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An overview of lactation curve models for predicting milk yield in Murrah Buffalo

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Abstract

Milk production is a continuous physiological process during lactation, characterized by the rate of milk secretion as lactation progresses. Even under consistent environmental and managerial conditions, the biometric traits of lactation vary among genetic groups. Although the quantitative levels of milk production differ, the overall trend remains similar, with an initial phase of rapid increase leading to a peak, followed by a gradual decline. In this review, various models have been evaluated for their effectiveness in describing milk yield patterns and predicting 305-day milk yield based on daily milk yield records.

Keywords: Murrah Buffalo, lactation, daily milk yield, Milk production, physiological process

Introduction

Buffalo holds significant importance in India's dairy industry, contributing nearly half of the nation's total milk production (BAHS, 2023) [5]. This underscores the widespread adoption of the Murrah breed of buffalo among Indian farmers. Known for their higher milk fat content compared to cattle, buffaloes are extensively reared in peri-urban and rural farming systems with a primary focus on quality milk production.

In buffaloes, milk production traits exhibit a curvilinear pattern throughout the lactation. Analysing the lactation curve of dairy animals provides valuable insights into the dynamics of milk production traits, which are significantly influenced by both genetic and non-genetic factors. Non-genetic factors such as the calving period, season of calving, age at first calving, and parity have a profound impact on lactation parameters. Understanding these influences enables breeders to enhance economically important traits like milk production.

The lactation curve is a graphical depiction of milk yield over time (Brody *et al*., 1923) [10] or can also represent the rate of milk secretion as lactation advances. It typically comprises two distinct phases: a rapid increase from calving to peak yield in the early lactation stage, followed by a gradual decline until the end of lactation (Leon-Velarde *et al*., 1995) [49]. The ascending phase reflects a steep, linear rise in milk yield, the persistent phase showcases the animal's innate capacity for consistent milk production, and the descending phase is shorter and usually associated with the drying-off stage.

The biometric characteristics of lactation vary across its stages, even when environmental and managerial conditions remain constant (Yadav and Sharma, 1985) [94]. Economically, the shape of the lactation curve is vital, as animals producing a steady, moderate level of milk throughout lactation are preferred over those that peak highly but taper off quickly. A sharp decline in milk yield post-peak increases production costs as the yield becomes unevenly distributed. Factors like lactation yield and persistency significantly influence milk production costs. Identifying cows with specific lactation patterns and persistency can provide an additional selection criterion for dairy herds.

Modelling the lactation curve offers numerous benefits, including predicting a cow's milk yield during lactation with minimal error. It aids in cow/sire evaluation, allowing for decisions about culling or identifying animals with subclinical diseases (Vargas *et al*., 2000) [89].

Furthermore, it helps predict production potential from field records and provides a concise summary of biological efficiency and persistency in dairy animals. Knowledge of lactation curves is also crucial for herd management, selection strategies, and genetic evaluation aimed at improving milk production traits.

The effectiveness of a lactation model depends on its ability to replicate the biological lactation process and adjust for environmental and other influencing factors. The goal of modelling lactation curves is to predict milk yield at any point during lactation with high accuracy. Numerous studies have been conducted on dairy cattle to fit lactation curve models (Dongre *et al*., 2011 and Banu *et al*., 2012) [62, 7], but limited research exists on fitting such models for Murrah buffaloes (Sahoo *et al*., 2014) [73].

Review of Literature

Non-genetic factors affecting lactation curve

The various non-genetic factors *viz.* the Period of calving, the Season of calving, Parity and Age at first calving affect the shape of the lactation curve. The effect of these factors has been studied by various workers in different regions on dairy animals.

Effect of period of calving

In Holstein Friesian cattle, the period of calving (POC) has been found to significantly influence the upward slope of the lactation curve (Wood, 1967) [91]. A similar effect of POC on the shape of the lactation curve was observed in Sahiwal cattle by Rao and Sundaresan (1979) [67] and in Hariana cattle by Mehto *et al*. (1980) [51] using the Wood function.

