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RESEARCH ARTICLE

# Assessment of productive lifespan of dairy cattle using accelerated failure time models

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**Abstract:** Augmenting productivity and productive lifespan (PL) of dairy cow, to meet the increased demand of milk in Kerala needs identification of factors influencing PL of dairy cow and developing model to estimate the influence of different factors on PL. The PL of 205 cross breed cows which had first date of calving in between 2010 and 2018 and milked in University Livestock Farm and Fodder Research and Development Scheme (ULF & FRDS), College of Veterinary and Animal Sciences, Mannuthy was analysed using survival regression models. The median PL obtained was 1426 days (nearly three years eleven months). As per the results of the study, Age at First Calving (AFC) had a significant and negative correlation with PL ($p<0.05$) whereas, first lactation yield had a positive and significant ($p<0.05$) correlation with PL. Analysis of various accelerated failure time models based on their accuracy measures revealed Weibull regression model with information on AFC as the appropriate model with least AIC (2631.92) and RMSE (970.92 for testing set) for predicting PL. Better PL were observed in cattle with AFC of two to 2.5 years. Hence, the study provides an optimum model for prediction of PL of dairy cattle and also depicts the importance of AFC in optimising PL of dairy cattle.

**Keywords:** Dairy cattle, Productive lifespan, Survival analysis, Accelerated failure time model

## Introduction

Dairy industry has a significant role in human development. It helped many countries to make profound impact on their economy. The demand for milk production is expected to increase markedly for the next few decades. This will provide tremendous opportunities to millions of people to improve nutrition, health, income and livelihood. However, in some parts of the world dairy consumption and production are comparatively low due to poor genetic makeup, inadequate feeding, management, poor infrastructure, lack of effective policies, socio-cultural and economic factors (Adesogan and Dahl, 2020). Adequate strategies are needed to be formulated to achieve a global sustainability in milk production.

In India dairying is considered as an important source of socio-economic development and contributes a major part to the rural economy. The application of various breeding programmes, implementation of polices and advancement in technology had helped dairy industry in India to a large extent to attain sustainability in terms of milk production. It is a matter of pride that India is world's largest milk producer and contribute 23 per cent of global milk requirements. According to Basic Animal Husbandry Statistics 2022 (BAHS, 2022), milk production in India was 221.06 million tonnes, with an annual growth rate of 5.29%. Cows accounted 52 per cent of the total milk produced in the country. Kerala stands in the twelfth place in terms of milk production. As per the report, milk production in Kerala in 2021-22 was 25.32 lakh metric tonnes but the total requirement of milk in the state during this period was 33.51 lakh metric tonnes. This indicates the necessity for establishing various schemes and programmes in order to achieve self-sufficiency in milk production in Kerala.

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Productive lifespan (PL) of cattle is an important trait that affects sustainability and the overall profitability of dairy industry as well as the welfare of cows (Grandl et al. 2019). Normally, the length of PL of cow is shorter than their natural lifespan. The length of PL of cow is measured as the time from first calving to the exit of cow from the herd. The exit from the herd may either be due to the death of the cow or culling decision made by the herd manager (Compton et al. 2017). In most of the developed countries the average PL is approximately three to four years. The evaluation of length of PL of cattle is relevant because it supports farmers in decision making regarding culling and replacement of cows at the same time to maximise profit.

The availability of modern, powerful computer systems and advanced software packages allowed the application of sophisticated statistical techniques to study the length of PL of dairy cattle. Survival analysis using parametric survival models is found to be more appropriate for evaluating PL of dairy cattle. The main advantages of using parametric survival models for the study is due to the fact that they can accommodate censored observation, time-dependent and independent factors and manage skewed distribution (Hu et al. 2021). Considering all these facts, the main objectives of the study were to assess the influence of first lactation traits on PL and to develop model for predicting PL with first lactation traits of the cow.

