Comparison of Growth Curve Models for Ongole Grade Cattle

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Research Article

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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 3 years old in 2011 to 2019 obtained from the Beef Cattle Research Station. The data were analyzed using three non-linear growth curve models: von Bertalanffy, logistic, and Gompertz. The coefficients of determination (R^2) of the growth equation for the respective models were 0.996, 0.981, and 0.992. The estimated age and body weight at puberty for each model were 6.43 months and 144.09 kg, 13.94 months and 164.082 kg, and 11.76 months and 169.571 kg, respectively. The Gompertz function best fit the growth rate and exhibited the smallest standard deviation.

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 von Bertalanffy, logistic, Gompertz, Brody, 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 1,581 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, and 3 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 sex and dam age, as explained by Hardjosubroto (1994), using Eq. 1:

$$BWc = BW \times DACF \times CSCF \quad (1)$$

where BWc is the corrected body weight, BW is the actual body weight, $DACF$ is a correction factor based on dam age, and $CSCF$ is a correction factor based on calf sex.

Three non-linear mixed mathematical models of the growth curve (the 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.

Table 1
Mathematical models of growth curve

Model	Equation (Eq.)*		Model Weight of Inflection (*Ut*)	Inflection Time
von Bertallanfy	$Y = A\,(1\text{-}Be^{-kt})^3$	(2)	$A(8/27)$	$(\ln 3B)/k$
logistic	$Y = A\,(1\text{+}Be^{-kt})^{-M}$	(3)	$A(M/M\text{+}1)M$	$(\ln M)/k$
Gompertz	$Y = A\,exp\,(\text{-}Be^{-kt})$	(4)	Ae^{-1}	$(\ln B)/k$

* 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); *Ut* = *Ya* = proportion of mature animals compared to mature weight; *t* = time in units of the month.

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

Results

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 26.72 ± 3.35 kg, weaning weight averaged 139.45 ± 30.21 and 135.55 ± 31.2 kg, and yearling weight averaged 200.11 ± 51.34 and 197.85 ± 35.69 kg, respectively. The average body weights of 2- and 3-year-old cattle were 321.92 ± 70.39 and 417 ± 86.75 kg, respectively.

Table 2
Data structure of the Ongole Grade cattle

Age (month)	n (heads)	Male Body Weight (kg)	n (heads)	Female Body Weight (kg)	Total n (heads)	Average Body Weight (kg)
0	400	26.75 ± 3.35	403	26.72 ± 3.35	803	26.73 ± 3.52
7	97	139.45 ± 30.21	101	135.55 ± 31.2	198	137.46 ± 30.7
12	51	200.11 ± 51.34	62	197.85 ± 35.69	113	198.87 ± 43.26
18	77	284.44 ± 73.8	82	257.69 ± 50.12	159	270.65 ± 63.93
24	73	328.13 ± 79.89	71	315.54 ± 58.96	144	321.92 ± 70.39
36	80	448.3 ± 79.65	84	387.2 ± 83.05	164	417 ± 86.75

Table 3 shows 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, the Gompertz, logistic, and von Bertalanffy models required 18, 23, and 24 iterations, respectively. The value of parameter *A* was highest in the von Bertalanffy model. The highest value of *B* was obtained using the logistic model, followed by the Gompertz and von Bertalanffy models. The highest value of *k* was calculated by the logistic model, followed by the von Bertalanffy and Gompertz models. All predicted growth curves were generally sigmoid (Fig. 1). The three models also yielded distinct estimations of age and weight at puberty. With the von Bertalanffy model, the age at puberty was 6.43 months with a body weight of 144.09 kg, while the Gompertz and logistic models yielded ages of 11.76 and 13.94 months when the body weight reached 169.57 and 164.08 kg, respectively.

Table 3
Equation model of the growth curve of Ongole Grade cattle, number of iterations for the models, and value of the growth curve parameter

Model	von Bertallanfy	logistic	Gompertz
Equation	$Y = 486.298(1-0.572e^{-0.084t})^3$	$Y = 328.164(1+6.475e^{-0.134t})^{-1}$	$Y = 460.791exp(-2.354e^{-0.083t})$
$t_{(i)}$ (months)	6.43	13.94	11.76
$Y_{(i)}$ (kg)	144.09	164.082	169.571
Number of iterations	24	23	18
$A \pm SE$ (kg)	486.298 ± 33.985	328.164 ± 36.547	460.791 ± 35.444
$k \pm SE$ (%/day)	0.084 ± 0.011	0.134 ± 0.027	0.083 ± 0.013
B or $M \pm SE$ (unit)	0.572 ± 0.031	6.475 ± 1.867	2.354 ± 0.234

A = body weight (asymptotic), namely the value of *t* approaches infinity; *B* = scale parameter (the value of integral constant); *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); *SE* = standard deviation.

