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Evaluation of Nonlinear Growth Curve Models in Native Crossbred Chickens

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Abstrak

Mathematical models in poultry development programs can provide valuable information. The present study aimed to determine an appropriate non-linear growth model in native crossbred chickens (NCC). The data used in this study were from published article reporting body weight report of native crossbred chickens from natural mating between the male Sentul (SC) breed and the female Kampung chicken breed (KC). The NCC body weight (BW) was recorded weekly from 1 to 12 weeks. Three non-linear growth curve models (Gompertz, Logistic, and Weibull) were used to model NCC growth performances. The best-fit model was measured with a coefficient of determination (R^2), adjusted coefficient of determination ($AdjR^2$), and root mean square error (RMSE). The results showed that Gompertz models (R^2: 0.97, 0.96; $AdjR^2$: 0.97, 0.96; RMSE: 18.89, 13.63 for males and females, respectively) were more favorable. Age at inflection ranged from 9.29 to 11.30 weeks for males and 9.12 to 11.13 weeks for females, respectively. Estimated weights at inflection ranged from 686.13 g to 920.40 g for males and 553.46 to 742.09 g for females. In conclusion, the Gompertz model is the most suitable model for describing the growth curve of native crossbred chickens.

1. Introduction

According to Hidayat and Asmarasari (2015), Indonesia has 31 native chicken breeds. Kampung chicken (KC) and Sentul chicken (SC) are among them. The KC is the most common native chicken and is easily found in Indonesia. It has a high adaptation ability and is widely raised as a dual-purpose type of local chicken by farmers. However, KC has a low growth rate and egg productivity (Nataamijaya, 2008). On the other hand, the SC originated from Ciamis District-West Java and is known as a meat and egg producer. The SC has superior performance to KC in its growth rate and egg production (Mugiyono *et al.*, 2015). The average body weight of a one-day-old KC chicken is between 26.38 to 27.10 g (Pamungkas, 2005; Irmaya *et al.*, 2021) while SC is 33.58 to 35.98 g (Gultom *et al.*, 2021; Irmaya *et al.*, 2021; Wahyuni *et al.*, 2022). Therefore, the crossbreeding between SC males and KC females is necessary to get the potential benefit from both breeds in their offspring.

In livestock production, the response of crossbreeding can be seen in the offspring's performance, including its body weight (BW). The change in the BW in the time unit is considered growth and is known as a quantitative trait. Thus, it is essential to understand chicken growth to get the optimal genetic improvements (Narinç *et al.*, 2017). One of the methods used to describe animal growth is the non-linear model approach. The most common mathematical models in chickens are Gompertz, Logistic, Richards, Weibull, Von Bertalanffy, Brody, Lopez, Janoschek, and Bridges (Rizzi *et al.*, 2013; Eleroğlu *et al.*, 2014; Moharrery & Mirzaei, 2014; Selvaggi *et al.*, 2015; Faraji-Arough *et al.*, 2019; Boonkum *et al.*, 2021). However, to our knowledge, no studies have been conducted to evaluate the growth model of native crossbred chicken in Indonesia. Therefore, this study aimed to compare three non-linear growth models (Gompertz, Logistic, and Weibull) that describe the native crossbred chicken growth pattern.

2. Materials and Methods

2.1 Data Sources

Body weight records for native crossbred chicken (NCC) from natural mating between male Sentul chicken and female Kampung chicken were used in this study. The data presented body weights at 0 to 12 weeks of age of NCC (Sopian *et al.*, 2015).

2.2 Statistical Analysis

The models were fitted to the data using CurveExpert 2.2 software. Each model was compared using the coefficient of determination (R^2), adjusted coefficient of determination (adj. R^2), and root mean square error (RMSE) (Table 1). The growth functions used in this study were Gompertz, Logistic, and Weibull (Haqani *et al.*, 2021), as presented in Table 2. The average body weight was grouped by sex and then analyzed using a t-test (Irmaya *et al.*, 2021).

Table 1. The criteria of Goodness of fit for functions.

Criteria	Equation
R^2	1-(SSE/SST)
Adj. R^2	$R^2-((p-1/n-p)(1-R^2))$
RMSE	(SSE/n) ^ (1/2)

R^2: coefficient of determination; Adj. R^2: Adjusted coefficient of determination; RMSE: root mean square error; SSE: sum of square errors, SST is the total sum of squares, p is the number of parameters, and n is the number of observations.