For Holstein cows, Dedkova and Nemcova (2003) [21] reported a highly significant effect of POC. In Murrah buffaloes, Patil *et al*. (2011) [62] observed a significant impact of POC ($p<0.01$) on age at first calving, while Barman *et al*. (2013) [9] documented its significant effect on lifetime milk yield, productive life, and herd life. Geetha (2005) [33] noted a significant influence of POC on all monthly test-day milk yields, except for the 35th, 215th, and 305th test days. Similarly, Rana (2008) [66] highlighted its significant effect on all first lactation cumulative test-day milk yields, while Thiruvenkadan *et al*. (2014) [86] observed a significant impact on complete lactation milk yield (CLMY), lactation length, peak yield, and 305-day milk yield, along with its effect ($p<0.05$) on days to attain peak yield. Dass and Sadana (2000) [18], Jakhar *et al*. (2017) [39], and Thiruvenkadan *et al*. (2010) [87] reported a highly significant ($p<0.01$) effect of POC on age at first calving, further confirmed by Thiruvenkadan *et al*. (2015) [85].

POC also significantly affects reproduction traits ($p<0.05$) and production traits ($p<0.01$), as highlighted by Jamuna *et al*. (2015) [40]. Narwaria *et al*. (2017) [54] reported a highly significant ($p<0.01$) impact on total milk yield, milk yield per lactation length, and milk yield per calving interval. Verma *et al*. (2016) [90] found a significant ($p<0.05$) effect on total milk yield and 305-day milk yield, with similar results observed by Sarkar *et al*. (2006) [74]. Pareek and Narang (2015) [59] noted a highly significant ($p<0.01$) influence of POC on persistency, 305-day milk yield, and peak yield.

In Murrah buffaloes, Chitra *et al*. (2018) [14] demonstrated a highly significant ($p<0.01$) effect on milk constituents and their yield traits. Dangar and Vataliya (2018) [16] observed a significant ($p<0.05$) impact on complete lactation milk yield in Jaffarabadi buffaloes, while Mire *et al*. (2019) [52] reported a highly significant ($p<0.01$) effect on CLMY and lactation length. In Sahiwal cattle, Pandey *et al*. (2019) [58] documented POC's influence on first lactation 305-day milk yield and lifetime milk yield. Suresh *et al*. (2004) [82] found a highly significant ($p<0.05$) effect on days to attain peak yield, and Sigdel *et al*. (2015) [75] identified a significant ($p<0.05$) effect on daily and 305-day milk yields in Murrah buffaloes. Kumar *et al*. (2003) [46] noted a significant ($p<0.05$) impact on the first total lactation milk yield (TLMY), while Penchev *et al*. (2011) [65] reported a significant ($p<0.01$) effect on daily milk yield in Bulgarian Murrah buffaloes.

Ambhore *et al*. (2016) [2] highlighted the highly significant ($p<0.01$) impact of POC on all first lactation traits except for the first service period, which showed significance at ($p<0.05$). Tailor and Singh (2011) [83] observed a significant ($p\leq0.05$) effect on the 1st, 4th, 6th, and 7th monthly test-day milk yields, while Kumar *et al*. (2012) [64] reported a highly significant ($p\leq0.01$) influence on the 9th test-day milk yield. Singh (2014) identified a highly significant ($p<0.01$) effect of POC on the 305-day first lactation milk yield and all monthly test-day milk yields except for the 9th. Gajbhiye and Tripathi (1999) [30] noted a highly significant ($p<0.01$) influence on the first lactation 305-day milk yield, with similar findings reported by Dhirendra *et al*. (2003) [23] in Murrah buffaloes and Pathodiya and Jain (2004) [61] in Surti buffaloes.

In Murrah buffaloes, a significant effect of POC on 305-day milk yield was documented by El-Arian (1986) [27], Gajbhiye (1987) [31], Tomar and Tripathi (1988) [88], Singh *et al*. (1990) [80], Ipe and Nagarcenkar (1992) [38], Sahana (1993) [70], Dass and Sharma (1994) [19], Nath (1996) [55], Saha (1998) [69], Lathwal (2000) [48], and Gupta (2009) [35]. Dev *et al*. (2015) [22] also reported its significant impact on first lactation milk yield and first lactation peak milk yield, while Pander *et al*. (2017) [57] noted its significant influence on the first service period in Hardhenu cattle.

Effect of season of calving

Yadav *et al*. (1977a) [92, 93] applied the gamma function to average yields in Hariana cattle and reported a significant effect of Season of Calving (SOC) on all parameters of the Wood function. Similarly, Rao and Sundaresan (1979) [67] found a significant impact of SOC on the shape of the lactation curve in Sahiwal cattle, which was also observed in Hariana cattle by Mehto *et al*. (1980) [51] for all three parameters of the gamma function. Additionally, Tekerli *et al*. (2000) [84] and Atashi *et al*. (2009) [3] documented a significant influence of SOC on the shape of the lactation curve in Holstein Friesian cattle.

