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Research Article

Analysis of growth pattern of Rhode Island Red chicken using nonlinear models

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Abstract

Growth traits are quantitative in nature, with a continuum between high and low performing birds. Growth of the birds up to the point of marketing age is the most crucial, for which, body weights at different time points may be recorded and analyzed. This study was aimed to model the body weights of Rhode Island Red (RIR) chicken for assessment of the best fitted nonlinear model for growth analysis in the present data set. The data on body weights at different ages of RIR chicken were recorded from the experimental layer farm of the ICAR-Central Avian Research Institute, Izatnagar (India) and sex-wise average body weights were estimated. Different nonlinear statistical models (Gompertz, Logistic and Bertalanffy models) were fitted to the body weights, and the goodness of fit of the models was tested using different test statistics. To test the assumptions about the independence of errors in the models, Durbin Watson (DW) test was used, and to test the normality of the errors, Shapiro Wilk's test was used. It was observed that the logistic model was the best fitted model for describing the variations in the body weights of male chicks, while Gompertz model was found to be the most suitable model for explaining growth patterns in female chicken as well as in combined sexes. The expected average body weight of RIR chicken could be determined at any given age under normal conditions utilizing these fitted models.

Keywords: Durbin Watson test, Growth curves, Modeling of body weights, RIR chicken, Shapiro Wilk's test

Highlights

- Chick weight increased to 2183.93, 1831.71 and 2022.10 grams at 28 weeks in RIR male, female and combined sexes.
- Logistic model was the best fitted model for describing the growth pattern in RIR male birds.
- Gompertz model best described the body weight growth in females and combined sexes of RIR chicks.

INTRODUCTION

In poultry, body weight is one of the most significant traits and is associated with the bird's growth rate (Kumar *et al.*, 2022). Growth occurs as a result of a continual, correlated, and coordinated rise in body weight or body mass over a certain length of time (Kausar *et al.*, 2016; Kumar *et al.*, 2022). Growth of the birds up to the point of marketing age is the most crucial, for which, body weights at different time points may be recorded and analyzed. Depending on the goal, growth patterns can be examined throughout a variety of time frames and can be explained using mathematical equations fitted to a growth curve (Kumar *et al.*, 2022). The aim of the growth curve is to

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describe the rise in body weight over time or age using mathematical parameters that are biologically interpretable (Brody, 1945; Kausar *et al.*, 2016; Kumar *et al.*, 2022). Statisticians use different models for assessment of the best fitted model for growth analysis. The log-linear model assumes a constant absolute growth rate, while the linear model assumes a constant relative growth rate. These growth rates do, however, vary depending on the individual and the environment. A nonlinear model, which would be unbiased, offers a better fit since it generates less residuals (Kumar *et al.*, 2022). Several nonlinear models have been used in poultry which could define the relationship between age and live body weight (Paul *et al.*, 2011; Kausar *et al.*, 2016). From these models, one can determine the expected average body weight of a group of birds of the same breed at any given age under normal conditions (Kausar *et al.*, 2016). As the wide range of weather conditions across the country makes generalizations difficult, periodic evaluation of growth traits of poultry breeds is essential and an important pre-requisite for developing future breeding strategies.

Rhode Island Red (RIR) is a brown-egger dual purpose chicken breed. It was imported in ICAR- Central Avian Research Institute, Izatnagar (India) almost 35 years ago and has undergone long-term selection for 30 generations on the basis of 40-week part-period egg production. In the present investigation, the growth pattern of body weights of RIR chicks, recorded up to 28 weeks of age, was analyzed using nonlinear models to compare them and to identify the best fitted model which explains the growth performance of RIR chicks in the most precise manner.

MATERIALS AND METHODS

Experimental birds and husbandry adopted: Two-hundred eighty six straight run chicks were obtained in four hatches and used in this investigation. The chicks were wing banded, dubbed and vaccinated against Newcastle disease (ND) in the hatchery. The Floor space, brooding temperature and light regime were provided as per the standard protocol being followed at the institute (Das *et al.*, 2015). After attaining the age of four weeks, the chicks were shifted into new brooder house until 16 weeks of age. The pullets were then shifted into individual cages for laying. Fresh water and feed were provided twice daily *ad libitum* with all possible measures adopted to reduce wastage of feed. The birds were fed on the institute-formulated starter ration (CP 20.65%, ME 2694.64 Kcal kg^{-1}, calcium 1.02%, available phosphorous 0.45%, lysine 1.05% and methionine 0.41%) at the age of 0-8 weeks, grower ration (CP 16.78%, ME 2536 Kcal kg^{-1}, calcium 1.15%, available phosphorous 0.40%, lysine 0.76% and methionine 0.37%) at the age of 9-20 weeks and layer ration (CP 18.18%, ME 2676.52 Kcal kg^{-1}, calcium 3.61%, available phosphorous 0.34%, lysine 0.83% and methionine 0.36%) at the age of 21 weeks onwards. Vaccination was done as per the Institute's schedule (Das *et al.* 2016).

