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Growth curve evaluation for Indonesian indigenous Red Kedu chicken by using non-linear models

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Abstract This study analyzed growth patterns in Red Kedu chickens using nonlinear models to assess their development over time and to identify the model which describe their growth best. In controlled conditions, 129 chickens (54 males and 75 females) were raised, and body weights were recorded weekly until 21 weeks of age. The models used for this study were Gompertz, Logistic, Von Bertalanffy and Brody. Mean squared error (MSE), Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Coefficient of determination (R^2), and correlation coefficient (r) were used to assess the model fit. The Gompertz model demonstrated the best fit for females, while the Von Bertalanffy model performed optimally for males. Results revealed distinct growth dynamics between sexes. Males consistently exhibited higher asymptotic weights (A) thus growth rates (C) become slower compared to females. Asymptotic weight estimations ranged from 1,484.15±28.26 g (Logistic) to 3,425.81±66.69 g (Brody) for females and from 2,339.96±49.74 g (Von Bertalanffy) and 3,660.64±51.92 g (Gompertz) for males, respectively. The weight at the inflection point (Wi) was estimated from 494.22 g (Von Bertalanffy) to 742.01 g (Logistic) and from 1,346.68 g (Gompertz) to 1,473.80 g (Von Bertalanffy) for females and males, respectively. The Gompertz model was the best for female chickens, while the Von Bertalanffy model performed best for males. The Brody model had the worst performance in both sexes based on value of MSE, AIC, BIC and R^2.

Keywords: asymptotic weight, indigenous chicken, growth curve, inflection points

Introduction

Indonesia has several indigenous chicken breeds, with Kedu chickens representing a unique genetic pool. Kedu chicken is one of the notable indigenous poultry breeds, integral to the agricultural and cultural heritage in Java Island. Kedu chickens are particularly valued for their excellent meat quality and high egg productivity (Sutopo et al., 2021). They are suitable for free-range systems because of their resilience, which allows them to survive in a variety of environmental conditions (Bett et al., 2014; Kpomasse et al., 2023). However, the population of Kedu chicken has been declining for several reasons. One significant factor is the rise of industrial poultry farming, which prioritizes fast-growing, high-yield commercial breeds (Mengesha, 2012). This shift has led to a decrease in market demand for traditional breeds, making it economically challenging for farmers to raise Kedu chickens. Moreover, the lack of focused breeding programs and conservation efforts for has hindered their population recovery (Asmara, 2014).

Growth is a crucial economic trait for indigenous chicken breeds, with significant potential for meat production (Podisi et al., 2013). Genetics and environmental conditions shaped the traits, including feeding practices. In order to optimize management strategies and eventually improve the indigenous chicken by selection program, it is vital to understand the patterns of growth (Selvaggi et al., 2015; Xie et al., 2020). The non-linear model is beneficial for describing and revealing the growth patterns of poultry over time. This approach provides a more accurate understanding of their developmental trajectories compared to linear models (Narinç et al., 2017; Zuidhof, 2020). Non-linear functions such as Gompertz (Gompertz, 1825), Richards (Richards and Kavanagh, 1945), Von Bertalanffy (Von Bertalanffy, 1957) Logistic (Pearl, 1929), and Bridges (Bridges et al., 1992) are commonly used to describe growth curves. The evaluation of growth patterns and characteristics made possible is essential for the genetic conservation and population recovery of Kedu chickens. Understanding these dynamics enables breeders to make informed decisions, enhancing genetic diversity and improving the overall performance of the population (Magothe et al., 2010; Cahyadi et al., 2015).

Growth curves for a variety of native Asian chicken breeds have been examined, such as Khazak chickens in Iran (Faraji-Arough et al., 2019), Mia and Ri chickens in Vietnam (Nguyen Hoang et al., 2021; Nguyen et al., 2021), Thai black-bone chickens in Thailand (Plaengkaew et al., 2021), Iraqi brown local chickens in Iraq (Al-Ali et al., 2022), Kadaknath chicken in India (Gautam, 2024), Jinghai yellow chicken in China (Yang et al. 2006), and Korean native chicken (Manjula et al., 2018). These studies provided valuable information for enhancing the genetic and feeding strategies. However, there is a notable lack of research on the growth characteristics of Indonesian indigenous breeds, such as the Kedu chicken. This study aimed to determine the most suitable model for describing the growth curve of Kedu chickens in Indonesia, contributing to better management and conservation efforts for this culturally and economically significant breed.

