Comparative Study of Growth Patterns for Three Strains of Broiler Chickens Using Mathematical Models

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Summary

The aim of the current study was to investigate the growth pattern of three genetic strains of broiler chickens including Ross 308, Cobb and Arbor Acres by mathematical models. For this purpose, the body weight of 500 broilers for each strain was recorded weekly. Gompertz, Logistic and Richards functions were considered for data fitting. Three functions were compared by adjusted determination coefficient (R^2) and root mean square error (RMSE). For all three models, R^2 had high values, ranging from 0.987 to 0.999. The difference among the fitted functions by RMSE was significant compared to the R^2. The Richards function had more appropriate description for the growth curve of the Cobb strain, because of having the minimum RMSE, 61.57 compared to 85.43 and 66.61, for Gompertz and Logistic functions, respectively. However, the Gompertz function with the maximum R^2, and the minimum RMSE, 73.32 and 3237, respectively, was the most suitable function to describe the growth curve of Arbor Acres strain.

Key words

broiler, genetic strains, mathematical models, growth pattern

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INTRODUCTION

The growth curve represents changes in weight of an animal over time, which is sigmoidal. It could be possible to investigate growth pattern differences between species, sex, nutrition, and other factors (Aggrey, 2002). Mathematical models have biological interpretations due to summarizing a large quantity of data collected from body weight over time (Aggrey, 2002; Safari Alighiralou et al., 2013; Masoudi and Azarfar, 2017; Safari Alighiralou et al., 2017). There are many functions for investigating the growth curve which can predict the total production. Moreover, given the great variation in form of the growth curve, it is possible to estimate the features of the curve by growth curve function, and choosing appropriate curve shape (Golian and Ahmadi, 2008). There is a significant association between characteristics and parameters of the growth curve with the production rate; by having data about this relationship, it is possible to obtain appropriate indicators for changing the curve aimed to increase the production level. Based on these indices, birds can also be evaluated and selected (Golian and Ahmadi, 2008; Yang et al., 2006; Kaewtapee et al., 2011).

The growth curve is usually expressed for a set of birds using a nonlinear mathematical model based on daily or weekly summarized records. Growth as an indicator in the biological system defined as the increase in animal body mass per time (Yang et al., 2006). It is an important economic trait in broiler industry. The prediction of growth rate at different stages of animal husbandry has the advantage of being able to identify required nutrients aimed to provide the most economical nutrition management program, which leads to increasing the economic revenue of the project (Abbas et al., 2014). Growth models are mathematical equations which provide a set of parameters to describe the growth pattern of body weight and its components over time. In other words, these functions could display the summarized growth information in some indices, which may also have biological interpretation (Goliomytis et al., 2003; Ahmadi and Mottaghitalab, 2007). Differences in growth curves of inter-species (Anthony et al., 1991; Knizetova et al., 1994) and intra-species have been investigated in different studies (Gous et al., 1999; Marcato et al., 2008). In recent years, many studies have been performed to improve accuracy of models which describe growth curves, egg production, etc. by introduction of novel models or modification of existing models (Lopez et al., 2000; Safari Alighiralou et al., 2018).

The relative growth rate is different among different species, based on weight at puberty, maturity of chicks (no need to parental support after birth) at birth and increased skeletal muscle mass in the postnatal period (Ramos et al., 2013; Narinc et al., 2014; Demuner et al., 2017). So far, various nonlinear functions have been suggested for mathematical modeling and description of growth pattern in broilers, which are greatly different in their fit and estimation, but so far no studies have been performed comparing strains (Tompić et al., 2011; Faraji-Arough et al., 2019; Koushandeh et al., 2019; Mouffok et al., 2019). Several equations have been used in broilers including Logistic, Gompertz, Bertalanffy, Lopez and Richards (Mohammed, 2015). Therefore, the objective of the current study was to investigate the growth curve in three strains of broiler chickens using nonlinear functions in order to select the most appropriate model to describe the growth curve in considered strains.

