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RESEARCH ARTICLE

Factors influencing the shape components of the lactation curves of Jersey crossbred cows

Mokidur Rahman[1], I. Gayari[1], Sylvia Lalhmingmawii [1], T.V. Raja[3] and Ajoy Mandal[1](✉)

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Abstract: The present study was conducted to elucidate the effect of important environmental factors on lactation curve parameters and traits of Wood's function in Jersey crossbred cattle. Data on 33906 fortnightly test day milk of 1718 lactation record of Jersey crossbred cows maintained at the Eastern Regional Station of ICAR-National Dairy Research Institute, Kalyani, Nadia, West Bengal were collected over a period of 40 years and utilized for this study. Lactation curve parameters viz. initial milk yield after calving (a); ascending slope up to peak yield (b); and descending slope after peak yield (c) and lactation curve traits viz. peak milk yield (Y_{max}), time of peak yield (N_{max}) and persistency (P) of Wood's function were included for this study. The lactation curve parameters and traits of individual cow for each lactation were estimated using Incomplete gamma function (Wood's model) by fitting Gauss–Newton algorithm as an iteration method using PROC NLIN procedure. The effect of environmental factors on the studied traits were determined by Least squares analysis of variance. The overall least squares means for a, b, c, Y_{max}, N_{max}, and P were 9.07±0.21 kg, 0.340±0.017, 0.108±0.004, 11.22±0.18 kg, 39.45±1.58 days and 3.13±0.03, respectively. Periods of calving had significant ($P<0.05$) effect on all the lactation curve parameters and traits of animals. Seasons of calving significantly ($P<0.01$) affected the curve parameter 'a' and curve traits like Y_{max}, N_{max} and P of animals. Cows calved in summer seasons were poor persistent and peaked earlier than the cows calved in winter and rainy seasons. Parity of cows had significant influence ($P<0.01$) on all the lactation curve parameters and traits except the curve parameter 'b'. Significant effects of different environmental factors on lactation curve parameters/traits indicate that these factors must be taken into consideration for improving the shape of lactation curve of Jersey crossbred population under study.

Key Words: Non-genetic factors, Lactation curve parameters, Peak yield, Persistency, Incomplete Gamma Function, Cattle

[1]ICAR-National Dairy Research Institute, Eastern Regional Station, Kalyani, 741235, West Bengal, India
[2]Project Center for Agro Technologies, Skolkovo Institute of Science and Technology (Skoltech), Moscow 121205, Russia.
[3]ICAR- Central Institute for Research on Cattle, Grass Farm Road, Meerut Cantt, Meerut, Uttar Pradesh 250 001, India

Ajoy Mandal(✉)
E-mail: ajoymandal@gmail.com

Introduction

Basically, a lactation curve is the graphical representation of milk yield against lactation period which describes the pattern of milk production of dairy cows in lactation. A typical lactation curve has three phase's viz. ascending phase, peak and descending phase. Based on different phases of lactation curve, the biological and economic efficiency of cows can be determined (Scott et al. 1996), and it can be an important factor for economic herd management for improvement of milk production traits (Sherchand et al. 1995). Moreover, milk production cost of dairy herd largely depends on the persistency of lactation defined as the rate of decline in milk production after attaining peak milk production (Hickson *et al.* 2006). Cows with flatter lactation curve are more persistent and are always associated with a slow declining rate in milk production, where as a rapid rate of decline in milk yield after peak yield results into poor persistency of cows which is not economically viable (Cole and Van Raden, 2006). In order to improve the lactation yield and persistency of milk yield of dairy animal in a herd, it important to understand the shape of lactation curve with the different phases of lactation.

The biological properties of milk production of dairy animal can be best represented in a lactation curve by three parametric models only (Rekaya *et al.* 2000). The incomplete gamma function proposed by Wood (1967), can be considered as one of the most popular (Macciotta *et al.* 2011) and widely accepted (Dijkstra *et al.* 2010) three parametric model to describe the lactation curve. This model accounts for the main parameters of the lactation curve such as initial milk yield in a lactation, rate of increase as well as rate of decreases of milk yield after peak yield. Moreover, this model also capable to generate the lactation curve traits such as peak yield, time of peak yield and persistency from the estimated parameters (Lopez-Ordaz *et al.* 2009). Hence, studying the lactation curve of dairy animal using this model could be useful to describe the shape of lactation curve and to explore the biological efficiency of dairy cows. The shape of the lactation curve is affected by a number of environmental factors such as cow's parity, age at first calving, dry period, seasons of calving and management of farm (Macciotta *et al.* 2005; Roche *et al.* 2006). Adjustment of this factors is essential for precise estimation of the shape of lactation curve. Therefore, the aim of the present experiment was to investigate the non-genetic factors that affect the shape of the lactation curve of Jersey crossbred cows estimated by incomplete gamma function.

