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A brief review of lactation curve models for predicting milk yield and various factors influencing the lactation curve in Murrah buffalo

Rana Partap Singh Brar, Simarjeet Kaur and Tejas C Shende

Abstract

Throughout the lactation, milk production is a continuous physiological function that describes the rate of milk secretion as lactation progresses. Even when environmental and managerial elements are constant, the biometrical features of lactation differ amongst genetic groups. Despite of different quantitative levels of milk production, the trend of milk production exhibits the same tendency of an early period of rapid growth up to a peak, followed by a more or less gradual decrease. Different models have been tested for their capacity to describe milk yield patterns as well as forecast 305-day cumulative milk yield using daily milk yield lactation records.

Keywords: Murrah, Lactation, Daily milk yield

Introduction

Buffalo is the animal of prime importance for the dairy industry in India as it produces nearly half of the country's total milk production in India (BAHS 2019) [5]. This highlights the high level of countrywide acceptance of Murrah breed of buffalo among the farmers. Buffaloes, due to their higher milk fat content than cattle, they are extensively reared in India under peri-urban and rural farming systems, with the primary aim of quality milk production.

In buffaloes milk production trait follows a curvilinear pattern over the complete lactation course. Understanding of the lactation curve of dairy animals provides an insight into the behaviour of milk production traits. This behaviour of milk production is very highly affected by genetic as well as non-genetic factors. The effect of non-genetic factors *viz.* the period of calving, the season of calving, age at first calving and parity affecting the lactation parameters will help us as breeders to improve economic traits like milk production.

The lactation curve can be defined as the graphical representation of the milk yield against time (Brody *et al.* 1923) [10] or it can also be referred to as the curve representing the rate of milk secretion with the advancement of lactation. The typical shape of the lactation curve has two characteristic parts i.e. a rapid increase from calving to a peak period in the early stage of lactation and a gradual decline from peak yield to the end of lactation (Leon-Velarde *et al.* 1995) [49]. The ascending phase indicates the initial steep rise in the milk yield, which is usually linear. The persistent phase represents the inherent capacity of the animal for sustainable milk production while the descending phase is comparatively short and usually associated with the drying-off stage of an animal.

The biometrical properties of lactation are varying at different stages of lactation, even if the environmental and managerial factors are constant (Yadav and Sharma, 1985) [94]. Economically, the configuration of the lactation curve is important since the animal which produces milk at a moderate level steadily throughout the lactation is preferred than one which produces more at peak but little thereafter. The abrupt decline in the milk production after peak increases production cost because yield is distributed less equally over the complete lactation. The cost of milk production also depends to a large extent on the lactation yield and persistency. Identifying cow with a particular pattern and persistency of lactation milk yield can serve as an additional selection criterion in a dairy herd.

There are lot of advantages of evaluation or modeling the lactation curve such as to predict the milk yield of a cow in a lactation with minimum error and to use it in the process of cow/sire evaluation, thus enabling an anticipate choice of animals that have to be culled or that are affected by some disease without showing any clinical signs (Vargas *et al.* 2000) [89]. It also helps in predicting expected production potential on field records and gives a concise summary of biological efficiency and persistency of dairy animals. Further, the knowledge of lactation curves in dairy animals is important for decisions on herd management and selection strategies and can be a key element for the genetic evaluation of dairy cows for improvement of milk production traits (Macciota *et al.* 2005).

The extent of the usefulness of a lactation model depends on how well it succeeds in imitating the biological lactation process and how well it adjusts for environmental and other factors that could influence production. The aim of modeling the lactation curve is to predict the milk yield at any point of the lactation with minimum error. Many studies have been conducted in the past in dairy cattle using various lactation curve models to fit the lactation curve (Dongre *et al.* 2011 and Banu *et al.* 2012) [7, 26]. However, information is scanty on the fitting of lactation curve models using milk yield in 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) had a significant effect on the inclining slope of the lactation curve (Wood 1967) [91]. In Sahiwal cattle significant effect of POC on the shape of the lactation curve was observed by Rao and Sundaresan (1979) [67] and also in Hariana cattle by Mehto *et al.* (1980) [51] using the Wood function.