MATERIALS AND METHODS

Examination of birds and management

The experiment was conducted in a local broiler farm in Rasht, Iran (37°16'50" N, 49°34'59" E). All procedures used in the present study were approved by the Institutional Animal Care and Use Committee of University of Guilan. The study was carried out on a breeding farm and utilized 500 chickens (1-day old) for each Ross 308, Cobb 500, and Arbor Acres strains. The breeding broiler management of each strain was set according to the related manufacturer catalog (Arbor Acres, 2019; Cobb 500, 2019; Ross 308, 2019). Broilers were housed on the floor and lighting regimen provided 22 hours of continuous light per day. Feed and water were distributed ad libitum but the consumed values were calculated. Vaccination program followed the recommendations of the manufacturer. The chicks were weighed individually once a week from day 1 to 42. Weekly body weights were applied to fit nonlinear mathematical functions. The descriptive statistics of body weight traits of the stains are presented in Table 1.

Mathematical models

Three non-linear functions including Logistic, Gompertz and Richards were fitted by the NLIN procedure of SAS (SAS Institute, 1999) and the parameters for each model were obtained (Table 2). The differences between the three groups were compared using Tukey test. Alpha levels less than 0.05 were considered significant.

Two criteria for evaluating the growth models were:

1) Adjusted determination coefficient (R^2 adj)

In order to compare the functions, effect of scale for observation measurement need to be eliminated. When the number of parameters for the function is unlike, the corrected coefficient of determination could be used to compare the equations. This coefficient is calculated as follows:

$$R^2\ adj=1-[(n-1/n-p)(1-R^2\ model)]$$

where **R^2 adj** is the corrected coefficient of determination, **n** is the number of observations, **p** is the number of parameters, and **R^2** model is the coefficient of determination of the model. This coefficient is the SSR/SST ratio, where SSR is the regression square sum and SST is total sum of squares.

2) Root Mean Squared Error (RMSE)

The accuracy of models was evaluated by residuals. Mean square error (MSE) is calculated through dividing the sum of squares of errors by the degree of freedom, which is as follows: MSE = SSRes/n-p; where **SSR**es is sum of squares of errors, **n** is the number of observations, and **p** is the number of parameters.

$$RMSE=\sqrt{(SSRes/n-p)}$$

RESULTS AND DISCUSSION

The estimated growth parameters by nonlinear models for three strains of broilers are shown in Table 3. The parameters were related to initial and final weights with relatively low error in all the fitted models. Changes in body weight (observed vs. estimated) using three functions are presented in Figures 1, 2, and 3.

Table 1. Statistical description of body weight (g) during a period of 42-days for three chicken strains

Strain	Age (day)	Mean ± SD	Minimum	Maximum
Cobb	1	42.1 ±21	38	44
	7	203.2 ± 37	187	213
	14	512 ± 36	415	580
	21	919 ± 57.6	545	1050
	28	1520 ± 41	1350	1680
	35	2225.2 ± 185	1870	2310
	42	2750.8 ± 212	2650	3012
Ross 308	1	42 ± 13	39	44
	7	195.7 ± 12	156	218
	14	425 ± 58	365	530
	21	883.6 ± 78	712	980
	28	1480.8 ± 101	1390	1520
	35	2220.2 ± 175	1890	2380
	42	2780 ± 201	2680	3050
Arbor Acres Plus	1	41.5 ± 17	38	47
	7	186.7 ± 56	145	212
	14	506.4 ± 87	385	720
	21	886 ± 101	675	1020
	28	1450.8 ± 98	1050	1680
	35	2200.2 ± 124	1560	2560
	42	2670.8 ± 212	2470	3120

SD, standard deviation

Table 2. Mathematical description of growth functions, and biological parameters (Grossman and Bohren, 1985)

