J. Agr. Sci. Tech. (2020) Vol. 22(6): 1449-1462

Description of Growth Patterns in a Crossbred Population of Native×Commercial Broiler Chicken

R. Seifi Moroudi[1], S. Ansari Mahyari[1*], R. Vaez Torshizi[2*], and H. Ahmadi[3]

ABSTRACT

Four nonlinear models including Logistic, Gompertz-Laird, Richards, and von Bertalanffy were compared to achieve the best prediction of growth parameters describing the growth curve in a crossbred chicken population. Growth data (weekly body weights of chicken from birth to 84 days of age) were collected on 303 birds (174 females and 129 males) of F_2 cross of the Arian line broiler chicken (Line B) and Urmia native chicken. Some statistical criteria such as Akaike Information Criterion (AIC), Corrected Akaike Information Criterion for small sample sizes (AICc), and Bayesian Information Criterion (BIC) were used to find the best model. The results showed that the estimated values of the initial weight (W_0) and final Weight (W_f) in male were significantly ($P< 0.01$) higher than the female birds in all models. The average estimated initial weight calculated by Gompertz-Laird (0.038 kg) was closer to the average observed initial weight (0.044 kg). Regardless of sex of the birds, the calculated age (t_i) and Weight (W_i) at the inflection point were relatively the same in Gompertz-Laird, Richards and von Bertalanffy models, indicating that the growth patterns described by these models are similar. Meanwhile, the different t_i and W_i values between the sexes in the four models revealed the different growth pattern in males and females. The goodness of fit indices (R^2 and adjusted R^2) were higher than 0.97 in all models, indicating that these models could appropriately be fitted on the growth data. However, based on the AIC, AICc, and BIC criteria, Gompertz-Laird model showed better performance, therefore, it was chosen as the best model to analyze the growth pattern in crossbred of .

Keywords: Arian chicks, Gompertz-Laird model, Growth model, Urmia chicks.

INTRODUCTION

Growth is an essential characteristic of biological systems and an important economic trait in the selection plans in broilers (Forni *et al.*, 2009; Narinc *et al.*, 2014). Growth mathematical functions named 'growth models' have been used in poultry researches to illustrate the growth patterns (Narinc *et al.,* 2017). Growth models can be used to optimize and manage animal production and determine nutrient efficiency (Darmani-Kuhi *et al.*, 2010). Growth equations decline the number of weight-age data to a few parameters, so, the error effects are decreased in the models (Aggrey, 2002). Study of growth models could help researchers to monitor the variation of the shape of growth curve during the selection and to estimate the derived parameters such as growth rate and inflection points (Hyankova *et al.*, 2001).

As animal growth is nonlinear, nonlinear models are suitable to describe the growth curve (Forni *et al.,* 2009). The most useful non-linear regression models in poultry science are the three-parameter models such as Gompertz, Gompertz-Laird, and Logistic

[1] Department of Animal Science, College of Agriculture, Isfahan University of Technology, Isfahan, 841583111, Islamic Republic of Iran.
[2] Department of Animal Science, College of Agriculture, Tarbiat Modares University, Tehran, 14115-336, Islamic Republic of Iran.
[3] Bioscience and Agriculture Modeling Research Unit, Department of Poultry Science, Tarbiat Modares University, Tehran, 14115-336, Islamic Republic of Iran.
[*]Corresponding authors; e-mails: s.ansari@iut.ac.ir ; rasoult@modares.ac.ir

