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NONLINEAR GROWTH MODELS FOR INDIGENOUS VIETNAMESE RI CHICKEN

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ABSTRACT

Chicken growth performance is an important economic trait, so finding the growth curve is essential for the chicken industry including indigenous chicken. Vietnam has many different native chicken breeds and Ri is one of the most famous native chickens. The objective of this study was to find out the best model to estimate the growth of Ri chicken. The body weight of 358 Ri chicken was measured every week until week 20 of age and growth data was analyzed in R using six mathematical functions (Bertalanffy, Bridges, Janoschek, Gompertz, Logistic, and Richards). The results showed that the best models to describe the growth of Ri males and females were Gompertz and Bridges, respectively. The upper asymptotic body weight (α) was estimated for males from 2,130 g (Logistic) to 2,600 g (Bertalanffy), whereas this α value for females was from 1,500 g (Logistic) and 1,816 g (Bertalanffy). Age at the start of the growth acceleration phase was estimated from 2.80 to 3.90 weeks for males and from 2.00 to 3.30 weeks for females. The inflection point for males (7.54 to 9.72 weeks of age) was higher than for females (7.10 to 9.43 weeks of age). Age at the end of the growth deceleration phase was estimated from 16.65 to 24.80 weeks for males and from 12.70 to 25.15 weeks for females. In conclusion, the best model for reporting the Ri chickens' growth curve was the Gompertz for males and Bridges for females.

Keywords: Body weight, breeding, broilers, growth, modeling

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INTRODUCTION

Vietnam is located in Southeast Asia and has good conditions for agricultural development including poultry production. Poultry is raised more than 3000 years ago and is well developed in different regions in Vietnam (Duc and Long 2008). There are at least 37 local chicken breeds that were recognized in Vietnam (Lan Phuong *et al.* 2015), and they play an important role in the development of the chicken industry. The native chicken population was approximately 70% of the total chicken in Vietnam (Hanh *et al.* 2007) and produced about 75% of the egg production (Tieu *et al.* 2008).

Ri is one of the most famous indigenous chickens and is very popular in different areas of Vietnam (Moula *et al.* 2011). Ri chicken has similar characteristics and morphology as other Vietnamese native chickens, such as yellow skin and a red single comb, however, the Ri male has a black-tailed red color and the feather of the Ri female is yellow (Su *et al.* 2004). Ri chicken has the highest annual egg performance, and it can adapt well to difficult conditions compared to other indigenous chickens (Lan Phuong *et al.* 2015; Mui and Dang 2016). Although the body weight of Ri chicken is small, Ri chicken is still very famous because of its meat quality. Thus, Ri chicken plays an important position in livestock production and the speciality chicken market in Vietnam (Thinh *et al.* 2020).

Understanding animal growth plays an important role in providing solutions for feeding practices to maximize the growth rate, and the growth curve in chickens has been investigated in Vietnam (Nguyen Hoang *et al.* 2021), Italy (Selvaggi *et al.* 2015), Ghana (Osei-Amponsah *et al.* 2014), and China (Yang *et al.* 2006). The poultry growth curve is nonlinear and has been described by various mathematical functions that include Bertalanfy (Von Bertalanffy 1957), Bridges (Bridges *et al.* 1992), Janochek, Gompertz (Gompertz 1825), Logistic (Pearl 1977), and Richards (Richards and Kavanagh 1945). Estimating the growth of Ri chicken in Vietnam using the Gompertz model had investigated by Moula *et al.* 2011, however, whether or not Gompertz was the best model for describing the growth of Ri chicken. The comparison of some models that describe the growth of chicken have been investigated, for example, Richards, Logistics and Gompertz (Aggrey 2002), Bertalanffy, Logistics and Gompertz (Zhao *et al.* 2015, and Yang *et al*. 2006). In this study, six mathematical functions (Bertalanffy, Bridges, Janoschek,

Gompertz, Logistic, and Richards,) were used for reporting the growth of Ri chicken raised on an industrial farm in the north-central region of Vietnam and the objective of this study was to find out the best model to describe the growth of Ri chicken in Vietnam among nonlinear growth models.