Table 4 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 were 19.455, 34.377, and 63.509 for the Gompertz, von Bertalanffy, and logistic models, respectively. Fig. 2 shows the mean data deviations for all three models; the mean deviation of the Gompertz curve was the smallest.

Table 4
Correlation value of the parameters, determination coefficient and Root Mean Squared Error of models

Model	*A**k*	*A**B*	*B**k*	R^2	RMSE
von Bertallanfy	-0.92	-0.317	0.599	0.996	34.377
logistic	-0.191	-0.732	0.736	0.981	63.509
Gompertz	-0.304	-0.877	0.657	0.992	19.455

A = asymptotic live weight; *B* = folding point of growth; *k* = growth rate; R^2 = coefficient of determination; RMSE = Root Mean Squared Error.

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 (1,500 cattle) (Table 2). The mean birth, weaning, and yearling weights determined here (25.02, 122.40, and 147.97 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* (Table 3). Differences in mature weight (*A*) were also found by Budimulyati et al. (2012) and Tutkun (2019) for Friesian Holstein cattle, Bahaswan et al. (2015) for Dhofari cattle, and Selvaggi et al. (2016) for Podolica bulls; the von Bertalanffy 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 (Bahaswan et al. 2015; Maharani et al. 2017; Tutkun 2019). Various results for each parameter were obtained, as indicated by the correlations among parameters (Table 4). 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 von Bertalanffy and logistic models required more iterations than did the Gompertz model (Table 3). A greater number of iterations indicates that the model has more difficulty achieving convergence (Inounu et al. 2007). The age at puberty was younger with the von Bertalanffy model than with the Gompertz and logistic models; notably, the Gompertz and logistic models also yielded the lowest estimated weight at puberty. The actual age and weight at puberty obtained from the database averaged 12.57 months and 205.86 kg, respectively; the results of Gompertz and logistic models were closest, while the von Bertalanffy model tended to overestimate these values. These conclusions were confirmed by the R^2 and RMSE analyses (Table 4). 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 Gompertz model, indicating high accuracy. 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 Gompertz model most closely matched the real data. Therefore, we consider the Gompertz model to have better accuracy. Maharani et al. (2017) obtained different results for Ongole Grade cattle, which might have been related to differences in study environment. 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 Gompertz model estimated the parameters most rapidly, while the von Bertalanffy model required the most computation. All three models had high degrees of accuracy, but the Gompertz model provided better estimates based on the low deviation value. Therefore, we recommend using the Gompertz model to predict the growth rate of Ongole Grade cattle during puberty.

Declarations

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Conflict of interest statement. The authors declare that they have no conflict of interest.

Author contributions. 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.

Data availability. The datasets analysed 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.

Statement of animal rights. There were 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.