[DOR: 20.1001.1.16807073.2020.22.6.18.4]

and the four-parameter models such as Richards, Lopez, and von Bertalanffy. A review study on growth models evaluation indicated that Gompertz was the most commonly used growth model (Narinc *et al.*, 2017). Richards function has variable point of inflection and is more flexible than the Gompertz and Logistic functions that have fixed growth forms with the point of inflection at about 50 and 37% of the mature weight, respectively (Porter *et al.*, 2010). The point of inflection usually happens at weights less than half of the final weight, depending on age, sex, breed, and type of animal (Darmani-Kuhi *et al.*, 2010). Hence, ignoring model complexity, the four-parameter functions implemented better than the three-parameter models and Richards model is better than the others (Darmani-Kuhi *et al.*, 2010). However, the Richards model sometimes shows difficulty in estimating initial weight (France *et al.*, 1996). Another problem of the Richards is that this equation is not able to estimate an adequate mature weight when weight is not recorded after 90 d of age for the chicken populations. In this case, the mature weights are estimated extremely high (Rizzi *et al.*, 2013). Next to these models, the Gompertz-Laird is a special type of flexible Richards' model with variable inflection point without problems of Gompertz and Richards models.

There are many statistical indices to fit the models, such as R^2, adjusted R^2, bias, Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Modeling Efficiency (ME) and concordance correlation (Brun *et al.*, 2006). Although R^2 and RMSE are often used, they are not an appropriate metric to evaluate the fit of nonlinear models due to not accounting for the number of parameters (Brun *et al.*, 2006). Therefore, in order to find the best model among growth models, different statistical criteria can be used: F test, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), or the likelihood ratio test (Zucchini, 2000; Burnham, 2002; Ritz and Streibig, 2008; Lewis *et al.*, 2011).

Up to the present, many studies have used different models on different strains of broiler chickens across environmental conditions and different outputs have been reported. The difference in outcomes may be due to many reasons, such as breed or population structure, sex, nutrition, environmental conditions, sampling, and statistical methods.

Due to the importance of the growth curve in breeding plans, in the last years, a chicken strain suitable for free range breeding was developed by crossing the fast-growing Arian broiler line and slow-growing Urmia native chicks in Iran. Until now, many researches have been carried out to evaluate the growth traits, meat production and quality, immunity, residual feed intake and metabolic traits in this strain (Emamgholi-Begli *et al.*, 2017; Emrani *et al.*, 2017; Maghsoudi *et al.*, 2017; Raeesi *et al.*, 2017; Javanrouh-Aliabad *et al.*, 2018). Consequently, the objective of this research was the comparison of four nonlinear models to achieve the best prediction of growth parameters and the best growth model in this crossbred broiler chickens population.

MATERIALS AND METHODS

Experimental Animals

In this study, growth data were collected from the second generation of Arian line and Urmia native chicken at the research farm of the faculty of agriculture, Tarbiat Modares University. A total of 303 chickens, 174 females and 129 males, were weighed weekly from birth to 84 days of age. The first generation was the result of a reciprocal crossing between the Arian line broiler chicken (Line B) and Urmia native chicken, and the second-generation birds were the result of a inter crossing between the first-generation birds. The birds were reared in a controlled environmental conditions from hatch until the end of the trial. The chicks had free access to feed (Table 1) and water. The feed form was crumbled for the first 8 wk of age and then pelleted. The initial diet was used for two weeks, and the growth diet, first end diet, and the second end diet were used to feed the birds from 2 to 7 weeks, 8 to 10 weeks, and 10 to 12 weeks, respectively. The light program in the first week of breeding was 24 hours light. Breeding was continued for 22 hours of light and 2 hours of darkness. Room temperature was set at 33°C on the first day and gradually decreased weekly to 22°C. During this period, the birds received no vaccine and no antibiotics in their diet.

2.2. Mathematical Growth Models

The growth functions considered in this study were Logistic, Gompertz-Laird, Richards and von Bertalanffy (Table 2). The models were fitted to the data using the PROC NLIN of SAS software (SAS Institute Inc-2008).

The derived parameters including: Age at the inflection point (t_i); weight at the inflection point (W_i); Growth Rate (GR), and the mature weight (for Gompertz-Laird) (W_f) are shown in Table 3.

