Comparison of growth curve models for Ongole Grade cattle

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Abstract
Growth curves are important for understanding the growth phase and specific characteristics of farm animals. This study evaluated growth curve models to predict the age at puberty and growth rate of Ongole Grade cattle. The study used the weights of cattle from birth to 5 years old in 2011 to 2019 obtained from the Beef Cattle Research Station. The data were analyzed using four non-linear growth curve models: Brody, von Bertalanffy, logistic, and Gompertz. The coefficients of determination ($R^2$) of the growth equation for the respective models were in the high range. The lowest Akaike’s information criterion (AIC) value for males and females was obtained by the Brody and logistic models, respectively. Males with the von Bertalanffy, logistic, and Gompertz models had an estimated age and body weight at puberty of 12.56 months and 198.93 kg, 21.46 months and 298.43 kg, and 15.71 months and 235.49 kg, respectively, while females had an estimated age and body weight of 11.79 months and 166.44 kg, 13.94 months and 164.08 kg, and 11.76 months and 169.57 kg, respectively. The Brody function best fit the growth rate and exhibited the smallest mean deviation.

Keywords Growth curve · Age at puberty · Body weight · Ongole Grade cattle · Non-linear model

Introduction
Ongole Grade cattle were developed around 1930 by crossing Javanese cattle (in some reports, local cattle on Java) and Sumba Ongole cattle, a local cattle breed on Sumba Island, Indonesia, which are descendants of Ongole cattle (Astuti 2004). Evidence of this hybridization has been revealed by multiple molecular analyses, although studies mainly mention the *Bos indicus*–*Bos javanicus* introgression (Sudrajad et al. 2020). In Indonesia, there are approximately 2.8 million head of Ongole Grade cattle (approximately 16% of the total beef cattle population in Indonesia); they are present in most provinces (BPS 2020). This breed has high adaptability and reproductive performance in the tropics and requires low external inputs (Volkandari et al. 2021). Therefore, Ongole Grade cattle are valuable for livestock development in Indonesia, the largest beef producer in Southeast Asia (Soedjana and Priyanti 2017).

Body weight is the most important trait for evaluating cattle-producing capacity (Lee et al. 2014). The age at sexual maturity for the first mating in cattle is determined by the optimal body weight; it is influenced by genetic factors, feed intake, and rearing management (Budimulyati et al. 2012). Kusuma et al. (2017) reported that Ongole Grade cattle were first mated at 23.06 months; they noted various body weights in first matings. Scientists, farmers, and animal keepers require knowledge of the growth curve characteristics of a cattle breed to make reliable selection decisions (Bahashwan et al. 2015). Growth curve analysis is associated with body weight gain in a particular age range (Granie et al. 2002). There are various non-linear mixed mathematical models for growth curves, such as the Brody, von Bertalanffy, logistic, Gompertz, Richards, monomolecular, and Weibull models (Waiz et al. 2019). Of these, the first three are used in breeding programs to improve livestock production (Budimulyati et al. 2012; Hafiz et al. 2015). The logistic and Gompertz functions yield fixed inflection points at 50.0% and 36.8%
of the asymptotic weight, respectively, while the von Bertalanffy function has a fixed inflection point between 29.6 and 36.8% of the final weight (Selvaggi et al. 2016).

The use of a reliable growth curve can assist in estimating puberty onset and the right time for initial conception. This study examined the best growth curve model for describing and predicting the changes in body development of Ongole Grade cattle. The study will provide basic information that can be used to improve beef cattle production in Indonesia.

Materials and methods

Animals

This study was conducted at the Beef Cattle Research Station (BCATRES), a government farm for beef cattle in Pasuruan, East Java, Indonesia. The study analyzed the body weights of 1656 head Ongole Grade cattle recorded from 2011 to 2019. These body weight data were recorded at birth, weaning, yearling, and the ages of 1.5, 2, 3, 4, and 5 years. The cattle at the BCATRES are housed properly; they are fed concentrate and forage in a 2-to-3 ratio. The cattle are weighed at 3-month intervals. All animal procedures, including cattle care and health programs, were conducted by the BCATRES staff and complied with standard management practices.

Statistical analysis

First, the weights of each individual were adjusted based on dam age, as explained by Hardjosubroto (1994), using Eq. 1:

\[ BW_c = BW \times DACF \]  

(1)

where \( BW_c \) is the corrected body weight, \( BW \) is the actual body weight, and \( DACF \) is a correction factor based on dam age.