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Figures

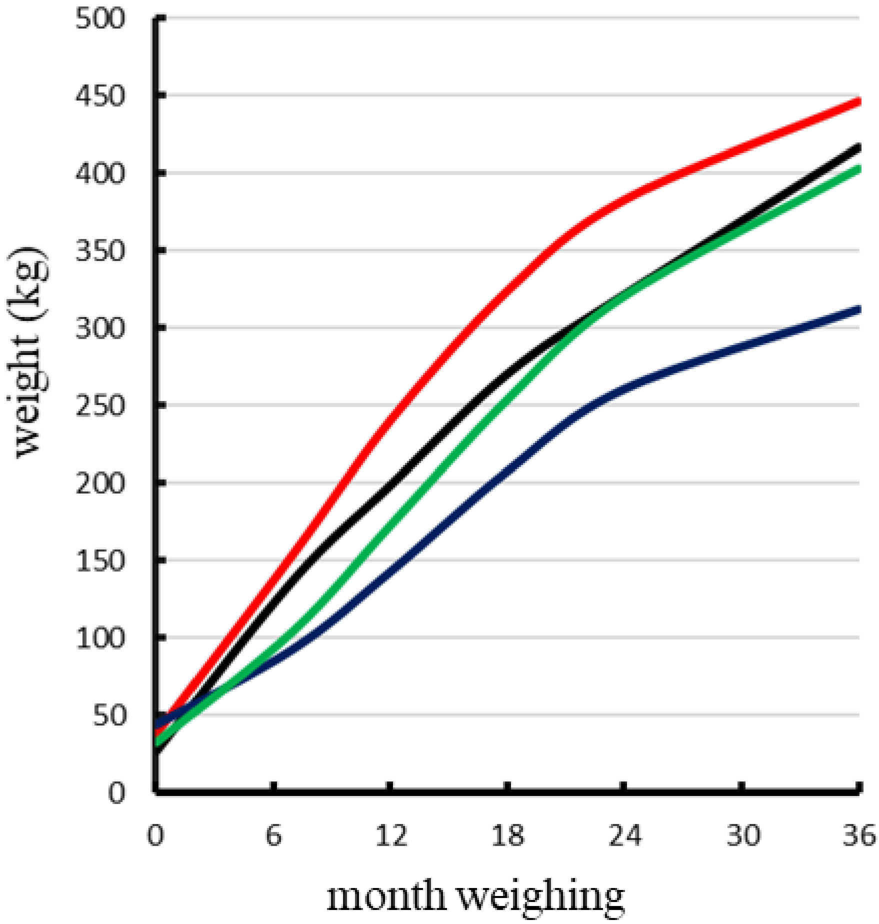

Figure 1

Ongole grade cattle growth. The colour pattern represent weight (kg) in observation: black line for actual field data curve, red line for von Bertallanfy curve, blue line for logistic curve, and green line for Gompertz curve

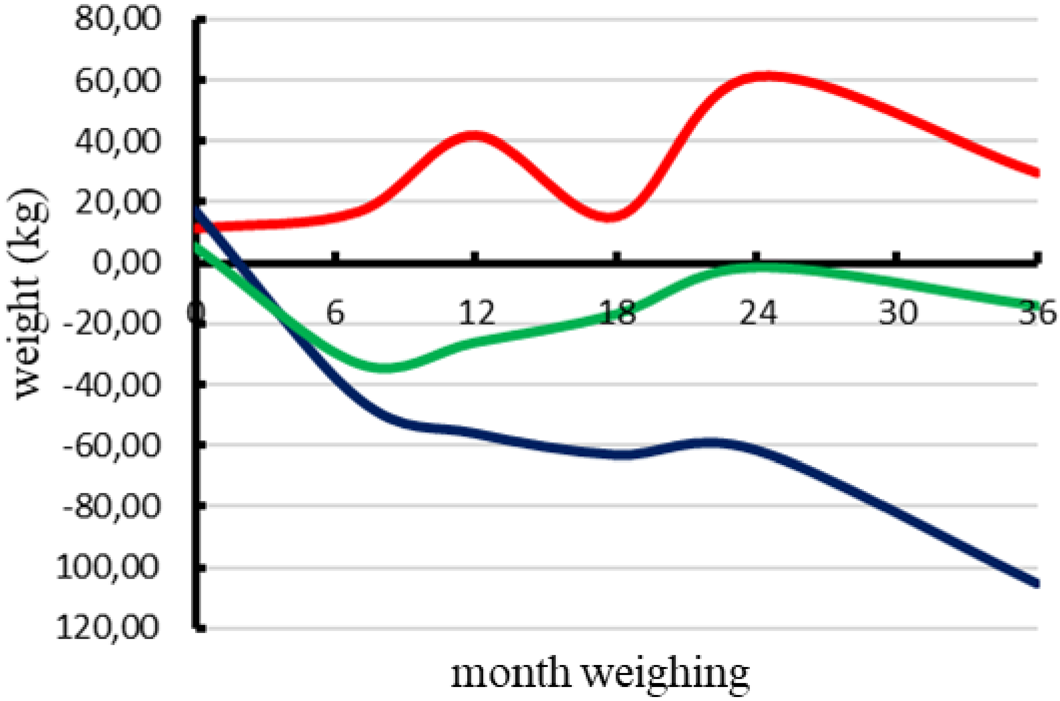

Figure 2

Graph of average data deviation compared to the field data of each model. The colour pattern represent weight in models: red line for mean deviation in von Bertallanfy curve, blue line for mean deviation in logistic curve, and green line for mean deviation in Gompertz curve

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