic correlations[1] between cows' energy-corrected milk (ECM, kg), survival rates[2], and type traits[3].

Trait	ECM	$SURV_2$	$SURV_3$	$SURV_4$	$SURV_5$	$SURV_6$	MU_5	MU_{85}	MU_{180}	MU_{280}	MU_{360}	BCS_5	BCS_{45}	BCS_{160}	BCS_{280}
$SURV_2$	−0.03														
$SURV_3$	−0.08	0.71													
$SURV_4$	−0.12	0.45	0.63												
$SURV_5$	−0.12	0.25	0.36	0.56											
$SURV_6$	−0.10	0.13	0.19	0.30	0.53										
MU_5	0.08	−0.02	−0.06	0.00	0.00	−0.03									
MU_{85}	0.09	−0.02	−0.06	0.00	−0.01	−0.04	0.99								
MU_{180}	0.10	−0.02	−0.06	−0.01	−0.01	−0.04	0.97	0.99							
MU_{280}	0.10	−0.02	−0.06	−0.01	−0.01	−0.05	0.91	0.96	0.99						
MU_{360}	0.11	−0.02	−0.06	−0.02	−0.01	−0.05	0.86	0.91	0.96	0.99					
BCS_5	0.04	0.00	−0.02	0.01	−0.01	−0.03	0.50	0.50	0.49	0.47	0.45				
BCS_{45}	0.04	0.00	−0.02	0.01	−0.01	−0.03	0.50	0.50	0.50	0.48	0.46	1.00			
BCS_{160}	0.05	0.00	−0.03	0.01	−0.01	−0.03	0.48	0.50	0.51	0.50	0.49	0.98	0.99		
BCS_{280}	0.05	0.00	−0.03	0.00	−0.01	−0.04	0.46	0.48	0.50	0.51	0.51	0.94	0.96	0.99	
BCS_{360}	0.06	0.00	−0.04	0.00	−0.01	−0.04	0.44	0.47	0.50	0.51	0.52	0.91	0.93	0.97	1.00

[1] Pearson's correlation coefficients were employed for continuous variables (ECM, MU, and BCS); point-biserial correlations were used for binary and continuous variables; Jaccard-Needham correlations (Zhang and Srihari, 2003) were used for binary variables.
[2] $SURV_2$: second lactation achieved (1) or not (0); $SURV_3$: third lactation achieved (1) or not (0); $SURV_4$: fourth lactation achieved (1) or not (0); $SURV_5$: fifth lactation achieved (1) or not (0); $SURV_6$: sixth lactation achieved (1) or not (0).
[3] Muscularity (MU) and body condition score (BCS) in first lactation of each cow obtained through regression models in Buonaiuto et al. (2022) for Simmental cows; see Fig. 2.

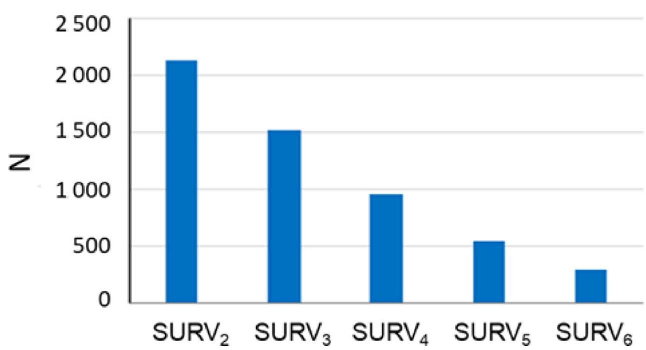

Fig. 4. Number of cows for each survival rate[1] ($SURV_n$). [1]Ability to complete lactation 'n' and start the subsequent one, e.g., to complete first and start the second lactation for $SURV_2$.

tend to exhibit a higher *P* of survival at all the different parities analyzed in the study, with an average increase of more than 2%, compared to cows with low and high ECM levels (Fig. 5). However, the survival *P* varied across different parities. For example, at parity 5, cows with medium MU condition and medium ECM level had a lower *P* of survival (32.48%) compared to cows with high ECM (37.74%). At parity 6, cows with medium MU condition at 280 DIM had a survival *P* of 21.14% compared to 19.85% and 18.56% for low and high ECM levels, respectively.