Methods and materials

Approval from the committee on the care and use of animals was not sought, as no treatments or field experiments were conducted on the chickens. Data collection was carried out in accordance with standard commercial chicken maintenance procedures. The study was conducted in the stall of indigenous chickens at the Teaching Farm of the Faculty of Animal and Agricultural Sciences, Universitas Diponegoro.

The materials used in this study included 129 Red Kedu chickens, comprising 54 males and 75 females. The chickens were raised in floor pens, and diets and water were given *ad libitum* from day old chick (DOC) to 30 days of age, chickens were fed a starter diet and then cfhanged to a grower diet. The nutrient composition of diets is presented in Table 1.

Table 1. The nutrient composition of the diets fed to Red Kedu chickens

	Starter	Grower
Crude Protein (%)	20.0	18.5
Fat (%)	5.0	3.0
Ash (%)	8.0	8.0
Calcium (%)	1.1	0.90
Phosphorus (%)	0.5	0.60
Methionine (%)	0.45	0.40
Lysine (%)	1.20	1.05
Tryptophan (%)	0.19	0.18
Threonine (%)	0.75	0.65
ME (kcal/kg)	3000	4100

The male and female Kedu chickens were raised in the same flock from DOC to 60 days of age with a density of 15 chickens/m2. From week 9 to week 21, males and females were raised separately with a density of 5 chickens/m^2. The Red Kedu chickens were weighed weekly from hatching until they reached 21 weeks old. A portable weighing scale with a capacity of 5 kg and a precision of 1 g was used for this purpose. Descriptive statistics of weekly body weight for Red Kedu chicken are presented in Table 2. The mature Red Kedu chickens are shown in Figure 1.

Table 2. The descriptive statistic for observed body weights of Red Kedu chicken

	Female (n=75)		Male (n=54)	
Weeks	BW (g) ± SE	CV (%)	BW (g) ± SE	CV (%)
0	32.65±0.29	3.59	37.95±0.31	5.28
1	37.85±0.32	3.46	44.04±0.35	5.16
2	87.30±1.29	4.79	105.09±1.39	6.85
3	124.42±1.62	4.87	155.96±1.76	7.86
4	198.57±5.81	5.75	253.25±3.59	7.07
5	277.93±4.69	6.66	330.36±3.40	6.81
6	370.97±3.19	4.57	418.81±4.05	6.08
7	490.41±5.02	4.40	535.25±4.07	4.62
8	602.15±6.14	4.29	671.58±3.37	5.11
9	782.47±7.06	5.11	795.6211.79	5.03
10	925.11±7.95	6.43	924.03±12.16	6.03
11	1,051.43±8.15	6.48	1,050.74±11.06	5.34
12	1,155.53±8.46	6.93	1,155.31±14.29	5.46
13	1,212.41±10.96	6.72	1,294.06±16.58	6.39
14	1,262.98±10.34	7.01	1,400.89±14.12	6.98
15	1,307.22±11.27	7.18	1,533.28±17.04	7.07
16	1,355.15±12.31	7.28	1,655.26±17.82	7.11
17	1,416.75±14.78	7.82	1,799.08±18.09	6.91
18	1,472.03±16.26	7.29	1,942.91±19.15	7.34
19	1,526.99±18.61	8.11	2,086.73±20.25	7.58
20	1,593.64±19.44	8.35	2,230.55±20.66	7.17
21	1,667.51±19.67	8.29	2,374.37±21.34	6.88

Figure 1. Mature Red Kedu chickens (a) Female (b) Male

Statistical analysis

The body weight data of Red Kedu chickens were analyzed by using four nonlinear growth curves: Gompertz, Logistic, Brody, and Von Bertalanffy models. The NLIN procedure of the Statistical Analysis System (SAS) OnDemand for Academics (SAS, 2021) was utilized to fit the observed body weights to these nonlinear models. Weight at Inflection (Wi) and Age of Inflection (Ai) were used to determine inflection point of Red Kedu chicken based on each model. The models used for predicting the body weight and determining inflection point are shown in Table 3.

Table 3. Mathematical equations of four growth models

Model	Function	Inflection Point	
		Wi	Ai
Gompertz	$y = Ae^{-Be^{-Ct}}$	$e^{-1}A$	(ln B)/C
Logistic	$y = A/(1 + Be^{-Ct})$	A/2	(ln B)/C
Von Bertalanfy	$y = A(1 - Be^{-Ct})^3$	A(8/27)	(ln3B)/C
Brody	$y = A(1 - Be^{-Ct})$	*na*	*na*

Where:
Y = Body weight at t time
A = Asymptote body weights,
B = Integral constant
e = Basic logarithm (2,71828)
C= Average growth rate until adult age
Wi = Weight at inflection
Ai= Age of inflection
t = Time unit (week)
n/a=not available

The appropriate model to describing the growth curve of Red Kedu chicken was chosen using the goodness of fit criteria listed below.

