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Survival analysis of productive life in Florida dairy goats using a Cox proportional hazards model

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Abstract

Longevity is an economically important trait, since extending the functional life of a doe would allow us to keep the most productive females in the herd as long as possible, and this could result in the increased profitability of dairy farms. Thus, the objectives of this study were to determine the most important factors that influence the length of productive life (LPL) of female Florida goats and to estimate its genetic additive variance using a Cox proportional hazards model. The data consisted of 70,695 productive life records from 25,722 Florida females kidding between 2006 and 2020. A total of 19,495 does had completed their productive life while 6227 (24.2%) does had censored information. The pedigree contained information on 56,901 animals. The average censoring age and average failure age after first kidding for LPL were 36 and 47 months respectively. The model included, as time-independent effects, the age at first kidding and the interaction between herd, year and season of birth of the doe, and as time-dependent effects, the age at kidding, the interaction between herd, year and season of kidding, the within-herd class of milk production deviation, and the interaction between the lactation number and the stage of lactation. All fixed effects had a significant effect on LPL ($p < 0.05$). Does with older ages at the first kidding and an earlier age at kidding were at higher risk of being culled. A large difference among herds was observed in terms of culling risk, which highlighted the importance of adequate management practices. Also, high-producing does were less likely to be culled. The estimate of the additive genetic variance was 1.844 (in genetic standard deviation), with a heritability estimate of 0.58 ± 0.012. The results of this study are expected to contribute to the development of a genetic model for genetic evaluation of the length of the productive life of Spanish dairy goat breeds.

KEYWORDS

Cox model, dairy goat, genetic parameters, productive life

1 | INTRODUCTION

Nowadays, the breeding programmes for Spanish dairy goats are generally focused on improving milk production and milk composition traits (Menéndez-Buxadera et al., 2010; Molina et al., 2018), or somatic cell score (Jimenez-Granado et al., 2022), on morphological, and more recently, reproductive traits (Ziadi, Muñoz-Mejías, Sánchez, et al., 2021; Ziadi, Muñoz-Mejías, Sánchez Rodríguez, et al., 2021). However, the undesirable consequences have been widely reported of selection for high milk production on the health and fertility of animals, which decreases longevity (Oltenacu & Broom, 2010). Nevertheless, up to now, no estimations of genetic parameters have been made available for traits related to female longevity in Spanish dairy goats. Longevity is an indirect global trait quantifying the productive lifespan of livestock, and taking it into consideration would help increase the profitability of dairy farming (Palhière et al., 2018; Pritchard et al., 2013). Longevity combines many traits related to the permanence of an animal in the herd (Tsuruta et al., 2005), as well as productivity and reproductive performance. A longer productive life of females such as dairy goats allows an older age structure and consequently, greater herd milk production, and it also reduces replacement costs (Castañeda-Bustos et al., 2017; Serradilla et al., 1997).

In dairy ruminants, two different definitions of longevity were proposed by Ducrocq et al. (1988): (i) true longevity, defined as the ability to avoid culling for all reasons, including culling due to milk production; and (ii) functional longevity, defined as the ability to delay involuntary culling (all culling reasons, except milk production). The use of functional longevity provides new information, more or less independent from production traits and then, more useful in breeding programmes (Kern et al., 2016).

Regarding the genetic evaluation of longevity, several approaches have been used, namely, linear, threshold, random regression and proportional hazards model (PH). However, it is generally assumed that the use of linear models in the genetic analysis of longevity traits is inadequate due to the violation of the normality assumptions (Lagakos, 1979). In the same way, random regression linear models, which are frequently used to analyse the length of productive life (LPL), cannot be fully considered, since censored data and the non-linearity of the factors cannot be satisfactorily dealt with (Caraviello et al., 2004). Survival analysis is considered the most relevant statistical approach for the genetic evaluation of longevity in cows (Olechnowicz et al., 2016). In goats, however, PH procedures are used to model the hazard function of a goat at time *t* derived from survival from first kidding to culling, death or censoring. One of the main advantages of PH over other methods of studying longevity is that they accommodate censored records and time-dependent covariates more suitably, and can handle the skewed distribution of longevity characteristics (Imbayarwo-Chikosi et al., 2017). The Cox proportional hazards model is a semi-parametric method which has been used to estimate genetic parameters of longevity traits in dairy cows (Zhao, 2013). This model is used to analyse the factors that affect the survival time without a clear benchmark risk rate function, which shows high statistical efficiency (Stokes, 2019).

