

Evaluation of Logistic, Gompertz, and Weibull models for describing growth curves in three varieties of Kedu Chickens

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ABSTRACT

This study evaluated three nonlinear growth models (Logistic, Gompertz, and Weibull) to describe the growth performance of male and female Kedu chickens, including three phenotypes: Red Comb Kedu (RCK), Black Comb Kedu (BCK), and White Kedu (WK). Body weight data from 0 to 10 weeks of age were analyzed, and model fit was assessed using Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), coefficient of determination (R^2 and adjusted R^2), and correlation coefficient (r). All models showed high accuracy with R^2 values ranging from 0.96 to 0.98 in both sexes, indicating that more than 96–98% of the variation in body weight was explained by the models. Among them, the Gompertz model provided the best fit, achieving the highest R^2 (0.9884 in WK males and 0.9818 in BCK females). This model also produced biologically reasonable predictions, with inflection points occurring between the 7th and 8th weeks. In contrast, the Weibull model, despite comparable R^2 values, generated unrealistic estimates in some groups, such as a maximum body weight of 34,770.5 g and an inflection age of one week in WK females. The Logistic model showed fluctuations in the final growth phase, failing to reflect the biological growth pattern. These results confirm the Gompertz model as the most appropriate for describing Kedu chicken growth and support its application in breeding and management programs for local chickens.

Introduction

Kedu chicken is one of Indonesia's indigenous breeds that has been designated as a Genetic Resource of Livestock (SDGT) through the Decree of the Minister of Agriculture of the Republic of Indonesia No. 2481/Kpts/LB.430/8/2012. Originating from Temanggung Regency, Central Java, this breed is recognized for its relatively high egg production, reaching approximately 200 eggs per hen per year (Sutopo *et al.*, 2022), as well as its good meat quality, which makes it attractive to consumers (Setiaji *et al.*, 2025). Kedu chickens comprise several phenotypic varieties, including Red Kedu, White Kedu, and Black Kedu (red comb and black comb) (Sartika *et al.*, 2016). This phenotypic diversity reflects the high genetic variability of Kedu chickens, which provides great potential for further development through breeding and conservation programs (Sartika *et al.*, 2023).

In the poultry industry, body weight is a key economic parameter as it is associated with productivity, feed efficiency, and market value (Schmidt, 2008). The greater the body weight achieved during rearing, the higher the potential income generated (Triani *et al.*, 2024). Moreover, body weight is a heritable trait, making it a valuable target for improvement through breeding programs (Khobondo, 2021). To support this, non-linear growth modeling can be applied to more accurately estimate chicken growth curves (Nguyen *et al.*, 2021).

A growth curve describes the ability of an individual or population to develop body components until reaching maximum (mature) size under given environmental conditions (Moharrery and Mirzaei, 2014). Exploring growth curves allows a clearer understanding of body weight dynamics and animal development, while also enabling more accurate prediction of growth stages (Fan and Ye, 1997; Roush and Branton, 2005).

Non-linear growth curves are represented by several models, including Logistic, Gompertz and Weibull (Nguyen *et al.*, 2021; Şengül *et al.*, 2024). Among them, the model with the highest coefficient of determi-

nation (R^2) is considered the best fit. These non-linear models have been widely used to predict body weight in chickens, including Mexican native chickens (Mata-Estrada *et al.*, 2020), Indian native chickens (Gautam, 2024), Nigerian native chickens (Sanusi and Oseni, 2020; Lamido *et al.*, 2025), Chinese native chickens (Liu *et al.*, 2022), Iranian native chickens (Neysi *et al.*, 2023), Italian native chickens (Soglia *et al.*, 2020), Kampung Unggul Balitnak (KUB) chickens (Urfa *et al.*, 2017), as well as broilers (Koushander *et al.*, 2019; Setiaji *et al.*, 2023; Osaiyiwu *et al.*, 2024).

Based on the above background, this study aimed to evaluate the suitability of the Logistic, Gompertz, and Weibull models in describing the growth patterns of Kedu chickens according to phenotypic varieties and sex. The findings of this study are expected to contribute to the development of Kedu chickens as one of Indonesia's local poultry genetic resources.

Materials and methods

Animals and management

This study was conducted over a period of 10 weeks at the Poultry House, Faculty of Animal and Agricultural Sciences, Diponegoro University. A total of 136 Kedu day-old chicks (DOCs) were used as research samples, consisting of 99 Red Comb Kedu chickens (65 males and 34 females), 29 Black Comb Kedu chickens (5 males and 24 females), and 8 White Kedu chickens (6 males and 2 females).

During the first four weeks, the chickens were reared in group housing, and then moved to individual cages for further observation. Commercial feed was provided *ad libitum*, containing 20% crude protein and metabolizable energy ranging from 2900 to 3000 kcal/kg. Drinking water was also made available *ad libitum*. Body weight was recorded weekly from the beginning of the rearing period until the 10th week. The weekly body weight data of male and female Kedu chickens from week 0 to week

10 are presented in Table 1 and Table 2.

