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Research Article

CHARACTERIZATION OF LACTATION CURVE PATTERNS USING PART MILK YIELD RECORDS IN CROSSBRED COWS

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ABSTRACT

The present study was conducted to examine the effectiveness of different non-linear models considering first lactation total fortnightly milk yields (TFMYs) upto 300 days of lactation in crossbred cows. Data between 1990-2019 pertaining to 529 crossbreds maintained at Instructional dairy farm of G.B. Pant University of Agriculture and Technology, Pantnagar were used. Three models viz., parabolic exponential function (PEF), inverse polynomial function (IPF) and mixed log function (MLF) were used to simulate lactation curves utilizing average fortnightly milk yield. The inverse polynomial function (IPF) with highest coefficient of determination (R^2=97.62), lowest root mean square error (RMSE=2.26 Kg) and least absolute mean deviation (AMD=1.52 Kg) demonstrated the best fit for primiparous cows. The parabolic exponential function exhibited the least fit for the data. Lactation curve modeling with an inverse polynomial function may be useful in establishing farm-level management plans; nevertheless, modeling must be optimized on a regular basis before being used to improve production in crossbred cows.

Keywords: Crossbred, Lactation curve, Milk yield, Non-linear modelling

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A lactation curve depicts the pattern of daily milk output in dairy cows during lactation. The graph of milk yield presented against time is known as the lactation curve (Arya *et al.*, 2020). Three phases that can be identified in a typical lactation curve of milk production consist of an ascending phase between calving and peak yield, a sustaining phase during peak yield, and a descending phase following the peak. Lactation curve modeling in dairy cows can be used to specify feeding and breeding methods (Jiang *et al.*, 2020). The milk yield as well as the herd's overall lactation output can be predicted using lactation curve models at any stage of lactation. Since the lactation curve doesn't exhibit a linear trend over time, a linear model cannot be used to fit it. Numerous animal-level and herd-level variables, including breed, age, parity, calving season, and management techniques, have an impact on the lactation curve. As a result, there may be variations in how well the parameters calculated from the various mathematical models match to a normal lactation curve depending on the animal-level and the environment-level effects (Bangar and Verma, 2017). The models may also be beneficial if any records are missing. Since, it is difficult to get complete records pertaining to fortnightly milk yield from the field and there is a potential that data will be lost because of some unavoidable instances. These mathematical models could be useful in this situation for accurately forecasting missing records. Fitting a mathematical model to the lactation curve is one such exercise that can accurately forecast future herd performance provided that relevant data is available (Thorat *et al.*, 2019). The lactation curve of native, crossbred, and exotic cattle has been fitted using a variety of models. Therefore, the current study was conducted with the goals of fitting and comparing three non-linear models for defining the shape of the lactation curve in crossbred cows and identifying the most appropriate model that can best forecast the stage of prospective output and in implementing enhanced management programs.

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MATERIALS AND METHODS

Data: For the current study, data on total fortnightly milk yields (TFMYs) for the first lactation of 529 crossbred cows were gathered from daily milk recording sheets at Dairy Farm of G.B. Pant University of Agriculture and Technology, Pantnagar distributed over a period of 30 years (1990 to 2019). The animals were housed in a loose housing system. The dry and green fodder were fed in 2:1 proportion, respectively. The concentrate combination used to feed the various types of animals was tailored to meet their nutritional needs. Cows were milked twice daily using full hand milking.

Statistical analysis: A total of 20 fortnightly milk yield averages at an interval of 15 days were considered for the present study. This study did not include crossbred cattle with a history of abortion, stillbirth, infertility, or other reproductive issues were not included in the study. To characterize the lactation curve of crossbred cows, several lactation curve models were fitted, including:

Parabolic exponential function (Sikka, 1950): $Y_t = A.e^{bt+ct^2}$

Inverse polynomial (Nelder, 1966): $Y_t = t(b_0+b_1t+b_2t^2)^{-1}$

Mixed log function (Guo and Swallve, 1995): $Y_t = A + b\ t + c \log t$

Based on the models described above, Y_t = average daily yield on the tth fortnight of lactation, A = initial milk yield immediately following calving, e = exponential constant (2.71828), t = number of days since calving, b = an inclining slope parameter up to peak yield, b_0 = theoretical value at the time of calving, b_1= rising extreme of the curve, b_2 = decreasing extreme of the curve and c = falling slope parameter.

