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Modelling Lactation Curve for Genetic Evaluation of Crossbred Cattle

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ABSTRACT

The present study was conducted on first lactation 4415 monthly test-day milk yield records of 466 crossbred (CB) cattle sired by 89 bulls during 2000–2018 (19 years) maintained at Directorate of Livestock Farms, GADVASU, Ludhiana, Punjab, India. The crossbred cattle with lactation length of minimum 100 days were considered for the study. The aim was to develop the best lactation curve model and to compare the breeding values of sires based on actual and predicted first lactation 305-day milk yield (FL305DMY). The data were classified and coded according to different season and age at first calving groups for first lactation 305-day milk yield. Monthly test-day milk yields of first lactation were used to develop the best lactation curve model. The Polynomial Regression Function (PRF) model was the best model amongst all the models based on both R^2 and RMSE values. The breeding values of 60 HF crossbred sires with two or more daughters were estimated from the actual and predicted FL305DMY using Polynomial Regression Function by applying two sire evaluation methods viz. least squares method (LSQ) and restricted maximum likelihood method (REML). The effectiveness of LSQ and REML methods of sire evaluation was compared on the basis of Spearman's rank correlations, coefficients of determination (R^2) and coefficients of variation (CV). LSQ was found most efficient and accurate method for sire evaluation using actual and predicted first lactation 305-day milk yield in HF crossbred cattle.

KEYWORDS: Crossbred cattle, CV, lactation curve, PRF, R^2, sire evaluation

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Milk production is one of the most important economic traits in dairy cattle. Improving milk productivity of Indigenous cow has been pursued since many decades in India. It is conceded that average yield of an Indian cow is very low, at about 1000 L lactation^{-1} (Dohare et al., 2014). Cross breeding with exotic European breeds are the best alternative to improve the genotype and milk producing capability of the low yielding Indian cows.

Test day records are expressions of a trait that changes over time. These records are used to predict total 305-day yields which are required to evaluate the additive genetic merit of sires and cows in traditional evaluation (Schaeffer et al., 2000, Takma and Akbas, 2007, Salamone et al., 2022). Different statistical models have been used to genetically evaluate milk production using test-day observations (Savegnago et al., 2013).

Lactation curve is the graphical representation of milk yield against time or it can also be referred as the curve representing the rate of milk secretion with the advancement in lactation. Since the early work of Brody et al. (1923) various authors have modelled the lactation curve in dairy cattle in different parts of the world (Landete-Castillejos and Gallego, 2000, Tekerli et al., 2000, Rekik et al., 2003, Silvestre et al., 2006, Macciotta et al., 2011). Lactation curves generally reach their peak yield after calving and then decrease steadily from then until drying up (Lopez et al., 2019). Animals with more persistency are preferred over animals achieving higher peak lactation with low persistency as the later one increases production cost because yield is distributed less equally over the complete lactation.

Modelled lactation curves have been used to calculate milk production at the individual cow level using the peak day yield, days to peak, and 305-day cumulative milk production as the estimated parameters (Bouallegue et al., 2015). Various mathematical functions have been fit to the lactation curve for the milk, fat, somatic cell count as well as genetic parameter estimation in different breeds of dairy cattle (Druet et al., 2003, Macciotta et al., 2005, Silvestre et al., 2009, Adediran et al., 2012, Graesboll et al., 2016). Models to describe the lactation curve have been classified into two main groups: linear and nonlinear models. Nonlinear parametric functions have represented the preferred tools for modeling lactation curves with the main aim of predicting yields and parameters describing the shape of the curve in addition to important parameters such as peak yield and persistency (Bouallegue and M'Hamdi, 2020).

Some studies have reported atypical shapes, such as the absence of peak yield, in approximately 20 to 30% of cases (Macciotta et al., 2005). Despite their considerable proportion, such cases have been considered outliers or disregarded in analyses, as they are difficult to explain using previously developed equations (Daniel et al., 2018, Jeretina et al., 2013). To facilitate precision dairy farming, however, it is useful to identify and analyze lactation curve shapes that can be influenced by individual variation, feed management, or disease (Lee et al., 2020, Shija et al., 2022).

The main objective of any breed improvement program is to bring about genetic progress by selection of superior sires and dams. The sires are genetically evaluated on the basis of first lactation 305-day milk yield of their daughters at organized farms. Genetic evaluation based on 305-day milk yield results in enhanced generation interval, lower genetic gain per unit of time and fewer numbers of daughters per sire due to requirement of 305 days of lactation. Accordingly, the present investigation has been undertaken to evaluate HF crossbred cattle to compare different sire evaluation methods using best lactation curve predicted and actual 305-day first lactation milk yield.