Statistical analysis

The Logistic, Gompertz, and Weibull models were employed to estimate the live body weight of Kedu chickens throughout the rearing period. These three non-linear models were applied to predict body weight based on weekly growth data. The mathematical formulations of the Logistic, Gompertz, and Weibull models followed those described by Nguyen *et al.* (2021) and Şengül *et al.* (2024).

Logistic growth model

$$Y_t = \frac{A}{(1 + B \cdot \exp(-K \cdot t))}$$

The logistic growth curve, introduced by Verhulst in 1838, is commonly used to model somatic growth with an upper asymptote.

$$W_i = \frac{A}{e}; A_i = \frac{\ln B}{K}$$

Gompertz growth model

$$Y_t = A \cdot \exp(-B \cdot \exp(-K \cdot t))$$

The Gompertz function has a point of inflection at (W_i and A_i).

$$W_i = \frac{A}{2}; A_i = \frac{\ln B}{K}$$

Weibull growth model

$$Y_t = A - B \cdot \exp(-K \cdot t^\alpha)$$

For Weibull function, age (W_i) and weight (A_i) at point of inflection,

$$W_i = A - B \cdot \exp\left(-\left(1 - \frac{1}{a}\right)\right); A_i = \left(\frac{(a-1)}{Ka}\right)^{\frac{1}{a}}$$

Where:

Y = Body weight at t time

A = Asymptotic body weight (maximum weight)

B = Integration constant

K = Average growth rate until adult age

e = Euler's number (2.71828)

α = Shape parameter (specific to the Weibull model)

W_i = Body weight at the inflection point

A_i = Age at the inflection point

t = time unit (week)

The selection of the best-fitting growth model was based on several evaluation criteria, including Mean Squared Error (MSE), coefficient of determination (R^2), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). The MSE value was calculated by dividing the sum of squared errors (SSE) by the degrees of freedom. The most appropriate model is indicated by the lowest AIC and BIC values and an R^2 value closest to 1 (Şengül *et al.*, 2024).

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

$$SSE = \sum (Y_i - \hat{Y}_i)$$

where:

SSE = The Sum of Squared Errors

Y_i = observed value

$\hat{Y}_i$ = predicted value

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

where:

"MSE" = observed value

"SSE" = predicted value

n = number of observations

p = number of estimated parameters

Akaike Information Criterion (AIC) was developed by Akaike (1974) to compare the goodness of fit among competing models. AIC balances model fit and complexity by introducing a penalty for the number of parameters. The AIC value is calculated using the following formula:

$$AIC = n \cdot \ln\left(\frac{SSE}{n}\right) + 2p$$

where:

"AIC" = Akaike Information Criterion

"SSE" = predicted value

n = number of observations

p = number of estimated parameters

$\ln$ = natural logarithm

Bayesian Information Criterion (BIC) was developed by Schwarz (1978) as an alternative to AIC, incorporating a stronger penalty for model complexity. It is calculated using the formula:

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

BIC = Bayesian Information Criterion

SSE = predicted value

n = number of observations

p = number of estimated parameters

$\ln$ = natural logarithm

To describe the growth patterns of Kedu chickens, three non-linear growth models were applied, namely Logistic, Gompertz, and Weibull. These models were chosen because they have been widely used in poultry growth studies and are considered to provide accurate estimates of growth curve parameters. The Logistic model assumes a symmetric sigmoidal pattern (Aggrey, 2002; Beiki *et al.*, 2013), the Gompertz model represents an asymmetric growth curve that is often more suitable for chickens (Masoudi and Azarfar, 2017; Nguyen *et al.*, 2021), while the Weibull model offers greater flexibility in describing different growth trajectories (Cordeiro *et al.*, 2023; Suleiman *et al.*, 2024).

Table 1. Observed body weight of male Kedu chickens.

