Comparison of Five Different Lactation Curve Models to Estimate Milk Yield of Friesian Holstein Cows at BBPTU HPT Baturraden

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Abstract. The objective of this study was to compare the accuracy of five different lactation curve models to estimate 305 days milk yields in Friesian Holstein (FH) dairy cow at BBPTU HPT Baturraden. Appropriate lactation curve could provide useful information for genetic breeding programs, herd nutritional management, decision taking on the culling cows and milk production simulation systems. The analysis was carried out on a total of 8,167 milk yield records based on test day (TD) from first to fourth lactation from 2014 to 2017. The models compared were Wood, Yadav, Ali-Schaeffer, Wilmink, and Guo and Swalve models. The results showed that the Ali-Schaeffer's model was the best model to predict milk production. It is known from the coefficient of determination at first, second, third, and fourth lactation respectively were 0.99156, 0.99074, 0.98985, 0.96706, correlation between predicted and observed values \(r\) were 0.99577, 0.99536, 0.99491, 0.98339, and \(S_e\) were 0.30, 0.37, 0.38, 0.63.

1. Introduction

Lactation curve refers to a graphic representation of the ratios between milk production and lactation time starting at calving and can be studied using mathematical models [1,2]. Mathematical models is a tools that can mimic fundamental processes of milk production in different scenarios [3]. The curves of animal lactation facilitate the prediction of the total yield from partial yield, which aids in early animal disposal and breeding evaluation when the lactation records of the progeny are incomplete. The lactation curve models used the function parameters to estimate lactation curve characteristics with economic significance, including early yield, peak yield, time from onset to lactation peak, persistency and total lactation yield [2]. Appropriate curve models provide useful information for genetic breeding programs, herd nutritional management, decision taking on the culling cows and milk production simulation systems [1,4,5,6,7].

The first mathematical model of the lactation curve in dairy cattle was developed by Brody et al. [8], who proposed a decreasing exponential function to fit the declining phase of the lactation pattern in dairy cattle [3]. Brody model could not represent an increase in production in the beginning of lactation and underestimating in the peak yield [1]. Brody model was useful to outline only in declining phase of the curve [9]. Therefore, this model was not suitable to describe the entire lactations of cows that were highly specialized in milk production, but the model was adequately fitted for low milk production crossbred animals reared in tropical conditions [1]. Since then, studies on lactation curve modelling have experienced a rather waving pattern and numerous mathematical models have been developed by specific needs of the dairy industry [3,10,11].

The use of lactation models become more popular after Wood's model [12]. The model was proposed to use incomplete gamma function to describe the curve and it obtained a better fit at ascending and descending phases of the curve, than the models used until that time [9]. Another important feature of Wood's model was its simplicity and a reduced number of parameters [12], but limitations of the Wood
model are also well known [3]. Overestimation of daily milk yield in the first part of the curve, underestimation around and after the peak have been reported [13].

After Wood's model, there have been numerous studies to develop linear and nonlinear lactation curve models. In the linear, models proposed by Ali and Schaeffer [14] and Guo and Swalve [15], while in the nonlinear, models proposed by Yadav [16] and Wilmink [17] have been developed. The models are considered worthy to be investigated, because they have been proven to have a better fit than Wood in several studies. But these model need to be tested before it used, because not all models are fit to be used in Indonesia. Using the different set data and number of lactation with previous study, the objective of this study is to compare the accuracy of five different lactation curve models on test days milk yields in Friesian Holstein dairy cows at BBPTU HPT Baturraden.

2. Materials and Methods
The data were obtained from nucleus breeding centre of dairy cattle, BBPTU HTP Baturraden in Central Java, Indonesia from 2014 to 2017. The study used 2,354, 2,711, 1,903, and 1,199 records for first, second, third, and fourth lactation, respectively. Each lactation consisted of 11 point of measurement from day 8 to 305 with interval time of 30 days. The models evaluated are presented in Table 1.

| Researcher               | Model                                                                 |
|--------------------------|------------------------------------------------------------------------|
| Wood (1967)              | $y_t = at^b 2,7183^{-ct}$                                              |
| Yadav (1977)             | $y_t = \frac{t}{a + bt + ct^2}$                                       |
| Ali-Schaeffer (1987)     | $y_t = a+b\left(\frac{t}{305}\right) + c\left(\frac{t}{305}\right) + dln\left(\frac{305}{t}\right) + f t^2$ |
| Wilmink (1987)           | $y_t = a + b, 2,7183^{-0.05t} + ct$                                   |
| Guo and Swalve (1995)   | $y_t = a + b\sqrt{t} + cln(t)$                                        |

In all functions, t was DIM, a, b, c, d, and f were parameters to be estimated, and $\gamma$ was milk yield at DIM t. The parameters were estimated with the help of proc-nonlin within SAS 9.0. The best fit was compared with the value of coefficient of determination, correlation between observed and predicted data (r), and standard error (Se). Models resulting in higher ($R^2$) and (r) and smaller (Se) were considered to be superior.