Materials and Method

Data structure

Data pertaining to test day milk yield and pedigree record of Jersey crossbred cows utilized in the present investigations were collected from Animal breeding section of Eastern Regional Station of ICAR-National Dairy Research Institute, Kalyani, India. Initially a total of 33906 fort-nightly test day milk yield belongs to 1718 lactation record of Jersey crossbred cows was collected over a period of 40 years. The record of Jersey crossbred cows with known pedigree and normal lactations only were included for the present study. Culling, abortion, stillbirth and diseased animal were removed from the data sets. Cows having less than 100 days of lactation length and less than 2 kg daily milk yield at the begging of lactation were discarded. The outliers in the data sets were removed to ensure normal distribution of data sets for all the traits before analysis. Data on fortnightly test day milk were classified into 8 periods of calving (5 consecutive years of calving in each period), 3 seasons of calving (winter, summer, rainy) and 7 parities of cows.

Fitting lactation curve

The lactation curve of Jersey crossbred cows was described by Incomplete gamma function or Wood's model (Wood, 1967). The lactation curve parameters of Wood's function were derived by using the nonlinear model: $Y_t = at^b e^{-ct}$, where Y_t is the daily milk yield at t^{th} test day, and 'a' (initial milk yield after calving), 'b' (ascending slope up to peak yield) and 'c' (descending slope after peak yield) are the model parameters that described the biological property and shape of the lactation curves. The lactation curve parameters (a, b and c) of incomplete gamma function of each individual Jersey crossbred cows for each lactation were estimated based on fortnightly test day milk by using PROC NLIN procedure of SAS 9.3 (SAS Institute Inc. 2011) where Gauss–Newton algorithm was used as an iteration method. From the estimated lactation curve parameters, the lactation curve traits such as peak milk yield (Y_{max}), time of peak milk yield (N_{max}) and persistency of milk yield (P) for individual animals for each lactation were generated as described by Wood (1976).

Statistical analysis

Least squares analysis of variance (Harvey, 1990) was applied to determine the effects of different non-genetic factors viz. period of calving, season of calving, parity of cow on lactation parameters and traits of animals. The following model was used

$$Y_{ijkl} = \mu + P_i + S_j + (PA)_k + b(AC)_{ijkl} + e_{ijkl}$$

Where, Y_{ijkl} is the observation of the studied traits, μ = Overall mean value of studied traits. P, S, and (PA) are the effects of i^{th} period of calving, j^{th} season of calving, k^{th} parity respectively. b is the regression coefficient for age at calving (AC) and e_{ijkl} is the residual error ~ NID (0, σ^2_e). Modified Duncan's multiple range test (Kramer,1957) was used for testing differences among least squares means.

Results and discussion

Based on estimated parameters of Wood's model, it was observed that out of the total 1718 individual lactation records, 16.88 % revealed atypical lactation curve due to negative estimates of parameter 'b' and/or 'c' and. Hence a total of 1428 individual lactation records of Jersey crossbred cows showed typical lactation curve were subjected to further analysis.

Environmental factors affecting lactation curve parameters

Least-squares means along with standard errors of different lactation curve parameters in Jersey crossbred cows have been presented in Table 1. The overall least-squares means of lactation curve parameters a, b and c were 9.07±0.21, 0.34±0.02 and 0.11±0.004, respectively.