Age (weeks)	Red Comb Kedu (n=65)			Black Comb Kedu (n=5)			White Kedu (n=6)		
	BW (g) (Mean $\pm$ SD)	SE	CV (%)	BW (g) (Mean $\pm$ SD)	SE	CV (%)	BW (g) (Mean $\pm$ SE)	SE	CV (%)
0	30.94 $\pm$ 2.95	0.37	9.54	32.60 $\pm$ 2.07	0.93	6.36	31.00 $\pm$ 1.67	0.68	5.4
1	62.62 $\pm$ 6.58	0.82	10.51	65.80 $\pm$ 8.32	3.72	12.64	66.50 $\pm$ 10.77	4.4	16.19
2	120.42 $\pm$ 12.82	1.59	10.65	124.00 $\pm$ 13.15	5.88	10.61	123.67 $\pm$ 20.66	8.43	16.7
3	191.80 $\pm$ 21.92	2.72	11.43	205.80 $\pm$ 26.57	11.88	12.91	200.17 $\pm$ 15.16	6.19	7.57
4	295.20 $\pm$ 41.61	5.16	14.09	324.80 $\pm$ 65.82	29.44	20.27	299.67 $\pm$ 56.93	23.24	19
5	426.38 $\pm$ 49.31	6.12	11.57	434.00 $\pm$ 47.36	21.18	10.91	438.33 $\pm$ 41.79	17.06	9.53
6	567.69 $\pm$ 55.70	6.91	9.81	588.00 $\pm$ 69.34	31.01	11.79	580.00 $\pm$ 40.12	16.38	6.92
7	711.46 $\pm$ 77.55	9.62	10.9	741.00 $\pm$ 88.42	39.54	11.93	707.50 $\pm$ 51.45	21.01	7.27
8	846.15 $\pm$ 83.39	10.34	9.86	857.00 $\pm$ 117.24	52.43	13.68	851.67 $\pm$ 34.74	14.18	4.08
9	1027.69 $\pm$ 101.06	12.54	9.83	1073.00 $\pm$ 130.99	58.58	12.21	1008.33 $\pm$ 69.98	28.57	6.94
10	1165.54 $\pm$ 106.60	13.22	9.15	1207.00 $\pm$ 119.93	53.63	9.94	1140.83 $\pm$ 69.53	28.38	6.09

BW = average body weight; SD = standard deviation; SE = standard error; CV = coefficient of variation (%); n = sample size

Table 2. Observed body weight of female Kedu chickens.

Age (weeks)	Red Comb Kedu (n=34)			Black Comb Kedu (n=24)			White Kedu (n=2)		
	BW (g) (Mean $\pm$ SD)	SE	CV (%)	BW (g) (Mean $\pm$ SD)	SE	CV (%)	BW (g) (Mean $\pm$ SE)	SE	CV (%)
0	31.50 $\pm$ 3.21	0.55	10.2	32.17 $\pm$ 3.12	0.64	9.69	30.50 $\pm$ 0.71	0.5	2.32
1	60.65 $\pm$ 7.06	1.21	11.64	64.63 $\pm$ 7.45	1.52	11.52	59.50 $\pm$ 2.12	1.5	3.57
2	114.06 $\pm$ 12.80	2.2	11.22	120.71 $\pm$ 12.21	2.49	10.11	111.50 $\pm$ 7.78	5.5	6.98
3	176.21 $\pm$ 15.63	2.68	8.87	182.25 $\pm$ 20.40	4.16	11.19	178.00 $\pm$ 15.56	11	8.74
4	261.59 $\pm$ 30.25	5.19	11.56	270.88 $\pm$ 34.79	7.1	12.84	268.50 $\pm$ 31.82	22.5	11.85
5	378.24 $\pm$ 34.83	5.97	9.21	389.79 $\pm$ 36.34	7.42	9.32	352.50 $\pm$ 45.96	32.5	13.04
6	486.18 $\pm$ 39.06	6.7	8.03	504.38 $\pm$ 39.93	8.15	7.92	437.50 $\pm$ 45.96	32.5	10.51
7	597.65 $\pm$ 57.63	9.88	9.64	624.79 $\pm$ 50.40	10.29	8.07	535.00 $\pm$ 56.57	40	10.57
8	708.68 $\pm$ 72.22	12.39	10.19	744.58 $\pm$ 61.98	12.65	8.32	625.00 $\pm$ 77.78	55	12.45
9	841.18 $\pm$ 71.94	12.34	8.55	887.92 $\pm$ 71.32	14.56	8.03	747.50 $\pm$ 102.53	72.5	13.72
10	954.56 $\pm$ 75.93	13.02	7.95	1011.88 $\pm$ 77.71	15.86	7.68	847.50 $\pm$ 116.67	82.5	13.77

BW = average body weight; SD = standard deviation; SE = standard error; CV = coefficient of variation (%); n = sample size

Results

This study analyzed the growth of male and female Kedu chickens representing three different phenotypes based on comb and feather coloration: Red Comb Kedu (RCK), Black Comb Kedu (BCK), and White Kedu (WK). Three non-linear growth models, Logistic, Gompertz, and Weibull, were used. Model parameter estimates, inflection points, and model evaluation criteria are presented in Tables 3, 4, 5, and Fig 1.

Growth model parameters

The Logistic model yielded asymptotic body weights (A) up to 1,400.0 g for BCK males and 1,175.0 g for BCK females. It also tended to produce higher growth rate constants (K), ranging from 0.4961 to 0.5703. The Gompertz model provided higher asymptotic estimates, with the highest A observed in BCK males (2,424.3 g) and BCK females (1,959.9 g), while the estimated growth rate constants (K) were lower (0.1795 to 0.1978). In contrast, the Weibull model generated extreme values, with the A estimate for WK females reaching 34,770.5 g, which is biologically implausible. The shape parameter (α) of the Weibull model ranged from 1.34 to 1.90.