In terms of BCS (Fig. 6), the survival *P* followed a distinct pattern compared to MU. Generally, at 5 and 160 DIM, cows with medium BCS and lower production levels had a lower survival *P* (e.g., at parity 5: 30.89% at 5 DIM) compared to cows with medium (e.g., at parity 5: 31.66% at 5 DIM) and high (e.g., at parity 4: 32.11% at 5 DIM) ECM levels. Conversely, during the other time points (45, 280, and 360 DIM), cows with low ECM levels exhibited a higher survival *P* (e.g., at parity 4: 51.96% at 360 DIM) compared to cows with medium (e.g., at parity 4: 50.07% at 360 DIM) and high (e.g., at parity 4: 51.44% at 360 DIM) milk production.

Fig. 7 illustrates the survival *P* curves of cows according to the season of first calving for each level of ECM. The confidence intervals of estimates given in Table 5 allow for a comparison of seasons. Considering different combinations of season and ECM

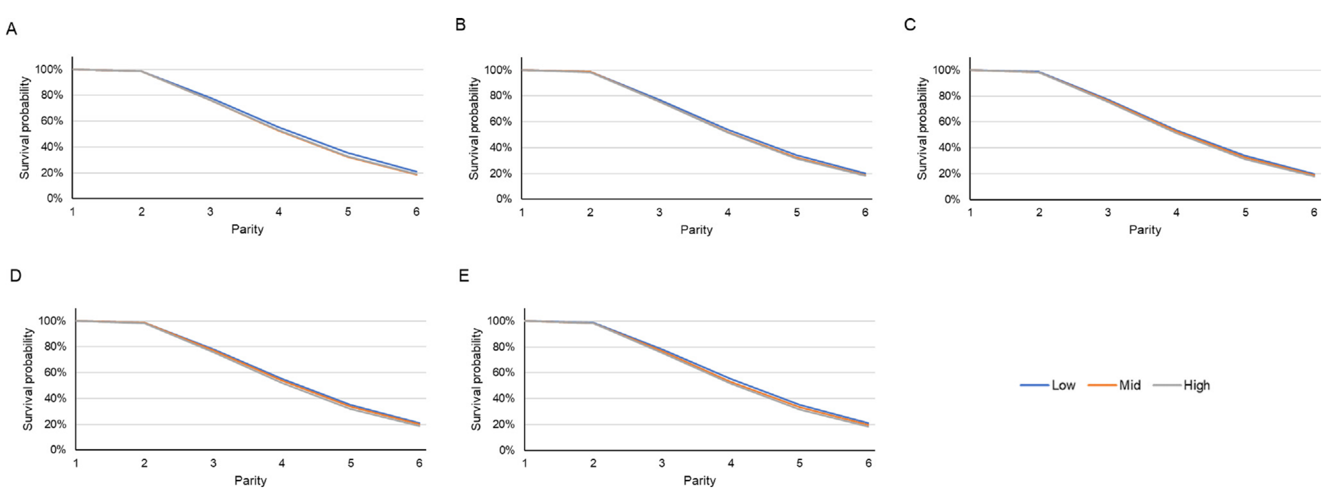

Fig. 5. Kaplan–Meier curves[1] of survival *P* at different ECM[2] levels for cows with muscularity (MU) measured at five different time points[3] during the first lactation. [1]Confidence interval (95%), as reported in Table 3. [2]Three levels - low, medium and high – of energy-corrected milk (ECM, kg) were considered. [3]As reported in Fig. 2, time points identified by Buonaiuto et al. (2022) for MU correspond to: A = onset of lactation (5 days in milk); B = nadir of muscle reserves loss (85 days in milk); C = maximum recovery of muscle (180 days in milk); D = start of reduction in muscle (280 days in milk); E = end of lactation (360 days in milk).