These three characteristic parameters of the Wood function determine the shape of the lactation curves of Jersey crossbred cows. Perusal of Table 1 revealed that period of calving significantly (P<0.01) affected the initial milk yield after calving (a), ascending slope up to peak yield (b) and descending slope after peak yield (c) of a lactation curve obtained by Woods function in Jersey crossbred cows. Animals calved during the periods 8 (2016-2020) and 7 (2011-2015) periods had significantly higher estimates for initial yield after calving (a) than the earlier calving periods. From our study, it was observed that the estimate for initial milk yield after calving (a) in Jersey crossbred cows improved over the period of time. Significant effects of period of calving on initial milk yield were also reported in Holstein purebred cattle (Güler and Yanar, 2009) and Holstein crossbred cattle (Osorio Arce and Segura Correa, 2005). The estimates for ascending slope up to peak yield (b) and descending slope after peak yield (c) were found to be significantly (P<0.01) higher in cows calved during the year 2006 onwards than the earlier years of calving in this crossbred cows. Similar to present findings, Batra (1986), Osorio Arce and Segura Correa (2005), Güler and Yanar (2009) and Atashi *et al.* (2009) also reported significant influence of calving period on parameters 'b' and 'c' of the Wood's function in different breeds of cattle. Tekerli *et al.* (2000) observed that calving period had only significant effect on descending slope after peak yield (c) in Holstein cattle. Contrary to present findings, Rao and Sundaresan (1979) did not find any influence of calving period on ascending slope up to peak yield (b) and descending slope after peak yield (c) of a lactation curve of Sahiwal cows. Significant variation in lactation curve parameters with respect to different calving periods in Jersey crossbred cows could be attributed to differences in herd management such as feeding, nutrition, and health management over the period of time; changes in the environment such as temperature, rainfall, and humidity in different periods; and interaction between environmental changes and management interventions over time.

In the present study, seasons of calving was highly significant ($P<0.01$) on parameter 'a' of Wood's function in Jersey crossbred cows. Cows calved in winter (9.43±0.25) and summer (9.36±0.24) season has significantly ($P<0.01$) higher estimates of initial milk yield after calving (a) than cows calved in rainy (8.44±0.24) season. However, there were no significant differences ($P>0.05$) between winter and summer calvers' with respect to initial milk yield estimates. Güler and Yanar (2009); Atashi *et al.* (2009); Boujenane and Hilal (2012) and Torshizi (2016) observed that calving seasons had significant influence on initial milk yield estimate in Holstein cows, which was in consistent with our findings. However, Rao and Sundaresan (1979) and Tekerli *et al.* (2000) revealed non-significant effect of seasons of calving on initial milk yields estimates (a). In our study, cows calved during the rainy season had lower initial yields than cows calved during the summer and winter seasons. This could be because of cows calved during the rainy season passed through the majority of their pregnancy period during the summer seasons, and pregnant cows during the summer seasons were subjected to the most stress conditions due to high ambient temperature and humidity, as well as a lack of availability of green fodder, which may affect the optimal growth and proliferations of udder secretory cells resulting poor initial milk yield after calving. The initial milk yield of lactating cows is determined by the growth and exponential increase of udder secretary cells during the pregnancy period (Knight and Wilde, 1993). Further, non-significant ($P>0.05$) effect of seasons of calving on ascending slope up to peak yield (b) and descending slope after peak yield (c) was observed in our study (Table 1). These findings were consistent with the findings of Tekerli *et al.* (2000), Osorio Arce and Segura Correa (2005) and Torshizi (2016), who reported that the season of calving had non-significant effect on the estimates for the ascending and descending slopes of the lactation curve in different breeds of cattle.

All lactation curve parameters except the parameter 'b of Wood's function varied significantly ($P<0.05$) among different parities of

Table 1: Least-squares means along with standard errors of different lactation curve parameters in Jersey crossbred cows