## Materials and methods

### Source of data

The data required for the present study were taken from records maintained at University Livestock Farm and Fodder Research and Development Scheme (ULF & FRDS), College of Veterinary and Animal Sciences, Mannuthy. The data on production and reproduction traits of cross breed cows were collected from breeding registers and daily milk recording registers maintained in the farm itself. The PL was defined as the number of days from first calving to culling, death or censoring date. The PL of alive cows was taken as right and progressively censored whereas, the PL of cows which were exited from herd were known and uncensored. Censoring indicator was coded as one for uncensored observations and coded as zero for censored observations. The lactation milk yield was recorded in kilogram and AFC, productive life, lactation length was recorded in days. The data set contained information on 205 cows. The number of cows which were exited from the herd was 173 and the number of alive cows was 32.

### Statistical analysis

As the first step of the analysis, the data obtained were cleaned and had been summarized using descriptive statistics to study the nature of the data. The association of PL with first lactation traits were assessed by using the method of correlation. Survival models were used for modelling PL of the dairy cattle. Data set was divided in to training set and testing set in the ratio 80:20 after arranging chronologically. Models were fitted to training set and validated using testing set. Step wise variable selection was performed to obtain significant factors in the models. Best model for PL with first lactation traits were selected on the basis of accuracy measures. Descriptive and correlation analysis was carried out using Statistical Product and Service Solutions (SPSS) package (version 24.0) and modelling was done by using R library ‘survival’ in R programming.

### Spearman correlation coefficient

In order to assess the relationship between PL and first lactation traits Spearman rank correlation coefficient was used. Spearman rank correlation coefficient or Spearman’s ρ is a nonparametric measure of rank correlation and it measures the strength and association between two ranked variables. Spearman’s rank correlation coefficient is a distribution-free measure, which does not make any assumptions about the parameters of the population (Agarwal, 2013). Assume that the ranks of the individuals in two characteristics are known. If we assume that there is no tie, then the Spearman’s rank correlation coefficient, usually denoted ρ (Rho) is given by the formula

$$\rho = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

where, d is the difference between the pair of ranks of the same individual in the two characteristics and n is the number of pairs.

### Accelerated Failure Time (AFT) Model

Product lifespan can be modelled using AFT model incorporating its relationship with first lactation traits. In AFT model, the distribution of time to event T, as a function of p covariates is written as,

$$\log T = a_0 + \sum_{J=1}^{P} a_j x_j + \sigma\varepsilon$$

where $x_j$, j=1, 2, …, p are the covariates, $a_j$ , j=1, 2, …, p are the coefficients, $\sigma$ ($\sigma > 0$ ) is an unknown scale parameter, and $\varepsilon$ , the error term, is a random variable with known forms of density function g ( ε, d) and survivorship function G ( ε, d) but unknown parameter d. This model is called AFT model, because the effect of the covariates is multiplicative on time scale and it is said to either accelerates or decelerates survival time (Lee and Wang, 2013).

On the basis of the distribution of T and ε different parametric survival models can be defined. When T follows exponential distribution and ε has a double exponential or extreme value distribution then the model is known as exponential regression model. If T follows Weibull distribution and follows $\varepsilon$ a double exponential or extreme value distribution, the model is termed as Weibull regression model. When T has lognormal distribution and ε follows standard normal distribution then the model is known as lognormal regression model. The model is termed as log-logistic regression model, when T has log-logistic distribution and ε has logistic distribution.

**Accuracy measures**

In order to select the most appropriate model the following accuracy measures were used in the study. These measures help to compare different models and to assess the error in the regression.

**Akaike information criteria**

Selection of appropriate model can be based on minimum Akaike information criteria (AIC) (Klein and Moeschberger, 2003) which is calculated as

AIC = -2(log-likelihood) + 2k

where k is the number of parameters in the model.

**Schwarz's Bayesian information criteria**

Another simple selection procedure known as Bayesian Information Criteria (BIC) (Lee and Wang, 2013) is given as

$$BIC = -\text{log-likelihood} + k\frac{\ln(n)}{2}$$

k denotes the number of parameters estimated in the model and n is the total number of observations.

***Root Mean Square Error (RMSE)***

The RMSE is given by the relation,

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n}}$$

where $Y_i$ are the observed and $\hat{Y}_i$ are the corresponding fitted values.