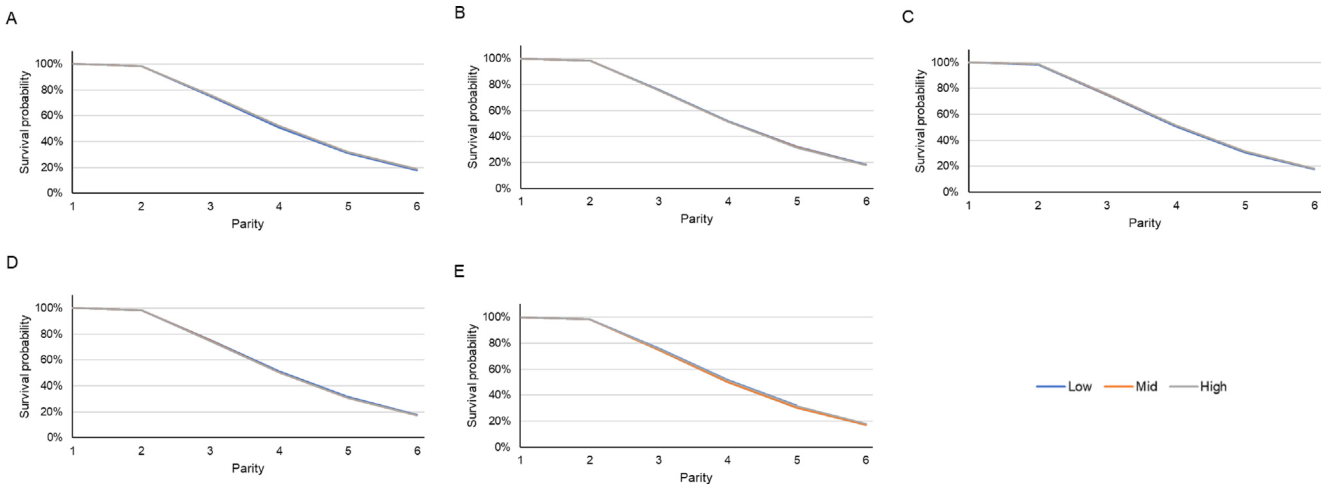

Fig. 6. Kaplan–Meier curves[1] of survival *P* at different ECM[2] levels for cows with body condition score (BCS) measured at five different time points[3] during the first lactation. [1]Confidence interval (95%), as reported in Table 4. [2]Three levels - low, medium and high - of energy-corrected milk (ECM, kg) were considered. [3]As reported in Fig. 2, time points identified by Buonaiuto et al. (2022) for BCS correspond to: A = onset of lactation (5 days in milk); B = nadir of fat reserves losses (45 days in milk); C = maximum recovery of fat reserves (160 days in milk); D = start of reduction in fat reserves (280 days in milk); E = end of lactation (360 days in milk).

Table 3
Confidence interval (95%) of hazard ratios in Fig. 5 estimated through culling age[1] for cows with different levels of energy-corrected milk (ECM) and muscularity (MU) at given time points[2].

ECM class	Time point				
	MU_5	MU_{85}	MU_{180}	MU_{280}	MU_{360}
Low					
Parity 2	(0.981;0.991)	(0.981;0.991)	(0.980;0.991)	(0.982;0.991)	(0.982;0.991)
Parity 3	(0.717;0.817)	(0.738;0.809)	(0.736;0.807)	(0.749;0.816)	(0.749;0.815)
Parity 4	(0.503;0.608)	(0.492;0.594)	(0.488;0.591)	(0.506;0.605)	(0.507;0.604)
Parity 5	(0.304;0.410)	(0.293;0.395)	(0.290;0.392)	(0.307;0.407)	(0.308;0.406)
Parity 6	(0.173;0.259)	(0.164;0.246)	(0.162;0.244)	(0.174;0.256)	(0.175;0.256)
Medium					
Parity 2	(0.980;0.990)	(0.980;0.990)	(0.980;0.990)	(0.981;0.990)	(0.980;0.990)
Parity 3	(0.731;0.795)	(0.727;0.795)	(0.729;0.796)	(0.726;0.796)	(0.735;0.802)
Parity 4	(0.481;0.572)	(0.477;0.572)	(0.479;0.573)	(0.474;0.573)	(0.487;0.583)
Parity 5	(0.283;0.373)	(0.279;0.372)	(0.282;0.374)	(0.276;0.374)	(0.288;0.384)
Parity 6	(0.156;0.228)	(0.153;0.227)	(0.155;0.228)	(0.150;0.229)	(0.160;0.237)
High					
Parity 2	(0.980;0.990)	(0.979;0.990)	(0.979;0.990)	(0.979;0.990)	(0.979;0.990)
Parity 3	0.731;0.798)	(0.724;0.791)	(0.720;0.789)	(0.726;0.796)	(0.721;0.792)
Parity 4	(0.482;0.577)	(0.471;0.566)	(0.465;0.563)	(0.474;0.573)	(0.467;0.568)
Parity 5	(0.283;0.379)	(0.273;0.367)	(0.268;0.363)	(0.276;0.374)	(0.270;0.368)
Parity 6	(0.156;0.233)	(0.149;0.224)	(0.145;0.220)	(0.150;0.229)	(0.146;0.224)