Statistical Analysis

The R^2, adjusted R^2, and RMSE were used to assess the goodness of fit of the models (Archontoulis and Miguez, 2015). The significance of the goodness of fit was evaluated by using the F-test for comparing two models either with the same or a different number of parameters (Rizzi *et al.*, 2013). To find the best model, statistical criteria such as AIC, AICc, BIC were used (Archontoulis and Miguez, 2015).

RESULTS

Weekly body weight means for both sexes are presented in Table 4. The body weight of males at different ages was significantly higher than females ($P< 0.01$). The values of the main and derived parameters of each model (Gompertz- Laird, Logistic, Richards, and von Bertalanffy) are shown in Tables 5 and 6, respectively.

The estimated values of the initial Weight (W_0) and final weight [or mature Weight (W_f)] in males were significantly ($P< 0.01$) different from females (male birds showed higher weight than female birds), except in the Gompertz-Laird that the initial weight of females and males was similar, because the difference between W_0 in females and males was not significant ($P= 0.461$). The Gompertz-Laird model gave a lower SE value in comparison with the other models.

The Gompertz-Laird W_0 values are close to the observed initial average weight (Table 7). The W_0 of the Logistic model is higher than the other models, whereas the Logistic W_f values are lower than the other models.

Table 1. Chemical composition of the basal diet fed to second generation chickens.

	Initial diet	Growth diet	First end diet	Second end diet
Crude protein (%)	22.5-22.8	19.5-20	17.5-18	16.5
Fat (%)	2.5-3.5	2.6-4	2.6-4	2.5-4
Fiber (%)	3.9	3.9	3.9	3.9
Calcium (%)	1	1	1	1
Chlorine (%)	0.18-0.2	0.16-0.2	0.15-0.2	0.15-0.2
Lysine (%)	1.34	1	0.9	0.9
Methionine (%)	0.65	0.45	0.42	0.42
Methionine+Cysteine (%)	1	0.75	0.7	0.7
Available phosphorus (%)	0.5	0.47	0.46	0.43
Metabolizable energy (kcal kg^{-1})	3000-3025	2940-2960	3040-3070	3100-3120
Humidity (%)	10-12	10-12	10-12	10-12
Dry matter (%)	88-90	88-90	88-90	88-90

Table 2. Functions used for modeling the growth curves in this study.[a]

Models	Functions	Number of parameters	Parameters
Gompertz laird	$W_t = W_0 \exp[(\mathrm{L/b})(1-\exp(-bt))]$	3	W_0, L, b
Logistic	$W_t = W_0 W_f/[W_0 + (W_f - W_0)\exp(-bt)]$	3	W_0, W_f, b
Richards	$W_t = W_0 W_f/[W_0^n + (W_f^n - W_0^n)\exp(-bt)]$	4	W_0, W_f, b, n
Von Bertalanffy	$W_t = [W_\mathrm{f}^v - (W_f^v - W_0^v)\exp(-bt)]^{1/v}$	4	W_0, W_f, b, v

[a] W_t= The Weight of bird at time t (g); W_0= The initial (hatch) BW (g); W_f= The asymptotic (mature) BW (g); t= Time (day); b, L, n and v are constants; b= The coefficient of relative growth or maturing index (smaller b indicates later maturity, while larger b indicates earlier maturity) (per day); L= The instantaneous growth rate (per day), (which measures the rate of decline in the growth rate); n= The shape parameter (n≥ −1).

Table 3. The derived parameters of growth models used in this study.[a]

Models	$\mathbf{t_i}$	$\mathbf{W_i}$	**GR**	$\mathbf{W_f}$
Gompertz laird	(1/b) log(L/b)	$W_0\exp[(\mathrm{L/b})^{-1}]$	$bW\ln(W_f/W)$	$W_0\exp$ (L/b)
Logistic	1/b{ln[(W_f-W_0)/W_0)]}	0.5W_f	$bW(1-W_f/W)$	……
Richards	1/b{ln[(W_f^n-W_0^n)/nW_0^n]}	W_f/(n+1)$^{1/n}$	$bW[(W_f^n - W^n)/\, nW_f^n]$	…….
von Bertalanffy	1/b{ln[(W_f^v-W_0^v)/(vW_f^v)]}	W_f (1-v)$^{1/v}$	$(bW_f^v/\mathrm{v})W^{1-v} - (b/v)W$	……