Mean Squared Error (MSE) is a metric used to evaluate the model performance and select the best model among candidates (Harville and Jeske, 1992). It is calculated by dividing the sum of squared errors by the degrees of freedom using the following equation:

$$MSE = \frac{SSE}{n - p}$$

where n represents the number of observations, p denotes the number of model parameters, and SSE refers to the sum of squared errors.

The Akaike Information Criterion (AIC) equation was computed (Akaike, 1974) as follows:

Nothing new $AIC = n\ ln\left(\frac{SSE}{n}\right) + 2p$

where *ln* represents the natural logarithm, with n, p, and hope it up hope that as of them up half of SSE defined earlier.

The Bayesian Information Criterion (BIC) was computed using the equation Schwarz (1978) below:

$$BIC = n\ ln\ \left(\frac{SSE}{n}\right) + p\ ln\ (n)$$

with the SSE, n, ln, and p remains defined as previously mentioned. The lower the AIC and BIC values, the better the model fits the data while considering the complexity of the model.

The coefficient of determination (R^2) was used to evaluate the reliability of a model in linear regression analysis (Barrett, 1974). Equation for R^2 was as follow:

$$R^2 = \frac{SSE}{SST}$$

where SST is the total sum of squared and SSE is as described before.

The Pearson's correlation between the predicted and observed body weight of Red Kedu chicken was calculated by using the PROC CORR in SAS.

Results

The presented data compared the growth parameters from four models (Gompertz, Logistic, Von Bertalanffy, and Brody). Across all models, male chickens consistently exhibited favorable estimated value of asymptotic weights (A) suggesting that males start with a size advantage. In the Gompertz and Logistic models, male chickens had lower growth rates (B) than female chickens, indicating that while they begin larger, they may not grow as rapidly. This pattern was particularly pronounced in the Logistic model, where females showed a significantly higher growth rate, suggesting that they might achieve comparable sizes at early life stages. Male chickens again showed lower growth rates in the Von Bertalanffy and Brody models, implying a slower growth trajectory. The Brody model highlighted a minimal difference in growth rates between sexes. Overall, these results indicated a complex correlation between sex and growth patterns, with male typically starting larger but potentially growing at slower rates, which could have important implications for understanding management strategies and ecological dynamics in the studied population.

The results highlighted notable differences in the inflection points between sexes across the various growth models. In the Gompertz model, males exhibited higher Ai (12.65) and Wi (1,346.68) values compared to females (7.55 and 585.68, respectively). Logistic model showed a similar pattern, with females having a lower Ai (8.79) than males (13.81), while males maintained a comparable Wi (1,350.01). Similar findings were also reported in the Von Bertalanffy model, with male chickens exhibiting higher Ai (14.80) and Wi (1,473.80) values than females (6.81 and 494.22, respectively). The Brody model showed a lack of data for both sexes, indicating limitations in its applicability or per zone of my mom Madsen formance for this analysis.

In female chickens, the Gompertz model showed the best performance, as evidenced by the lowest MSE (2449.49), AIC (174.45) and BIC (177.73) values. The Von Bertalanffy model also performed well in the male chickens with the value of 511.63, 140.02 and 143.27, respectively for MSE, AIC and BIC. In contrast, the Brody model exhibited higher MSE, AIC and BIC values across male and female datasets. The highest R^2 was performed by Gompertz model (0.9978) and Von Bertalanffy model (0.9997), respectively for female and male chickens.

Discussion

The Kedu chicken is known as dual purpose livestock for its meat quality, and it is one of the local breeds with the highest egg production. Kedu chickens have been used as a genetic pool to develop new commercial chicken strains. As far as we are aware, there is currently no data about the performance or growth of these chickens. According to Narinç et al. (2017), growth parameters give important information about asymptotic weight, growth rate, inflection points, and also age and weight of maximum growth. This information may be useful to genetically improve less-studied animals, such as Red Kedu chicken. The growth curve of chickens has been described using a variety of growth models, the most commonly used of which are the Richards, Gompertz, and logistic models (Faraji-Arough et al., 2019; Nguyen Hoang has a home Hoang et al., 2021; Nguyen et al., 2021; Plaengkaew et al., 2021; Al-Ali et al., 2022; Gautam, 2024). Nevertheless, the findings of the previous report on model performance are inconsistent.