MATERIALS AND METHODS

This study was carried out from October 2020 to March 2021 on Ri chicken raised under industrial conditions in Dien Chau district, Nghe An province, Vietnam. Nghe An is located in the centre of Vietnam which has a seasonal change based on wind direction, with two distinct seasons of summer and winter (GSO 2018). The average temperature is about 25.2^{o} C and the total sunshine time is about 1,420 h (GSO 2018).

A total of 318 Ri chickens (159 males and 159 females) on the first day of age were used in this study. Chickens that were healthy and had good conditions at hatching were chosen and the sex of each young chick was identified based on feather and vent sexing. Males and females were raised separately on floor pens with rice husks litter in the same ventilated building. All chickens were given the same feed (Table 1) and the same vaccine program (Table 2) based on their age. From birth to week 4 of age, the chickens were kept under a heat lamp with a density of 20 chickens per square meter. The densities were 15 and 5 chickens per square meter for the period from 5 to 8 weeks and 9 to 20 weeks, respectively. The chickens were supplied *ad libitum* feed and water from the first day. The chicken body weight (BW) was measured individually on day 1 and every week until 20 weeks of age. The growth of chicken is calculated based on initial and mature BW and Ri chicken is mature around 20 weeks of age. Additionally, according to local knowledge, the Ri chicken was selected for breeding at 20 weeks of age.

Table 1. The diets from the first day to 20 weeks of age for Ri chicken.

Diets	1-4 week	5-8 week	9-20 week
Metabolizable energy (kcal/kg)	3,000	2,950	3,050
Crude protein (%)	22.0	19.0	15.5
Crude fiber (%)	5.0	5.0	5.0
Calcium (%)	1.5	1.5	0.8
Phosphorus (%)	1.1	0.8	0.8
Lysine (%)	1.05	1.10	1.03
Methionine (%)	0.70	0.66	0.45

Table 2. Vaccination program for Ri chicken.

Age (day)	Vaccine	Method
1	Marek	Subcutaneous injection
3	Newcastle	Oral vaccination
7	Gumboro	Subcutaneous injection
14	Newcastle	Oral vaccination
21	Gumboro	Subcutaneous injection

Statistical data and growth curves were analyzed in R software (R version 4.0.5, R Core Team 2021). Six functional models including Bertalanfy (Von Bertalanffy 1957), Bridges (Bridges *et al.* 1992), Janochek, Gompertz (Gompertz 1825), Logistic (Pearl 1977), and Richards (Richards and Kavanagh 1945) (Table 3) were used for describing the growth for males and females separately. The BW was estimated every week from the first day until 20 weeks of age using different models.

The growth performance of Ri chicken was analyzed using a randomized complete block design with sex as the experimental unit and week of age as the blocks. Analysis of variance was generated using the lm() command in the stats package in R software. The anova() command was used for testing the significance of effects. A linear model including the fixed effects (sex, week of age) and interaction between these two factors is presented in the statistical model as below:

$$y_{ijk} = \mu + S_i + W_j + S_i*W_j + e_{ijk}$$

where, y_{ijk} = growth performance of chicken k; μ = overall mean; S_i = fixed effect of sex i (male, and female); W_j = fixed effect of week j (j = 1 to 20); S_i*W_j = interaction between sex and week; e_{ijk} = residual errors. The means of body weight were compared using Tukey's test.

The six mathematical equations (Bertalanffy, Bridges, Janochek, Gompertz, Logistic, and Richards) were fitted using the nlsLM() function in the minpack.lm package (Elzhov *et al.* 2016) in R for each gender, and then some parameters were created such as the upper asymptotic body weight (α), estimated mature growth rate (k), which characterizes the first part of growth before the point of inflection (β) and the shape parameter determining the position of the curve point (m).

In addition, Akaike's information criterion (AIC) and Bayesian information criterion (BIC) were generated using AIC() and BIC() commands in R software. The AIC and BIC parameters were usually used for comparing model performance. The best model was confirmed if AIC and BIC were the lowest.

The predicted BW of the chicken was calculated using the predict() function and then plotted using the ggplot2 package in R software. The Pearson's correlation was calculated between the predicted BW and measured BW using the cor() function in R software.

Table 3. The details of different nonlinear growth models.