Therefore, the current study aimed to identify the possible risk factors and to estimate genetic parameters for the length of productive life in the Florida dairy goat breed, as an example of a Spanish breed with a high level of intensification, using a survival analysis based on the Cox proportional hazards model.

2 | MATERIALS AND METHODS

2.1 | Data

Milk production records and genealogical information were available from the National Association of Florida Goat Breeders (ACRIFLOR). The Florida breed is raised under semi-extensive to intensive production systems. The description of the breed is available in the study by Rodríguez-Hernández et al. (2022). In the analysis, we included records on Florida females born between 2004 and 2018 with at least the first kidding occurring between 2006 and 2020. Female longevity was evaluated using the length of productive life (LPL), estimated as the number of days between the first kidding and the last known lactation end date or culling. Contemporary groups that had less than 10 records were removed from the analysis. Does younger than 12 or older than 24.6 months at first kidding and does whose kidding interval fell outside the range 5.7–17.1 months were also pruned out, as were females with an incomplete record (age at the first kidding unknown or some intermediate kidding not controlled). After data editing, the final data set consisted of 70,695 lactation records from 25,722 females belonging to 83 herds. Genetic links between herds were ensured by the use of artificial insemination and the sale of bucks. Censorship was considered for goats that are still alive or with incomplete information at the time of study. The does were classified as presenting records which were uncensored (for dead animals) or censored (for living animals). Right-censored data (24.2%) included animals alive at the time of the analysis.

The pedigree was traced back for as many generations as available in the breed herd book and 56,901 animals were included.

2.2 | Estimation of genetic parameters

A preliminary analysis by fitting a Weibull hazard survival model to determine the statistical significance of each of the fixed effects was performed using Likelihood ratio tests, all of which had a significant effect on LPL at a significance level of at least 0.05. The estimates of these fixed effects were expressed as culling risks, which were determined as the ratio between the risk of culling under a particular class of non-genetic factors and a specific reference class. The effects evaluated as time-independent effects were the age at first kidding, herd–year–season of birth of the doe and they were assumed to influence the whole productive life of the females. Time-dependent effects were the age at kidding, herd–year–season of kidding, within-herd class of milk production deviation and the combination of lactation number and stage of lactation.

The length of productive life of the does was evaluated by survival analysis, using a Cox's proportional hazards model (Cox, 1972). A piecewise distribution of the baseline hazard function was assumed to allow an accurate description of the cyclic pattern of the hazard over successive lactations. The Cox model can be described as follows:

$$\lambda(t) = \lambda_0(t)\exp\{\text{agefirst}_i + \text{birth\_herd} * \text{year} * \text{season}_j + \text{kidding\_herd} * \text{year} * \text{season}_k + \text{age}_l + \text{levelprod}_m + \text{lactation number} * \text{stage of lactation}_n + g_o\}$$

where $\lambda(t)$ is the hazard function of the doe t days after its first kidding, $\lambda_0(t)$ is the baseline hazard function t days after the most recent kidding, agefirst_i is the time-independent effect of the i age at first kidding (monthly intervals from 12 to 15; >15 to 19; >19 to 24); birth_herd*year*season_j is the time-independent effect of the j herd combined with the year and season of birth of the doe (667 classes); kidding_herd*year*season_k is the time-dependent effect of the k herd combined with the year and season of kidding (726 classes); age_l is the time-dependent effect of the l age at kidding (monthly intervals from 15 to 19; >19 to 24; >24 to 36; >36 to 48; >48 to 60; >60 mo); levelprod_m is the time-dependent effect of the m within-herd class of milk production deviation (four classes)—this effect was calculated as the annual deviation of milk production for each doe with respect to the average production of its herd; and lactation number*stage of lactation_n is the time-dependent effect of the n lactation number (1–6) combined with lactation stage (1–4), resulting in 20 baseline hazard functions according to this combined factor. Classes of lactation stage are defined empirically: 210d, 240d and 300d, and a piecewise baseline hazard function to model survival for each lactation number*stage of lactation group to obtain a better fit for the data; finally, g_o is the random additive genetic value of the o animal in the pedigree.