[a] t_i= age at the inflection point (day) (t_i is the maximum growth rate longitudinal time frame of live weight); W_i = body weight at the inflection point (g); GR= Growth Rate (g d^{-1}); W_0= The initial (hatch) BW (g); W_f= The asymptotic (mature) BW (g); t= Time (day); b, L, n and v are constants; b= The coefficient of relative growth or maturing index (per day); L= The instantaneous growth rate (per day), (which measures the rate of decline in the growth rate); n= The shape parameter (n≥ −1).

Table 4. Means and standard deviations for Body Weight (BW) at different ages in the cross breed of Arian line and Urmia chicken.

Age (day)	Male (n= 129)	Minimum	Maximum	Female (n= 174)	Minimum	Maximum
1	0.044 ± 0.004	0.033	0.056	0.044 ± 0.004	0.290	0.570
7	0.093 ± 0.018	0.055	0.134	0.092 ± 0.019	0.041	0.135
14	0.228 ± 0.063	0.083	0.325	0.212 ± 0.060	0.069	0.320
21	0.449 ± 0.107	0.203	0.651	0.397 ± 0.093	0.157	0.594
28	0.754 ± 0.175	0.346	1.141	0.641 ± 0.145	0.307	0.949
35	1.093 ± 0.220	0.532	1.535	0.925 ± 0.176	0.498	1.320
42	1.459 ± 0.273	0.770	2.050	1.214 ± 0.201	0.680	1.660
49	1.827 ± 0.325	1.005	2.550	1.492 ± 0.219	0.890	1.975
56	2.189 ± 0.325	1.460	3.035	1.762 ± 0.243	1.000	2.480
63	2.579 ± 0.363	1.560	3.700	2.053 ± 0.264	1.260	3.080
70	2.937 ± 0.371	2.000	3.955	2.305 ± 0.296	1.355	3.680
77	3.242 ± 0.421	2.230	4.265	2.546 ± 0.337	1.625	4.150
84	3.188 ± 0.387	2.295	3.995	2.569 ± 0.367	1.736	4.105

[DOR: 20.1001.1.16807073.2020.22.6.18.4]

Table 5. Estimated growth parameters using different growth functions (male and female data. set)

	Male	SE	Female	SE
Gompertz Laird				
W_0	0.037	0.0047	0.038	0.0035
b	0.0350	0.0010	0.0352	0.0008
L	0.166	0.0084	0.157	0.0062
Logistics				
W_0	0.116	0.0059	0.105	0.0041
W_f	3.54	0.042	2.74	0.025
b	0.071	0.0014	0.069	0.0011
Richards				
W_0	0.040	0.011	0.034	0.0077
W_f	4.31	0.196	3.38	0.124
b	0.036	0.0039	0.033	0.0029
n	0.028	0.102	-0.044	0.0796
von Bertalanffy				
W_0	0.040	0.011	0.034	0.0077
W_f	4.31	0.196	3.38	0.124
b	0.036	0.0039	0.033	0.0029
v	-0.028	0.102	0.044	0.0796

Table 6. Derived growth curve parameters, inflection point traits, and growth rate using different growth functions (male and female data set).

	Male	Female
Gompertz Laird		
W_i	1.60	1.22
W_f	4.36	3.33
t_i	44.54	42.39
Average GR	0.040	0.031
Maximum GR[a]	0.056	0.043
Logistics		
W_i	1.77	1.37
t_i	47.87	46.26
Average GR	0.038	0.029
Maximum GR	0.062	0.048
Richards		
W_i	1.61	1.22
t_i	44.64	42.198
Average GR	0.040	0.031
Maximum GR	0.056	0.043
von Bertalanffy		
W_i	1.61	1.22
t_i	44.64	42.198
Average GR	0.040	0.031
Maximum GR	0.056	0.043

Table 7. The observed initial average weight and the estimated initial weight of different growth functions.