***Mean Absolute Error (MAE)***

The MAE is given by the relation,

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|Y_i - \hat{Y}_i\right|,$$

where $Y_i$ are the observed and $\hat{Y}_i$ are the corresponding fitted values.

**Mean Absolute Percentage Error (MAPE)**

The MAPE is the mean or average of the sum of all of the percentage error for a given data set taken without regard to sign. It is calculated by the formula,

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|Y_i - \hat{Y}_i|}{Y_i} \times 100$$

A model with smallest AIC / BIC, RMSE, MAE and MAPE is considered as the best model.

**Results and Discussion**

The descriptive statistics for all the traits in the data set are given in the Table 1. The number of cows with at least one parity was 205.The minimum and maximum of PL of the cows in the study were 75 and 3522 days (nearly nine years seven months) respectively. The median and mean PL were 1426 days (3.9 yrs) and 1531.82 days (4.2 yrs) respectively. Relatively similar results have been reported by different studies. In India, mean PL was reported as 1439.32±87.64 days for Holstein Friesian cows by Singh et al. (2002), 3.57± 0.09 years for Frieswal cattle by Atrey (2005), 3.81± 0.12 years for Frieswal cows by Kumar et al. (2014), and 1510.36 ± 21.46 days for Karan Fries cattle by Dash et al. (2018). Relatively higher mean PL were reported by Singh et al.

**Table 1:** Descriptive statistics of all traits in the whole data set

| Traits | N | Mean | SD | Median | $Q_1$ | $Q_3$ | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| PL (days) | 205 | 1531.82 (4.2 yrs) | 897.77 (2.5 yrs) | 1426 (3.9 yrs) | 738 (2 yrs) | 2224.50 (6.1 yrs) | 75 (2.5mths) | 3522 (9.6 yrs) |
| Parity | 205 | 3.34 | 1.86 | 3 | 2 | 5 | 1 | 9 |
| AFC (days) | 205 | 1078.17 (35 mths) | 187.04 (6 mths) | 1057 (35 mths) | 957 (31 mths) | 1195 (39 mths) | 608 (20 mths) | 1801 (60 mths) |
| LL1 (days) | 205 | 327.26 | 84.12 | 330 | 278 | 381.5 | 67 | 591 |
| LY1 (Kg) | 205 | 2163.77 | 811.30 | 2078.10 | 1644.40 | 2738.60 | 53.60 | 4735.80 |
| LY1305 (Kg) | 123 | 2296.15 | 563.37 | 2207.10 | 1872.10 | 2648.80 | 996.50 | 3862.70 |

N-Number of cows, SD-Standard Deviation, $Q_1$-First quartile, $Q_3$-Third quartile, yrs-Years, mths-Months, PL-Productive lifespan, AFC- Age at first calving, LL1- First lactation length, LY1- First lactation yield, LY1305- First lactation yield in 305 days

(2011) as 1872.28±100.28 days for Sahiwal cattle and Ambhore et al. (2017) as 1875±28 days for Phule Triveni cows. Zambrano-Sepulveda et al. (2014) reported an average PL of 1386.26 days (nearly three years nine months) based on 272 crossbred cattle in Venezuela. The minimum and maximum age at first calving (AFC) were 20 and 60 months respectively. The mean and median AFC were 1078.17 days (2.95yrs) and 1057 days (2.89yrs) respectively. Singh et al. (2011) observed mean AFC as 1329.25± 14.53 days for Sahiwal cattle. Eastham et al. (2018) reported mean and median AFC as 29 and 28 months respectively for pedigree Holstein and Holstein-Friesian primiparous cows. The median lactation length of first lactation (LL1) was 330 days. Mean value for first lactation milk yield (LY1) was 2163.77 Kg. Milk records of cows which had lactation length equal to or greater than 305 days were considered for computing average 305-days milk yield. The average 305 days milk yield (LY1305) was obtained as 2296.15 Kg for the first lactation.