Table 2. Three non-linear growth curve models used in the study.

Criteria	Models		
	Gompertz	Logistic	Weibull
Equation	y=a*exp(-b*exp(-c*x)	y=(b*a)/(b+(a-b)*exp(-c*x)	y=a-(a-b)*exp(-(c*x)^d)
Age at inflection (Ai)	ln(b)/c	1/c*ln((a-b)/b)	(1/c)^(((d-1)/d)^1/d))
Weight of inflection (Wi)	a/e	a/2	a-(a-b)exp(-(d-1)/d)

y: body weight at a given age; x: time duration; a: asymptotic weight; b: constant for the initial body weight; c: constant for the instantaneous growth rate; d: shape parameter.

3. RESULTS AND DISCUSSION

Results of the growth performance of native crossbred chicken (NCC) up to 12 weeks old are shown in Table 3. The bird's body weight (BW) increased from 28.35 to 1007.68 g in males and 27.83 to 823.62 g in females. Males had higher BW than females ($P<0.05$), except in the first two weeks. As reported by the previous study, these differences between male and female BW are due to dimorphism (Faraji-Arough *et al.*, 2019). The average BW of NCC was higher than kampung chicken BW in several previous studies but lower than Sentul chicken BW at the same age (Gultom *et al.*, 2021; Irmaya *et al.*, 2021; Resnawati and Sartika, 2010). The BW of KC in the previous study ranged from 755 to 978 g (Irmaya *et al.*, 2021; Urfa *et al.*, 2017). The current study indicated that using male SC as sire could improve the BW of KC offspring.

Table 3. NCC body weight is different for males and females of various ages.

Age (week)	BW (Mean±SE)	BW (Mean±SE)
0	28.35±0.47[a]	27.83±0.42[a]
1	44.38±1.55[a]	48.07±6.66[a]
2	74.75±3.05[a]	69.88±2.08[a]
3	119.70±4.63[a]	107.95±3.34[b]
4	164.70±6.36[a]	153.47±4.55[b]
5	238.53±7.58[a]	212.98±5.93[b]
6	330.48±10.96[a]	287.87±7.50[b]
7	421.25±12.98[a]	354.42±9.57[b]
8	532.90±13.91[a]	442.92±10.98[b]
9	636.58±14.43[a]	531.40±13.99[b]
10	757.78±17.10[a]	632.62±16.31[b]
11	888.80±19.92[a]	736.62±17.45[b]
12	1007.68±21.87[a]	823.62±18.29[b]

BW: body weight; SE: standard error
Means in a column with different superscripts are significantly different (p< 0.05)

Table 4 shows the estimated growth curve parameters and goodness of fit criteria for NC chicken. The mathematical model comparison indicates that the Weibull and Gompertz models had a similar coefficient of determination (R^2) compared to the Logistic model (0.97) in male chickens. The same trend was observed in female chickens (0.95) for the Gompertz, Weibull, and Logistic models, respectively. However, the Gompertz model was more favorable based on the RMSE value; thus, the Gompertz model was found to fit the growth curve of NCC. In agreement with this finding, Selvaggi *et al.* (2015), Rizzi *et al.* (2013), and Boonkum *et al.* (2021) found that the Gompertz model fitted live weight better than the Logistic and Richard models. In contrast, Moharrery and Mirzaei (2014) suggested that Richard's model has superiority to other models while Mata-Estrada *et al.*, (2020) reported the correctness of Von Bertalanffy's growth model. The differences among studies could be affected by genetic and environmental variables.