Effects	N	Initial milk yield after calving (a)	Ascending slope up to peak yield (b)	Descending slope after peak yield (c)
Overall Mean (μ)	1428	9.07±0.21	0.340±0.017	0.108±0.004
Periods of Calving				
PD1 (1981-85)	38	9.01±0.58^{b}	0.258±0.046^{c}	0.079±0.012^{d}
PD2 (1986-90)	103	8.59±0.40^{b}	0.301±0.032^{bc}	0.099±0.008^{cd}
PD3 (1991-95)	139	8.83±0.34^{b}	0.317±0.027^{bc}	0.098±0.007^{cd}
PD4 (1996-2000)	195	9.04±0.31^{b}	0.347±0.024^{bc}	0.106±0.006^{c}
PD5 (2001-05)	184	8.99±0.29^{b}	0.361±0.023^{b}	0.112±0.006^{bc}
PD6 (2006-10)	224	8.66±0.28^{b}	0.430±0.023^{a}	0.136±0.006^{a}
PD7 (2011-2015)	224	9.36±0.30^{ab}	0.377±0.024^{ab}	0.127±0.006^{ab}
PD8 (2016-2020)	321	10.14±0.25^{a}	0.328±0.020^{bc}	0.106±0.005^{c}
Seasons of calving				
Winter	476	9.43±0.25^{a}	0.357±0.020	0.106±0.005
Summer	480	9.36±0.24^{a}	0.337±0.019	0.113±0.005
Rainy	472	8.44±0.24^{b}	0.325±0.019	0.104±0.005
Parities of dam				
P1	422	8.98±0.33^{c}	0.308±0.026	0.073±0.007^{c}
P2	314	10.54±0.23^{a}	0.285±0.018	0.088±0.005^{c}
P3	245	10.36±0.22^{a}	0.313±0.017	0.102±0.005^{b}
P4	161	10.15±0.32^{ab}	0.313±0.025	0.105±0.007^{b}
P5	115	9.19±0.44^{bc}	0.350±0.035	0.118±0.009^{ab}
P6	87	8.06±0.57^{cd}	0.397±0.046	0.132±0.012^{a}
P7 (>6 lactations)	84	6.83±0.72^{d}	0.411±0.057	0.138±0.015^{a}

Means with different superscript between the rows in a column differs significantly cows in the current study (Table 1). Cows in first parity exhibited significantly ($P<0.01$) lower initial milk yield after calving (a) than cows of subsequent parities (up to 4th parity) and thereafter started to decline as as the parity advanced beyond fourth and the estimate for initial milk yield found to be lowest in the 7th parity or above in Jersey crossbred cows in our study. As observed in the present study, significantly higher estimates of initial milk yield in second, third and fourth parity than first parity was also observed by Gebreyohannes *et al.* (2013) in crossbred cattle. Osorio Arce and Segura Correa (2005) reported the highest estimate of parameter 'a' during the fourth parity and declines thereafter as parity progressed in crossbred cows, which support the current findings. On contrary, non-significant effect of parity of cow on initial milk yield was observed in Holstein cattle (Tekerli *et al.* 2000; Güler and Yanar, 2009). Significantly higher estimates of initial milk yield in second to fourth lactation than first lactation of Jersey crossbred cows in our study could be associated with higher bodyweight, maturity and aging of multiparous cows over primiparous cows. Moreover, most of the feed energy was utilized for body growth in heifers rather than milk production could be another reason of low estimates of initial milk yield. Cows in greater than fourth parities had lower initial milk yield estimates in our study which could be due to old age, declining physical and physiological condition, and degeneration caused by multiple pregnancies. In our study, ascending slope up to peak yield (b) of lactation curve was unaffected by different parities of Jersey crossbred cows which was in agreement with the findings of Tekerli *et al.* (2000), Osorio Arce and Segura Correa (2005) and Güler and Yanar (2009) in different cattle breeds. In our study, significantly lower estimates of descending slope after peak yield (c) was observed in cows of first two lactations than cows of subsequent parities. As the lactation advances, the descending slope up after peak yield (c) increased and reached maximum in sixth and above lactation in Jersey crossbred cows. Similar to the present results, Atashi *et al.* (2009), Boujenane and Hilal (2012) and Gebreyohannes *et al*. (2013) found that the descending slope up to peak yield increases significantly as lactation progresses in various cattle breeds. . The regression of age at calving was also highly significant ($P<0.01$) for initial milk yield in the present study (Table 1).

Environmental factors affecting lactation curve traits

Table 2 showed the least-squares means along with standard errors of different lactation curve traits in Jersey crossbred cows. The average values of different lactation curve traits, peak milk yield (Y_{max}), time of peak yield (N_{max}), persistency (P) were estimated as 10.22±0.18 kg, 39.45±1.58 days and 3.13±0.03, respectively. In this study, cows calved in different years/periods showed significant ($P<0.05$) variations in Y_{max}, N_{max} and P in Jersey crossbred cows (Table 3). Animal calved during PD8 (2016-2020) period had significantly ($P<0.01$) higher peak milk yield (11.32±0.22 kg) than cows calved in earlier periods in our study. Significant effect of calving period on variation of peak milk yield,

Table 2: Least-squares means along with standard errors of different lactation curve traits in Jersey crossbred cows