Patro and Bhat (1979) [63] observed a highly significant effect ($p<0.01$) of SOC on the first lactation 305-day milk yield in Murrah and Nili-Ravi buffaloes, with higher yields recorded for lactations beginning between July and December compared to January to June. El-Arian (1986) [27] also reported a significant effect of SOC on the 305-day lactation milk yield in Murrah buffaloes, noting that summer calvers produced more milk than winter calvers, followed by autumn and rainy season calvers. Dhirendra *et al*. (2003) [23] confirmed similar findings for 305-day lactation milk yield. In Hardhenu cattle, Pander *et al*. (2017) [57] found a significant effect only on the first service period.

Thiruvenkadan *et al*. (2014) [86] reported that SOC significantly affected total lactation milk yield (TLMY) and had a highly significant ($p<0.01$) impact on peak yield, days to attain peak yield, and 305-day milk yield in Murrah buffaloes. A significant ($p<0.05$) effect on age at first calving was observed by Thiruvenkadan *et al*. (2015) [85], who also noted that milk yields were highest for winter calvers, followed by rainy and summer season calvers, findings supported by Pawar *et al.* (2012) [64]. Dass and Sadana (2000) [18], Verma *et al.* (2016) [90], and Sarkar *et al.* (2006) [74] also highlighted the significant effect of SOC on TLMY.

In Egyptian buffaloes, Hassan *et al.* (2017) [36] revealed a highly significant (p<0.01) impact of SOC on daily milk yield, 305-day milk yield, lactation length, and TLMY. Winter calvers had the highest daily milk yield compared to other seasons, with the fourth parity yielding the best results. Kamble *et al.* (2014) [42] reported longer lactation lengths among buffaloes calving in winter, whereas summer calvers exhibited shorter lactation lengths.

Ambhore *et al.* (2016) [2] noted that SOC significantly (p<0.05) influenced first lactation 300-day milk yield but had no significant effect on other first lactation traits. Jamuna *et al.* (2015) [40] found SOC significantly impacted service periods and days to first service, while Parmar *et al.* (2018) [60] reported a highly significant (p<0.01) effect on all test-day yields. Additionally, Patil *et al.* (2011) [62] observed a significant (P<0.01) effect on the first service period, and Narwaria *et al.* (2017) [54] found a significant (p<0.01) impact on milk yield per lactation length.

Sigdel *et al.* (2015) [75] documented a significant effect of SOC on daily milk yield (p<0.01), lactation length (P<0.05), and 305-day milk yield (p<0.01) in Nepalese Murrah buffaloes. Pareek and Narang (2015) [59] reported SOC significantly affected peak yield. Dev *et al.* (2015) [22] found significant effects on the first service period and first calving interval in Murrah buffaloes.

Garcha and Dev (1994) [32] observed a significant influence of SOC on all test-day milk yields in Murrah buffaloes, while Dass (1995) [20] noted its effect on the 2nd, 6th and 7th monthly test-day milk yields in Surti buffaloes. Tailor and Singh (2011) [83] reported a significant (p≤0.05) impact of SOC on all test-day milk yields in Surti buffaloes. However, Kumar *et al.* (2012) [64] found a significant effect only on the 2nd test-day milk yield in Murrah buffaloes.

Effect of age at first calving

Yadav *et al.* (1977b) [92, 93] applied the Wood function to average weekly yields in Hariana cattle and its Friesian crosses, finding a significant effect on the inclining and declining parameters of the lactation curve. Using the Wood function in Sahiwal cows, Rao and Sundaresan (1979) [67] reported a significant influence of age at first calving (AFC) on the lactation curve's shape. Similarly, Mehto *et al.* (1980) [51] observed in Hariana crossbreds that initial milk yield increased linearly with advancing age of the cows, as indicated by their lactation sequence. Dedkova and Nemcova (2003) [21], studying Holstein cattle, noted that cows with a lower age at first calving exhibited the best persistency, while a slower growth in the slope up to the production peak was observed in cows with a higher age at calving, as modeled by the Wood function.