Inflection point

The inflection points, represented by W_i (inflection weight) and A_i

(age at inflection), were generally higher in males. For the Gompertz model, A_i ranged from 7.21 to 7.99 weeks for males and from 7.32 to 7.73 weeks for females. The Weibull model showed inflection ages approaching one week, which deviates from the normal biological growth phase of chickens, suggesting a potential modeling bias in early growth stages.

Model evaluation criteria

The Gompertz and Weibull models exhibited higher coefficients of determination (R^2) and correlation coefficients (r) than the Logistic model, indicating a better fit to the growth data. The Gompertz model for WK males produced $R^2 = 0.9884$ and $r = 0.9942$, while the Weibull model for the same group resulted in $R^2 = 0.9883$ and $r = 0.9941$. Conversely, the Logistic model yielded higher AIC and BIC values in some groups, for example RCK males (AIC = 6030.98), indicating suboptimal model fit.

Growth curves

The growth curves based on actual and predicted body weights from each model are shown in Fig 1., which consists of six subpanels: RCK males (a), BCK males (b), WK males (c), RCK females (d), BCK females (e), and WK females (f).

Visually, the Gompertz model demonstrated a sigmoidal curve that reflected the biological growth pattern of chickens, with a slow initial phase, a rapid growth phase around weeks 7 to 8, and a plateau as the

growth slowed toward the end of the period. The inflection point was clearly visible in the Gompertz curve, representing the peak growth rate. The Logistic model displayed a symmetric curve, but for some groups it deviated from actual data during the late growth phase. The Weibull curve often appeared either too steep or too flattened, especially in WK females, thus failing to capture the natural growth dynamics.

These results confirm that the Gompertz model provides not only the most statistically robust estimates but also the most biologically and visually realistic representation of Kedu chicken growth. Its consistent performance across phenotypes and sexes highlights its suitability for further application in breeding programs and growth modeling of local chicken populations.

Table 3. Estimated parameters of non-linear growth models (Logistic, Gompertz, and Weibull) in Kedu chickens.

Model	Phenotype	Male				Female			
		A	B	K	α	A	B	K	α
Logistic	RCK	1390	34.44	0.52	-	1105	27.87	0.51	-
	BCK	1400	31.26	0.52	-	1175	28.33	0.51	-
	WK	1225	32.54	0.57	-	930	22.16	0.50	-
Gomperz	RCK	2244.5	4.28	0.19	-	1742	4.00	0.19	-
	BCK	2424.3	4.21	0.18	-	1959.9	4.05	0.18	-
	WK	2026.6	4.16	0.20	-	1559.1	3.72	0.18	-
Weibull	RCK	2327.6	2283.5	0.01	1.90	1940	1899.7	0.01	1.78
	BCK	3392.4	3353.2	0.01	1.75	2187.3	2141.3	0.01	1.81
	WK	1994.2	1947.8	0.01	1.90	34770.5	34751.6	0.00	1.35

RCK = Red Comb Kedu; BCK = Black Comb Kedu; WK = White Kedu; A = asymptotic body weight (maximum weight); B = integration constant; K = Average growth rate until adult age; α = Shape parameter (specific to the Weibull model)

Table 4. Estimated Inflection Points of Kedu Chickens Based on Growth Models.

Model	Phenotype	Male		Female	
		Wi	Ai	Wi	Ai
Logistic	RCK	695	6.78	552.5	6.49
	BCK	700	6.64	587.5	6.57
	WK	612.5	6.11	465	6.25
Gomperz	RCK	825.71	7.75	640.85	7.34
	BCK	891.85	7.99	721.01	7.73
	WK	745.54	7.21	573.56	7.32
Weibull	RCK	905.5	0.10	714.86	0.10
	BCK	1208.71	0.10	817.46	0.10
	WK	781.8	0.10	7903.69	0.10

RCK = Red Comb Kedu; BCK = Black Comb Kedu; WK = White Kedu; Wi = Body weight at the inflection point; Ai = Age at the inflection point

Table 5. Statistical Evaluation Criteria for Assessing the Fit of Logistic, Gompertz, and Weibull Models to Growth Data of Kedu Chickens.