**Relationship of productive lifespan with first lactation traits**

As per the Shapiro Wilk test, PL was not following normal distribution ($P<0.05$). Hence Spearman rank correlation coefficients were computed for assessing the relationship of PL with first lactation traits and is given in Table 2. Among the traits considered, AFC and LY1 were significantly ($P<0.05$) correlated to PL whereas, lactation length and 305 days milk yield of first lactation were not significantly ($P>0.05$) correlated to PL. AFC had a significant and negative correlation with PL ($P<0.05$). The correlation coefficient of AFC was negative with value -0.185 which indicates that, as AFC increased, PL decreased. This trend shows the importance of reducing AFC in order to increase PL. Nilforooshan and Edriss (2004) and Siriak et al. (2022) had also reported a negative association of AFC on PL. In contrast, studies conducted by Rogers et al. (2004) and Raguz et al. (2011) reported that AFC were insignificant on PL. AFC didn't show any significant correlation with LL1, LY1 and LY1305. LY1 had a significant and positive correlation with PL. This indicates that, as first lactation yield increases PL also increases. Atrey et al. (2005) also observed that LY1 had significant effect on PL. Significant correlations were observed between LL1, LY1 and LY1305.

**Modelling productive lifespan with factors of first lactation**

For developing models for PL with factors of first lactation, records on 205 cows were considered, out of which 173 cows were either culled or dead and 32 cows were alive. The data were divided in to training set and testing set in the ratio 80:20 after arranging the data set chronologically according to the date of birth of cow. For the analysis, four parametric models were considered. They were exponential, Weibull, log-logistic and lognormal. These models were first fitted to the training set then validated by the testing set. For each model stepwise variable selection was carried out. Models were compared on the basis of various accuracy measures and is given in Table 3.

Weibull regression model was selected as the best model as it was evident from Table 3 that the values of accuracy measures AIC (2631.92) and BIC (2641.20) of training set and RMSE (970.92) and MAE (838.88) of testing set were least for Weibull regression model. In the model selected, the only factor that had a significant

**Table 2:** Spearman rank correlation coefficients (p-value) of PL with first lactation traits

| Traits | PL | AFC | LL1 | LY1 |
|---|---|---|---|---|
| AFC | $-0.185^{**}$(0.008) | | | |
| LL1 | $0.100^{ns}$ (0.153) | 0.009 (0.901) | | |
| LY1 | $0.195^{**}$ (0.005) | 0.058 (0.410) | 0.720** (<0.001) | |
| LY1305 | $0.078^{ns}$ (0.390) | 0.101 (0.267) | 0.195* (0.031) | 0.888** (<0.001) |

*ns- non-significant at 0.05 level; **- Significant at 0.01 level,* AFC- Age at first calving, LY1- First lactation yield, LL1- First lactation length, LY1305- First lactation yield in 305 days.

**Table 3:** Accuracy measures of models for PL with factors of first lactation

| | TRAINING SET | | | | | | TESTING SET | | |
|---|---|---|---|---|---|---|---|---|---|
| Model | Factors | AIC | BIC | RMSE | MAE | MAPE | RMSE | MAE | MAPE |
| Exponential | Intercept | 2686.95 | 2690.04 | 851.74 | 708.94 | 1.02 | 1095.18 | 939.34 | 0.64 |
| Weibull | AFC | 2631.92 | 2641.20 | 857.72 | 734.46 | 1.15 | 970.92 | 838.88 | 0.64 |
| Log-logistic | AFC LY1 | 2645.49 | 2657.86 | 863.77 | 672.94 | 0.76 | 1179.00 | 1058.12 | 0.62 |
| Lognormal | AFC LY1 | 2643.72 | 2656.10 | 876.21 | 675.23 | 0.74 | 1209.88 | 1083.52 | 0.61 |