Effects	N	Peak milk yiled (Y_{max}) in Kg	Time of peak yiled (N_{max}) in days	Persistency of milk yield (P)
Overall Mean	1428	10.22±0.18	39.45±1.58	3.13±0.03
Periods of calving				
PD1 (1981-1985)	38	9.85±0.50^{b}	45.45±4.31^{a}	3.40±0.09^{a}
PD2 (1986-1990)	103	9.59±0.34^{b}	34.33±2.96^{b}	3.15±0.06^{b}
PD3 (1991-1995)	139	9.95±0.30^{b}	39.43±2.55^{ab}	3.17±0.05^{b}
PD4 (1996-2000)	195	10.43±0.27^{b}	41.09±2.30^{ab}	3.14±0.05^{b}
PD5 (2001-2005)	184	10.33±0.25^{b}	40.44±2.18^{ab}	3.14±0.04^{b}
PD6 (2006-2010)	224	10.02±0.25^{b}	41.07±2.12^{ab}	2.98±0.04^{c}
PD7 (2011-2015)	224	10.27±0.26^{b}	35.08±2.21^{b}	2.98±0.04^{c}
PD8 (2016-2020)	321	11.32±0.22^{a}	38.74±1.89^{ab}	3.11±0.04^{b}
Seasons of calving				
Winter	476	10.98±0.22^{a}	42.46±1.86^{a}	3.16±0.04^{a}
Summer	480	10.23±0.21^{b}	35.01±1.80^{b}	3.05±0.04^{b}
Rainy	472	9.45±0.21^{c}	40.89±1.77^{a}	3.20±0.04^{a}
Parities of dam				
P1	422	11.07±0.29^{b}	49.56±2.48^{a}	3.50±0.05^{a}
P2	314	11.80±0.20^{a}	38.51±1.73^{b}	3.22±0.03^{b}
P3	245	11.48±0.19^{ab}	36.98±1.62^{b}	3.13±0.03^{c}
P4	161	11.09±0.27^{b}	36.49±2.35^{b}	3.09±0.05^{c}
P5	115	10.22±0.39^{c}	40.00±3.32^{b}	3.04±0.07^{c}
P6	87	8.77±0.50^{d}	37.87±4.27^{b}	3.02±0.08^{c}
P7 (>6 lactations)	84	7.12±0.62^{e}	36.76±5.36^{b}	2.94±0.11^{c}

Means with different superscript between the rows in a column differs significantly as observed in this study, was also reported by Lakshmi *et al.* (2010) in Frieswal, Torshizi (2016) in Holstein cattle and Roy *et al.* (2024) in Jersey crossbred cattle. Variations of peak milk yield in different calving periods were also observed in purebred cattle (Tekreli *et al.* 2000 and Atashi *et al.* 2009). The time to reach peak yield was higher (45.45±4.31 days) in cows calved during the PD1 (1980-85) and lower in cows calved during PD2 (1986-90) and PD7 (2011-15) and these differences were statistically significant (P<0.05). Similarly, persistency of milk yield was also found to be significantly (P<0.01) higher in cows calved during PD1 (1981-85) and lower in cows that calved during PD6 and PD7 (Table 2). The present findings were supported by the findings of Gahlot *et al.* (1989); Tekerli *et al.* (2000); Atashi *et al.* (2009) and Güler and Yanar, (2009), who found significant influences of calving period on time of peak yield and persistency of milk yield in various crossbred and purebred cattle. The lactation curve traits of Jersey crossbred cows in the present study were affected by different periods of calving. However, there was no definite trend for time of peak yield and lactation persistency over the periods which could be the result of differences in the managemental strategies and environmental changes over the period of time.