Model	Phenotype	Male					Female				
		AIC	BIC	R ²	Adj R ²	r	AIC	BIC	R ²	Adj R ²	r
Logistic	RCK	6030.98	6044.69	0.97	0.97	0.99	2978.58	2990.35	0.97	0.97	0.99
	BCK	481.15	487.17	0.97	0.96	0.98	2063.15	2073.88	0.98	0.98	0.99
	WK	436.97	442.99	0.98	0.98	0.99	176.44	179.71	0.97	0.97	0.98
Gomperz	RCK	432.11	607.25	0.97	0.97	0.99	409.59	545.07	0.98	0.98	0.99
	BCK	445.61	479.91	0.97	0.97	0.98	431.16	515.46	0.98	0.98	0.99
	WK	402.7	428.68	0.99	0.99	0.99	408.82	375.49	0.97	0.97	0.99
Weibull	RCK	603.43	611.41	0.97	0.97	0.99	2916.25	2931.95	0.98	0.98	0.99
	BCK	475.67	483.7	0.97	0.97	0.98	2012.05	2026.36	0.98	0.98	0.99
	WK	496.77	505.53	0.99	0.99	0.99	173	177.36	0.98	0.97	0.99

RCK = Red Comb Kedu; BCK = Black Comb Kedu; WK = White Kedu; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; R² = coefficient of determination; Adj R² = adjusted coefficient of determination; r = correlation coefficient.

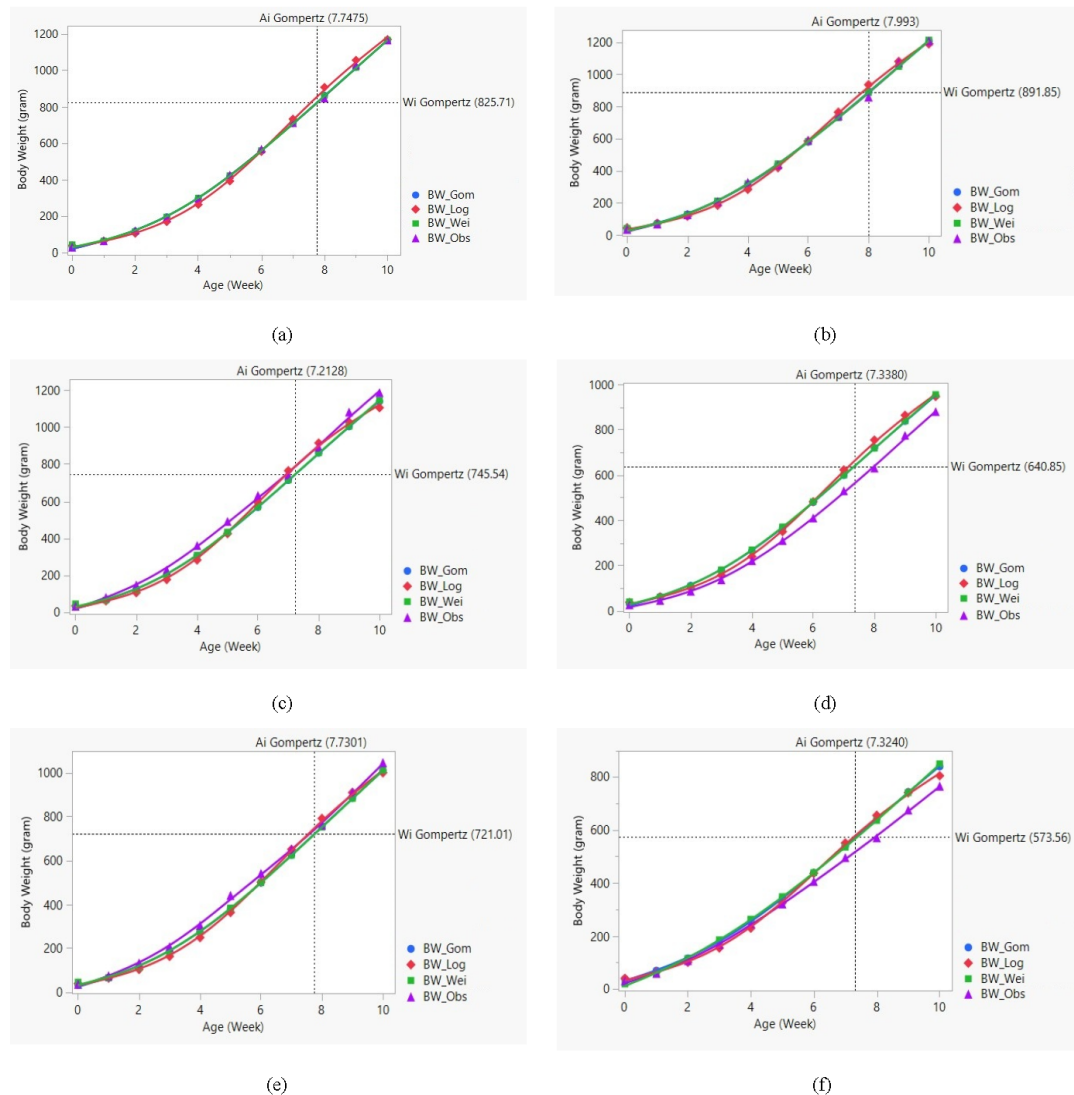


Fig. 1. Growth curves of Kedu chickens based on observed data and predictions from non-linear models. (a) RCK male, (b) BCK male, (c) WK male, (d) RCK female, (e) BCK female, and (f) WK female. BW_Obs indicates the observed body weight, while BW_Gom, BW_Log, and BW_Wei represent predicted body weights based on the Gompertz, Logistic, and Weibull models, respectively.