In Holstein cows highly significant results for the effect of the period of calving as reported by Dedkova and Nemcova (2003) [21]. In Murrah a significant effect of same ($P<0.01$) on age at first calving was shown by Patil *et al.* (2011) [62], a significant effect on Life Time Milk Yield, Productive life and Herd Life was also observed by Barman *et al.* (2013) [9]. Geetha (2005) [33] reported a significant effect of POC on all the monthly test-day milk yields except on the 35th, 215th and 305th test day milk yields. Rana (2008) [66] shown its significant effect on all the first lactation cumulative test day milk yields, similarly a significant effect on complete lactation milk yield (CLMY), lactation length, peak yield, 305-day milk yield, and ($P<0.05$) on days to attain peak yield was observed by Thiruvenkadan *et al.* (2014) [86], Dass and Sadana (2000) [18], Jakhar *et al.* (2017) [39], Thiruvenkadan *et al.* (2010) [87] reported highly significant ($P<0.01$) influence of POC on age at first calving by Thiruvenkadan *et al.* (2015) [85].

POC also showed significant effects on reproduction traits ($P<0.05$) and production traits ($P<0.01$) as reported by Jamuna *et al.* (2015) [40] simultaneously a highly significant ($P<0.01$) effect on Total Milk Yield, Milk Yield/Lactation Length and Milk Yield/Calving Interval reported by Narwaria *et al.* (2017) [54]. Verma *et al.* (2016) [90] reported significant ($P<0.05$) effect on Total Milk Yield and 305-day Milk Yield and similar results were shown by Sarkar *et al.* (2006) [74], nevertheless a highly significant ($P<0.01$) effect of POC on persistency, 305-days milk yield and peak yield was observed by Pareek and Narang (2015) [59].

A highly significant ($P<0.01$) effect on both milk constituents and their yield traits in Murrah Buffaloes presented by Chitra *et al.* (2018) [14], in Jaffarabadi buffaloes a significant ($P<0.05$) effect on complete lactation milk yield was observed by Dangar and Vataliya (2018) [16] and a highly significant ($P<0.01$) effect on complete lactation milk yield (CLMY) and lactation length (LL) by Mire *et al.* (2019) [52]. In Sahiwal cattle effect of POC on first lactation 305 days milk yield and life time milk yield by Pandey *et al.* (2019) [58]. Suresh *et al.* (2004) [82] revealed highly significant effect ($P<0.05$) on days to attain peak yield whereas in Murrah buffaloes a significant ($P<0.05$) effect on daily milk yield and 305 milk yield in Nepal was seen by Sigdel *et al.* (2015) [75]. For the first total lactation milk yield (TLMY), a significant ($P<0.05$) effect was reported by Kumar *et al.* (2003) [23]. Penchev *et al.* (2011) [65] reported the significant ($P<0.01$) effect on daily milk yield in Bulgarian Murrah buffaloes. The effect of POC was highly significant ($P<0.01$) on all the first lactation traits except the first service period which showed significance at ($P<0.05$) by Ambhore *et al.* (2016) [2].

Tailor and Singh (2011) [83] observed significant effect ($P\leq0.05$) on 1st, 4th, 6th and 7th monthly test-day milk yields and its highly significant effect ($P\leq0.01$) on 9th test-day milk yield was published by Kumar *et al.* (2012) [7] while, Singh (2014) observed POC effect on 305-day first lactation milk yield and all the monthly test-day milk yields which was highly significant ($P<0.01$) except on Monthly test-day 9th. Gajbhiye and Tripathi (1999) [30] observed a highly significant effect ($P<0.01$) on the first lactation 305-day milk yield. Dhirendra *et al.* (2003) [23] in Murrah buffaloes observed a significant effect on 305-day first lactation milk yield, similar findings were reported in Surti buffaloes by Pathodiya and Jain (2004) [61]. Jamuna (2012) [41] in Murrah buffaloes observed a significant effect on 305-day milk yield.

In Murrah buffaloes, the first lactation 305-days milk yield was reported to be significantly affected as noticed by El-Arian (1986) [27], Gajbhiye (1987) [31], Tomar and Tripathi (1988) [88], Singh *et al.* (1990), 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] in Murrah buffaloes reported its significant effect on first Lactation milk yield and first lactation peak milk yield. Pander *et al.* (2017) [57] in Hardhenu cattle reported a significant effect only on the first service period.