Table 4. Estimated growth curve parameters and goodness of fit criteria NCC

Model	Sex	a	b	c	d	R^2	Adj R^2	RMSE
Logistic	Male	1372.26	27.61	0.357	-	0.97039	0.97286	22.64
	Female	1106.92	26.81	0.361	-	0.95489	0.95865	13.58
Gompertz	Male	2501.91	1.49	0.132	-	0.97135	0.97374	18.89
	Female	2017.21	1.47	0.132	-	0.95534	0.95906	13.63
Weibull	Male	21224.97	21198.52	0.001	1.67	0.97155	0.97392	25.38
	Female	2942.78	2911.48	0.003	1.82	0.95531	0.95904	15.78

a: asymptotic weight; b: constant for the initial body weight; c: constant for the instantaneous growth rate; d: shape parameter; Adj. R2: adjusted coefficient of determination; RMSE: root mean square error;

The estimated age of inflection (A_i) and weight of inflection (W_i) at the inflection point of fitted models are shown in Table 5. The values of A_i and W_i were more significant in the Gompertz model than those in the Logistic models for both sexes. The females had a lower estimated inflection age (9.12 to 11.13 weeks) than males (9.29 to 11.30 weeks). The result was consistent with earlier studies on other local chickens, such as Mia chicken (Nguyen *et al.*, 2023), Italian chicken (Rizzi *et al.*, 2013; Selvaggi *et al.*, 2015), Khazak chicken (Faraji-Arough *et al.*, 2019) and Thai native chicken (Boonkum *et al.*, 2021). Moreover, the NCC had better potential genetics than those other native chickens from Ghana, Italy, and Turkey (11.4 to 13.99 weeks) in terms of growth rate based on A_i.(Eleroğlu *et al.*, 2014; Osei-Amponsah *et al.*, 2011; Selvaggi *et al.*, 2015). In addition, male chickens showed higher Wi than females, similar to as reported by other authors (Boonkum *et al.*, 2021; Eleroğlu *et al.*, 2014; Faraji-Arough *et al.*, 2019; Osei-Amponsah *et al.*, 2011; Rizzi *et al.*, 2013; Selvaggi *et al.*, 2015).

Table 5. The inflection points traits of NCC

Model	Sex	Ai (wk)	Wi (g)
Logistic	Male	9.29	686.13
	Female	9.12	553.46
Gompertz	Male	11.30	920.40
	Female	11.13	742.09

Ai: age at inflection; Wi: weight at inflection

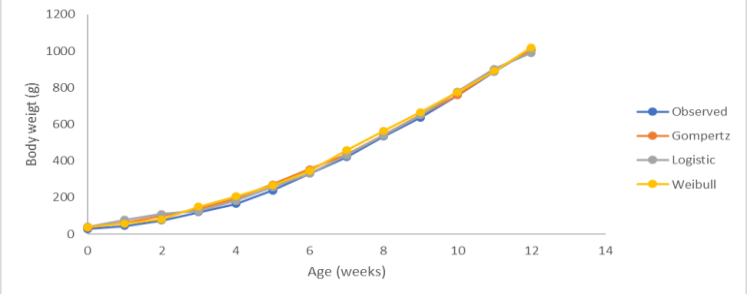

Figure 1. Growth curve parameters of the male NCC

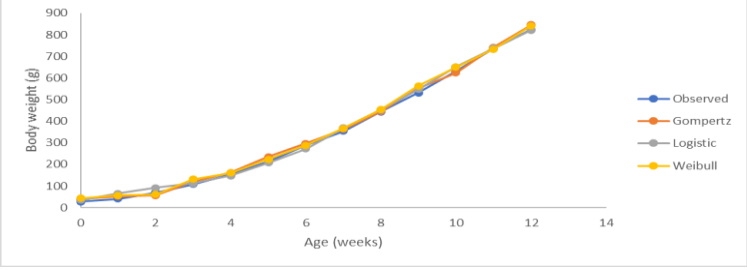

Figure 2. Growth curve parameters of the female NCC

The actual and estimated BW based on three models are shown in Figures 1 and Figures 2 for males and females. All predicted BW growth curves from the three models in this study were more significant than the observed BW for both sexes in most weeks. At 12 weeks, the body weight range is estimated at 990 to 1020 g (males) and 821 to 846 g (females) for each model. The results are in agreement with previous research, which also reported an overestimated BW on Italian chicken in non-linear models (Rizzi *et al.*, 2013) and Vietnamese chicken (Nguyen *et al.,* 2023).

4. Conclusion

A comparison of three non-linear growth models revealed that the Logistic, Gompertz, and Weibull models could be used to estimate the BW growth curve of NCC. However, the Gompertz model is preferred based on both sexes' goodness-of-fit criteria (R^2 and RMSE values). The findings in this study could be used in NCC development and selection in further research.

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