Discussion

Based on the results of this study, the Gompertz model consistently provided the most appropriate fit to describe the growth curves of both male and female Kedu chickens. This finding is in line with the observations of Zuidhof (2020); Ridho *et al.* (2021), and Setiaji *et al.* (2025), who reported that the Gompertz model effectively reflects the sigmoidal growth characteristics commonly observed in poultry, including a slow initial phase, a rapid middle growth phase, and a gradual deceleration toward the end of the rearing period. Visually, the Gompertz curve presented in Fig 1., also shows a smooth pattern with a clear inflection point, accurately representing the physiological growth dynamics of chickens.

Physiologically, male chickens have a higher asymptotic body weight (A) and inflection point (Wi and Ai) than female chickens. This condition is related to the role of androgen hormones that stimulate skeletal and muscle development, resulting in faster male growth rates (Sakomura *et al.*, 2011; Li *et al.*, 2020). In the Gompertz and Logistic models, Ai values generally appear at 7–10 weeks of age, which corresponds to the peak growth phase of native chickens (Zhao *et al.*, 2015; Mancinelli *et al.*, 2023). The findings of this study also indicate that the inflection point coincides with the onset of puberty or approaching sexual maturity, as also reported by Podisi *et al.* (2013) and Zuidhof *et al.* (2020).

Although the Weibull model achieved high statistical accuracy in terms of coefficient of determination (R^2) and correlation (r), it generated

biologically implausible estimates for the inflection age (Ai), often predicted around the first week. At this stage, chickens have not yet entered the rapid growth phase, making such estimates unrealistic. This reflects the high flexibility of the Weibull model, which, without proper parameter constraints, can yield extreme or non-biological values (Kaps and Lamberson, 2004). Moreover, the exceedingly high asymptotic body weight predicted for WK females (34,770.5 g) suggests potential overfitting, particularly when late growth data are limited. Thus, while statistically robust, the Weibull model requires cautious interpretation and biological validation.

The Logistic model showed limitations in describing the later growth phase. Although it achieved a relatively high R^2 , the estimated inflection age (6–6.5 weeks, 465–700 g) was lower than expected. This contradicts previous findings (Zhao *et al.*, 2015; Mancinelli *et al.*, 2023), which indicate that native chickens typically reach their growth peak between 7 and 10 weeks, suggesting that the Logistic curve predicted the peak earlier than observed.

Furthermore, phenotypic differences such as plumage color and comb type in Kedu chickens did not result in substantial variation in growth patterns, indicating that these visual traits have no significant influence on growth performance. This supports previous findings that Kedu chickens originate from the same genetic lineage, with phenotypic diversity mainly expressed in morphological traits (Ulfah *et al.*, 2015; Sartika *et al.*, 2023). Therefore, growth models can be applied generally to

Kedu chicken populations without distinguishing between plumage and comb color variations.

Sexual dimorphism is one of the key factors influencing growth patterns. Consistent with previous studies, male chickens exhibit higher asymptotic body weight (A) and inflection points (Wi and Ai) compared to females (Sakomura *et al.*, 2011; Li *et al.*, 2020). This difference is mainly attributed to the effects of androgens, which stimulate skeletal and muscle development, leading to faster growth in males. In contrast, females experience earlier development of the reproductive system, resulting in earlier sexual maturity but with relatively lower body weight (Benyi *et al.*, 2015; England *et al.*, 2023). Overall, the statistical fit, biological consistency, and visual agreement of the Gompertz model with the observed data confirm its superiority in describing the growth performance of male and female Kedu chickens.

Conclusion

Among the models evaluated, the Gompertz model emerged as the most suitable for describing the growth trajectories of both male and female Kedu chickens, owing to its superior statistical performance and strong biological plausibility. The higher asymptotic weights and inflection points observed in males reflect inherent physiological differences in growth dynamics between sexes

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Conflict of interest

The authors have no conflict of interest to declare.