Effect of season of calving

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

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

Thiruvenkadan *et al.* (2014) [86] reported the significant effect on TLMY and a highly significant ($P<0.01$) effect on Peak Yield, days to attain peak yield and 305-day MY in Murrah buffaloes. A significant ($P<0.05$) effect on age at first calving was reported by Thiruvenkadan *et al.* (2015) [85], and their team also revealed that the highest milk yield was obtained in animals calving in the winter season followed by the rainy and the summer season and Pawar *et al.* (2012) [64] also reported similar findings. Dass and Sadana (2000) [18], Verma *et al.* (2016) [90] and Sarkar *et al.* (2006) [74] also reported the significant effect of SOC on TLMY.

Hassan *et al.* (2017) [36] in Egyptian buffaloes revealed that the statistical analysis showed a highly significant ($P<0.01$) effect on daily milk yield, 305 MY, lactation length and TLMY. He also concluded that the winter calvers had the highest values of DMY compared to those calved in the other seasons and buffalo produce best milk yield at fourth parity and those calved in winter season. Kamble *et al.* (2014) [42] reported that the longer lactation length was observed among buffaloes calved during the winter season while the summer calvers showed shorter lactation length.

The effect of SOC was found to be significant ($P< 0.05$) on first lactation 300 days milk yield and non-significant on rest of the first lactation traits by Ambhore *et al.* (2016) [2], on Service Period and Days to first service by Jamuna *et al.* (2015) [40] as well as effect of SOC was found highly significant ($P<0.01$) effect on all test-day yields by Parmar *et al.* (2018) [60], a significant ($P<0.01$) on first service period by Patil *et al.* (2011) [62] and significant ($P<0.01$) on Milk Yield/Lactation Length by Narwaria *et al.* (2017) [54].

Sigdel *et al.* (2015) [75] in Murrah buffaloes reported a significant effect of SOC on daily milk yield ($P<0.01$), Lactation length ($P<0.05$) and 305 milk yield ($P<0.01$) in Nepal. Pareek and Narang (2015) [59] reported that the effect of SOC was significant on Peak yield. Dev *et al.* (2015) [22] in Murrah buffaloes reported a significant effect on the first service period and the first calving interval.

Garcha and Dev (1994) [32] in Murrah buffaloes reported that the effect of SOC was significant on all test-day milk yields but Dass (1995) [20] in Surti buffaloes observed a significant effect on 2nd, 6th and 7th monthly test-day milk yield. Tailor and Singh (2011) [83] in Surti buffaloes observed significant effect ($P\leq0.05$) on all test-day milk yields but on the other hand, Kumar *et al.* (2012) [7] observed a significant effect on 2nd test-day milk yield in Murrah buffaloes.

Effect of age at first calving

Yadav *et al.* (1977b) [92] fitted Wood function in Hariana and its Friesian crosses to average weekly yield and reported a significant effect on the inclining and declining parameters of the Wood function. Rao and Sundaresan (1979) [67] using the Wood function in Sahiwal cows reported a significant effect of age at first calving (AFC) on the shape of lactation curve and Mehto *et al.* (1980) [51] in Hariana crossbreds observed that initial milk yield linearly increased with advancement in age of the cows in terms of her lactation sequence similarly Dedkova and Nemcova (2003) [21] in Holstein cattle found that cows with lower age at first calving showed the best persistency while a slowing growing slope up to production peak was found with higher age at calving using Wood function.

In Holstein Cows, significant results of AFC ($P<0.05$) were reported for peak yield while, its significant effect on lactation yields in the lactation curve was observed by Tekerli *et al.* (2000) [84]. A highly significant ($P<0.01$) effect on service period and lactation length were seen by Jamuna *et al.* (2015) [40] and a highly significant ($P<0.01$) effect of age at first calving group was observed for all lactation test day yields for AFC by Parmar *et al.* (2018) [60]. In Sahiwal cattle, a significant effect on life time milk yield was reported by Pandey *et al.* (2019) [58]. Rana (2008) [66] reported that the regression of cumulative test-day milk yields were showing significant effect ($P<0.05$) on first test-day and which was highly significant ($P<0.01$) in remaining cumulative test-day and 305-day milk yield. Singh (2014) [25] reported highly significant ($P\leq0.01$) on first lactation 305-day milk yield and monthly TD-1, TD-2, TD-3, TD-4, TD-7, TD-9; significant ($P\leq0.05$) on monthly TD-5.