The analysis of length of productive life was carried out using the Survival Kit version 6 software (Mészáros et al., 2013). Given the non-linear nature of the models used in the survival analysis, there is no heritability definition equivalent to that from the linear models. The estimate of heritability was calculated using the following equation derived from Yazdi et al. (2002):

$$h^2 = \frac{\sigma_a^2}{\frac{1}{P} + \sigma_a^2}$$

where σ_a^2 = additive genetic variance and P = proportion of uncensored records.

The reliability R^2 for each estimated breeding value (EBV) was estimated as:

$$R^2 = 1 - \frac{pev}{\sigma_a^2}$$

where pev is the prediction error variance calculated as the square of the standard error for each EBV.

3 | RESULTS AND DISCUSSION

In the current study, we have genetically analysed the length of the productive life in the Florida goat, as a model of a Spanish breed with high level of intensification. Survival analysis was carried out using a Cox proportional hazards model.

Comparisons with other studies are difficult because of the scarcity of studies of longevity using a proportional hazards model in dairy goats and due to differences in the definition of longevity. In fact, few studies on longevity using a Cox model have been carried out until now in dairy goats (Ferreira et al., 2020). However, these authors only evaluated the influence of environment effects, together with morphometric and type traits (Ferreira et al., 2020) or milk solids (Gautam et al., 2017) on female culling, and no genetic parameters were estimated. Up to now, there have been no studies on the estimation of genetic parameters for productive life in Spanish dairy goats, or with a proportional hazards model, so the current study is the first one to fit these kinds of models.

Table 1 shows the distribution of censored and uncensored records for the length of productive life in the Florida breed. The proportion of right-censored

TABLE 1 Descriptive statistics of censoring and failure time (d) in the Florida breed.

Right censored records	6227 (24.21%)
Minimum censoring time	214
Maximum censoring time	4263
Average censoring time	1096.93
Uncensored records	19,495
Minimum failure time	240
Maximum failure time	4761
Average failure time	1445.55

TABLE 2 Likelihood ratio last test statement for LPL in the Florida breed survival analysis.

	CHI^2	Prob > CHI^2	R^2 Maddala
Age at first kidding	19.229	0.0001	0.4623
Herd–year–season of birth of the doe	1792.1	0.0000	0.4240
Age at kidding	14.861	0.0214	0.4624
Herd–year–season of lactation	3506.4	0.0000	0.3843
Within-herd class of milk production deviation	413.64	0.0000	0.4540
Lactation number*stage of lactation	245.17	0.0000	0.4576

Abbreviation: LPL, length of productive life.

records was quite low (24.2%), being smaller than that reported in New Zealand dairy goats (32.85%; Gautam et al., 2017) and greater than the value observed in the Saanen breed (19.52%; Ferreira et al., 2020). LPL ranged from 214 to 4761 days (7–156 months). Average censoring age and average failure age after first kidding for LPL were 1096.93 and 1445.55 days (36 and 47 months) respectively. Previous studies with different definitions of longevity in dairy goats estimated an average of 625 d for productive life at 72 months in US breeds (Castañeda-Bustos et al., 2017), 1726 d for length of true life in UK dairy goats (Geddes et al., 2018), 967 d for functional longevity in Saanen and 1007 d in Alpine (Palhière et al., 2018).

Female longevity is a highly significant trait in Florida goats, due to its high level of intensification in comparison with other Spanish breeds (e.g. Payoya). This breed is known for its high milk production, with an average milk yield of 611.4 ± 7.8 kg (ARCA, 2022) per lactation. In addition, extending the productive life of the does is highly advisable, as it enhances farm profit by producing a larger number of lactations. A previous study determined that only 52.7% of Florida females have more than six parities, compared with 78.6% in the Payoya breed (Ziadi, Muñoz-Mejías, Sánchez, et al., 2021). In this regard, the inclusion of longevity traits in the selection programme of this breed could be highly relevant.

3.1 | Fixed effects and culling risks

Table 2 presents the results of the Likelihood ratio tests assessing the statistical relevance of all the factors assumed for defining hazard risk in the doe. All covariates in the fixed model significantly contributed to the risk of culling at $p < 0.0001$, except for the effect of age at kidding, which was significant at $p < 0.02$. The same environment factors were found to greatly influence longevity in dairy cattle (Mhamdi et al., 2010 in Tunisian Holstein breed; Kern et al., 2016 in Brazilian Holstein; Imbayarwo-Chikosi et al., 2017 in South African Holsteins).