The observed initial average weight	0.044
The estimated initial weight	
Gompertz Laird	0.038
Logistic	0.110
Richards	0.036
von Bertalanffy	0.036

Furthermore, final weight in Gompertz-Laird was higher than the Richards and von Bertalanffy models, but SE in the Richards and von Bertalanffy models was higher than the Gompertz-Laird model. The Gompertz-Laird equation calculates lower b values in comparison to the other models.

In the present study, age and weight at the inflection point, final weight, maximum growth rate and average growth rate in males are higher than females (Table 6). The predicted growth curves for live weight are shown in Figures 1 and 2 for males and females, respectively. The shape of the growth curve is typically sigmoid. Live body weight rapidly increases until the age at the inflection point. Age at the inflection point is very important because at which the maximal growth rate was attained. As can be deduced from Table 6, male chickens reached the inflection point at a later age than the females. Age and weight at the inflection point in the Logistic model are higher than the Gompertz-Laird, Richards, and von Bertalanffy models. These three models showed approximately the same values in both males and females. Comparison of growth curves indicates that Gompertz-Laird, Richards and von Bertalanffy models could be perfectly fitted on each other but logistic showed a different pattern in both sexes (Figure 3).

The growth rate curves are shown in Figures 4 and 5 for males and females, respectively, for all models. Maximum growth rate occurs at the inflection point. After this age, growth rate declined and reached zero at the age of maturity. In Figure 6, the peak of Gompertz-Laird, Richards and von Bertalanffy growth rate curves was earlier and lower than the peak of Logistic growth rate and they reached zero at later age in both sexes. In the male, the average GR and maximum GR were significantly ($P< 0.01$) higher than female (Table 6).

Gompertz-Laird, Richards, and von Bertalanffy models have more parameters than the Logistic model, which included L, n, and v, respectively. ‘L’ value in the male was higher than female. The ‘n’ and ‘v’ parameters are different in male and female chicks (Table 6).

Numerical statistical indices R^2, adjusted R^2, and RMSE were compared to assess the goodness of fit (Table 8). The indices of