	Mathematical Expression	Weight at Inflection	Time to Inflection (t*)	Growth Rate (dw/ dt)
Gompertz	$W = W_0 \exp\{[1 - \exp(-bt)]\ln(W_f/W_0)\}$	$0.368\ W_f$		$bW\ln[1 - W_f / w]$
Logistic	$W = W_0 W_f / [W_0 + (W_f - W_0)\exp(-bt)]$	$0.5\ W_f$		$bW[1 - W_f / w]$
Richards		$W_f / (n + 1)^{1/n}$		$bW[(W_f^n - W^N) / nW_f^n]$

In all models, W_t refers to live body weight (g) at age t (day), W_0 is the initial body weight (g), b is the coefficient of relative growth or maturing index; t is the age of bird (day), and W_f is the mature body weight (g), Ti (day) is age at the inflection point; Wi is body weight at inflection point (g)

Table 3. Growth parameters for three broiler strains in fitted models

Model	Parameters of model			
	W_0 ± SE	W_f ± SE	b ± SE	n ± SE
Gompertz				
Cobb	36.7[ab] ± 3.47	2992.5[b] ± 324.9	0.038[a] ± 0.0045	
Ross 308	37.50[a] ± 7.75	2893.3[c] ± 128.53	0.025[b] ± 0.0004	
Arbor Acres Plus	33.15[ab] ± 8.35	2932.1[e] ± 95.42	0.032[a] ± 0.0009	
Logistic				
Cobb	44.33[bc] ± 10.65	2978.8[b] ± 45.04	0.124[a] ± 0.0022	
Ross 308	56.2[a] ± 8.74	2893[c] ± 49.33	0.048[c] ± 0.0007	
Arbor Acres Plus	49.61[c] ± 2.99	2903.5[a] ± 67.07	0.115[b] ± 0.0017	
Richards				
Cobb	43.02[a] ± 9.54	2880[a] ± 164.2	0.113[a] ± 0.0118	0.97[a] ± 0.092
Ross 308	37.20[a] ± 1.46	2829[c] ± 1.07	0.049[c] ± 0.0007	0.87[b] ± 0.0034
Arbor Acres Plus	42.46[a] ± 2.43	2870[a] ± 109.47	0.114[a] ± 0.0019	0.96[a] ± 0.006

W_0, initial weight (at birth); W_f, final weight; b, growth rate; n, shape parameter; SE, standard error

Functions were different in predicting the growth curves for different strains. By fitting the Gompertz model, the initial weight of Arbor Acres Plus was poorly estimated. With regard to the final weight, the highest and lowest estimated values were related to Cobb and Arbor Acres Plus, respectively. Ross 308 had the lowest growth rate of 0.025, compared to 0.032 for Arbor Acres and 0.038 for Cobb (Table 3) that could explain the lower final weight in this strain. Changes in body weight (observed vs. estimated) using different models are presented in Figures 1, 2, and 3. Generally, the comparison of the estimated weights with the observed weights by the Gompertz function showed that this model made an underestimation of initial weight values for most strains. In Logistic function, the highest and lowest estimated weight at birth were related to Ross 308 and Cobb, respectively. The difference of predicted final weight was also significant among all strains, with the highest estimation for Ross 308 and the lowest for the Arbor Acres Plus. The difference in growth rate estimated by this function was significant between all strains, the highest growth rate observed in the Cobb and the lowest rate was for the Ross 308.

The growth rate values obtained from Logistic function were different from those obtained by Gompertz, but both models showed a similar trend, meaning heavier strains required less time than lighter strains to reach the final weight. In contrast to the Gompertz function, the use of Logistic function for predicting growth curve resulted in an overestimation for actual and final weights of strains.

The shape parameter, which could only be estimated by Richard function, was different between the Ross 308 and other two strains. The highest and lowest shape parameter was observed in Cobb and Ross 308 strains, respectively. As a result, lower difference between estimated and actual values using Richards in comparison to Gompertz and Logistic functions clearly showed that Richards function is an appropriate estimator for our studied strains. This may be due to an additional parameter (n, the shape parameter) in this model, which makes it more flexible and accurate model than two other models.