In dairy goats, studies have been carried out to identify risk factors for the culling of females (Malher et al., 2001 in Alpine and Saanen; Pérez-Razo et al., 2004 in Mexican breeds; Gautam et al., 2017 in New Zealand breed; Ferreira et al., 2020 in Saanen), but they remain scarce in comparison with the abundant information available for dairy cattle.

The estimates of the time-independent and time-dependent fixed effects expressed as culling risks are provided in Figure 1 and Figure 2 respectively. Age at first kidding significantly influenced LPL (Figure 1a). Higher risk estimates were observed in females which were older at first kidding. Indeed, the highest risk (0.15) was for does whose first kidding age was above 19 months, while the lowest risk (0.00) was for does starting to kid at early ages (>12–15). The greater culling risk for older ages at first kidding may be related to reproductive problems (Vukasinovic et al., 2001). Consequently, this affects production, resulting in fewer kiddings and lactations (Sewalem et al., 2005). In contrast, some authors have reported that age at first parity in dairy females has no effect on functional longevity (Ducrocq et al., 1988; Vukasinovic et al., 2001). Conversely, Essl (1998) indicated that there is some evidence of antagonism between early maturity and longevity.

It was noticeable that the highest risk (3.32) for age at kidding was for young females (>12–15 months), which then decreased suddenly until the last ages (Figure 2a). There was also a wide variation in the estimates of risk from one herd to another, and for the year and season of birth of the doe, oscillating from −1.14 to 3.99 for the birth year effect (Figure 1b–d). In the same way, risk estimates based on herd, year and season of kidding covered a wide range of values from 1.27 to 5.01 for the kidding year