Climatic conditions: Data on body weights were collected from the birds at the experimental layer farm of ICAR-Central Avian Research Institute, Izatnagar (India), located at 28.21° North latitude and 78.23° East longitude with an altitude of 165 meters (544 ft) above mean sea level (MSL). The climate of the experimental location is of sub-tropical (sub-humid) in nature. The maximum temperatures ranged from 42°C to 43°C in June and minimum temperature was 4-5°C in January. The maximum rainfall was 320 mm in July and minimum 4 mm in November with an average annual rainfall of 1150 mm. In winter, the wind velocity was 2-5 km/hr, whereas in summer was 9-11km/hr. (Source: Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar; Indian Air Force, Izatnagar).

Growth trait recorded: Body weights (g) at 0 day (CW), 2nd (BW2), 4th (BW4), 6th (BW6), 8th (BW8), 10th (BW10), 12th (BW12), 16th (BW16), 24th (BW24) and 28th (BW28) weeks of age were recorded using digital weighing balance during morning hour before feeding. Overall and sex-wise average body weights were calculated and used in different models for developing growth curves.

Statistical analyses: Following nonlinear models were used for the analysis of the growth pattern of body weight in RIR chicken by using JMP 9.00 statistical program package (SAS, 2010):

Gompertz model: $y_t = a\exp(-b\exp(-ct)) + e$

Logistic model: $y_t = \dfrac{a}{1+b\exp(-ct)} + e$

Bertalanffy model: $y_t = A\left[l\text{-}b\ \exp(\text{-}ct)\right]^3 + e$

Where y_t, observed body weight of the chick at t[th] week; t, age of the chick in weeks; e, error term assumed independently normally distributed; a, an asymptotic weight; b, scaling parameter; c, rate of maturity.

The goodness of fit of the models was checked by coefficient of determination (R^2), adjusted coefficient of determination ($\bar{R}^2$), root mean square error (RMSE), Akaike Information Criterion (AIC) and Schwartz Bayesian Information Criteria (SBC). In order to test the assumptions about the independence of errors, the Durbin Watson (DW) test was used. Shapiro Wilk's test was used to test the normality of errors.

RESULTS

Overall and sex-wise average body weights of RIR chicks at different ages of zero day to 28[th] weeks are presented in Table 1. The estimated body weights showed that the male chick weight increased from 35.29 g to 2183.93 g at 28[th] week of age, while the female chick weight increased from 34.24 g to 1831.71 g at 28[th] week of age and from 34.81 g to 2022.10 g for combined sexes.

Three models viz. Gompertz, Logistic, and Bertalanffy were fitted on the average body weights of male and female chicks aged 0 day to 28 weeks as well as on both sexes together. The parameter estimates of the fitted models are given in Table 2.

The goodness of fit statistics of different models is presented in Table 3. The results of Shapiro Wilk's test for testing the normality of residuals in different models are presented in Table 4.

The R^2 coefficients of determination values were high for all growth models. Among the

Table 1. The estimated means (± SE, standard error) of body weights of RIR chicks at different weeks of age

Age of the birds	Body weights in grams (Mean ± SE)		
	Male birds	Female birds	Combined sexes
0 day	35.29±0.71	34.24±0.71	34.81±0.50
2nd week	89.92±2.59	83.43±2.15	86.94±1.73
4th week	201.37±6.12	176.37±4.86	189.88±4.15
6th week	389.68±10.45	351.24±8.89	372.02±7.18
8th week	645.25±14.70	551.88±13.30	602.35±10.92
10th week	886.28±23.47	744.80±18.04	821.28±16.52
12th week	1161.62±28.88	978.53±22.09	1077.50±20.48
16th week	1645.40±43.48	1371.76±29.74	1519.68±30.03
20th week	2105.30±50.31	1614.61±33.24	1879.85±38.84
24th week	2298.07±52.05	1699.14±32.35	2022.88±42.59
28th week	2183.93±48.31	1831.71±45.06	2022.10±37.16

Table 2. The parameter estimates of different nonlinear models fitted to growth curves for RIR Chicks