The curve functions (A, b and c) were obtained using the PROC NLIN SAS technique using SAS 9.3 Version, and the model parameters and accompanying standard errors were generated using the Newton iteration approach. The goodness of fit (quality of prediction) *viz.*, coefficient of determination (R^2), root mean square error (RMSE) and the absolute mean deviation (AMD) were used to fit the data and to compare the efficacy of several models in explaining variability in first lactation fortnightly milk output in crossbred cattle. The model with the highest R^2 value and the lowest values for RMSE and AMD was the most suitable for explaining the lactation curve in crossbred cows.

RESULTS AND DISCUSSION

Records of twenty fortnightly average milk production from first lactation in crossbreds cows were utilised to fit three nonlinear lactation models *viz.*, parabolic exponential function (PEF), inverse polynomial function (IPF) and mixed log function (MLF). Table 2 provides the estimated lactation curve functions (A, b, and c). Perusal of Table 3 depicts measures of the models' goodness of fit (accuracy prediction). Except for the "b" value of the MLF, all parameters of other two models were determined to be positive. The negative "b" value found in this study is consistent with the negative "b" parameter for MLF reported by Bangar and Verma (2017) in Gir crossbred cattle, which is -9.69 and Raja *et al.* (2021) in Kankrej cows as -5.731. Similarly, the findings reported by Hossein-Zadeh (2019) in Iranian Holstein cows confirm the favorable values for other functions such as PEF and IPF found in the present study.

The parameter 'A' was discovered to be positive, ranging from 138.31 for the parabolic exponential to 230.12 for the mixed log function. Furthermore, the parameter 'b' also varied between the models. The parameter 'b' estimates ranged from -110.36 (MLF) to 0.021 (PEF). Similarly, variations in the 'c' parameter values were observed in models fitted for fortnight milk yield. The 'c' parameter were 0.001 in PEF and 87.98 in MLF. Existing discrepancies in these parameters (A, b, c) could be due to differences in genetic, dietary, managerial, and climatic factors and confirm the findings reported by Prakash *et al.* (2019) while Subham et al. (2017) and Ali *et al.* (2023) reported negative 'b' estimates -0.002 and -0.0004, respectively for PEF in crossbred cows to compare lactation curve parameters using different non-linear models. In PEF and MLF models, the positive parameter 'A' clearly revealed that this parameter accounted the rising portion of the lactation curve. It was concluded that the inverse polynomial function (IPF) curve and mixed log function (MLF) used to match the 300 days of milk data were typical standard curves for crossbred dairy cows based on the sign/direction of the parameters "b" and "c" acquired in the current study.

Furthermore, the inverse polynomial function predicted average first lactation fortnight milk yields with the highest degree of accuracy (R^2= 97.62%), while the parabolic exponential function predicted the values with the lowest degree of accuracy (R^2= 76.65%) as depicted in Table 3. The inverse polynomial function predicted average first lactation total fortnight milk yields with the lowest RMSE (2.26 Kg), while the parabolic exponential function forecasted the milk yields with the highest RMSE (7.56 Kg). Higher R^2 =99.9% and lower RMSE =0.172 Kg were also discerned by Gupta *et al.* (2020) for first lactation test day milk output prediction using inverse polynomials in HF crossbred cattle while Prakash *et al.* (2019) reported that parabolic exponential function fitted well with higher R^2 value (R^2 = 86.30%) and lower RMSE = 0.0076 Kg followed by mixed log function with R^2 = 85.07%; RMSE= 0.0085 Kg and inverse polynomial function (R^2 = 79.06%; RMSE = 0.0260 Kg).

The parabolic exponential function revealed a broad range of variation between observed and anticipated yield till the conclusion of lactation (Table 1 and Fig. 2). As a result, PEF did not explain the rising, peak yield, and declining phases of lactation in crossbred cows. Meanwhile, a high coefficient of determination value (R^2= 97.62%) explained by the inverse polynomial function which showed that during the first stage of lactation, the anticipated milk yield was maximum between 60-75 days and for later phase of lactation, it eventually diminished to dryness roughly in line with the actual milk yield. In comparison to other functions, the inverse polynomial function had a very low beginning (0-15 days) milk output with a sharp climbing phase.

Figs. 2-5 depicted the observed and predicted milk yields for different lactation curve functions in crossbred

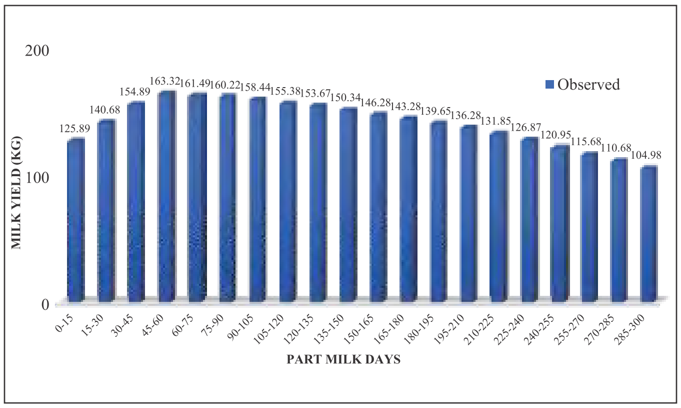

Fig. 1. Observed total fortnightly milk yields upto 300 days of lactation in Crossbred cows.