No	Functions	Equation	Age at inflection	Weight of inflection
1	Bertalanffy	$BW_t = \alpha \times (1 - \beta \times e^{-kt^3})$	$\frac{\ln(3\times\beta)}{k}$	$\frac{8\times\alpha}{27}$
2	Bridges	$BWt = BW_0 + \alpha \times (1 - e^{-kt^m})$	-	-
3	Janochek	$BW_t = \alpha - (\alpha - BW_0) \times e^{-kt^m}$	$\frac{(m-1)}{(k\times m)^{\frac{1}{m}}}$	$\alpha - (\alpha - k) \times e^{\frac{-(m-1)}{m}}$
4	Gompertz	$BWt = \alpha \times e^{-\beta \times e^{-kt}}$	$\frac{\ln(\beta)}{k}$	$\frac{\alpha}{e}$
5	Logistic	$BWt = \frac{a}{\beta \times (1 + e^{-kt})}$	$\frac{\ln(\beta)}{k}$	$\frac{\alpha}{2}$
6	Richards	$BWt = \frac{\alpha}{(1 - \beta \times e^{-kt})^{\frac{1}{m}}}$	$\frac{\ln(m\times\beta)}{k}$	$\frac{a}{(m+1)^{\frac{1}{m}}}$

BWt—body weight (g) at the time t; BW_0 - initial body weight (g); α - upper asymptotic body weight (g); t - age (weeks); β, k, and m - parameters specific for the function; β - characterizes the first part of growth before the point of inflection; k describes the second part in which growth rate decreases until the animal reaches the upper asymptotic body weight or mature body weight (α), m is the shape parameter determining the position of the curve point inflection, e – the Euler's number (~ 2.718282).

RESULTS

The BW of Ri chicken increased steadily during the research period (Table 4), and the BW of males was higher than females at all time-points (Table 4). At the 20th week of age, the BW of Ri chicken was 2,103.10 g and 1,456.50 g for males and females, respectively.

The estimated parameters for the growth curve model in Ri chicken were different between males and females (Table 5). The upper asymptotic body weight (α) reaches the maximum value when the chicken is mature. In this study, α values for males were higher than females in all models that were suitable for reality. This α value for Ri males was estimated from 2,130.00 g (Logistic) to 2,600.0 g (Bertalanffy) and this value for females was from 1,500.00 g (Logistic) and 1,816.00 g (Bertalanffy). The α was the highest in the Bertalanffy model and was the lowest in the Logistic model for both genders.

The estimated mature growth rate (k) of males in the Richards, Bertalanffy Logistic, and Gompertz, models was higher than that of the females. The k values of the Logistic model were highest, and the k values in the Bridges and Janochek model were lowest.

The goodness of fit or coefficient of determination (R^2), AIC, and BIC of growth curves are important criteria to evaluate a fitted model. The best model for the growth curve was identified if it had the highest R^2 and the lowest AIC and BIC. The R^2 of the growth curve for Ri chicken at all models herein was higher than 96% (Table 6). For the males, the Gompertz function was the best model that described growth rate with the highest coefficient of determination (R^2 = 97.25 %) and the lowest was AIC and BIC values (AIC = 40328 and BIC = 40352.3) among the six models (Table 6). However, the Bridges function was the best model that described the growth rate of Ri females, because this Bridges model had the highest coefficient of determination (R^2 = 98.74) and the lowest AIC and BIC (AIC = 37905.8 and BIC = 37936.2).

Interestingly, the Logistic function was the worst described growth rate with the lowest coefficient of determination, and AIC and BIC values were the highest in both males and females.

In addition, correlations between the measured BW and predicted BW in all models were always higher than 0.98 (Table 6). The correlation value of the Bridges function was the highest for female data while the correlation values of the Logistic function were the lowest for both males and females data. The growth curves of the measured BW and predicted BW using the best models (Gomperts (GOM) for males and Bridges (BRI) model for females) were overlapped (Figure 1). The similar values of measured BW and predicted BW (Figure 1) indicated that Gomperts and Bridges are the best models to describe the growth of Ri males and females.

Table 4. The body weight of Ri chicken from the first day to 20 weeks.