3. Result and Discussions
The results shows that the estimated parameters value is differs for each lactation even though it analized with the same model. Parameter ‘a’ affected by parity and production level of animals; parameter ‘b’ affected by farm, season of calving, and lactation number; parameter ‘c’ affected by farm and season of calving, these parameters are crucial for estimating lactation features, including early yield, milk yield at lactation peak, time between the onset of lactation and lactation peak and persistency [2]. Parameter ‘a’ was explained as a beginning of milk yield. The lowest value found in Ali-Schaeffer’s model, while the highest value was found in Wilmink’s model. Parameter ‘b’ was explained as a slope until accession of the value of highest milk yield. The values was found as the highest in Ali-Schaeffer’s model, while the lowest value found in Wilmink’s model. Parameter ‘c’ was explained as slope after the value of highest milk yield. This value was found as the highest in Wilmink’s model, and the lowest value was found in Ali-Schaeffer’s model for all lactation. For parameter b value, the results in this study have similarities with the research done by Cilek and Keskin [18], but the value of other parameters are different. The estimated parameters value for all models from first to fourth lactation are shown in Table 2.
Despite the different of parameters value, all five models can properly describe the lactation curve. In the beginning of the lactation period the milk yield is low and then it will rise rapidly (first phase) until it reaches the peak yield, and then gradually descend (second phase) [3]. Based on the results of the analysis, Ali-Schaeffer’s and Yadav’s model reach peak yield in the second month of recording or at DIM 35 in all lactation. Meanwhile, Wood’s model reached peak yield at DIM 35 in the 2nd and 3rd lactation, and reached peak yield at DIM 65 in 1st and 4th lactation. The Wilmink’s model reached peak yield at DIM 35 in 3rd lactation, and reached peak yield at DIM 65 on 1st, 2nd, and 4th lactation. In the Guo and Swalve’s model, peak yield at DIM 35 occurs in 2nd, 3rd, and 4th lactation, whereas in 1st lactation peak yield was reached at DIM 65. The difference in peak yield are because of these functions differ chiefly in the type of regression, the number of parameters, and the degree of
associations with the main characteristics of a typical lactation pattern: i.e., peak yield, time at peak, and persistency [19].

3.1. Coefficient of Determination ($R^2$)
Table 2 shows value of the coefficient of determination ($R^2$ value) for each model in first, second, third, and fourth lactation. It was observed that Ali-Schaeffer’s model has the highest coefficient of determination ($R^2$ value) compared to the other model in all lactation, while Wood’s model has the lowest coefficient of determination ($R^2$ value) in almost all lactation. It means that Ali-Schaeffer’s model indicated a small diversity, while Wood’s model indicated a wide diversity between the observed and predicted yield, starting from the initial phase until the end of lactation [6]. The $R^2$ values obtained in this study were higher than the value reported by Koçak and Ekiz [4] and Biswal et al. [20]. However, the result showed in this study has similarity with those reported by Koçak and Ekiz [4] and Biswal et al. [20] that the Ali and Schaeffer Model has the highest $R^2$ values and gave the best fit to model the lactation curve.

3.2. Correlation Values (r)
The correlation for each model in first, second, third, and fourth lactation are presented in Table 2. The results showed that Ali-Schaeffer’s model has the highest correlation value (r) compared to the other model in all lactation. The correlation value (r) of Ali-Schaeffer’s model for first to fourth lactation were 0.99577, 0.99536, 0.99491, 0.98339, respectively, which means that Ali-Schaeffer’s model has a high accuracy in estimating actual milk yield at BBPTU HPT Baturraden. According to Surrakhman [21] correlation value (r) range between 0.9 and 1 has a very high level of accuracy. Although the other four models also have correlation values (r) at 0.9 in almost all lactation periods, Ali-Schaeffer’s model has a correlation value (r) that is closer to one compared to other models. The study by Nugroho et al. [22] showed similar result with this current study. In his study Nugroho et al. [22] compare eleven models of lactation curves in first and second lactation, and the results showed that Ali-Schaeffer’s model was the best lactation curve to estimate milk yield at BBPTU HPT Baturraden.

3.3. Standard Error (SE)
SE has been used as a standard statistical metric to measure model performance [23]. SE indicate the deviation of the lactation curve in estimating actual milk yield. Table 2 also shows the value of SE for each model in first, second, third, and fourth lactation. The result showed that Ali-Schaeffer’s model has the lowest SE compared to the other four models in all observed lactation periods. It means the deviation of Ali-Schaeffer's model in estimating milk production is smaller than other models. The study by Nugroho et al. [22] also shows that Ali-Schaeffer’s model has the lowest SE compared to the other models. Although SE in this current study was lower than the study done by Nugroho et al. [22] in 1st and 2nd lactation period. Therefore the Ali-Schaeffer’s model was proven to be the best model to predict milk yields at BBPTU HPT Baturraden. The shape of Ali-Schaeffer lactation curve model compare with the actual milk yield are presented in Figure 1.
Figure 1. Shape of Ali-schaeffer Lactation Curve Model Compare with Actual Milk Yield in (a) 1st, (b) 2nd, (c) 3rd, and (d) 4th Lactation, respectively. The actual milk yield \( \longrightarrow \); The Ali-Scheffer Model \( \bullet \).

4. Conclusion

Five mathematical functions for modeling the lactation curve in friesian holstein dairy cows were compared for accuracy of predicting milk yields from test day records. The results showed that Ali-Schaeffer’s model was the best model to predict milk yields at BBPTU HPT Baturraden. It is known from the coefficient of determination were 0.99156, 0.99074, 0.98985, 0.96706, correlation between predicted and observed values \( r \) were 0.99577, 0.99536, 0.99491, 0.98339, and \( Se \) were 0.30, 0.37, 0.38, 0.63 at 1st, 2nd, 3rd, and 4th lactation respectively.

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