Effect of parity

Rao and Sundaresan (1979) [67] in Holstein Friesian cattle stated that the least-squares analysis of traits associated with lactation curve shape indicated that parity had a significant effect on the lactation curve, whereas similar result was reported by Tekerli *et al.* (2000) [84]. Horan *et al.* (2005) [37] in Holstein Friesian cows reported the significant effect on all three lactation curve parameters more specifically on peak production and the persistency of lactation. Higher parity animals had higher intercept values, and greater incline and decline parameters. Atashi *et al.* (2009) [3] reported that parity had a significant effect on the lactation, however Singh and Yadav (1987) [77] reported that the daily milk yield of Murrah buffalo is increased with increase in the number of lactation.

Thiruvenkadan*et al* (2014) [86] reported in Murrah buffaloes that the daily milk yield of buffaloes increased from first to fourth parities. They also reported a highly significant ($P<0.01$) effect of parity on TLMY, 305 MY, Peak Yield and lactation length and also revealed that the days to attain peak yield decreased from first to fifth parity.

In Murrah buffaloes, the parity ($P<0.01$) had a significant effect on 305 MY by Dass and Sadana (2000) [18], Jamuna *et al.* (2015) [40], Verma *et al.* (2016) [90] and Jakhar *et al.* (2017) [39]. Chaudhary *et al.* (2000) [13] observed that the peak yield was found to be 9.8 ± 0.55 kg for first parity buffaloes which showed growth till 4th parity then declined thereafter.

Sigdel *et al.* (2015) [75] in Murrah buffaloes revealed a significant effect on daily milk yield in Nepal. The 305 day milk yield and total lactation milk yield were significantly ($P<0.01$) affected by the order of parity. A significant ($P<0.05$) effect of parity on reproduction traits and production traits ($P<0.01$) was reported by Jamuna *et al.* (2015) [40].

Hassan *et al.* (2017) [36] in Egyptian buffaloes revealed that the parity has significant effect on daily milk yield and also concluded that it has a significant effect ($P<0.01$) on lactation length and TLMY of which highest TLMY was observed in the fourth parity and decreased thereafter in purebred Egyptian buffaloes.

Sundaram and Harharan (2013) [81] revealed that the 305-day milk yield was found to be significantly ($P<0.05$) affected by lactation number in Murrah buffaloes. In swamp buffaloes, Peak yield was significantly ($P<0.01$) influenced by parity and increased gradually from first to the fourth parity and thereafter showed declined trend reported by Das *et al.* (2015).

Comparative efficiency of different lactation curve models

Singh and Bhat (1978) [76] observed that lactation of varying duration (<44 weeks) was better explained by parabolic exponential function in Hariana cattle. This model gave good fit (R^2 = 74%) for milk yield during the first lactation in Hariana cattle. They reported 97.3% of R^2 value for gamma function in describing the average lactation curve in Hariana cattle. The inverse polynomial explained 99.9% of the variation in Hariana cattle.

Ali and Schaeffer (1987) [1] studied three models for describing the shape of the lactation curve for individual cows. Models were ranked regression model, gamma function, and inverse quadratic polynomial function in order of best to worst. The best combination of parameters of the gamma function gave a relative efficiency of 74.7% as compared to selection for 305 day yield alone.

Gahlot *et al.* (1988) [29] reported that the parabolic exponential model gave good fit (R^2 = 74%) for milk yield during the first lactation and inverse polynomial function gives the best fit but gamma function fitted to average monthly yields in Rathi cows and reported goodness of fit of 94.68%.

Olori *et al.* (1999) [56] reported the R^2 value with mixed log function as 96.4% in Holstein Friesian cattle. Catillo *et al.* (2002) [12] observed that the mixed log model was effective in estimating lactation curves of milk production traits and also observed that the goodness of fit for polynomial regression function was flexible enough to fit test day records of milk production in Italian water buffaloes.

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

Aziz *et al.* (2006) [4] reported R^2 values (96.0%) using gamma type function in Egyptian buffaloes. Similar findings were reported with R^2 values (87.90%) for weekly test day milk yields and (95.9%) for monthly test day yields in Karan Fries cattle by Rashia (2010) [68], (96.2%), Katneni (2007) [43] and R^2 values (99.6%) by Kumar (2007) [47] using exponential function in Murrah buffaloes. While Cilek and Keskin (2008) [15] reported (92.7%) R^2 value in Simmental cows using mixed log function.