[1] Obtained from survival rates, here defined as the ability of a cow to complete a lactation and start the subsequent.
[2] As reported in Fig. 2, time points identified by Buonaiuto et al. (2022) for MU correspond to: A = onset of lactation (5 days in milk); B = nadir of muscle reserves loss (85 days in milk); C = maximum recovery of muscle (180 days in milk); D = start of reduction in muscle (280 days in milk); E = end of lactation (360 days in milk).

class, low- and high- producing cows presented similar $SURV_5$ in all the seasons (data not shown), whereas cows with intermediate ECM were less likely to survive if they calved for the first time in autumn (Fig. 7), suggesting presence of a carryover effect throughout the lifetime. As depicted in Fig. 7, $SURV_5$ of medium-ECM cows was significantly lower in autumn (16%; with a 95% confidence interval delimited by 12.3 and 20.9%). Similarly, $SURV_4$ in cows with medium ECM level was significantly lower when the lactation started in autumn (24.1%) compared to other seasons, namely summer (33.2%), spring (33.4%), and winter (36.6%). The 95% confidence intervals were, in fact, equal to 19.7–29.6% (autumn), 28.4–39.2% (spring), 28.2–39.1% (summer), and 31.9–42.0% (winter; Table 5).

Discussion

Descriptive statistics and phenotypic correlations

With 246 023 cows and 1 659 herds officially registered in 2022, Emilia Romagna is the first Italian region for a number of dairy cows after Lombardia (AIA, 2023). The Simmental cows involved in the present investigation were characterized by slightly greater milk productivity (Table 1) if compared to the national Simmental breed performance (AIA, 2023). The average milk production reported in the present research is greater compared to the results reported by other authors (e.g., Karamfilov and Nikolov, 2019; Sahin et al., 2023) for Simmental cows farmed

Table 4
Confidence interval (95%) of hazard ratios in Fig. 6 estimated through culling age[1] for cows with different levels of energy-corrected milk (ECM) and body condition score (BCS) at given time points[2].