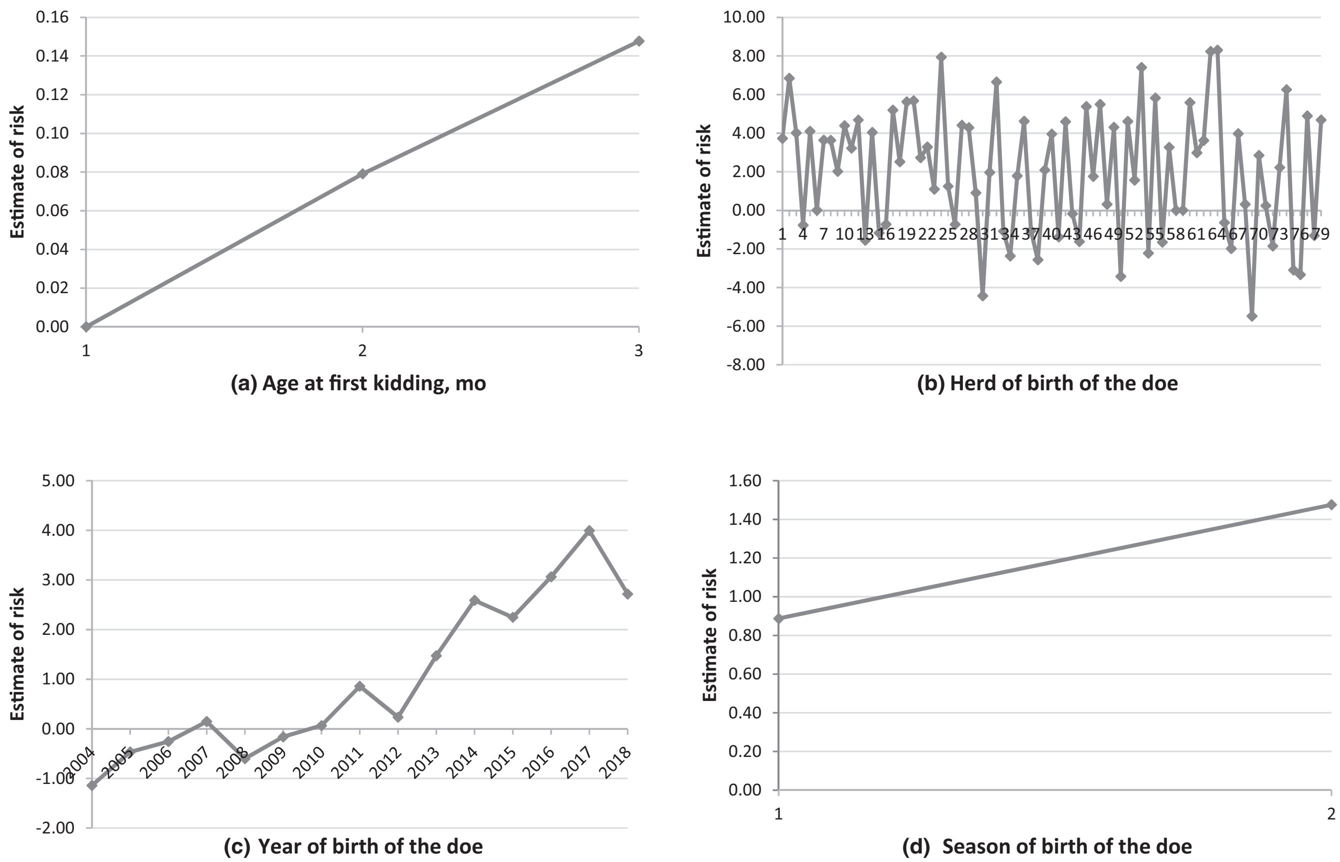

FIGURE 1 Time-independent effects expressed as estimates of culling risk for the length of productive life in Florida breed survival analysis.

(Figure 2b–d). This large discrepancy among herds could be explained by the differences in management practices, including nutrition, health, reproduction and strategy for replacing females.

The estimates of the risk of the within-herd class of milk production deviation revealed that does that produce low milk yields were at a higher risk of culling (0.75), while high-producing does were at lower risk of being culled (0.00) (Figure 2e).

Milk production has been identified as one of the main factors that affect the productive life of females, because of its relationship to profitability in the dairy industry. Many genetic evaluations for longevity include milk production as a covariate, since voluntary culling is based on phenotypic production (Sewalem et al., 2005; Mhamdi et al., 2010; Kern et al., 2016).

The effect of the lactation number*stage of lactation interaction, together with the baseline hazard, is shown in Figure 2f. As can be observed, the hazard rate increased sharply from the first to the second lactation, then decreased notably and stayed low until the last lactations. Also, the risk of being culled varied throughout the lactation. In general, the greatest risk was at the beginning and in the middle of the lactation, except for females in their second lactation and at their first stage of lactation (<210d).

According to Terawaki et al. (2006), culling during the early stage of lactation corresponds to extreme cases, such as those of very low milk production or severe functional problems. In contrast, the risk of culling is more intense at the end of lactation, when production is lower, when it is known whether the female is pregnant or not and when her body condition score is better (Ducrocq, 1999). Hence, the choice of a piecewise model within lactation number and stage of lactation accounts for these changes in risk of culling during productive life and ensures a better fit, compared to the use of a single baseline hazard function (Ducrocq, 2005; Terawaki et al., 2006).

3.2 | Heritability, EBVs and reliability

The estimates of parameters from the Cox survival analysis for LPL and the derived parameters (heritability, EBV averages, reliability and risk averages) are presented in Table 3. The marginal posterior mean estimate of the additive genetic variance in this study was 1.844, resulting in a heritability estimate of 0.58 ± 0.012.