Sex of the birds	Nonlinear model	Parameter	Estimate	SE
Male	Gompertz	a	2432.1	87.5935
		b	4.9783	0.6034
		c	0.1629	0.0151
	Logistic	a	2286.7	53.1144
		b	26.0004	4.9179
		c	0.2746	0.0194
	Bertalanffy	a	2539.7	137.7
		b	1.0095	0.1194
		c	0.1274	0.0164
Female	Gompertz	a	1918.2	26.3384
		b	4.4695	0.1905
		c	0.1588	0.00559
	Logistic	a	1791.2	32.4857
		b	22.0035	3.1586
		c	0.2720	0.0153
	Bertalanffy	a	2011.4	55.2019
		b	0.9251	0.0497
		c	0.1232	0.00793
Combined sexes	Gompertz	a	2196.9	46.8430
		b	4.7531	0.3288
		c	0.1610	0.00882
	Logistic	a	2059.5	33.5709
		b	24.1881	3.1621
		c	0.2730	0.0136
	Bertalanffy	a	2297.9	87.5141
		b	0.9726	0.0771
		c	0.1255	0.0113

SE: standard error; a: asymptotic weight; b: scaling parameter; c: rate of maturity

Table 3. The goodness of fit statistics of different nonlinear models fitted to growth curves for RIR chicks

Sex of the birds	Nonlinear model	Estimated values of the model statistics					
		R^2	$\bar{R}^2$	RMSE	AIC	SBC	DW
Male	Gompertz	0.9980	0.9975	70.92	6311.01	7034.41	1.74
	Logistic	0.9983	0.9979	64.69	5251.63	5853.60	1.76
	Bertalanffy	0.9970	0.9963	86.14	9310.55	10377.76	1.46
Female	Gompertz	0.9997	0.9996	21.51	580.71	647.27	2.36
	Logistic	0.9990	0.9987	40.71	2079.17	2317.49	1.09
	Bertalanffy	0.9993	0.9991	34.38	1482.92	1652.90	1.29
Combined sexes	Gompertz	0.9993	0.9991	37.97	1809.46	2016.87	1.51
	Logistic	0.9992	0.9990	41.29	2139.07	2384.26	1.15
	Bertalanffy	0.9985	0.9982	54.54	3733.21	4161.12	1.15

R^2: coefficient of determination; $\bar{R}^2$: adjusted coefficient of determination; RMSE: root mean square error; AIC: Akaike information criteria; SBC: Schwartz Bayesian information criteria; DW: Durbin Watson test statistic

Table 4. The Shapiro Wilk's test for testing the normality of residuals as assumed in the nonlinear models fitted to growth curves for RIR chicks

Nonlinear Model	Male birds		Female birds		Combined sexes	
	Test Statistic	p-value	Test Statistic	p-value	Test Statistic	p-value
Gompertz	0.9135	0.27	0.8939	0.16	0.9618	0.80
Logistic	0.9596	0.77	0.9105	0.25	0.9370	0.49
Bertalnaffy	0.9731	0.92	0.8957	0.16	0.9825	0.98

models, the values of R^2 and adjusted $\bar{R}^2$ coefficient of determination were the highest whereas RMSE, AIC and SBC statistics were the lowest for logistic model in males (Table 3). Shapiro-Wilk's test revealed that the residuals were normally distributed for males (Table 4). Durbin Watson (DW) test statistic indicated that there was positive autocorrelation among the residuals for the male chicks (Table 3), though found non-significant (Table 4). Thus, the logistic model was observed to be the best fitted model to describe the changes in body weights of the male chicks (Fig. 1).

In case of females, Gompertz model revealed the highest values of R^2 and adjusted $\bar{R}^2$, and the lowest values of RMSE, AIC and SBC in comparison to other models (Table 3). The residuals were normally distributed (Table 4). The values of DW statistic indicated positive autocorrelation among the residuals for the female chicks (Table 3), which was however non-significant. Therefore, Gompertz model was the best fitted models for describing the changes in the body weights of the female chicks during 0 day to 28 weeks of age (Fig. 2).

In combined sexes also, Gompertz model demonstrated the highest values of R^2 and adjusted $\bar{R}^2$, and minimum values of RMSE, AIC and SBC statistics (Table 3). The residuals were also normally distributed (Table 4). The values of DW statistic indicated positive autocorrelation among the residuals, which was however non-significant (Table 3). Hence, Gomperz model was the best fitted model for describing the variations in the body weights of the chicks of combined sexes (Fig. 3).