ECM class	Time point				
	BCS_5	BCS_{45}	BCS_{160}	BCS_{280}	BCS_{360}
Low					
Parity 2	(0.978;0.990)	(0.979;0.990)	(0.978;0.990)	(0.979;0.990)	(0.979;0.990)
Parity 3	(0.714;0.790)	(0.722;0.797)	(0.711;0.790)	(0.716;0.795)	(0.721;0.799)
Parity 4	(0.458;0.564)	(0.468;0.576)	(0.454;0.564)	(0.461;0.572)	(0.467;0.578)
Parity 5	(0.262;0.364)	(0.272;0.377)	(0.259;0.364)	(0.265;0.372)	(0.271;0.379)
Parity 6	(0.142;0.220)	(0.149;0.231)	(0.139;0.220)	(0.143;0.227)	(0.147;0.232)
Medium					
Parity 2	(0.979;0.990)	(0.979;0.990)	(0.979;0.990)	(0.978;0.989)	(0.978;0.989)
Parity 3	(0.722;0.791)	(0.723;0.791)	(0.721;0.790)	(0.713;0.784)	(0.711;0.782)
Parity 4	(0.471;0.566)	(0.470;0.565)	(0.468;0.563)	(0.457;0.554)	(0.455;0.552)
Parity 5	(0.274;0.366)	(0.273;0.365)	(0.271;0.364)	(0.262;0.355)	(0.259;0.352)
Parity 6	(0.150;0.223)	(0.149;0.222)	(0.148;0.221)	(0.141;0.213)	(0.139;0.211)
High					
Parity 2	(0.979;0.990)	(0.979;0.990)	(0.979;0.990)	(0.978;0.989)	(0.979;0.990)
Parity 3	0.726;0.795)	(0.721;0.790)	(0.722;0.792)	(0.712;0.784)	(0.721;0.791)
Parity 4	(0.474;0.571)	(0.467;0.565)	(0.469;0.567)	(0.456;0.554)	(0.468;0.566)
Parity 5	(0.276;0.373)	(0.270;0.366)	(0.272;0.368)	(0.260;0.355)	(0.271;0.367)
Parity 6	(0.151;0.229)	(0.147;0.223)	(0.148;0.225)	(0.140;0.214)	(0.147;0.223)

[1] Obtained from survival rates, here defined as the ability of a cow to complete a lactation and start the subsequent.
[2] As reported in Fig. 2, time points identified by Buonaiuto et al. (2022) for BCS correspond to: A = onset of lactation (5 days in milk); B = nadir of fat reserves losses (45 days in milk); C = maximum recovery of fat reserves (160 days in milk); D = start of reduction in fat reserves (280 days in milk); E = end of lactation (360 days in milk).

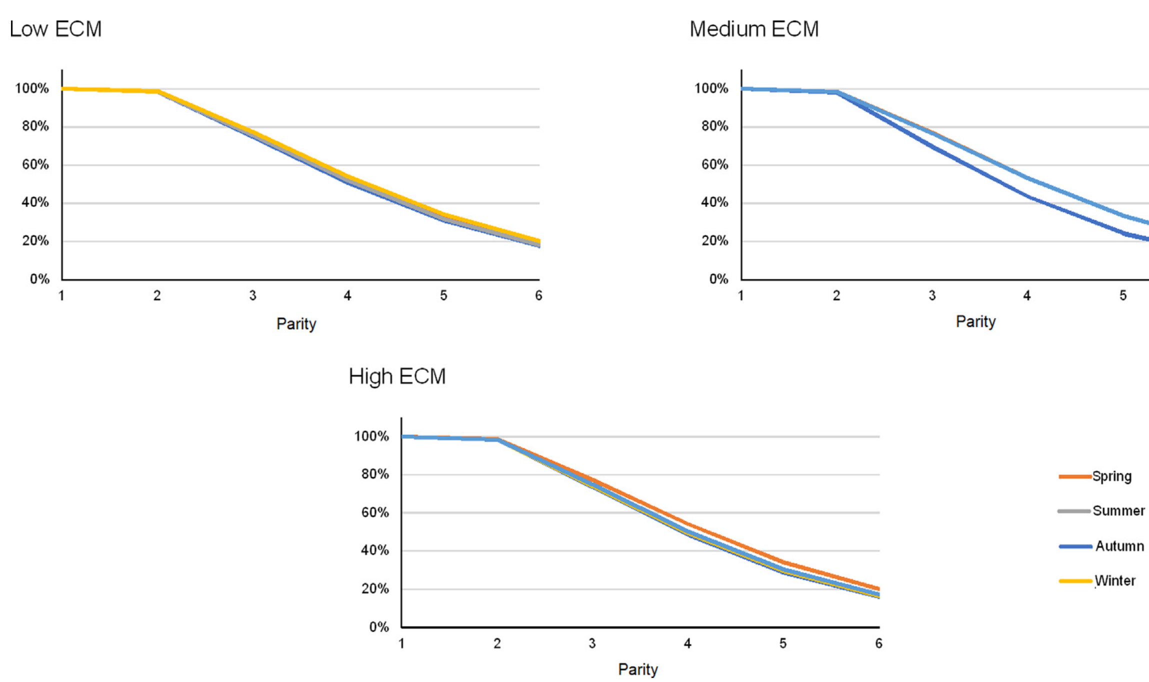

Fig. 7. Kaplan–Meier curves[1] of cows' survival *P* at different productivity[2] level and calving season[3]. [1]Confidence interval (95%), as reported in Table 5. [2]Three levels - low, medium and high - of energy-corrected milk (ECM, kg) were considered. [3]Season and ECM refer to cows' first lactation.