Four non-linear mixed mathematical models of the growth curve (the Brody, von Bertalanffy, Logistic, and Gompertz functions) were fitted to the weight–age data using the non-linear regression procedure in SPSS Statistics. An inflection point is the maximum increase in growth, where the growth rate changes from acceleration to retardation (Inounu et al. 2007; Selvaggi et al. 2016). Table 1 shows the mathematical equations of the models, along with their inflection weights and inflection times.

To select the best fitted model, the number of iterations, coefficient of determination \((R^2)\), root mean square error (RMSE), and Akaike’s information criterion (AIC) were used as adjustment criteria, as explained by Inounu et al. (2007), Moriasi et al. (2007), Chai and Draxler (2014), and Mäntysaari and Mäntysaari (2015).

Table 2 summarizes the observed body weights of Ongole Grade cattle at different ages. For males and females, birth weight averaged 26.75 ± 3.35 and 25.00 ± 0.15 kg, weaning weight averaged 139.45 ± 30.21 kg and 126.69 ± 2.90 kg, and yearling weight averaged 200.11 ± 51.34 and 184.91 ± 4.24 kg, respectively. Furthermore, the average body weights for males and females of 1.5-, 2-, 3-, 4-, and 5-year-old cattle were 284.44 ± 8.41 and 240.83 ± 5.17 kg, 328.13 ± 9.35 and 294.90 ± 6.54 kg, 446.36 ± 9.15 and 361.93 ± 8.63 kg, 518.12 ± 16.07 and 436.96 ± 19.13 kg, and 604.43 ± 22.85 and 511.63 ± 23.85 kg, respectively.

Tables 3 and 4 show the simulated growth curve parameters from birth to maturity, along with the age and weight of Ongole Grade cattle at the inflection point, based on the different equations. To calculate the parameters for males and females, the Brody, von Bertalanffy, logistic, and Gompertz models required 23 and 22, 19 and 22, 21 and 23, and 17 and 21 iterations, respectively. The value of parameter \( A \) for both males and females were highest in the Brody model. The highest value of \( B \) in both sexes was obtained using the Logistic model, followed by the Gompertz, Brody, and von Bertalanffy models. The highest value of \( k \) in both sexes was calculated by the Logistic model, followed by the Gompertz,

| Model               | \( M \) | Model weight of inflection (\( Ut \)) | Inflection time | Equation (Eq.)^* |
|---------------------|--------|--------------------------------------|-----------------|------------------|
| Brody               | 1      | \( na \)                              | \( na \)        | \( Y = A (1 - B e^{-kt}) \) (2) |
| von Bertalanffy     | 3      | \( A(8/27) \)                         | \( \frac{\ln 3B}{k} \) | \( Y = A (1 - B e^{-kt})^3 \) (3) |
| Logistic            | \(-1\) | \( A(0.5) \)                          | \( \frac{\ln B}{k} \) | \( Y = A (1 + B e^{-kt})^{-1} \) (4) |
| Gompertz            | \( M \to \infty \) | \( A e^{-1} \)                       | \( \frac{\ln B}{k} \) | \( Y = A e^{\left( -B e^{-kt} \right)} \) (5) |

*Source: Lawrence and Fowler (2002); \( A \), body weight (asymptotic), namely the value of \( t \) approaches infinity; \( B \), scale parameter (the value of integral constant); \( e \), logarithm base (2.718282); \( k \), the average rate of growth of the body until the animal reaches body maturity; \( M \), value of the function in the search for the inflection point (curve shape); \( U_t = Y_t \), proportion of mature animals compared to mature weight; \( t \), time in units of the month
von Bertalanffy, and Brody models. All predicted growth curves for both males and females were generally sigmoid (Fig. 1). The models, except Broody, also yielded distinct estimations of age and weight at puberty for both sexes. With the von Bertalanffy model, the age at puberty of males and females were 12.56 and 11.79 months with a body weight of 198.93 and 166.44 kg, while the logistic models yielded ages of 21.46 and 13.94 months when the body weight reached 298.43 and 164.08 kg and the Gompertz models yielded ages of 15.71 and 11.76 months when the body weight reached 235.49 and 169.57 kg, respectively.

Table 5 shows the statistics used to evaluate the equations for Ongole Grade cattle. There was no significant difference in $R^2$ for all models, although RMSE considerably differed among models; the RMSE values of males and females were 7.848 and 10.140, 15.390 and 16.630, 19.001 and 19.547, and 27.137 and 27.099 for the Brody, von Bertalanffy, Gompertz, and logistic models, respectively. Figure 2 shows the mean data deviations for all four models; the mean deviation of the Brody curve was the smallest.