Week	Male		Female	
	n	Mean ± SD	n	Mean ± SD
0	159	28.10±1.36	159	24.61±1.57
1	158	65.60 ±6.51	157	59.70±6.20
2	157	116.90 ±37.82	157	97.00±30.05
3	157	178.50±40.57	156	154.40±30.06
4	157	265.20 ±48.57	156	228.20±38.16
5	156	367.40 ±52.27	155	310.40±42.66
6	155	490.70±58.83	155	407.00±44.18
7	154	646.20±84.48	155	539.90±70.32
8	154	819.30±103.75	154	667.30±78.12
9	153	1,082.40±146.30	154	779.50±91.12
10	153	1,181.20±151.30	154	840.00±94.51
11	153	1,277.90±149.20	154	897.60±93.66
12	153	1,371.80±148.30	154	948.90±93.75
13	153	1,491.90±147.80	154	1,003.30±94.00
14	153	1,629.00±147.60	154	1,183.90±94.30
15	153	1,749.40±147.50	154	1,254.30±94.70
16	153	1,851.80±143.7	154	1,313.40±98.00
17	153	1,936.60±148.02	154	1,361.80±88.00
18	153	2,005.30±137.20	154	1,400.90±77.90
19	153	2,060.00±142.00	154	1,432.00±68.00
20	153	2,102.90±139.00	154	1,456.40±85.70

n: sample size; Mean: the average of body weight; SD: Standard deviation

Table 5. Different estimated parameters in growth curve models of Ri chickens.

Functions	Sex	α (g)	β	k (g/week)	m	BW_0
Bertalanffy	Male	2600.00±21.40	0.90±0.008	0.132±0.002	-	-
	Female	1816.00±14.42	0.81±0.006	0.125±0.002	-	-
Bridges	Male	2250.00±22.70	-	0.008±0.0004	1.92±0.03	32.30±6.04
	Female	1640.00±20.60	-	0.014±0.001	1.69±0.02	24.20±4.46
Janoschek	Male	2281.00±19.63	-	0.008±0.0004	1.92±0.03	32.34±6.04
	Female	1665.00±18.31	-	0.014±0.001	1.69±0.02	24.19±4.46
Gompertz	Male	2380.00±14.40	4.43±0.05	0.180±0.002	-	-
	Female	1670.00±9.97	3.83±0.04	0.170±0.002	-	-
Logistic	Male	2130.00±8.36	21.900±0.50	0.317±0.003	-	-
	Female	1500.00±6.04	16.300±0.33	0.296±0.003	-	-
Richard	Male	2380.00±16.60	0.0014±0.10	0.179±0.0035	0.0003±0.02	-
	Female	1780.00±25.40	0.712±0.07	0.134±0.006	0.269±0.04	-

BW_0 - initial body weight (g); α— upper asymptotic body weight (g); t—age (weeks); β, k, and m—parameters specific for the function; β characterizes the first part of growth before the point of inflection; k describes the second part in which growth rate decreases until the animal reaches the upper asymptotic body weight or mature body weight (α), m is the shape parameter determining the position of the curve point inflection.

Table 6. Coefficient of determination, correlation, Akaike's information criterion, and Bayesian information criterion in the models to estimate the growth of Ri chicken.

Functions	Sex	AIC	BIC	Cor	R^2
Bertalanffy	Male	40364.1	40388.4	0.9860	97.22
	Female	37907.08	37931.43	0.9863	97.28
Bridges	Male	40344.9	40375.3	0.9861	97.24
	Female	37905.8	37936.2	0.9937	98.74
Janoschek	Male	40344.9	40375.3	0.9861	97.24
	Female	37905.8	37936.2	0.9863	97.28
Gompertz	Male	40328	40352.3	0.9862	97.25
	Female	37948.1	37972.5	0.9861	97.24
Logistic	Male	40759.5	40735.2	0.9843	96.89
	Female	38464.7	38489.1	0.9838	96.79
Richards	Male	40330	40360.5	0.9862	97.25
	Female	37906.1	37936.5	0.9863	97.28

AIC: Akaike's information criterion,
BIC: Bayesian information criterion,
Cor: Pearson's correlation between predicted and actual body weights.
R^2: Coefficient of determination

Table 7. Estimated age and weight at different growth phases of Ri chicken.