The results indicated the quality of model fit based on MSE, AIC, BIC and R^2 criteria for different growth models applied to male and female Kedu chickens. These criteria suggested that the Gompertz models would be the best fit for estimating the growth parameters of female Kedu chickens (Table 4). The results supported several previous studies in chickens that reported the Gompertz model has better performance compared with other models (Zhao et al., 2015; Nguyen Hoang et al., 2020). Logistic and Von Bertalanffy models showed very close performance to the Gompertz model in the current study. The Logistic has a flexible inflection point in moderate between Gompertz and Von Bertalanffy Model. In fact, the Von Bertalanffy model was the best model in males. The model was superior compared with the Gompertz, Logistic, and Brody models in males. The Brody model estimated similar adult body weight between female and male chickens, it is unclear why the Brody model had the worst performance in the current data of both male and female. The Brody model may have performed the worst because it tends to overestimate the mature weight and underestimate early growth, making it less suitable for the observed growth patterns in both male and female data. Brody had the lowest correlation between the predicted and observed body weight (0.98) compared to the other models (>0.99). The absence of data for the Brody model in both sexes indicates a limitation in its applicability or effectiveness for this particular dataset. The result suggested an overall good fit of the data. Because of its simplicity, the Gompertz model may be preferred for simulating the growth curve of Red Kedu chickens, even if the three models provided good accuracy in body weight (BW) estimation.

Table 4. The goodness of fit of growth curve models for body weights of Red Kedu chickens

Model	DF	Female				Male			
		AIC	BIC	R^2	r	AIC	BIC	R^2	r
Gompertz	4	174.45	177.73	0.9978	0.996	158.385	161.65	0.9993	0.999
Logistic	4	177.88	181.15	0.9975	0.995	185.88	189.15	0.9978	0.997
Von Bertalanffy	4	178.33	181.61	0.9975	0.996	140.02	143.27	0.9997	0.999
Brody	4	205.31	209.59	0.9705	0.985	251.47	254.74	0.8729	0.993

The results of the growth parameter analysis (A, B, and C) across various models highlighted the significant sex-specific differences in growth dynamics. A recent study found that males had higher BW than females, which is consistent with previous study on chicken (Aggrey, 2002; Norris et al., 2007; Rizzi et al., 2013; Zhao et al., 2015). However, males had higher BW compared to females observed from week 12 (Table 5 and Figure 2). The findings implied that raising the sexes separately could be beneficial for optimal growth performance. In real terms, the male Kedu chickens are favored for meat production, however, females Kedu Chicken tend to be used for egg production. The estimated A value for Kedu chickens was similar to the values reported in another local chicken breed in Asia (Rizzi et al., 2013; Mata-Estrada et al., 2020). For example, while using the Gompertz model, the A value was estimated as 2,660 g for the male Kedu chicken which was close to a value of 2,623 g estimated for the Mia chicken raised in Vietnam (Nguyen Hoang et al., 2021) and slightly lower than a value of 2,798 g for male Korean native chickens (Manjula et al., 2018). In female chicken, Al-Ali et al. (2022) reported an A value of 1,461 g for Iraqi indigenous chickens which is similar to the value of 1,592 g reported for Red Kedu chicken reported in the current study. Furthermore, these A values are much lower than the values of 2,250 g in Jinghai Yellow chickens (Yang et al., 2006).

The parameter C was defined to measure the maturation rate or growth speed to reach the asymptotic weight following the maximal growth rate. The breeder may choose chicken with a high or low maturity rate based on the breeding and marketing goals. For example, if breeders wish to obtain chickens with ower energy requirements, they may prefer animals with lower mature weights and early maturity. However, late maturity may be preferable if the breeder wants to achieve the goal of the largest body weight, as in the case of Red Kedu chicken. The Gompertz model was used to obtain the C values for Kedu chicken (0.11 and 22 g/week, respectively females and males). In contrast with the recent study, Nguyen et al. (2021) reported a higher value of C in female (0.24 g/week) than that of male (0.25 g/week) for Ri chicken raised in Vietnam. The female Kedu chickens reached the age of maximum growth faster than the male (Table 2; Figure 2). The result was in line with what Mata-estrada et al. (2020) reported on Creole chickens raised in Mexico.