in different European countries. In addition to productivity, the population under observation was characterized by higher milk fat and protein yields than those production levels reported by Gerber et al. (2008) in Simmental cattle reared in Bavaria. Fat and protein percentages observed in the present research were consistent with those previously reported by Perišić et al. (2009). All the aforementioned differences may be related to the various management systems adopted for dairy cattle farming. Indeed, in Emilia Romagna, dairy cows are usually kept indoors in free stall barns, according to intensive farming conditions, i.e., with total mixed ratio administration using high-quality forages and concentrates (Buonaiuto et al., 2021; Cavallini et al., 2023) and environmental microclimate control systems (Bovo et al., 2020). In other European countries, including those previously mentioned, Simmentals cows tend to be reared in extensive or semi-extensive systems with access to grazing pasture (Perišić et al., 2009).

Comparing the descriptive statistics of MU observed in the present research is challenging because the data reported in the literature refer to different evaluation scales (e.g., Frigo et al., 2013). This discrepancy is due to a methodological update in the evaluation of Simmental cattle, where MU condition is no longer assessed on a scale from 1 to 9, but rather on a scale from 68 to 93, as reported by Buonaiuto et al. (2022). The BCS observed in the present research is consistent with that observed by Frigo et al.

Table 5
Confidence interval (95%) of hazard ratios[1] in Fig. 7 estimated through culling age[2] for cows with different levels[3] of energy-corrected milk (ECM) and with different calving seasons[3].

ECM class	Spring	Summer	Autumn	Winter
Low				
Parity 2	(0.981;0.991)	(0.979;0.991)	(0.978;0.990)	(0.981;0.991)
Parity 3	(0.708;0.796)	(0.716;0.803)	(0.708;0.796)	(0.734;0.814)
Parity 4	(0.450;0.573)	(0.461;0.585)	(0.450;0.573)	(0.485;0.603)
Parity 5	(0.255;0.373)	(0.264;0.386)	(0.255;0.373)	(0.286;0.406)
Parity 6	(0.136;0.226)	(0.142;0.238)	(0.136;0.226)	(0.158;0.255)
Medium				
Parity 2	(0.980;0.991)	(0.980;0.991)	(0.972;0.987)	(0.983;0.992)*
Parity 3	(0.732;0.806)	(0.731;0.805)	(0.652;0.744)	(0.757;0.822)*
Parity 4	(0.483;0.590)	(0.481;0.588)	(0.381;0.496)	(0.519;0.616)*
Parity 5	(0.284;0.392)	(0.282;0.391)	(0.197;0.296)	(0.319;0.420)*
Parity 6	(0.157;0.243)	(0.155;0.242)	(0.097;0.166)	(0.183;0.268)*
High				
Parity 2	(0.981;0.991)	(0.978;0.990)	(0.978;0.989)	(0.979;0.990)
Parity 3	(0.737;0.810)	(0.703;0.794)	(0.706;0.776)	(0.726;0.796)
Parity 4	(0.489;0.597)	(0.443;0.571)	(0.448;0.543)	(0.474;0.573)
Parity 5	(0.290;0.400)	(0.248;0.372)	(0.253;0.344)	(0.276;0.374)
Parity 6	(0.160;0.251)	(0.130;0.226)	(0.133;0.204)	(0.150;0.229)

[1] Significant ($P < 0.05$) interaction between ECM class medium and winter is indicated with the asterisk.
[2] Obtained from survival rates, here defined as the ability of a cow to complete a lactation and start the subsequent.
[3] Season and ECM refer to first lactation.