Functions	Sex	Start of growth acceleration phase[1]		Inflection point[2]		End of growth deceleration phase[3]	
		Age (weeks)	Weight (g)	Age (weeks)	Weight (g)	Age (weeks)	Weight (g)
Bertalanffy	Male	3.93	259.80	7.54	769.79	24.80	2338.34
	Female	3.29	181.63	7.10	538.16	25.15	1634.66
Janoschek	Male	3.85	228.06	8.42	869.14	19.00	2052.52
	Female	3.06	166.51	7.46	556.68	20.75	1498.51
Gompertz	Male	3.67	238.07	8.34	875.81	20.93	2142.64
	Female	2.86	166.73	7.93	613.35	12.70	1500.54
Logistic	Male	2.80	212.74	9.72	1063.71	16.65	1914.67
	Female	2.00	149.60	9.43	748.02	16.80	1346.43
Richards	Male	3.90	238.06	8.61	875.90	21.20	2142.50
	Female	3.30	177.94	7.27	734.18	24.10	1601.42

[1]Age at which the chick attains 10% of its final body weight and represents the beginning of the growth acceleration phase (Osei-Amponsah *et al*., 2014)
[2]Represents the end of the growth acceleration phase and the beginning of the deceleration phase.
[3]Age at which the chick attains 90% of its final body weight and represents the end of the growth deceleration phase (Osei-Amponsah *et al*., 2014).

The growth phases of Ri chicken using six models were different (Table 7). The Ri males had an estimated age and weight higher than that of females, except at the end of the growth deceleration phase (Table 7). Age at the start of the growth acceleration phase was estimated from 2.80 to 3.90 weeks for males and from 2.00 to 3.30 weeks for females, respectively. Similarly, the estimated age at the inflection point for males (7.54 to 9.72 weeks) was higher than for females (7.10 to 9.43 weeks). However, the estimated age at the end of the growth deceleration phase for males (16.65 to 24.80 weeks) was lower than for females (12.70 to 25.15 weeks). In addition, the males also had a higher estimated weight at the start of the growth acceleration phase, inflection point, and the end of the growth deceleration phase than the females in all models (Table 7).

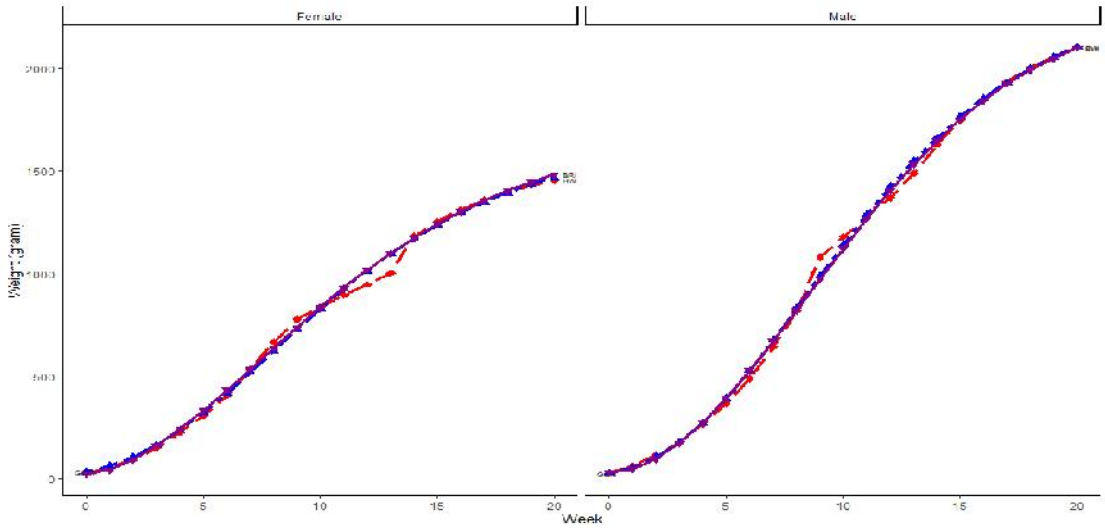

Figure 1. The growth curves of Ri chicken using measured and predicted body weight in the best models (Gomperts model for males and Bridges model for females). Red = measured body weight; Blue = predicted body weight.