Barbosa *et al.* (2007) [8] reported that Incomplete Gama was the best function to describe the lactation curve with values of the coefficient of determination, standard-deviation, coefficient of variation and standard-error as 95%, 0.068, 7.20, and 0.003, respectively.

Cankaya *et al.* (2011) [11] reported the results that Wood model with minimum residual standard deviation (3.562), maximum adjusted R^2 value (91.6%) and maximum persistency value (93.3%) performed the best fit to the data. Banu *et al.* (2012) [7] reported that polynomial regression function (PRF) showed the maximum accuracy (R^2 = 99.50%), Quadratic cum log model (R^2 = 99.20%) was almost equal to polynomial regression function.

Dongre *et al.* (2011) [26] stated that Inverse polynomial function described the best fit with highest coefficient of determination (99.92%) and with lowest value (0.107 kg) of root mean squares error (RMSE). Dohare *et al.* (2014) [25] observed that Mitscherlich x Exponential model provided best fit for fortnightly milk yield data in Frieswal cattle with the maximum accuracy (Adj. R^2 = 99.20%) obtained by Mitscherlich x Exponential model followed by Morant and Gnanasakthy (Adj. R^2 = 98.8%) and Wilmink model (Adj. R^2 = 96.0%). Ferreira *et al.* (2015) [28] stated that the Wood model showed the best fit in almost all evaluated situations in Holstein cows raised in South-western Parana.

Sahoo *et al.* (2015) [72] reported that Ali and Schaeffer's polynomial regression function (PRF) gave the highest value (0.998) of the coefficient of determination (R^2), and the lowest value (0.03) of Root Mean Squares Error (RMSE) indicating that it was the best fit. Singh *et al.* (2015) [72] reported coefficient of determination (R^2) and root mean squares error (RMSE) for Gamma Type Function (GF), Exponential Function (EF), Mixed Log Function (MLF) and Parabolic Regression Function were 96.42%, 98.65%, 98.48%, 99.86% and 0.077, 0.049, 0.052, 0.015, respectively. PRF fitted best to the test day data followed by EF based on higher R^2 and lower RMSE estimates, whereas GF fitted least in Murrah buffaloes.

Ghavi Hossein-Zadeh (2016) [34] reported that Dijkstra equation provided the best fit of MY for the first three parities of buffaloes.

Mohanty *et al.* (2017) [53] observed that Ali and Schaeffer model showed best fit giving highest degree of accuracy (R^2_{adj} = 97.8%), lowest value of Root Mean Square Error (RMSE) (0.328), Akaike's information criterion (AIC) (-91.208), corrected Akaike's information criterion (AICc) (-89.587) and Schwartz Bayesian information criterion (SBC) (-82.402) followed by Morant and Gnanasakthy models (R^2_{adj} = 95.6%), RMSE = 0.468, AIC = -61.454, AICc = -60.401 and SBC = -82.402) in Red Sindhi cows.

Bangar and Verma (2017) [6] reported that mixed log function provided the best fit of the lactation curve of first and remaining lactations of Gir crossbred cows. Kong *et al.* (2018) [44] reported that the curves made by the Nelder, Wood and Dhanoa models were close to the actual curves. These three models can be used to predict the 305-day yield for management decisions in farms and the genetic evaluation of Chinese Holstein cattle.

Sahoo *et al.* (2018) [71] observed that the Polynomial regression function was the best fit with the highest R^2 (99.3%) and lowest RMSE (0.3%) which was used subsequently to estimate the first lactation 305-day or less milk yield (FL305-DMY) from weekly test-day milk yields. Whereas, the exponential function had the lowest R^2 value (88.5%) with the highest (1.26%) RMSE value.

Conclusion

The effect of non-genetic factors *viz.* period of calving, the season of calving, age at first calving and parity have significant effect on milk production traits. Therefore, understanding the lactation curve has a lot of potential for improving the herd average. It also provides a brief review of buffalo's efficiency and enables the creation of appropriate breeding and management strategies for breed improvement programmes as well as genetic evaluation of buffaloes. The study on comparison of various lactation curve models to describe the shape of lactation curve in buffaloes has been evaluated and they found to be most useful in prediction of number of production traits/ parameters specially milk production traits.

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