Assessment of Mediterranean buffalo lactation curves shape using lactation models

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Abstract

In Italy, the number of buffalo has increased by the 173% from 1996 until now with a total of around 425000 buffaloes. In contrast to dairy cows, adoption of new technologies such as automatic systems is limited in buffalo. Milk yields are recorded by hand, making it time-consuming and error prone. As a result, few data are available in buffalo lactations. The analysis of lactation curve shape has been shown to be useful for technicians and farmers to understand the evolution of milk yields and support management decisions. Lactation curve models have not yet been explored in buffaloes opposed to dairy cows where lactation curve model have been adopted by the entire industry (e.g. Wood, Wilkmink or Milkbot). The aim of our work was to explore lactation curve models applied to Mediterranean Italian buffaloes by performing a comparative assessment of Wood and Milkbot equations. The analysis was performed on a large dataset containing the milk yield, calving date, lactation number and days in milk from 333 376 animals on 295 herds over a 4-year period from 2013 until 2016. Performance of the final models was evaluated using the coefficient of determination (R^2). Wood's model performed slightly better than Milkbot model with $R^2 = 0.75 \pm 0.24$ and 0.66 ± 0.23, respectively illustrating the ability of both models to fit buffalo daily milk production. These results encourage adopting a more analytical approaches to buffalo to obtain in-depth phenotypes on their milk productive capacity. Although, Milkbot performed slightly worse than Wood, it directly provides information on the loss of productivity capacity which can be converted into a measure of persistency. In conclusion, the final aim was promoting the use of mathematical models in the buffalo.

Keywords: Buffalo, Lactation curves, Wood, Milkbot, Mozzarella cheese.
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Holstein cows are generally recognised as the most important dairy species due to their high milk production. Even if dairy cattle represented the majority of the milk market, other species, such as sheep, goats or buffaloes, are still important producers of milk

Introduction

and dairy products. In particular, the buffalo sector has been constantly growing in the last years, especially in the Mediterranean countries. In Asia and South America buffalo farming is considered an important sector from an economic and social point of view. The buffalo sector in Italy changed from an extensive to intensive livestock system where small herds with few animals were replaced by bigger herds with more than 100 cows. Indeed, nowadays buffalo sector counted a total of around 425 000 buffaloes especially located in the South of Italy (BDN, Italy). The main output of buffalo farm is the "Mozzarella di bufala Campana PDO" and thanks to its organoleptic properties and taste, it is appreciated globally (Levante *et al*., 2023). To manage and cover the market request of buffalo milk a more data-driven approach to the industry is needed.

Lactation models (LC) are one of the pivotal tools to understand and forecast milk production and helps breeder make better management decisions. Due the key role of this tool, different lactation curves model has been developed over the last 50 years.

Since 1923, with the advent of the model theorized from Brody *et al*. (1923), various mathematical models have been introduced to characterize the shape of dairy lactation curves (LC) and provide insights into milk yield production. Among these models, the Wood equation stands out as one of the most utilized benchmarks for model evaluation (Radjabalizadeh *et al*., 2022). This equation, formulated by Wood in 1967, is based on an incomplete gamma function and comprises three key parameters: scale (a), ramp (b), and declining slope (c) (Wood, 1967).

A more recent addition to the repertoire of lactation curve models is the MilkBot model (Ehrlich, 2013). Like the Wood equation, the MilkBot model is an exponential equation, but it incorporates an additional parameter, enhancing its ability to capture the slope of lactation. Furthermore, this model introduced characteristics such as the time of maximal creation of productive capacity (offset, c) and the loss of productive capacity (decay, d). These parameters offered a more comprehensive understanding of the lactation process and can be easily translated into a measure of persistency.

All of those LC models have been poorly explored in buffaloes and only few papers were available in the literature (Khan *et al*., 2023; Metry *et al*., 1994; Şeahin *et al*., 2015). The purpose of this work is providing evidence on how the Wood and Milkbot equations describe the buffalo LC, giving information to benchmark animal performance and ultimately improve milk production in buffalo.

Material and methods

The analysis was performed on a large dataset containing milk yield, calving date, lactation number and days in milk from 333376 animals on 295 buffalo herds from 2013 until 2016 with lactation numbers ranging from 1 to 3. Animals with at least five observations per lactation were chosen to ensure a coherent fitting with at least the number of observations equal to the number of the regression parameters of the model. All data pre-processing was done through R software (version 4.3.2).