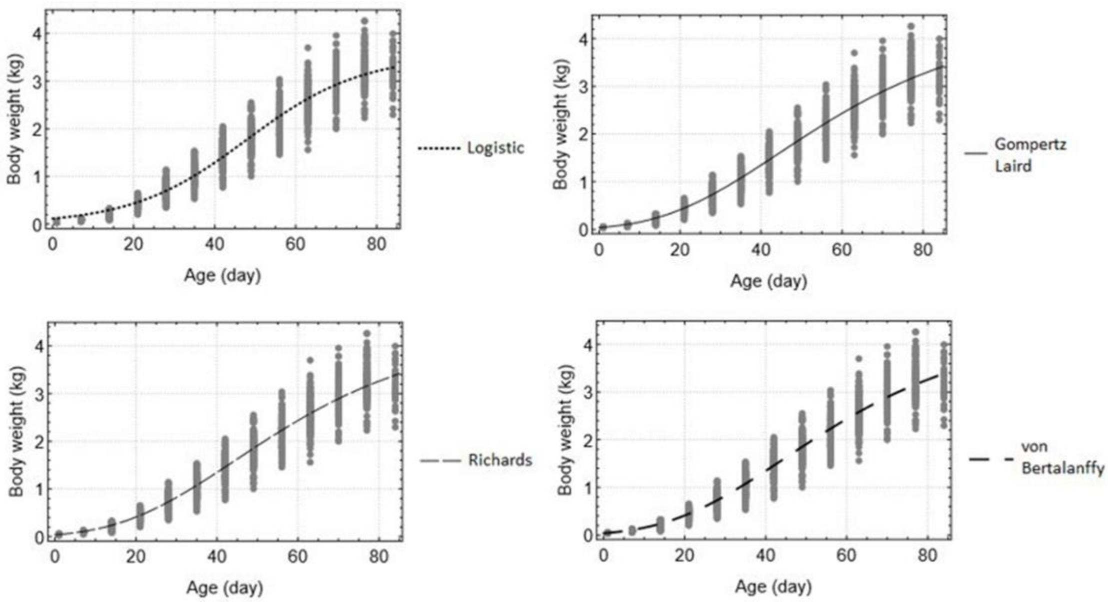

Figure 1. Logistic, Gompertz-Laird, Richards, and von Bertalanffy growth curves in males. (Age of maturity= 17, 22, 22 and 20 weeks for Logistic, von Bertalanffy, Richards, and Gompertz Laird, respectively).

[DOR: 20.1001.1.16807073.2020.22.6.18.4]

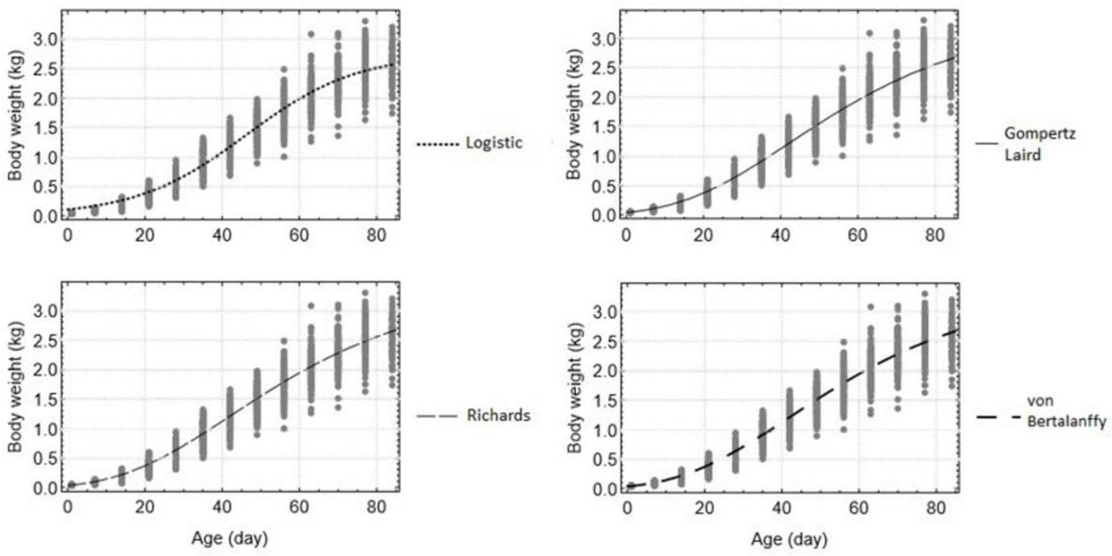

Figure 2. Logistic, Gompertz-Laird, Richards, and von Bertalanffy growth curves in females. (Age of maturity= 17, 20, 20 and 20 weeks for Logistic, von Bertalanffy, Richards, and Gompertz Laird, respectively).