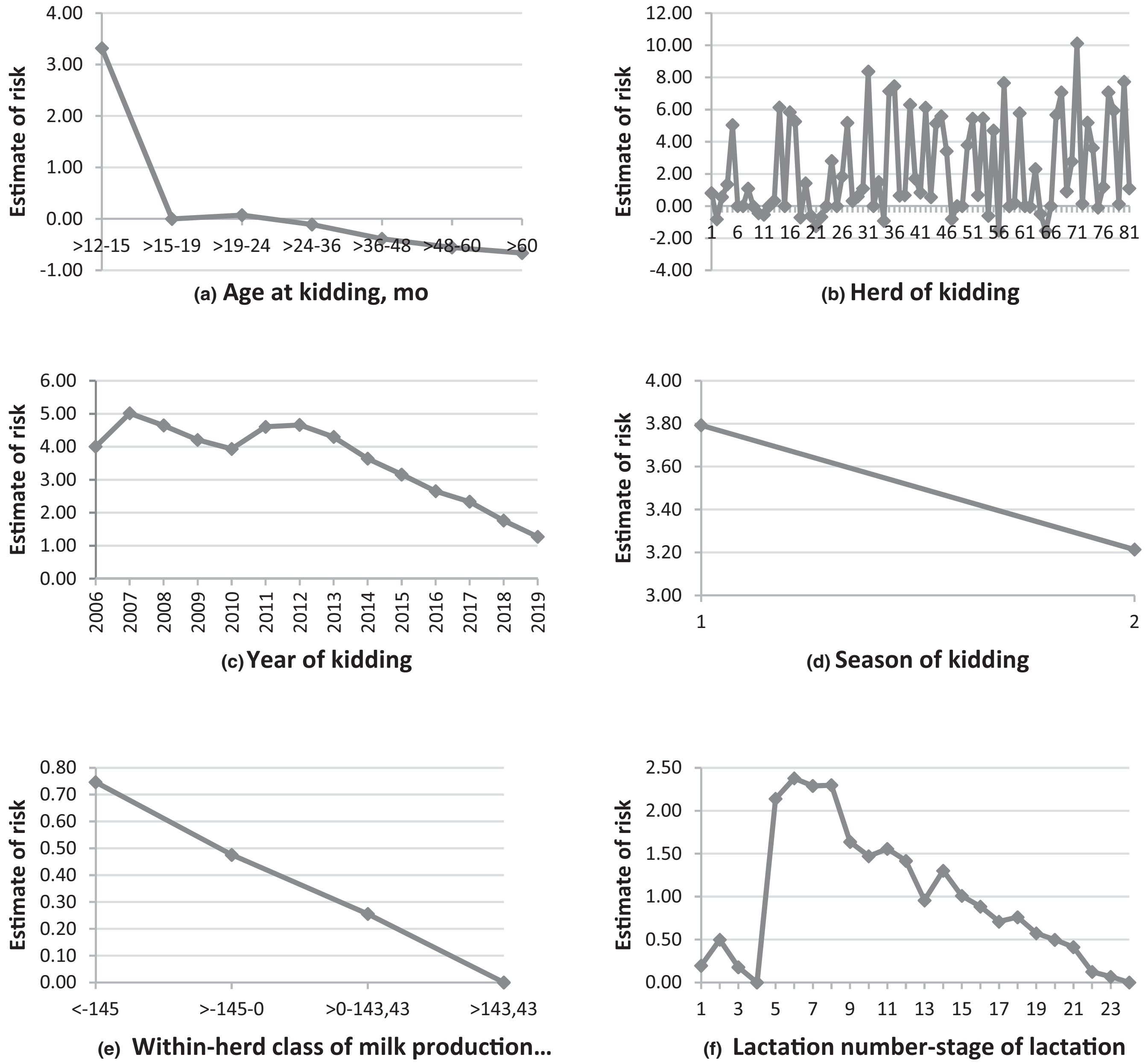

FIGURE 2 Time-dependent effects expressed as estimates of culling risk for the length of productive life in Florida breed survival analysis.

This indicated a large genetic variability for longevity of goat does, and thereby, it may be possible to improve the length of productive life in the Florida population by direct genetic selection for this trait. In a preliminary analysis in this same breed with a Cox model, not including the effects related to milk production, we obtained an h^2 of 0.17 (Ziadi et al., 2022). This finding highlighted the importance of the milk production level in the productive life of dairy females, and ignoring this effect in the survival model leads to an underestimation of heritability of this trait.

Previous studies conducted in dairy goats estimated lower heritability for longevity (0.19 in US breeds; Castañeda-Bustos et al., 2017; 0.14 in UK breeds; Geddes et al., 2018; 0.07 and 0.08 in Saanen and Alpine breeds, respectively; Palhière et al., 2018; 0.07 in New Zealand dairy goats; Scholtens et al., 2018). However, all these estimates have been obtained with linear models and the definition of the longevity trait was different from that of the present study, in addition to the proper genetic structure of the breeds. Indeed, it has been shown that linear, threshold and random regression models generally produce a lower estimation of longevity heritability than survival analysis models using the original scale (Ducrocq, 1997; Kern et al., 2014).

The reliability of genetic evaluation by survival analysis depends on the proportion of censored and uncensored records available, and increases as the ratio of censored records decreases. In our study, 24.21% of the data employed was censored, which was much lower than the maximum limit established by Vukasinovic et al. (1997), who recommended not much more than 40% of censored records in order to obtain accurate results.