2. MATERIALS AND METHODS

2.1. Data recording and standardization

The data on HF crossbred cattle (animal number, sire number, dam number, date of first calving, first lactation 305-day milk yield, monthly test-day milk yields) were collected from the history-cum pedigree sheets and daily milk recording registers maintained at the Dairy farm of Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab, India during 2000 to 2018. Culling in the middle of lactation, abortion, still-birth or any other pathological causes which affected the lactation yield were considered as abnormalities and thus, such records were not taken for the study. The CB cattle that had produced milk for at least 100 days and minimum of 800 kg were considered for the study.

2.2. Lactation curve models

The four lactation curve models viz. Inverse polynomial, Exponential, Polynomial regression and mixed log functions were fitted to predict the monthly test day milk yields in HF crossbred cattle. The most suitable model was identified on the basis of the highest adjusted R^2-value and lowest root mean square error (RMSE) value. The first lactation 305-day milk yield (FL305DMY) was estimated by addition of the 6th day milk yield and rest ten test day milk yields multiplied with 30 (of the best lactation curve model) up to 11th TD.

2.3. Sire evaluation

Least Squares Method (LSQ) and Restriction Maximum Likelihood (REML) methods of sire evaluation were used as they are the most widely used methods for the genetic evaluation of sires based on actual and predicted 305-day first lactation milk yields. The coefficient of determination (R^2-value) of different methods was estimated for judging the accuracy of sire evaluation methods. The coefficient of variation of first lactation 305-day milk yield from different models of sire evaluation was estimated for knowing the stability. The correlations between the rankings of the sires based on their breeding values estimated by the above methods were tested by using Spearman's rank correlation (Spearman, 1904):

$r_{(s)}=1-(6\sum d_i^2)/(n(n^2-1))$……………..(1)

$r_{(s)}$=Rank correlation coefficient

n=Number of sires under evaluation

d_i=Difference of rank between paired items under two methods

The significance of rank correlation was tested by:

$t=r\sqrt{(n-2)/(1-r^2)}$……………….(2)

This has a student t-distribution with n-2 degree of freedom.

3. RESULTS AND DISCUSSION

3.1. Lactation curve prediction of FL305DMY

The adjusted R^2- values of Inverse Polynomial Function (IPF), Exponential Function (EF), Polynomial Regression Function (PRF) and Mixed Log Function (MLF) are 99.90%, 86.68%, 99.31% and 88.80% respectively, whereas the average Root Mean Square Error (RMSE) with these functions were 0.172 kg, 0.176 kg, 0.035 kg and 0.161 kg, respectively. Thus, the best fit model was Polynomial Regression Function, which was better than other functions for prediction of first lactation TD in HF crossbred cattle in terms of both R^2 and RMSE values. The first lactation 305-day milk yield (FL305DMY) was obtained by addition of the PRF predicted monthly test days (per day average x 30) up to 12 months. This was in accordance with the findings of Ali and Schaeffer (1987) and Sharifi et al. (2009) in Holstein-Friesian cows, Cilek and Keskin (2008) in Simmental cows, Dimauro et al. (2005) in Italian water buffalo and Sahoo et al. (2021) in Murrah buffaloes.

The average estimated breeding values (EBVs) for 60 HF crossbred sires based on actual and predicted FL305DMY of their daughters by different sire evaluation methods are presented in Table 1.

3.2. Least squares method (LSQ)

The average breeding values of HF crossbred sires evaluated on the basis of actual first lactation 305-day milk yield by least squares method was 4117.34 kg. The results revealed that the estimated breeding values of 32 (53.33%) sires were above the average breeding value, while the remaining 28 sires (46.67%) had breeding value lower than the average breeding value. The difference between highest and lowest breeding values was 2592.28 kg. The overall estimated average breeding values of sires for the FL305DMY on the basis of polynomial regression function predicted monthly test-day milk yields was 3965.95 kg. The results revealed that the estimated breeding values of 32 (53.33%) sires were above the average breeding value, while the remaining 28 sires (46.67%) had breeding value lower than the average breeding value. The difference between highest and lowest breeding values was 2587.33 kg.

Table 1: Average expected breeding values (EBVs) of HF crossbred sires using actual and predicted first lactation 305-day milk yield by different sire evaluation methods

Sire evaluation methods	AverageEBV (kg)	No. of sires above average EBV	No. of sires below average EBV	Maximum EBV (kg)	Minimum EBV (kg)
Actual first lactation 305-day milk yield					
LSQ	4117.34	32	28	5458.11	2865.83
REML	4171.78	34	26	5732.64	2581.49
Predicted first lactation 305-day milk yield (Polynomial Regression Function)					
LSQ	3965.95	32	28	5368.18	2780.85
REML	4019.06	32	28	5989.32	2463.23

3.3. Restricted maximum likelihood (REML)

The average breeding values of HF crossbred sires evaluated on the basis of actual first lactation 305-day milk yield by restricted maximum likelihood was 4171.78 kg. The results revealed that the estimated breeding values of 34 (56.67%) sires were above the average breeding value, while the remaining 26 sires (43.33%) had breeding value lower than the average breeding value. The difference between highest and lowest breeding values was 3151.15 kg. The overall estimated average breeding values of sires for the FL305DMY on the basis of polynomial regression function predicted monthly test-day milk yields was 4019.06 kg. The results revealed that the estimated breeding values of 32 (53.33%) sires were above the average breeding value, while the remaining 28 sires (46.67%) had breeding value lower than the average breeding value. The difference between highest and lowest breeding values was 3526.09 kg.