(2013) in Simmental breed that report a mean BCS of 3.49. These results suggest that these cows are generally less prone to a reduction of BCS, and therefore subcutaneous adipose tissue, through lactation.

The official annual report of the Association of Austrian Fleckvieh breeders (AGÖF, 2021) states that the average number of calvings for Austrian Fleckvieh-Simmental is 3.83, while the estimated average productive life is 3.66 years. Strapák et al. (2010) reported a similar average productive life of 3.88 years (representing approximately 3.4–3.6 lactations) for Slovak Simmental dairy cows under favorable reproduction conditions. In comparison, the SURV values observed in the present study were higher than the mean rates of dairy cows reported by Pipino et al. (2023) for purebred Holstein cows in commercial dairy farms of Argentina. They reported SURV values of 89, 72, and 51% for parities two through four, respectively. Hardie et al. (2021) report that 84 and 80% of Holstein cows in US organic herds starting parity 1 and parity 2, respectively, were able to continue to the subsequent parity. Very similar SURV values to those reported in the present research (e.g., $SURV_3$ of 74%) were observed by Sölkner (1989) in Austrian Simmental dual-purpose cows and by Jamrozik et al. (2013) for Simmental dual-purpose cows. Moreover, according to that reported by Strapák et al. (2010), 58% of the Slovak Simmental dairy cows reach 36 months of age, and 31% reach 72 months of age. Overall, Simmental, and in general dual-purpose cows, had a greater lifespan compared to specialized dairy breeds like Holstein due to greater rusticity and resistance to diseases/disorders and stressors (Nieuwhof et al., 1989; Hare et al., 2006; Costa et al., 2019c). Additional information regarding the Italian Simmental selection scheme, size, and productivity performance can be found in Supplementary Material S1.

Survival curves

The Kaplan–Meier curves with survival *P* are presented in Fig. 5 (for MU) and Fig. 6 (for BCS). In this study, cows with low ECM levels and medium MU have the highest SURV compared to high-producing ones (Tables 3 and 4; Figs. 5 and 6). The reasons that could explain differences between SURV in early and late lactation may be linked to the metabolic stress experienced by high-producing cows in early lactation (Putman et al., 2018; Lean et al., 2023a; 2023b). van der Drift et al. (2012) reported that, especially during the peripartum period, the most productive dairy cows are more exposed to diseases, risk of severe negative energy balance, and reduction of immune competence (Costa et al., 2019a; Benedet et al., 2020). During these periods, dairy cows (in particular the high-producing ones) cannot fulfill energy deficits by increasing their feed intake (Harvatine and Allen, 2005). This condition promotes the mobilization of the animal's body reserves (such as fat and muscle tissue), prompting gluconeogenetic processes and diminishing glucose assimilation by non-mammary tissues (Accorsi et al., 2005). The depletion of body tissue starts right after calving (van der Drift et al., 2012; Schäff et al., 2013), with the most noticeable losses in the first period of lactation. This pattern was observed by several authors (Gallo et al., 1996; Gärtner et al., 2019; Walter et al., 2022) and arises because of homeorhesis-induced high mobilization of body reserves for milk production, especially in high-producing cows (Costa et al., 2019b). This is even worse in primiparous, as growing requirements must be considered in addition to gestation and maintenance. The findings reported by Ryder et al. (2023) support the observations made in the current study. In particular, these authors found that extensive muscle loss after calving is associated with suboptimal fertility irrespective of changes in BCS. In addition, the best fertility (e.g., start of luteal activity and estrous identification) was found in cows with very small muscle loss and increased body condition (Ryder et al., 2023). It has been demonstrated that cows that are able to start the second lactation with optimal morphological condition exhibit good performance and show increased resilience against metabolic and infectious disorders (Ingvartsen and Moyes, 2015; Wang et al., 2019; Siurana et al., 2023), particularly during the transition period. This period, which encompasses 3 weeks before and after calving (Wankhade et al., 2017), is characterized by notable shifts in metabolic equilibrium and is often characterized by several environmental stressors such as group change and diet change (Mezzetti and Trevisi, 2023). According to Lean et al. (2023b), older cows have greater culling risk due to the increased incidence of undesired events like clinical hypocalcemia, mastitis, and lameness.