In Holstein cows, Tekerli *et al.* (2000) [84] found AFC to have a significant effect (p<0.05) on peak yield, while its influence on lactation yields and the lactation curve was also noted. Jamuna *et al.* (2015) [40] observed a highly significant effect (p<0.01) of AFC on service period and lactation length. Parmar *et al.* (2018) [60] reported a highly significant effect (p<0.01) of AFC grouping on all lactation test-day yields. In Sahiwal cattle, Pandey *et al.* (2019) [58] highlighted a significant effect of AFC on lifetime milk yield.

Rana (2008) [66] documented that the regression of cumulative test-day milk yields showed a significant effect (p<0.05) on the first test day, which became highly significant (p<0.01) for the remaining cumulative test-day yields and the 305-day milk yield. Observed highly significant effects (p≤0.01) of AFC on the first lactation 305-day milk yield and monthly test-day yields TD-1, TD-2, TD-3, TD-4, TD-7, and TD-9, along with significant effects (p≤0.05) on TD-5.

Effect of parity

Rao and Sundaresan (1979) [67] stated that in Holstein Friesian cattle, least-squares analysis of traits linked to lactation curve shape showed that parity significantly influenced the lactation curve, a finding also reported by Tekerli *et al.* (2000) [84]. Horan *et al.* (2005) [37], studying Holstein Friesian cows, found parity had a significant impact on all three lactation curve parameters, particularly peak production and lactation persistency. They observed that higher parity animals had increased intercept values along with steeper incline and decline parameters. Similarly, Atashi *et al.* (2009) [3] reported a significant effect of parity on lactation, whereas Singh and Yadav (1987) [77] noted that daily milk yield in Murrah buffaloes increased with the number of lactations.

Thiruvenkadan *et al.* (2014) [86] reported in Murrah buffaloes that daily milk yield increased from the first to fourth parities. They also observed a highly significant effect of parity (p<0.01) on total lactation milk yield (TLMY), 305-day milk yield (305 MY), peak yield, and lactation length, with days to attain peak yield decreasing from the first to the fifth parity.

Dass and Sadana (2000) [18], Jamuna *et al.* (2015) [40], Verma *et al.* (2016) [90], and Jakhar *et al.* (2017) [39] found that parity significantly affected 305 MY (p<0.01) in Murrah buffaloes. Chaudhary *et al.* (2000) [13] reported a peak yield of 9.8±0.55 kg for first-parity buffaloes, which increased until the fourth parity and declined thereafter.

Sigdel *et al.* (2015) [75] observed in Murrah buffaloes a significant impact of parity on daily milk yield in Nepal, with the 305-day milk yield and TLMY significantly influenced by parity (p<0.01). Jamuna *et al.* (2015) [40] also reported a significant effect of parity on reproduction traits (p<0.05) and production traits (p<0.01).

Hassan *et al.* (2017) [36], studying Egyptian buffaloes, found parity had a significant effect on daily milk yield, lactation length, and TLMY (p<0.01), with the highest TLMY occurring in the fourth parity before declining. Sundaram and Harharan (2013) [81] revealed that 305-day milk yield was significantly affected (p<0.05) by lactation number in Murrah buffaloes. In swamp buffaloes, reported that peak yield was significantly influenced by parity (p<0.01), increasing gradually until the fourth parity and then declining.

Comparative efficiency of different lactation curve models

Singh and Bhat (1978) [76] found that lactation of varying durations (<44 weeks) in Hariana cattle was best described by the parabolic exponential function, which provided a good fit with an R^2 value of 74% for first lactation milk yield. They also reported an R^2 value of 97.3% for the gamma function in describing the average lactation curve in Hariana cattle, while the inverse polynomial function explained 99.9% of the variation.

Ali and Schaeffer (1987) [1] compared three models-ranked regression, gamma function, and inverse quadratic polynomial function for describing lactation curves in individual cows. The gamma function achieved a relative efficiency of 74.7% compared to selection based solely on 305-day milk yield.

Gahlot *et al.* (1988) [29] observed that the parabolic exponential model was a good fit ($R^2 = 74\%$) for first lactation milk yield, while the inverse polynomial function provided the best fit. Additionally, the gamma function explained 94.68% of the variation in average monthly milk yields in Rathi cows.