The lower difference between estimated final weight values using Richards and Logistic functions than the Gompertz model may be due to having a fixed inflection point relative to final weight, which could be one of the disadvantages of this model (Darmani Kuhi et al., 2010). Therefore, the estimated weight at puberty using Gompertz model is usually bigger than actual values. In previous studies, the Gompertz function was reported the best function for estimation of growth parameters in broiler chickens (Mouffok et al., 2019; Tompić et al., 2011; Yang et al., 2004). Norris et al. (2007) suggested Gompertz as an appropriate model to describe the growth curve in indigenous male Venda and Naked Neck chickens using three functions, comparable to our study. In their study, it was found that Richards function is better than Gompertz and Lopez for estimating the growth parameters. Mouffok et al. (2019) investigated some nonlinear functions to describe the broiler growth curve of the Cobb500 strain. The results showed that the Gompertz model was the most suitable till up to the four weeks of age. After one month of age, the Gompertz has a lower precision. Tompić et al. (2011) found that Richards and Gompertz functions are more reasonable to estimate final weight parameter of broilers

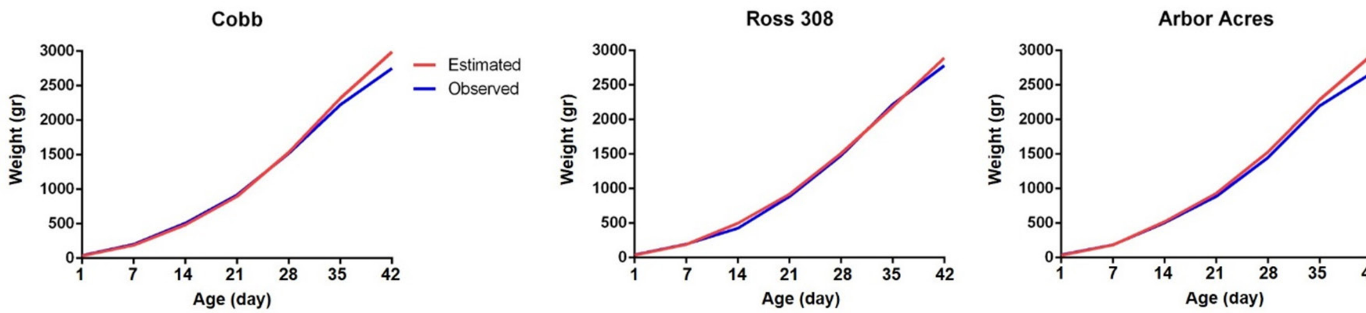

Figure 1. Change in body weight (observed vs. estimated) using Gompertz function

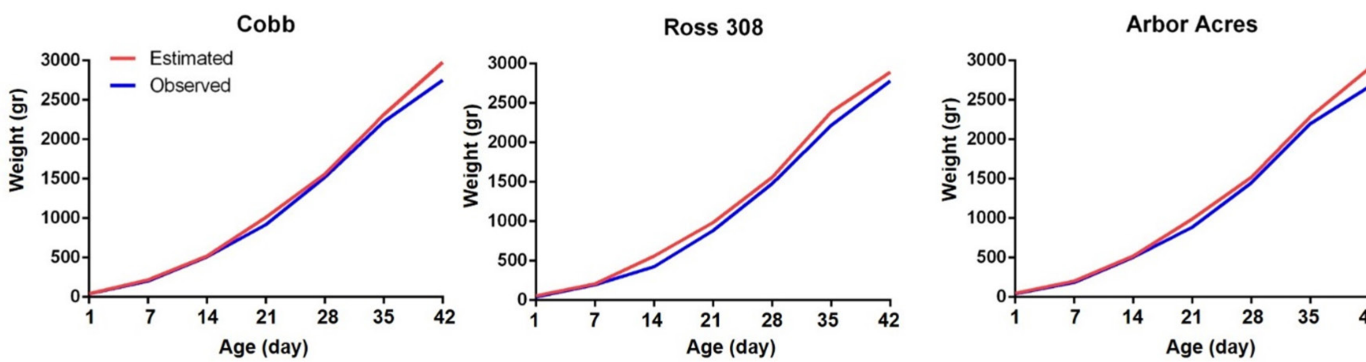

Figure 2. Change in body weight (observed vs. estimated) using Logistic function

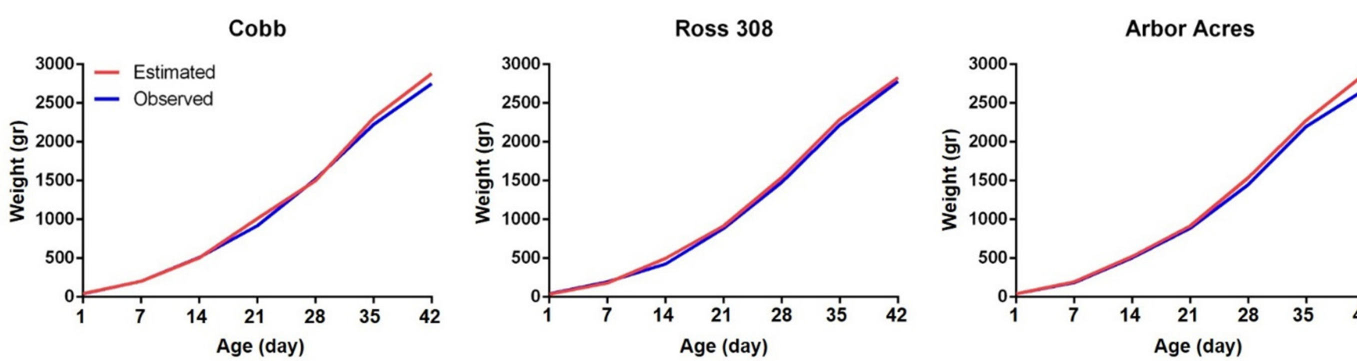

Figure 3. Change in body weight (observed vs. estimated) using Richards function

than Logistic function for Ross strain, which confirms the findings of the present study. Studies have also described that the Logistic model overestimates weight at birth, but however, underestimates final weight smaller than actual value, and the Gompertz function predicts final weight bigger than actual (Rizzi et al., 2013).