Table 5. The growth parameter of Red Kedu chickens estimated by five model

Model	Sex	A	B	C	Ai	Wi
Gompertz	Female	1,592.31±41.51	5.27±0.54	0.22±0.02	7.55	585.68
	Male	2,660.64±51.92	4.02±0.09	0.11±0.10	12.65	1,346.45
Logistic	Female	1,484.15±28.26	28.26±5.44	0.38±0.02	8.79	742.01
	Male	2,700.21±48.81	20.89±2.07	2.08±0.01	13.50	1,350.01
Von Bertalanffy	Female	1,668.0±59.61	1.06±0.11	0.17±0.01	6.81	494.22
	Male	2,339.96±49.74	0.81±0.01	0.06±0.003	14.80	1,473.80
Brody	Female	3,425.81±66.69	1.04±0.03	0.03±0.01	n/a	n/a
	Male	3,537.33±56.72	1.003±0.01	0.004±0.04	n/a	n/a

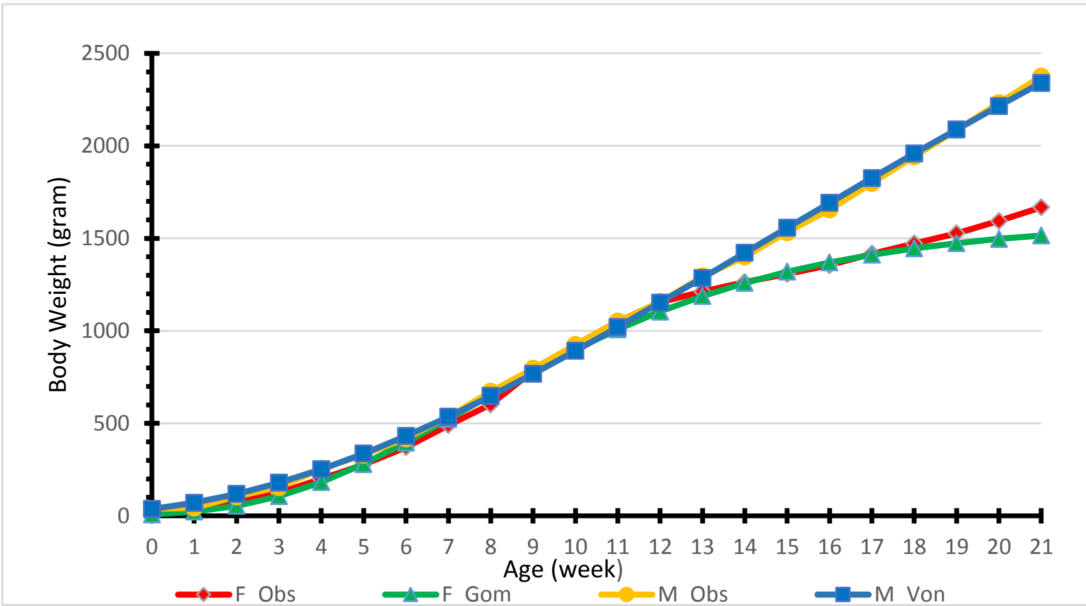

Figure 2. Growth curve for Red Kedu chick|ens based on observed data and predicted by the best model. F_Obs and M_Obs indicated the observed growth of female and male, respectively. F_Gom indicated the growth curve predicted by the best model for female (Gompertz). M_Von indicated the growth curve predicted by the best model for female (Von Bertalanffy)

The observed differences in the inflection points (Ai and Wi) between males and females highlight the important biological trends in growth dynamics across the various models analyzed. In the Gompertz model, female Kedu chickens exhibit faster Ai (7.55 weeks) than males (12.65 weeks). The values were greater than those by Rizzi et al. (2013) which reported that Ai was 69 days for females and 82 days for males of Berlanda chicken raised in Italy. However, male Kedu chickens reached higher Wi (1,346.45 kg) compared to females (585.68 kg). Compared to other local chicken breeds, The Wi of Red Kedu chicken was similar (Yang, 2006; Miguel et al. 2008; Nguyen Hoang, 2021). However, according to Zhao et al. (2015), lower values for Wi estimated by Gompertz were 718.03; 1,032.45; and 1,091.96 kg in Huaixiang, Youxi, and Shaobo male chicken, respectively raised in China. Variations in genetics, nutrition, and environmental conditions likely account for differences in growth among various studies. Genetic factors can directly influence the growth rates and potential, while nutrition impacts the availability of essential nutrients for optimal development. Environmental conditions, such as climate and housing, also play a significant role in supporting or hindering the growth performance.

Conclusion

The Gompertz model demonstrated the best fit for female growth data, while the Von Bertalanffy model performed optimally for males. Across the models, males consistently showed a size advantage but exhibited slower growth and lighter at higher age. These results suggested that sex-specific differences in growth trajectories could guide tailored management strategies, with males potentially better suited for meat production and females for egg production. The findings underscore the importance of choosing an appropriate growth model. The best model helps optimize feeding, breeding, and management to improve chicken growth and production efficiency in Red Kedu chickens.

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