References

- Aggrey, S.E., 2002. Comparison of three nonlinear and spline regression models for describing chicken growth curves. *Poult. Sci.* 81, 1782-1788.
- Akaike, H., 1974. A new look at the statistical model identification. *IEEE Trans. Auto. Control.* 19, 716-723.
- Beiki, H., Pakdel, A., Moradi-Shahrbabak, M., Mehrban, H., 2013. Evaluation of growth functions on Japanese quail lines. *J. Poult. Sci.* 50, 20-27.
- Benyi, K., Tshilate, T.S., Netshipale, A.J., Mahlako, K.T., 2015. Effects of genotype and sex on the growth performance and carcass characteristics of broiler chickens. *Trop. Anim. Health Prod.* 47, 1225-1231.
- Cordeiro, G.M., Biazatti, E.C., Santana, L.H.D., 2023. A new extended Weibull distribution with application to influenza and hepatitis data. *Stats.* 6, 657-673.
- England, A., Gharib-Naseri, K., Kheravii, S.K., Wu, S.B., 2023. Influence of sex and rearing method on performance and flock uniformity in broilers—implications for research settings. *Anim. Nutr.* 12, 276-283.
- Fan, Y.G., Ye, S.Z., 1997. Studi tentang Kurva Pertumbuhan dan Keuntungan Maksimum dari Anak Ayam Jantan Petelur. *Poult. Sci.* 38, 445.
- Gautam, L., 2024. Assessment of growth pattern in indigenous kadaknath chickens by non-linear models. *J. Anim. Plant Sci.* 34, 1012-1019.
- Harville, D.A., Jeske, D.R., 1992. Mean squared error of estimation or prediction under a general linear model. *J. Amer. Statist. Assoc.* 87, 724-731.
- Kaps, M., Lamberson, W.R., 2004. *Biostatistics for Animal Science* (2nd ed.). CABI Publishing.
- Khobondo, J.O., 2021. Genetic evaluation of breeding program for body weight of indigenous chicken in Kenya. *Genet. Biodivers.* 18, 112-119.
- Koushander, A., Chamani, M., Yaghobfar, A., Sadeghi, A.A., Baneh, H., 2019. Comparison of the accuracy of nonlinear models and artificial neural network in the performance prediction of Ross 308 broiler chickens. *Poult. Sci.* 98, 151-161.
- Lamido, M., Alade, N.K., Mukaddas, J., 2025. Comparative analysis of three growth models in indigenous normal feathered chickens of Nigeria. *J. Anim. Prod. Environ. Sci.* 1, 52-57.
- Li, D., Wang, Q., Shi, K., Lu, Y., Yu, D., Shi, X., Du, W., Yu, M., 2020. Testosterone promotes the proliferation of chicken embryonic myoblasts via androgen receptor mediated PI3K/Akt signaling pathway. *Int. J. Mol. Sci.* 21, 1152.
- Liu, C., Yang, J., Liu, S., Geng, W., Wei, S., Wang, W.C., Yang, L., Zhu, Y., 2022. The pattern of body growth and intestinal development of female Chinese native geese from 1 to 10 weeks of age. *J. Appl. Anim. Res.* 50, 380-385.
- Mancinelli, A.C., Menchetti, L., Birolo, M., Bittante, G., Chiattelli, D., Castellini, C., 2023. Crossbreeding to improve local chicken breeds: Predicting growth performance of the crosses using the Gompertz model and estimated heterosis. *Poult. Sci.* 102, 102783.
- Masoudi, A., Azarfar, A., 2017. Comparison of nonlinear models describing growth curves of broiler chickens fed on different levels of corn bran. *Int. J. Avian Wildl. Biol.* 2, 1-7.
- Mata-Estrada, A., González-Cerón, F., Pro-Martínez, A., Torres-Hernández, G., Bautista-Ortega, J., Becerril-Pérez, C.M., Vargas-Galicia, A. J., Sosa-Montes, E. 2020. Comparison of four nonlinear growth models in Creole chickens of Mexico. *Poult. Sci.* 99, 1995-2000.
- Moharrery, A., Mirzaei, M., 2014. Growth characteristics of commercial broiler and native chickens as predicted by different growth functions. *J. Anim. Feed Sci.* 23, 82-89.
- Neysi, S., Ghaderi-Zefrehei, M., Rafeie, F., Dolatabady, M.M., Elahi Torshizi, M., Zakizadeh, S., Smith, J., 2023. Estimasi parameter genetik untuk produksi, reproduksi, dan kurva pertumbuhan ayam lokal Fars. *Anim. Sci. J.* 94, e13808.
- Nguyen, T.H., Nguyen, C.X., Luu, M.Q., Nguyen, A.T., Bui, D.H., Pham, D.K., Do, D.N., 2021. Mathematical models to describe the growth curves of Vietnamese Ri chicken. *Braz. J. Biol.* 83, e249756.