### Discussion

Ongole Grade cattle have high growth potential, particularly for beef production, with a remarkable mean daily gain. Our study is the most recent analysis of the growth curve of Ongole Grade cattle and has the largest number of samples thus far (1656 cattle) (Table 2). The mean birth, weaning, and yearling weights for males and females determined here (26.75 ± 3.35 and 25.00 ± 0.15, 139.45 ± 30.21 and 126.69 ± 2.90, 200.11 ± 51.34 and 184.91 ± 4.24 kg, respectively) were higher than the values reported by Kurniawan et al. (2021). Furthermore, the mean body weights
of 2- and 3-year-old cattle were higher in our study than in the work by Maharani et al. (2017) (290 ± 59.8 and 330 ± 34.8 kg, respectively). Our results are consistent with the potential mature body weight of Ongole Grade cattle, which can exceed 400 kg, as indicated by Astuti (2004). Because intensive management can optimize cattle growth potential (Laya et al. 2020), the rearing system at BCATRES (where our samples were obtained) might have contributed to the high mean body weights in our study.

We found significant differences in the values of A, B, and k (Tables 3 and 4). Differences in mature weight (A) were also found by Marinho et al. (2013) for Nellore cows and Vijayakumar et al. (2020) for Friesian Holstein cattle; the Brody method yielded the highest values. For parameter B, similar results were obtained by Selvaggi et al. (2016), Maharani et al. (2017), and Tutkun (2019), who stated that the estimated value was highest using a logistic function. The logistic model also yielded the top growth rate (k) in our study, similar to the findings in other studies (Bahashwan et al. 2015; Maharani et al. 2017; Tutkun 2019). Various results for each parameter were obtained, as indicated by the correlations among parameters (Table 5). Selvaggi et al. (2016) reported that the von Bertalanffy and logistic functions usually provide the best results for *Bos indicus,*
although there are variations according to cattle breed and population structure.

The models can be accurately compared by the evaluating the overall growth curve analysis processes, as well as differences between actual and generated data. The number of iterations can be used to compare models; the Brody, logistic, and von Bertalanffy models required more iterations than did the Gompertz model (Tables 3 and 4). A greater number of iterations indicate that the model has more difficulty achieving convergence (Inouu et al. 2007). The age at puberty for males was younger with the von Bertalanffy model than with the Gompertz and logistic models; the age at puberty for females was younger with the Gompertz model than with the von Bertalanffy and logistic models; notably, the von Bertalanffy and logistic models also yielded the lowest estimated weight at puberty for male and female, respectively. The actual age and weight at puberty for females obtained from the database averaged 12.57 months and 205.86 kg, respectively; the results of Gompertz and von Bertalanffy models were closest, while the logistic model tended to overestimate these values. There was no information on the actual age and weight of males at puberty. These conclusions were confirmed by the $R^2$, RMSE, and AIC analyses (Table 5). Based on the accuracy of each model parameter, there were no differences in the $R^2$ values. However, the RMSE value was lowest for the Brody model, indicating high accuracy. The Brody model and the logistic model had the lowest AIC values for males and females, respectively. A smaller numerical value of AIC indicates a better fit model. Furthermore, the deviation between actual and estimated weights at different ages helps to compare models (Fig. 2). All deviation lines tend to point outwards from the beginning of the growth period. However, the deviation line of the Brody model most closely matched the real data. Therefore, we consider the Brody model to have better accuracy. Our results are in line with those described by Maharani et al. (2017). Body weight data obtained from identical environments would influence the goodness-of-fit of the mathematical models for explaining the variation in cattle body weight (Hafiz et al. 2015).

In conclusion, the Brody model was the most appropriate model in predicting growth for males, with high $R^2$, low RMSE, and AIC value, whereas for females, the Brody model was still the most appropriate model due to high $R^2$ and low RMSE, but logistic model was also appropriate based on AIC value. Females’ age and weight at puberty were best predicted by the Gompertz and von Bertalanffy models. All four models were highly accurate, but the Brody model provided better estimates due to its low deviation value. As a result, we advise using the Brody model to forecast the growth rate of Ongole Grade cattle.

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Author contribution Y.A., R.R.N., R.P., and C.L. were contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Y.A. The draft of the manuscript was written by Y.A. and P.S. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets analyzed during the current study are not publicly available due to government data usage restriction rules but are available from the corresponding author on reasonable request.
Declarations

Statement of animal rights There was no statement of animal rights required for this study. Cattle weighing were implemented as routine activity of the personnel following the standard operational procedure in the BCATRES.

Conflict of interest The authors declare no competing interests.

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