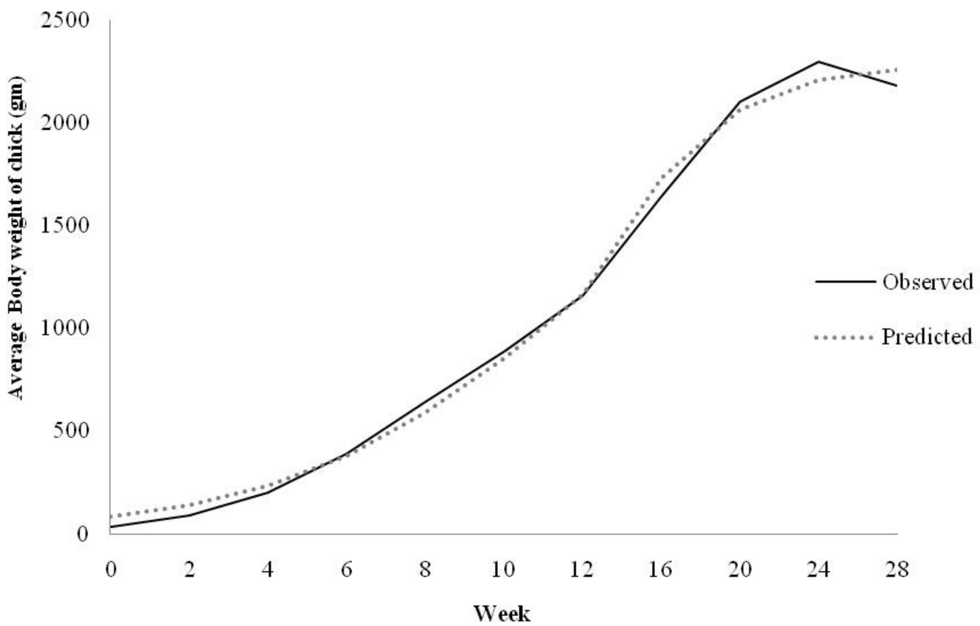

Fig. 1. Growth curve explained by Logistic model for RIR male chicks

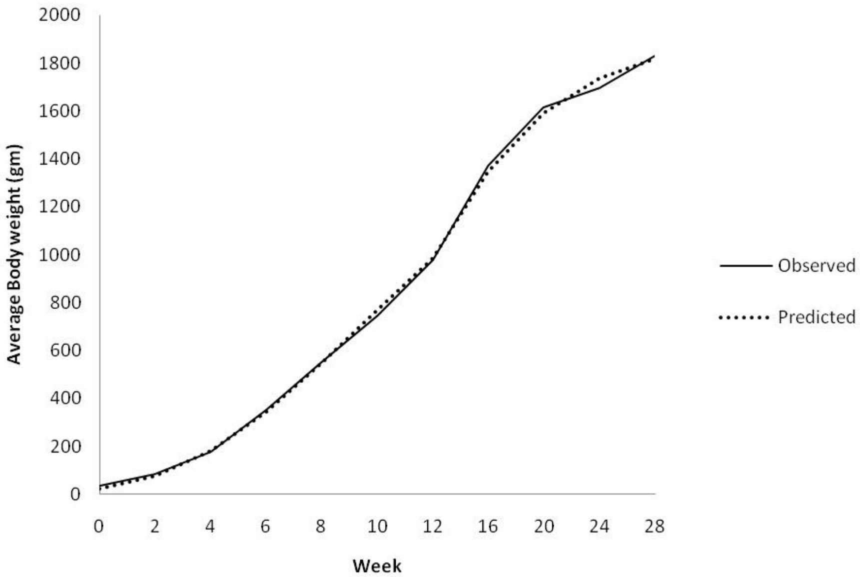

Fig. 2. Growth curve explained by Gompertz model for RIR female chicks

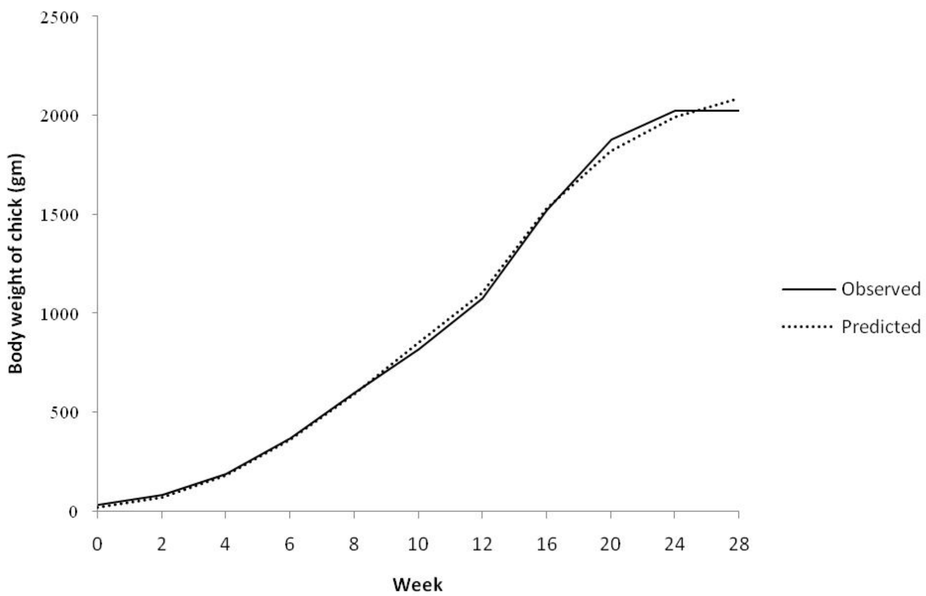

Fig. 3. Growth curve explained by Gompertz model for combined sexes of RIR chicks

DISCUSSION

The present estimates of body weights obtained at different ages of RIR chicks were in consistence with the estimates reported in the RIR birds of earlier generations maintained in the institute farm (Das *et al.*, 2014ab, 2017, 2018).

The R^2 coefficient of determination values were high for all growth models indicating a significant relationship between age and weight in either or combined sexes for RIR chicks in consistence to the earlier reports (Kausar *et al.*, 2016; Kumar *et al.*, 2022). It was inferred from various measures of goodness of fit of the models that all the three models effectively described the variations in the body weights of male and female chicks as well as of combined sexes. Among the models, the Logistic was the best fitted model to describe the changes in body weights of the male chicks (Fig. 1). Kuhi *et al.* (2003) reported better performance of Bertalanffy model than the Logistic and Gompertz models for describing the growth performance of various egg and meat strains of chicken. Kumar *et al.* (2022) also found that the Gompertz model was the best growth model in males of Aseel chicken. On contrary to the present findings, Kausar *et al.* (2016) drew inference, on the basis of different goodness of fit criteria, that Bertalanffy model was the best fit for the male birds of individual RIR strain (selected, control and white).

In case of female birds in the present study, Gompertz model was the best fitted models for describing the changes in the body weight of the female chicks during 0 day to 28 weeks of age (Fig. 2). In earlier investigation, Kausar *et al.* (2016) also observed the Gompertz model to be the best fitted model for the female birds of individual RIR strain (selected, control and white) on the basis of different goodness of fit criteria which confirms the findings of the present study. According to Laird (1966), the Gompertz function has been preferred over the Logistic function for fitting mono-phasic growth curves of chickens. Prasad *et al.* (2008) also observed that the Gompertz model best described the growth pattern in Indian native chicken, while Kumar *et al*. (2022) observed that the Logistic model was the best model to describe growth in females of Aseel chicken.