- Osaiyiwu, O.H., Oyebanjo, M.O., Coker, O.M., Akinyemi, M.O., 2024. Comparison of mathematical models describing the growth of tropically adapted Ross 308 commercial broiler chickens. *Anim. Res. Int.* 21, 5403-5414.
- Podisi, B.K., Knott, S.A., Burt, D.W., Hocking, P.M., 2013. Comparative analysis of quantitative trait loci for body weight, growth rate and growth curve parameters from 3 to 72 weeks of age in female chickens of a broiler-layer cross. *Bmc Genetics.* 14, 22.
- Ridho, M., Putra, W.P.B., Sola-Ojo, F.E., 2021. The growth curve of Gompertz and Logistic models in body weight of Ecotype Fulani chickens (*Gallus domesticus*). *IOP Publishing.* 637, 012098.
- Roush, W.B., Branton, S.L., 2005. Perbandingan Penyesuaian Model Pertumbuhan dengan Algoritma Genetika dan Regresi Nonlinier. *Poult. Sci.* 84, 494-502.
- Sakomura, N.K., Longo, F.A., Oviedo-Rondón, E.O., Boa-Viagem, C., Ferraudo, A.S., 2011. Modeling energy utilization and growth parameter for broiler chickens. *Poult. Sci.* 90, 1200-1208.
- Sanusi, A., Oseni, S., 2020. Nigerian Fulani ecotype chickens: Estimation of growth curve parameters. *Genet. Biodivers.* 17, 1-13.
- Sartika, T., Iskandar, S. dan Tiesnamurti, B., 2016. Sumberdaya genetik ayam lokal Indonesia dan prospek pengembangannya. Indonesian Agency for Agricultural Research and Development Press. Jakarta. Indonesia.
- Sartika, T., Saputra, F., Takahashi, H., 2023. Genetic diversity of eight native Indonesian chicken breeds on microsatellite markers. *HAYATI J. Biosci.* 30, 122-130.
- Schmidt, G.S., 2008. The effect of broiler market age on performance parameters and economics. *Braz. J. Poult. Sci.* 10, 223-225.
- Schwarz, G., 1978. Estimating the dimension of a model. *Ann. Stat.* 6, 461-464.
- Şengül, T., Çelik, Ş., Şengül, A.Y., İnci, H., Şengül, Ö., 2024. Investigation of growth curves with different nonlinear models and MARS algorithm in broiler chickens. *PloS one.* 19, e0307037.
- Setiaji, A., Lestari, D.A., Ma'rifah, B., Krismiyanto, L., Agusetyaningsih, I., Sugiharto, S., 2023. Gompertz non-linear model for predicting growth performance of commercial broiler chickens. *J. Indonesian Trop. Anim. Agric.* 48, 143-149.
- Setiaji, A., Lestari, D.A., Pandupuspitasari, N.S., Agusetyaningsih, I., Sutopo, S., Tamaningrum, T.D., Philco, T.V., Alfauq, M.N., Raza, M.S., Sugiharto, S., 2025. Growth curve evaluation for Indonesian indigenous Red Kedu chicken by using non-linear models. *J. Livest. Sci. Technol.* 14, 01-07.
- Soglia, D., Sartore, S., Maione, S., Schiavone, A., Dabbou, S., Nery, J., Zaniboni, L., Marelli, S., Sacchi, P., Rasero, R., 2020. Growth performance analysis of two Italian slow-growing chicken breeds: Bianca di Saluzzo and Bionda Piemontese. *Animals.* 10, 969.
- Suleiman, A.A., Daud, H., Ishaq, A.I., Kayid, M., Sokkalingam, R., Hamed, Y., Othman, M., Nagarjuna, V.B.V., Elgarhy, M., 2024. A new Weibull distribution for modeling complex biomedical data. *J. Radiat. Res. Appl. Sci.* 17, 101190.
- Sutopo, S., Lestari, D.A., Kurnianto, E., Setiaji, A., 2022. Egg weight, sex, and variety effects on body weights and growth ability of Kedu chickens. *Adv. Anim. Vet.* 10, 1017-1022.
- Triani, H. D., Yuniza, A., Marlida, Y., Husmaini, A.W., 2024. Evaluation of metabolizable energy and crude protein balance on productivity and income on male Kamang Ducks. *J. Sain Pet. Ind.* 19, 96-103.
- Ulfah, M., Perwitasari, D., Jakaria, Muladno, Farajallah, A., 2015. Breed determination for Indonesian local chickens based on matrilineal evolution analysis. *Int. J. Poult. Sci.* 14, 615.
- Urfah, S., Indrijani, H., Tanwirah, W., 2017. Model kurva pertumbuhan ayam Kampung Unggul Balitnak (KUB) umur 0-12 minggu (Growth curve model of Kampung Unggul Balitnak (KUB) chicken). *J. Ilmu Ternak Univ. Padjad.* 17, 59-66.
- Zhao, Z., Li, S., Huang, H., Li, C., Wang, Q., Xue, L., 2015. Comparative study on growth and developmental model of indigenous chicken breeds in China. *Open J. Anim.* 219-223.
- Zuidhof, M.J., 2020. Multiphasic poultry growth models: method and application. *Poult. Sci.* 99, 5607-5614.