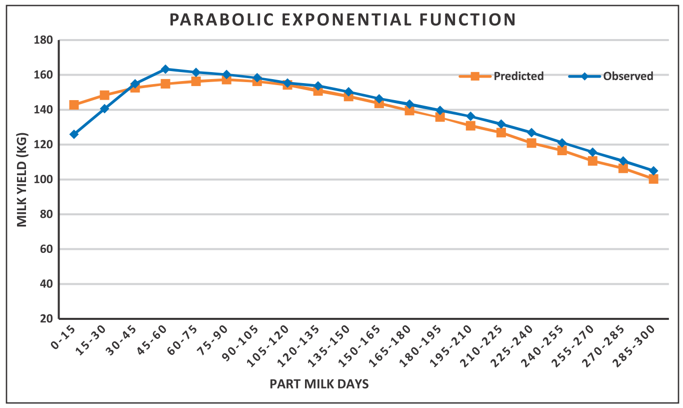

Fig. 2. Observed and predicted total fortnightly milk yields fitted under parabolic exponential function function

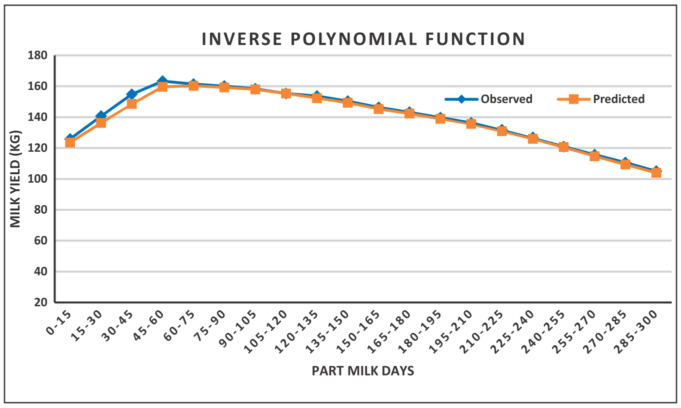

Fig. 3. Observed and predicted total fortnightly milk yields fitted under inverse polynomial function

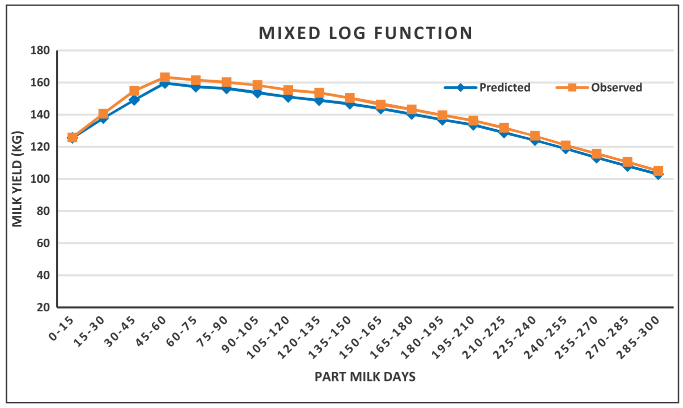

Fig. 4. Observed and predicted total fortnightly milk yields fitted under mixed log function.

cows on a fortnightly basis. The inverse polynomial function's trend in the figure 3, suggested that the function would be best suited to cows with low production during initial days of lactation, reaches its peak very quickly and then begins to decline rapidly. These findings substantiate the results of Savaliya *et al.* (2017) and Gupta *et al.* (2020) in Gir cattle (R^2= 99.76 %) and HF crossbred cows (R^2= 99.9%), respectively. Dongre *et al.* (2013) fitted fortnightly milk yield records using different lactation curve models and stated that higher R^2 = 99.92% for IPF provided the best fit.

Correspondingly, the inverse polynomial function had the lowest absolute mean deviation (AMD=1.52 Kg), which was followed by the mixed log (AMD=2.42 Kg) and the parabolic exponential (AMD=5.27 Kg) function. While comparing fortnightly test day milk yield in crossbreds, Arya *et al.* (2020) also concluded that AMD= 0.12 Kg was least for inverse polynomial and maximum for parabolic exponential (AMD=0.26 Kg). Therefore, it might be concluded that out of three models chosen for the study, the inverse polynomial function is the best mathematical model for explaining the shape of lactation pattern and for predicting the total fortnightly milk yields (TFMYs) in crossbred cows.