The estimated age and weight at inflection point by different functions was varied in three strains (Table 4). The results showed that the age and weight of birds at inflection point varied in three strains. The maximum weight at inflection point of Ross 308 (day 42) was related to Gompertz function. Since the growth rate of curve is linear before reaching the inflection point, it seems that the trend of growth in Ross 308 strain was estimated almost linear by this model. The weight had the lowest values when reaching the inflection point at day 41 in Arbor Acres Plus and day 39 in Cobb. These values based on Logistic model were different from the Gompertz function. Based on this model, Cobb and Ross 308 had the highest and lowest weight at inflection point. This trend in Richards function for Arbor Acres Plus was comparable to that of Gompertz and Logistic models, but Cobb and Ross showed the highest and lowest weight at the inflection point, respectively.

The younger age at inflection point, regardless of the fitted model, indicated decreasing trend of growth in the strains which had started earlier (Table 4). The age for reaching inflection point is 39.3 and 33.24 days for Cobb and Ross 308 strains, respectively (Lopez et al., 2000; Rizzi et al., 2013). There have been many published papers reporting a very low age at inflection point, regardless of growth model fitted in broiler chickens (Sakomura et al., 2011). Achieving a model describing the production curve and ability to estimate upcoming production using existing products can also be achieved by nonlinear models.

Table 4. Age (day) and weight (g) traits at inflection point for different functions

Strain	Gompertz		Logistic		Richards	
	t*	w	t	w	t	w
Cobb	39	2740	42	2350	45	2480
Ross 308	42	2840	39	2230	39	2330
Arbor Acres Plus	41	2430	41	2190	41	2430

*t, age (day) at inflection point; w, weight (g) at inflection point

In our study, fitting of the growth curves obtained from different nonlinear models and actual growth curves were consistent with the results from comparing the used criteria to select the most appropriate model. Based on the curves, all growth models, except for the Logistic which had a significant error in the early phase, were able to fit changes in the growth at different times.