The first mathematical model fitted to the data was the Wood equation (Wood, 1967) with the following formula:

$$Y(t) = at^{b}e^{-ct} \qquad (1)$$

Where *Y* is the milk production, *t* the days in milk, the magnitude *a*, *b* the time to peak and *c* is the decay.

The second model employed was the MilkBot (Ehrlich, 2013). The full MilkBot equation is shown as:

$$Y(t) = a\left(1 - \frac{e^{\frac{c-t}{b}}}{2}\right)e^{-dt} \quad (2)$$

Where *Y* is the milk production, *t* the days in milk, *a* the magnitude, *b* the time to peak*c* the offset and *d* the decay.

In this case, the fitting happened through the API version of the model (1.3), which was available online (Jim Ehrlich, API Milkbot). Wood and Milkbot equations required the employment of priors for the parameters a, b,c and d. Prior values were used as initial guesses to search the optimal solution. Initially, Wood and Milkbot models were fitted using priors based on a literature search (Khan *et al*., 2023; Şeahin *et al*., 2015). After the first fitting step, mean and standard deviation (sd) of regression parameters from the results were used to fit all lactations for a second time, At the end, the performance of the models was evaluated through the coefficient of determination (R^2).

$$R^2 = \frac{SS_{res}}{SS_{tot}} \quad (3)$$

where SS_{res} is the sum of the squared residuals and SS_{tot} is the total sum of squares. The *curve_fit* function from the *scipy* package was used to fit lactation data using Python v3.10.

Results and discussion

The presented research provides a preliminary approach to a mathematical model of the buffalo LC shape. The results suggest an overall better performance of the Wood equation compared to Milkbot.The results of the fitting of the Wood and Milkbot equations are shown in detail and discussed in this section. Results are shown for lactation number 1, 2 and 3.

Wood analysis

Table 1 reports the mean of parameters a,b,c ± *s.d*. and the R^2 ± *s.d*.

The mean values of *a, b, c* are coherent with Khan *et al*. (2023). We achieved high R^2 values, especially for lactations 2 and 3. Our results suggest that the Wood model achieved a good approximation of real milk yield despite the low sampling rates of time series. On the other hand, the standard deviation for each parameter and R^2 suggest that data are strongly variable about the mean, probably due to the variability in the number of milk points available for each lactation.

This is one of the first analysis applying the Milkbot model to buffalo LC. No literature was available to compare the obtained results. However, results seem coherent based

Table 1. Fitting metrics of the Wood model.

Parity	$\bar{a} \pm \sigma_a$	$\bar{b} \pm \sigma_b$	$\bar{c} \pm \sigma_c$	$\overline{R^2} \pm \sigma_{R^2}$
1	6.1±4.2	0.30±0.30	0.005±0.003	0.72±0.26
2	7.6± 5.1	0.29±0.30	0.006±0.004	0.78±0.22
3	7.9± 5.2	0.30±0.30	0.007±0.004	0.79±0.21

Table 2 reported the result for Milkbot equation.

Parity	$\bar{a} \pm \sigma_a$	$\bar{b} \pm \sigma_b$	$\bar{c} \pm \sigma_c$	$\bar{d} \pm \sigma_d$	$\overline{R^2} \pm \sigma_{R^2}$
1	13.5±2.4	30.67±0.06	-0.4992±0.001	0.0015±0.0001	0.58±0.26
2	15.9± 3.2	22.74±0.02	-0.7751±0.001	0.0026±0.0003	0.69±0.22
3	17.1± 3.6	25.07±0.75	0.0039±0.002	0.0029±0.0003	0.69±0.20

Milkbot analysis

on dairy cow parameters and their interpretation (Chen *et al*., 2022). Milkbot performed worse than Wood in terms of R^2 for each lactation.

The R^2 values suggest that Milkbot and Wood equations seem to be a promising technique for evaluating the LC of buffalo considering the very few milk points available during lactation that negatively affect the results. However, since the models are strongly influenced by the choice of the initial priors, more efforts to find suitable values of *a, b, c,* and *d* can improve the model performance. Finally, like in Holstein domain, the first lactations achieved worse result compared to the lactations 2+.

Conclusion

This work reported and compared the performance of Wood and Milkbot equations to describe the behaviour of buffalo milk yield. The results suggested that Wood performed better than Milkbot in terms of R^2 in buffalo cows. Moreover, Wood equation achieved better result than Milkbot employing few milk points available. Results are promising, but more efforts are needed to establish more accurate priors for buffalo cows.

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