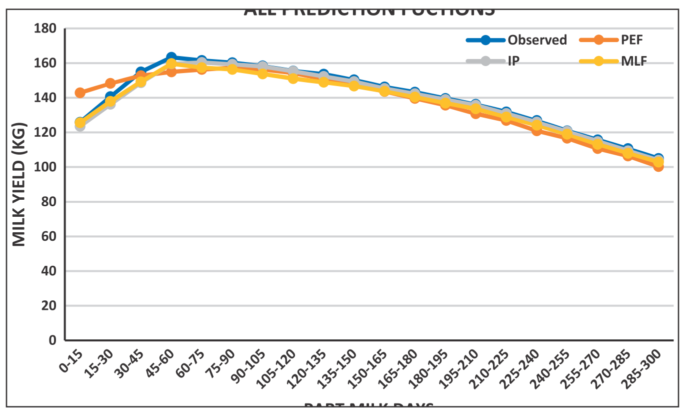

Fig. 5. Comparison between different lactation curve parameters in Crossbred cows using all prediction functions. PEF: Parabolic exponential function; IPF: Inverse polynomial function and MLF: Mixed log function.

CONCLUSION

Due to lower values for RMSE and AMD and higher values for R^2 than the other two models under consideration, inverse polynomial function offered the best fit for the lactation curve of primiparous cows. Conversely, the parabolic exponential function provided the least fit to the lactation curve. In order to increase the production in different grades of crossbred cows, it was recommended that lactation curve models would be useful for establishing

Table 1. Observed and predicted TFMYs and error (Kg) from different models in crossbred cows

Part days	Observed milk yield (Kg)	Parabolic exponential		Inverse polynomial		Mixed log	
		Predicted milk yield (Kg)	Error (Kg)	Predicted milk yield (Kg)	Error (Kg)	Predicted milk yield (Kg)	Error (Kg)
0-15	125.89	142.85	-16.96	123.56	2.33	125.65	0.24
15-30	140.68	148.35	-7.67	136.25	4.43	137.86	2.82
30-45	154.89	152.68	2.21	148.65	6.24	149.22	5.67
45-60	163.32	154.89	8.43	159.62	3.7	159.65	3.67
60-75	161.49	156.38	5.11	160.35	1.14	157.35	4.14
75-90	160.22	157.28	2.94	159.33	0.89	156.35	3.87
90-105	158.44	156.35	2.09	157.98	0.46	153.69	4.75
105-120	155.38	154.28	1.1	155.28	0.1	150.96	4.42
120-135	153.67	150.78	2.89	152.35	1.32	148.97	4.7
135-150	150.34	147.65	2.69	149.36	0.98	146.77	3.57
150-165	146.28	143.69	2.59	145.32	0.96	143.82	2.46
165-180	143.28	139.58	3.7	142.32	0.96	140.38	2.9
180-195	139.65	135.78	3.87	138.98	0.67	136.85	2.8
195-210	136.28	130.83	5.45	135.69	0.59	133.65	2.63
210-225	131.85	126.87	4.98	130.95	0.9	128.79	3.06
225-240	126.87	120.89	5.98	125.98	0.89	124.11	2.76
240-255	120.95	116.68	4.27	120.71	0.24	118.97	1.98
255-270	115.68	110.69	4.99	114.65	1.03	113.2	2.48
270-285	110.68	106.37	4.31	109.36	1.32	107.96	2.72
285-300	104.98	100.32	4.66	103.96	1.02	102.95	2.03

Table 2. Estimated lactation curve parameters for total fortnightly milk yields

S.No.	Non-linear models	Parameters					
		A	b	c	b_0	b_1	b_2
1	Parabolic exponential function (PEF)	138.31	0.021	0.001	-	-	-
2	Inverse polynomial function (IPF)	-	-	-	0.001	0.001	0.0003
3	Mixed log function (MLF)	230.12	-110.36	87.98	-	-	-

Table 3. Goodness of fit criteria for different lactation curve models

S.No.	Non-linear models	R^2 (%)	RMSE (Kg)	AMD (Kg)
1	Parabolic exponential function (PEF)	76.65	7.56	5.27
2	Inverse polynomial function (IPF)	97.62	2.26	1.52
3	Mixed log function (MLF)	93.14	3.56	2.42

management plans at the farm level. However, modeling must be periodically improved before implementation.

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