The good side of fit criteria for the nonlinear models is presented in Table 5. For all three models, R^{2s} were substantial, ranging from 0.977 to 0.999. The little differences in the estimates indicated that fitted functions could be respectable predictors for the growth curve of all three studied strains. However, these few differences caused difficulty to compare one model over another based on this criterion.

The existing difference for fitted functions by RMSE (Table 5), showing difference between actual and estimated production, was significant in comparison to the R^2 criteria. Based on RMSE, for the Ross 308 and Cobb strains, Richards function had more suitable description for the growth curve, because of having the minimum RMSE, 61.57 compared to 85.43 and 66.61 for Gompertz and Logistic, respectively.

The non-linear Gompertz function was superior in describing the growth curve of Ross 308 strain with regard to RMSE, 58.08 compared to 73.32 and 85.43 in Arbor Acres and Cobb, respectively. For Arbor Acres and Cobb strains, Richard model was superior for estimating the growth curve. However, the Gompertz function was not an appropriate predictor for Cobb 500, RMSE was 85.43, but its capability to describe the curve of Ross 308 was more appropriate in comparison to Arbor Acres.

Growth functions such as Gompertz, Logistic and Lopez have little flexibility in describing the growth pattern. The main reason is the dependence of inflection point of their curves on the weight at sexual maturity. Tompić et al. (2011) reported that Richards, by the least values of R2 (0.988 to 0.995), was better estimated than Gompertz and Logistic functions. In the current study, we couldn't see any significant difference for R2 of the fitted models. Therefore, our results were not in accordance with the results obtained by Tompić et al. (2011) and Selvaggi et al. (2015). Selvaggi et al. (2015) found that Gompertz function fitted live weight data very well, both for male and female birds being the best model for studying the growth of our animals. Hence, Darmani Kuhi et al. (2003) reported no model had superiority to other models statistically, which is in agreement with our results.

In this study, the minimum and maximum R^2 were 98.87% and 99.99% in males, and 98.67% and 99.99% in females, respectively. In the study of Ramos et al. (2013), although the R^2 values were low, ranging from 92.4 to 94.5, their little differences because of the fitting of the Gompertz and Logistic models were similar to the results of the present study.

Table 5. Different criteria for evaluation of fitted models

	RMSE	R^2	Value	Function
Cobb	1242.2	85.43	0.9917	Gompertz
	1239.3	86.61	0.9765	Logistic
	1178.5	61.57	0.9967	Richards
Ross 308	5385.8	58.08	0.9941	Gompertz
	5803	73.77	0.9809	Logistic
	5743	71.17	0.9815	Richards
Arbor Acres	3237	73.32	0.9929	Gompertz
	3258.3	84.26	0.9808	Logistic
	3251.6	81.99	0.9914	Richards

R^2, adjusted determination coefficient; RMSE, Root Mean Squared Error

Koushandeh et al. (2019) showed that the performance prediction of broiler chicks using the Gompertz function (R^2 = 0.9989) was more accurate than artificial neural network (R^2 = 0.95839). An opportunity to make selection strategies by changing feeding practices or genetic makeup of growth curve shape can be provided by the growth curve parameter. The estimated growth parameters by appropriate function could be included in genetic improvement program (Selvaggi et al., 2015).

Classical growth models could be used to estimate the growth parameters in different broiler strains. Our obtained results from comparison of different functions showed that although all of them had capability of fitting the growth curve and estimating related parameters, Richards function in the Cobb, which had higher growth rate than the Ross 308 and Arbor Acres, was the most appropriate function to describe the growth curve, which had the highest R^2 and also the lowest RMSE values. The Gompertz function with the maximum R^2 values, also with the lowest RMSE, was the most suitable function to describe the growth curve of the Ross and Arbor Acres strains.

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