Our investigation results report that also the calving season could affect the dairy cows' survival and thereby longevity (Fig. 7; Table 5). Indeed, heifers starting their productive period in autumn resulted in the worst in terms of SURV. Overall, the significantly higher *P* to have a shorter productive life compared to animals that started their milk production in other seasons can be attributed to the heat load and stress in the last months of gestation, which occurred during the warmer months. This is especially evident in Southern Europe, where cows are often exposed to temperature-humidity index out of the comfort range (Schär et al., 2004, Morabito et al., 2017; Moore et al., 2023). As reported by Pinedo and De Vries (2017) for Holstein cows and by Macciotta et al. (2023) for SI, cows conceived in winter exhibited better subsequent fertility, productive performance, and survival compared to cows conceived in summer. Environmental heat is a significant stressor that impairs cows' performance including milk quality and udder health (Zachut et al., 2017; Tao et al., 2020; Moore et al., 2023). Moreover, lactating dairy cows experiencing thermal stress often exhibit decreased feed intake (Garner et al., 2022), altered metabolism (Cartwright et al., 2023), increased susceptibility to diseases (Dahl et al., 2020), and impaired reproductive performance (Dash et al., 2016). In cattle, physiological mechanisms induce animals to reduce DM intake (Baumgard and Rhoads, 2012). This supports more rational management of reproductive and productive performance and the application of preventive measures to increase production and prevent disadvantageous phenomena.

In general, identifying factors affecting cow's survival is crucial for enhancing dairy herd profitability and sustainability (Hu et al., 2021). In specialized dairy breeds like Holstein, a long and productive life is economically advantageous because the cost of raising heifers can be spread over increased milk and solids yields. The culling date in those breeds - more than in dual-purpose - is therefore representing very well the longevity of a cow and may be used to calculate the overall length of productive life. In the herd, a high SURV permits to increase the productivity due to a greater presence of multiparous animals which have more production capacity compared with primiparous cows. On the other hand, small replacement rates lead to slow genetic progress in the herd.

In the case of crossbred or dual-purpose breeds, calves' and old cows' price can be 3–4 times higher compared to pure specialized dairy breeds. Using auction data, Dal Zotto et al. (2009) observed that Simmental calves showed greater price (> $6/kg) and market value ($426.97/calf) than dairy-specialized breeds. For example, in 2012, the average market value of Brown Swiss calves was estimated to be €145.5/calf (Penasa et al., 2012).

The findings of this study as a whole suggest that the culling date is not a good indicator of longevity in dual-purpose breeds like Simmental, as the mature cows culling is related to a decrease/increase in meat market price/demand. Culling is therefore not only related to impaired dairy performances (milk yield, udder health, or fertility).

Conclusions

Data of Italian Simmental dual-purpose cows were used to model SURV according to calving season, productivity level (ECM), and morphological characteristics (BCS and MU). Results suggest that i) cows' longevity can be potentially affected by ECM regardless of the body conformation traits and ii) cows undergoing the dry period and the late gestation phase in summer (i.e. calving in autumn) generally have a lower SURV throughout the productive life than the others.

A better understanding of factors affecting SURV in dual-purpose cows is advisable to correctly evaluate the longevity of cows. In fact, - regardless of the quantity of milk they produce - cows with higher MU are likely to be sold earlier due to favourable meat-related characteristics. When dealing with dual-purpose breed, the farmer's profit partly derives from animals culled for meat production. In the Italian Simmental breed, SURV does not strictly depend on milk-related performance as in highly specialized dairy breeds. Since the cows' morphology and the expected carcass value have a significant impact on the farmer's culling decision, it becomes difficult to provide a genetic evaluation for functional longevity and SURV that accounts for voluntary culling in this breed. The availability of detailed culling reasons data could represent a good starting point to select against unvoluntary culling of Italian Simmental lactating cows.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2024.101128.

Ethics approval

Not applicable.

Data and model availability statement

Data used in the present study are confidential and were not deposited in official repositories. The archive is available upon request from the corresponding author.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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Declaration of interests

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.

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