3.4. Effectiveness of sire evaluation methods

The rank correlations of EBVs estimated by actual 305-day milk yield and predicted 305-day milk yield are presented in Table 2.

The accuracy and stability of different sire evaluation methods were compared on the basis of coefficient of determination (R^2) and coefficient of variation, respectively (Table 3).

The rank correlation between EBVs for actual 305-day or less milk yield by LSQ and REML was very high (0.976). Ambhore et al. (2018) estimated the breeding values of 55 Phule Triveni sires for first lactation 300 day or less milk yield (FL300DMY) by using four different sire evaluation methods/models viz. Least Squares (LSQ), Simple Regressed Least Squares (SRLS), Best Linear Unbiased Prediction-Sire model (BLUP-SM) and Restricted Maximum Likelihood Method (REML). In their study, the REML method produced lowest error variance for FL300DMY and it was considered to be the most efficient method. However, for FL300DMY, BLUP-SM had the highest rank correlation of 0.61 with the most efficient REML method followed by SRLS (0.49) and LSQ (0.45).

Table 2: Rank correlations among breeding values of sires estimated by different methods on the basis of actual and predicted first lactation 305-day milk

Methods	Actual LSQ	Actual REML	Predicted LSQ	Predicted REML
Actual LSQ		0.976**	0.929**	0.898**
Actual REML	0.976**		0.924**	0.919**
Predicted LSQ	0.929**	0.924**		0.985**
Predicted REML	0.898**	0.919**	0.985**	

LSQ: Least Squares Method, REML: Restricted Maximum Likelihood Method; **Correlation is significant at the 0.01 level (2-tailed)

Table 3: Effectiveness of different sire evaluation methods for actual and predicted first lactation 305-day milk yield in HF crossbred cattle

Methods	Coefficient of determination (%)	Coefficient of variation (%)
Actual first lactation 305-day milk yield		
LSQ	82.85	14.85
REML	79.22	20.31
Predicted first lactation 305-day milk yield (Polynomial Regression Function)		
LSQ	73.88	14.31
REML	68.13	18.66

The rank correlation between EBVs for predicted 305-day or less milk yield for predicted LSQ and REML was also high (0.985). Kokate et al. (2012) estimated breeding values of Karan Fries sires for predicted first lactation 305-day by step-wise backward multiple regression using monthly test day milk yields. The effectiveness of the methods was compared on the basis of rank correlations, error variance, coefficients of determination (R^2) and coefficients of variation (CV). The rank correlation for LSQ with SRLS (0.92–0.99) was highest followed by LSQ with BLUP (0.89–0.91) and SRLS with BLUP (0.81–0.91) which were very close. The lowest rank correlation was observed in LSQ with CC (0.10–0.16) and SRLS with CC (0.10–0.17).

3.5. Coefficient of determination (R^2)

The coefficient of determination (R^2-value) of fitting LSQ and REML were estimated to judge the accuracy of these methods. The higher the R^2 value, the higher is the accuracy of fitting the model. It was observed that the R^2 value for both actual and predicted 305-day milk yield was higher for LSQ. Singh et al. (2014) also reported highest R^2-value for LSQ for first lactation milk production records of 965 Murrah buffaloes sired by 98 bulls.

3.6. Coefficient of variation (%)

Estimates of coefficient of variation were used as the criterion to compare the stability of different sire evaluation methods for first lactation 305-day milk yield. The CV (%) of unadjusted data for first lactation 305-day milk yield was 15.14%. The method which gives CV (%) very near to the unadjusted data is considered as more stable. The CV (%) for LSQ was lowest and hence considered the better method. Kokate et al. (2012) in Karan Fries cattle and Singh et al. (2014) in Murrah buffalo also reported nearly equal stability of different sire evaluation methods.

4. CONCLUSION

Based on this investigation it was recommended that the polynomial regression function should be used to predict monthly test day milk yields and first lactation 305-day milk yield in HF crossbred cattle based on coefficient of determination (adjusted R^2) and root mean square error (RMSE) values. Further, LSQ method should be applied for estimation of breeding values of sires based on actual and predicted first lactation 305-day milk yields for better accuracy and stability.

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