In combined sexes also, it may be inferred on the basis of different goodness of fit criteria of the models, that the Gomperz model was the best fitted model for describing the variations in the body weights of the chicken birds (Fig. 3). Prasad *et al*. (2008) also reported that the Gompertz model could be the best fitted model for describing the growth pattern in Indian native chicken. Further, Kumar *et al*. (2022) also found that the Gompertz model was the best growth model in pooled data of both sexes in Aseel chicken. However, Kausar *et al.* (2016) observed that the Bertalanffy model was the best fitted model for the combined sexes of RIR selected and control strain, while Logistic model best described the body weights of RIR white strain.

This investigation evaluated the growth patterns in body weights of RIR chicks through fitting of different nonlinear models viz., Logistic, Gompertz, and Bertalanffy models and estimated the various measures of goodness of fit. It was inferred from this study that the Logistic model was the best fitted model for describing the growth pattern in body weights of male birds. The Gompertz model was proved as the best fitted model for describing the changes in the body weights of female chicks as well as in combined sexes. Thus, one can determine the expected average body weight of RIR chicks at any given age under normal conditions utilizing these fitted models.

Conflict of interest: Authors of this manuscript declare that there is no conflict of interest for this research work.

Author's contribution: RY, SK: Conceived and designed the study, methodology; SK: Supervision, editing; RY, JD, AR: Immunization of birds, sample collection; RY: Data recording, data curation, writing; MRV: Formal analysis; AKD: Writing, final editing.

Ethical statement: All the experimental procedures on animals were carried out according to the recommendations and approval of the Institute Animal Ethics Committee (IAEC) as per the guidelines set forth by the Institutional Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA).

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