Olori *et al.* (1999) [56] reported an R^2 value of 96.4% for the mixed log function in Holstein Friesian cattle. Catillo *et al.* (2002) [12] demonstrated that the mixed log model effectively estimated lactation curves and noted that the polynomial regression function was flexible enough to fit test-day milk production records in Italian water buffaloes.

Kumar (2007) [47] reported R^2 values of 96.7% for the mixed log function, 99.7% for the polynomial regression function, and 99.6% for the exponential function in Murrah buffaloes. Dimauro *et al.* (2005) [24] observed R^2 values of 94.4% and 96.7% for the exponential and polynomial regression functions, respectively, in Italian water buffaloes.

Aziz *et al.* (2006) [4] reported an R^2 value of 96.0% for the gamma-type function in Egyptian buffaloes, consistent with findings by Rashia (2010) [68], who reported R^2 values of 87.9% for weekly and 95.9% for monthly test-day milk yields in Karan Fries cattle. Kumar (2007) [47] recorded a 99.6% R^2 value for the exponential function in Murrah buffaloes, while Cilek and Keskin (2008) [15] reported an R^2 value of 92.7% for the mixed log function in Simmental cows.

Barbosa *et al.* (2007) [8] identified the incomplete gamma function as the best for lactation curves, yielding a coefficient of determination of 95%, a standard deviation of 0.068, a coefficient of variation of 7.20, and a standard error of 0.003.

Cankaya *et al.* (2011) [11] found that the Wood model had the lowest residual standard deviation (3.562), the highest adjusted R^2 (91.6%), and the best persistency value (93.3%). Banu *et al.* (2012) [7] observed maximum accuracy ($R^2 = 99.5\%$) for the polynomial regression function, with the quadratic cum log model ($R^2 = 99.2\%$) performing nearly as well.

Dongre *et al.* (2011) [62] determined that the inverse polynomial function offered the best fit, with the highest R^2 value (99.92%) and the lowest root mean square error (RMSE) (0.107 kg). Dohare *et al.* (2014) [25] concluded that the Mitscherlich x Exponential model provided the best fit for fortnightly milk yield data in Frieswal cattle, achieving the highest adjusted R^2 value (99.2%).

Ferreira *et al.* (2015) [28] noted that the Wood model performed best in various scenarios for Holstein cows in southwestern Paraná. Sahoo *et al.* (2015) [78] found that Ali and Schaeffer's polynomial regression function yielded the highest R^2 value (0.998) and the lowest RMSE (0.03), indicating superior fit. Singh *et al.* (2015) observed R^2 values of 96.42%, 98.65%, 98.48%, and 99.86% for the gamma, exponential, mixed log, and parabolic regression functions, respectively, with PRF offering the best fit based on higher R^2 and lower RMSE.

Ghavi Hossein-Zadeh (2016) [34] reported that the Dijkstra equation best modeled milk yield across the first three parities in buffaloes.

Mohanty *et al.* (2017) [53] found that the Ali and Schaeffer model was the most accurate, with an adjusted R^2 of 97.8%, the lowest RMSE (0.328), and favourable AIC (-91.208), corrected AIC (-89.587), and SBC (-82.402) values.

Bangar and Verma (2017) [54] noted that the mixed log function best modeled the lactation curves for Gir crossbred cows. Kong *et al.* (2018) [44] concluded that the Nelder, Wood, and Dhanoa models closely matched actual lactation curves and could effectively predict 305-day milk yields for management and genetic evaluation in Chinese Holstein cattle.

Sahoo *et al.* (2018) [71] observed that the polynomial regression function provided the best fit, with the highest R^2 value (99.3%) and lowest RMSE (0.3%), for estimating first lactation 305-day milk yield (FL305-DMY) from weekly test-day records, whereas the exponential function had the lowest R^2 (88.5%) and highest RMSE (1.26%).

Conclusion

Non-genetic factors such as the period of calving, season of calving, age at first calving, and parity significantly influence milk production traits. Therefore, understanding the lactation curve holds substantial potential for enhancing the herd's overall performance. It also offers a valuable overview of buffalo efficiency, aiding in the development of effective breeding and management strategies for breed improvement programs and the genetic evaluation of buffaloes. Studies comparing various lactation curve models to describe the lactation curve shape in buffaloes have proven to be highly beneficial for predicting several production traits, particularly milk production at early stage of life for early culling/selection.

Conflict of Interest

Not available

Financial Support

Not available

Reference

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