Finally, the standardised average female trend in EBVs over time is shown in Figure 3. A favourable negative trend in LPL was found over time, indicating a decrease in the risk of culling over time and as a consequence a higher longevity. The decrease in EBVs was moderate (−0.63 genetic standard deviation in 14 years), but EBV decreased continuously until the last years. This means that young does had a higher probability of staying longer in the herd than their mothers and, as a consequence, a higher probability of achieving an increased number of kiddings and lactations. This improvement could have been due to the fact that a decision on female culling does not depend only on its genetic potential, but also on environmental conditions (management, health, environment etc.) and other aspects related to farm profitability, such as the price of milk and food. Thus, during the last decade, the increase in milk production level has caused an increase in reproductive and health (due to mastitis) problems in relatively young females. On the other hand, during the years in which the price of feed was controlled and the price of milk was adequate, the farmer could apply a higher replacement rate, replacing the less productive animals with the best ones. This in addition to the increase in the productive level of the herd. Actually, the panorama has changed, and with the increase in the price of feed that is not compensated by the sale price of milk, the farmer is forced to keep the females in the herd as longer as possible.

TABLE 3 Estimates of parameters from Cox analysis for LPL in the Florida breed.

Proportion uncensored/total	0.758
Estimated additive variance	1.844 ± 0.101
Heritability	0.58 ± 0.012
Reliability average	0.341 ± 0.001
Reliability average uncensored does	0.595 ± 0.001
Reliability average censored does	0.194 ± 0.001
EBV average	−0.149 ± 0.003
EBV average uncensored does	−0.034 ± 0.006
EBV average censored does	−0.206 ± 0.003
Risk average	1.059 ± 0.003
Risk average uncensored does	1.334 ± 0.008
Risk average censored does	0.913 ± 0.002

Abbreviation: LPL: length of productive life.

The results from this study suggest that the length of productive life is a suitable selection criterion for extending female lifespan in the Florida breed. This work should be extended to other Spanish dairy goat breeds with different production system, such as the Payoya breed.

4 | CONCLUSIONS

This study constitutes the first attempt to genetically analyse the length of productive life in a Spanish dairy goat breed, and the first goat analysis to use a proportional hazards model. According to our results, the age at first kidding, herd–year–season of birth of the doe, age at kidding, herd–year–season of kidding, within-herd class of milk production deviation and lactation number*stage of lactation interaction were important factors affecting longevity in the Florida goat breed. Does with older ages at first kidding and an earlier age at kidding presented the highest culling risk. Since differences among herds were very great, it is crucial to pay special attention to management

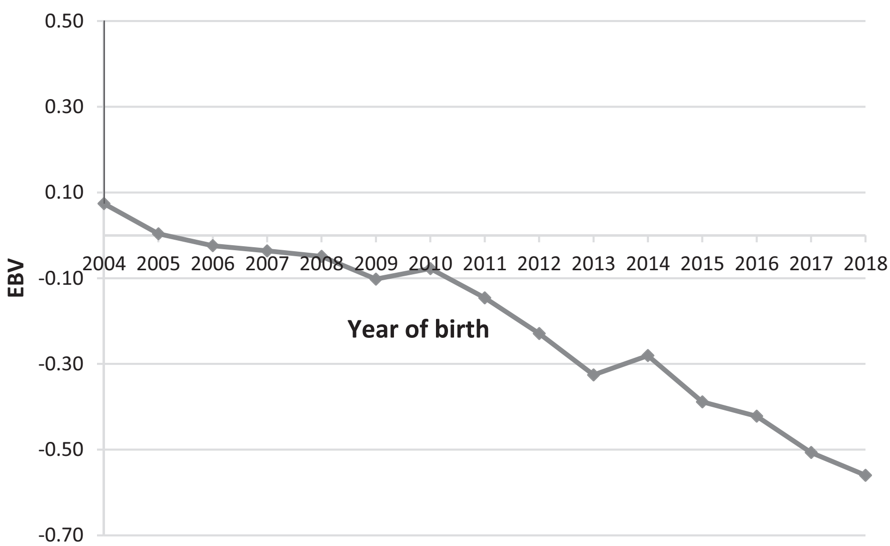

FIGURE 3 Trend in average standardised female EBVs over time for the length of productive life in Florida breed survival analysis.

practices. In our study, high-producing does were less likely to be culled, and a favourable negative trend in the risk of culling was found over time. The high heritability suggests that genetic variation exists for LPL which will allow for genetic improvement through direct selection for this trait.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest associated with the paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICAL APPROVAL STATEMENT

This study did not require manipulation or modification of the usual handling of the animals, since we have worked directly with the routine records provided by the breeders' association of the Florida breed.

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