The present study revealed that season of calving had highly significant (P<0.01) effect on all lactation curve traits considered for this study (Table 2). Winter calvers produced significantly higher peak milk yield (10.98±0.22 kg) than cows calved during summer season (10.23±0.21 kg) and rainy season (9.45±0.21 kg). The present findings agreed with those of Tekerli *et al.* (2000), Atashi *et al.* (2009) and Khalifa *et al.* (2018) who found that cows calved in winter season had higher peak yield than cows calved in any other seasons in different breeds of cattle. However, some researchers (Rao and Sundaresan, 1979; Güler and Yanar, 2009) observed non-significant effect of calving season on peak milk yield variation, which was contrary to our findings. Further, cows calved during winter and rainy seasons had significantly (P<0.01) higher persistency and time of peak yield than the cows calved in summer season. Seasons of calving had significant impact on lactation persistency (Atashi *et al.* 2009; Albarrán-Portillo and Pollott, 2011; Boujenane and Hilal, 2012; Hermiz and Hadad, 2020) and time of peak yield (Atashi *et al.* 2009; Albarrán-Portillo and Pollott, 2011) in different cattle breeds, which was consistent with our findings. In our study, Jersey crossbred cows calved in summer season was poor persistent and peaked earlier than the cows calved in winter and rainy seasons. Cows calved in summer season were prone to thermal stress due to high ambient temperature and humidity, which might be affected the lactation performances of animal as heat stress in summer season can reduce the milk production and also affect the normal physiological functions of cows (Bouraoui *et al.* 2002). Moreover, lack of availability of sufficient green fodders could be another reason of poor persistency and earlier time of peak yield in Jersey crossbred cows calved in summer season.

Parity-wise analysis of lactation curve traits revealed that all lactation curve traits viz. peak milk yield, time of peak yield and persistency of milk yield was significantly (P<0.01) affected by cow's parity in Jersey crossbred cows (Table 2). Peak milk yield was found to be significantly (P<0.01) higher in cows of 2nd and 3rd parities as compared to younger cows and afterwards the peak milk yield of cows started to decline as parity advances and it became lowest in the sixth and onward parities (Table 2). Similar to the present findings, Tekerli *et al.* (2000); Rekik *et al.* (2004) and Albarrán-Portillo and Pollott (2011) also noticed the significant influence of cow's parity on peak milk yield in various cattle breeds. According to Miller *et al.* (2006), the metabolic activity of mammary glands was higher in multiparous cows especially during peak lactation than primiparous cows, which could be the reason for higher peak milk yield during second or third lactation in the present study. As the lactation progressed beyond third, the peak yield declined which might be a result of declining physical and physiological condition, and degeneration caused by multiple pregnancies and old ages. Time of peak yield and persistency of milk yield were found to be significantly (P<0.01) higher in first lactation in Jersey crossbred cows in our study. Although, there were no differences of time of peak yield in subsequent parities but persistency of milk yield declined significantly as the lactation progressed. Several workers (Tekerli *et al.* 2000; Rekik *et al.* 2004; Atashi *et al.* 2009; Boujenane and Hilal, 2012) reported higher persistency and longer time of peak yield of animals in first lactation than subsequent lactations in various cattle breeds which were in agreement with our results. Cows take longer time to reach peak milk yield in the first lactation than subsequent lactations which indicates that milk secretary tissues of mammary gland of primiparous cow takes longer time to reach its peak activity than multiparous cows. Moreover, multiparous cows encounter various diseases (metabolic diseases, mastitis etc.) associated with lactation than primiparous cow, which ultimately affected the persistency of milk in later lactations of cows.

Conclusion

The present study revealed that different environmental factors, viz., period of calving, season of calving and parity of cows significantly affected most of the lactation curve parameters in Jersey crossbred cattle estimated by Wood's model significantly (P<0.01) under the prevalent management systems of the farm. Further, the different lactation curve traits (peak yield, time of peak yield and persistency of milk yield) were also significantly influenced by all environmental factors considered for this study. The aforementioned factors distinctly influence the configuration of the lactation curve, which in turn dictates the overall lactation performance and productivity of the animal. The variations observed across various periods and seasons of calving illustrate the impact of changes in management practices, environmental conditions, and climatic factors over time. The improvement in lactation performance that has been shown in recent periods is an indicative of improved herd management, nutrition, and breeding interventions. Additionally, the enhanced performance of cows during mid parities underscores the significance of physiological maturity in attaining optimal lactation efficiency, whereas the decrease observed in later parities may be linked to age related physiological impact. Therefore, the important environmental factors affecting these traits must be taken into consideration for improving the shape of lactation curve of Jersey crossbred cows which ultimately lead to improving the persistency and quantum of milk production in Jersey crossbred population. Moreover, the identified non-genetic factors/effects are not entirely breed-specific, as similar trends have been reported in other dairy breeds; however, the magnitude and direction of influence may vary under different genetic backgrounds and environmental conditions. These findings therefore, emphasize the importance of considering these environmental and physiological factors while designing herd management and breeding strategies for Jersey crossbred cattle.

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