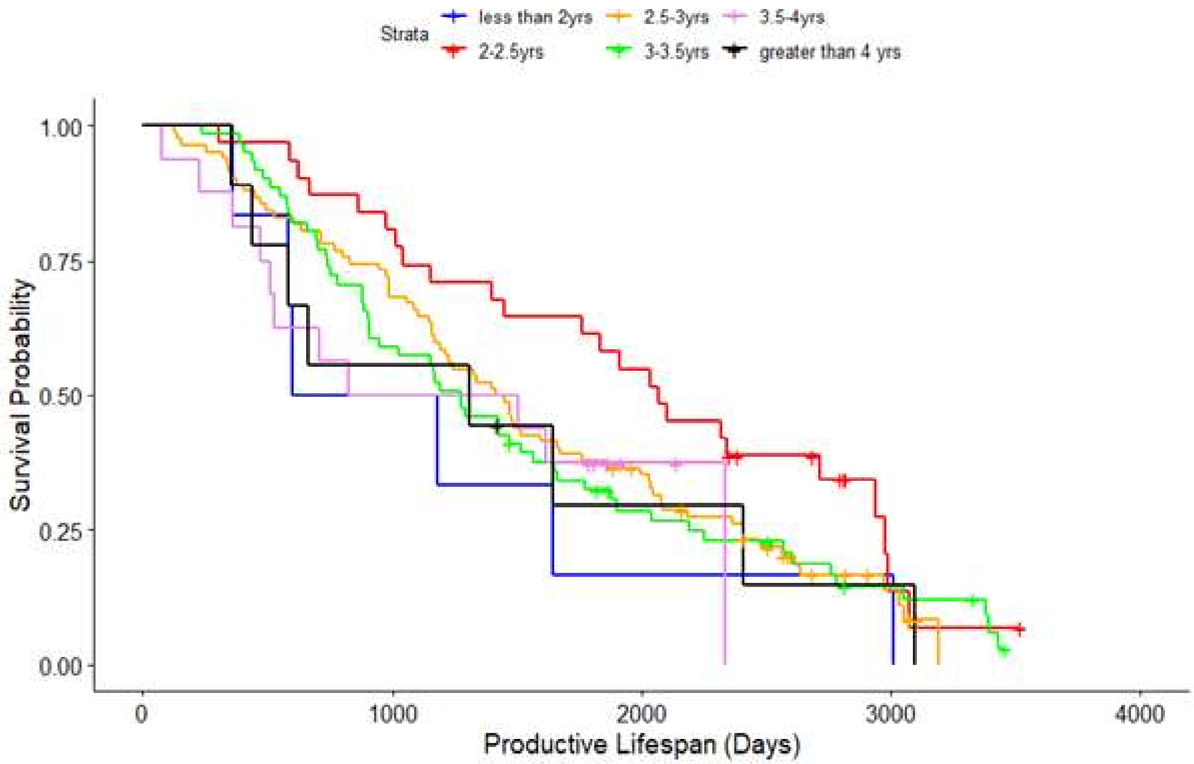


**Fig. 1** Kaplan-Meir curve of productive lifespan for different age at first calving

influence on PL was AFC. The parameters of Weibull regression model are presented in Table 4 along with its standard error. The estimates of parameters are used to represent the model.

The Weibull regression model for PL with factors of first lactation is expressed in the form

$$Log\ T_i = 7.82 - 0.00044(AFC)_i + 0.59\varepsilon_i$$

where, $T_i$ is the PL of the i[th] cow and follows Weibull distribution, $(AFC)_i$ is the age at first calving of i[th] cow and $\varepsilon_i$ follows extreme value distribution.

Weibull regression model is a unique model which satisfies both proportional hazard and AFT assumption. Log-logistic model satisfies proportional odds and AFT assumption. Lognormal distribution satisfies AFT assumption but not proportional odds

**Table 4:** Estimates of fitted parameters of Weibull regression model

| Factors | Coefficient | S. E. | Z value | P value |
|---|---|---|---|---|
| Intercept | 7.82 | 0.27 | 29.07 | <0.001 |
| AFC | -0.00044 | 0.00025 | -1.79 | 0.07 |