DISCUSSION

This study found that the best functions to describe the growth of Ri chicken were the Gompertz for males and Bridges for females. This finding was consistent with previous studies (Aggrey 2002; Rizzi *et al.* 2013; Zhao *et al.* 2015; Nguyen Hoang *et al.* 2021. Especially, some previous studies had a similar result that demonstrated the Gompertz model was the most appropriate for modeling chicken growth (Nguyen Hoang *et al.* (2021), Zhao *et al.* (2015), Moula *et al.* (2011).

The upper asymptotic body weight (α) of Gompertz function in Ri chicken was lower than the values reported in Ri chicken (Moula *et al.* 2011), Italian local chicken (Rizzi *et al.* 2013), Creole chicken (Mata-Estrada *et al.* 2020), Castellana Negra chicken (Miguel *et al.* 2008), and Mia chicken (Nguyen Hoang *et al.* 2021). In a similar study using Ri chicken raised in household conditions, asymmetric weight (α) of the Gompertz model reached 2,794.6 g for males and 1,714.2 g for females (Moula *et al.* 2011). This figure for Mia chicken was 2,623.86 g for males and 1,915.75 g for females (Nguyen Hoang *et al.* 2021). However, these α values in this current study were higher than chicken raised in Ghana (1,777 g for males and 1,322 g for females) (Osei-Amponsah *et al.* 2014). The differences among the studies are possibly from feeding, housing, breeding, management, and using the method for evaluation.

In terms of predicted performance, both coefficient of determination (R^2) and correlations (r) between the predicted and measured body weight was high in all models ($R^2 > 96\%$, and $r > 0.98$). This finding suggests that we can use any model in these six models to describe the growth of Ri chicken. Correlations in this study were lower than the correlations reported by Nguyen Hoang *et al.* (2021) (r = 0.99). However, the coefficient of determination (R^2) of all six models herein was higher than that in a study by Osei-Amponsah *et al.* (2014) (86.6 to 96.7 %) and lower than that by Yang *et al.* 2006 (99.52 to 99.91 %).

The growth rate factor (maturation rate k) observed by the Gompertz function for Ri chickens in this study was similar to males and females (k = 0.18 and 0.17 g/week for males and females, respectively). These results in our study were higher than the values studied in the Chinese Yellow chicken (k = 0.13 g/week for males and 0.14 g/week for females, Yang *et al.* 2006), Mia chicken (k = 0.13 g/week for both males and females, Nguyen Hoang *et al.* 2021), Ri chicken (k = 0.148 and 0.129 g/week for males and females, Moula *et al*. 2011), and Korean native chicken (k = 0.102 g/week, Manjula *et al.* (2018)).

In terms of the inflection point, the age and body weight of Ri chicken was estimated lower than the values obtained for other local chicken breeds (Yang *et al.* 2006; Miguel *et al.* 2008; Rizzi *et al.* 2013; Osei-Amponsah *et al.* 2014; Mata-Estrada *et al.* 2020; Nguyen Hoang *et al.* 2021). The age at the inflection point of Mia chicken was 9.32 weeks (males) and 8.53 weeks (females), Nguyen Hoang *et al.* (2021). However, this value for Creole chicken was from 64.3 to 80.9 days (males) and 54.4 to 72.4 days (females), Mata-Estrada *et al.* (2020). However, the age and body weight at the inflection point of Ri chicken was like the values studied in Shaobo, Huaixiang, and Youxi chicken raised in China (Zhao *et al.* 2015). The study by Osei-Amponsah *et al.* (2014) showed that the age at the start of the growth acceleration phase of Forest chicken in Ghana was from 3.6 to 4.7 weeks for females and from 4.1 to 5.0 weeks for males;

the age at the end of the growth deceleration phase of wild chicken in Ghana was from 21.5 to 24.7 weeks for females and from 22.6 to 26.6 weeks for males.

Conclusion: The best function for modeling the growth of Ri chicken was the Gompertz for males and Bridges for females. Thus, applying these models to predict the growth of Ri chicken is more accurate and it helps to improve the management of feeding programs, forecast the growth data, and make productive plans for chicken farming.

Ethical Approval: Not applicable for this type of study in Vietnam.

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

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