Scale(σ)=0.59

**Table 5:** Descriptive statistics for different AFC classes

| AFC (yrs) | n | Events | Mean PL (days) | Median PL (days) | SD |
|---|---|---|---|---|---|
| <2 | 6 | 6 | 1230.67 | 891 | 992.00 |
| 2-2.5 | 31 | 24 | 1953.77 | 2070 | 894.02 |
| 2.5-3 | 82 | 70 | 1527.68 | 1431.5 | 865.48 |
| 3-3.5 | 61 | 54 | 1478.38 | 1275 | 913.70 |
| 3.5-4 | 16 | 11 | 1168.19 | 1165.5 | 768.83 |
| >4 | 9 | 8 | 1325.67 | 1310 | 945.77 |

yrs-years, n-number of cows, SD-Standard deviation assumption (Kleinbaum and Klein, 2012; Klein and Moeschberger, 2003). Hu et al. (2021) recommended Weibull regression as appropriate model for efficient analysis of PL data in comparison with Cox model. Raguz et al. (2014) recommended the use of Weibull regression models while comparing with linear models as it could handle censored and uncensored observations. Comparison of different AFT models were found in Kulkarni et al. (2021) and Soares et al. (2023) while modelling the longevity of cattle and they selected lognormal model as appropriate model. Potocnik et al (2011), Najafabadi et al. (2016) and Kern et al (2016) used Weibull regression model for analysis of PL and found that culling risk increased with increase in AFC. Even though the correlation between AFC and PL was weak; while building the model it became a significant contributor in determining PL. It highlights the importance of including all relevant variables, even those with weak correlations, to obtain robust and reliable model. PL is influenced by several factors and so even weak correlations could help in identifying subtle effects that might be significant. These small effects accumulate and provide valuable insights. Therefore, including variables with weak correlations improve the overall predictive power of models. Impact of AFC on productive lifetime becomes evident in the survival regression model using the Weibull distribution.

In order to find the optimal class of AFC with highest PL, six AFC classes were formed after converting AFC in to years. The descriptive statistics for each class are shown in Table 5. Shortest PL was observed for AFC less than two years. From the table, it is evident that cows having AFC between two and two and half years have more PL. The Kaplan Meier curve obtained for the six AFC classes are given in Figure1. The plot also reveals the similar result. It can be seen that when AFC is examined by forming different classes, the lowest mean and median PL were observed when AFC was less than two years, and highest mean and median PL were observed when AFC was between two to 2.5 years. Therefore, in order to improve PL, it is better to have AFC between two and 2.5 years (730 - 913 days). Kumar et. al (2014), Atrey et al. (2005) and Siriak et al. (2022) reported significant effect of AFC on PL. Kumar et. al. (2014) observed shortest PL when AFC less than 800 days or greater than 1300 days. Whereas AFC less than 725 days or greater than 1251 days yielded shortest PL as per Atrey et al. (2005). Similar to the present study, optimum AFC proposed by Kumar et al. (2014) was 800 to 1000 days (2.2 to 2.74 yrs), by Atrey et al. (2005) was 726 to 950 days (1.99 to 2.6 yrs) and Siriak et al. (2022) was 24 to 26 months.

## Conclusions

The results shows that the first lactation traits like AFC and first lactation yield have significant ($P<0.05$) influence on PL. The negative correlation of AFC on PL suggests that PL decreases with increase in AFC. This indicates the necessity of decreasing AFC in order to increase PL. The positive association of first lactation yield on PL advocates to take necessary decisions to ensure high yield in first lactation to improve PL. Based on the results of the present study, the Weibull regression model could predict PL using only the age at first calving as a predictor variable. The proposed model facilitates the better understanding of the PL of the cow earlier in its lifetime. This helps the large farm holders as well as dairy farmers to take effective decisions on culling of cattle and to adopt appropriate practices to improve PL of cattle as early as possible. It was observed that AFC to be between 2 and 2.5 years is more suitable to improve PL. Therefore, we recommend implementing dairy cattle improvement programs with selection criteria targeting an optimal AFC of 2–2.5 years, complemented by improved nutritional and health management practices for heifers. Inadequate growth at the time of first calving may result in reduced milk yields during the first lactation, as the significant energy requirements for concurrent growth and lactation conflict with milk production. This can lead to the culling of animals unable to meet production standards. Additionally, the implementation of monitoring systems to track reproductive and production traits enables farmers to make informed decisions regarding early culling and management. Policymakers should promote awareness campaigns for the adoption of these practices to ensure sustainable enhancements in herd productivity.

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## Conflict of interest

The authors have not any conflict of interest to declare.

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