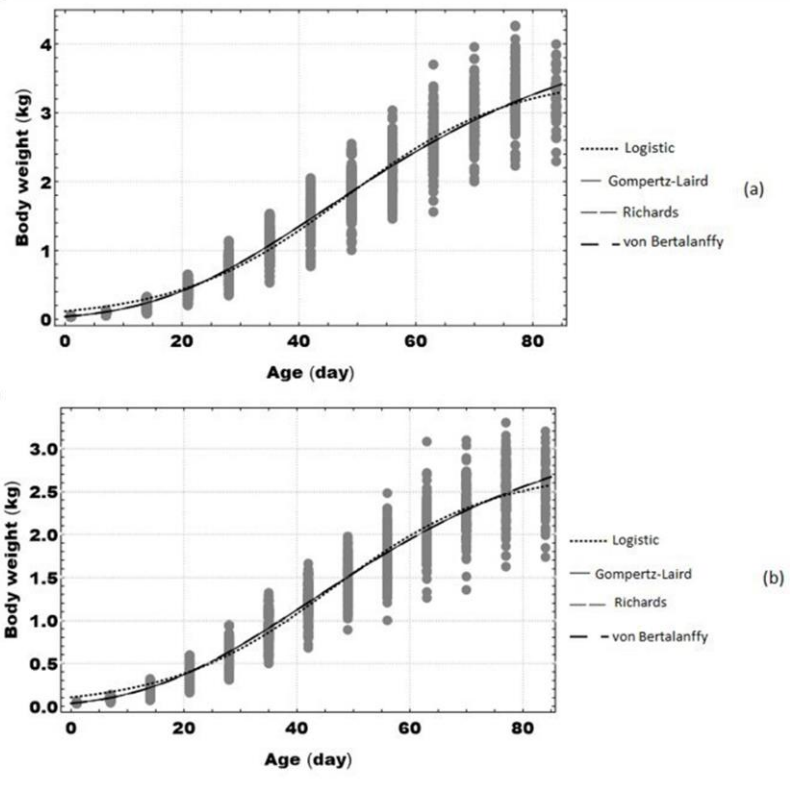

Figure 3. Comparison of growth curves of Logistic, Gompertz-Laird, Richards, and von Bertalanffy; in males (a) and females (b).

[DOR: 20.1001.1.16807073.2020.22.6.18.4]

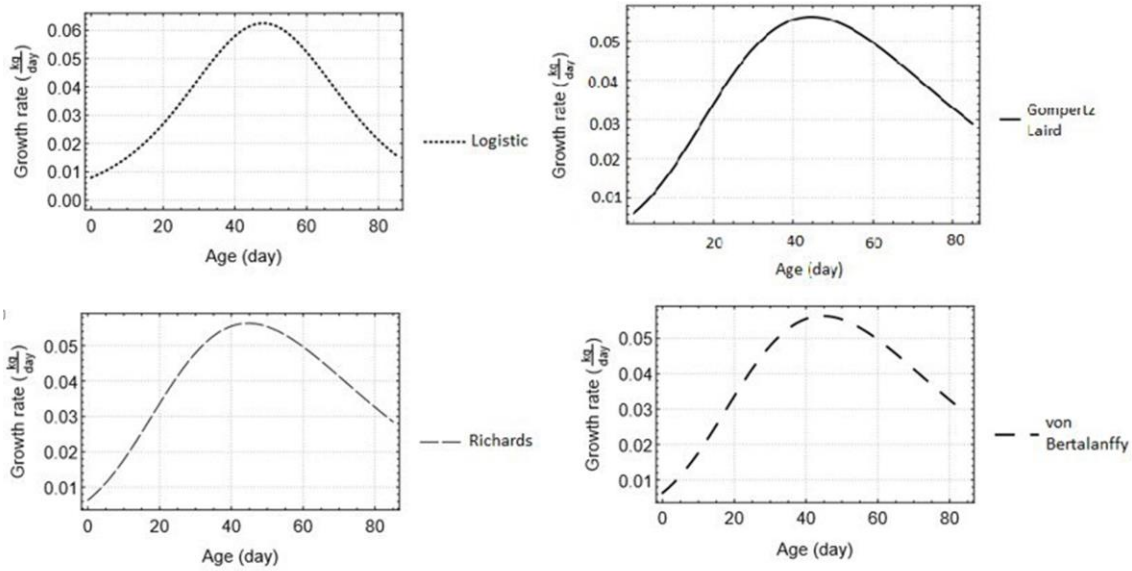

Figure 4. Logistic, Gompertz-Laird, Richards, and von Bertalanffy growth rate curves in F_2 male chickens.

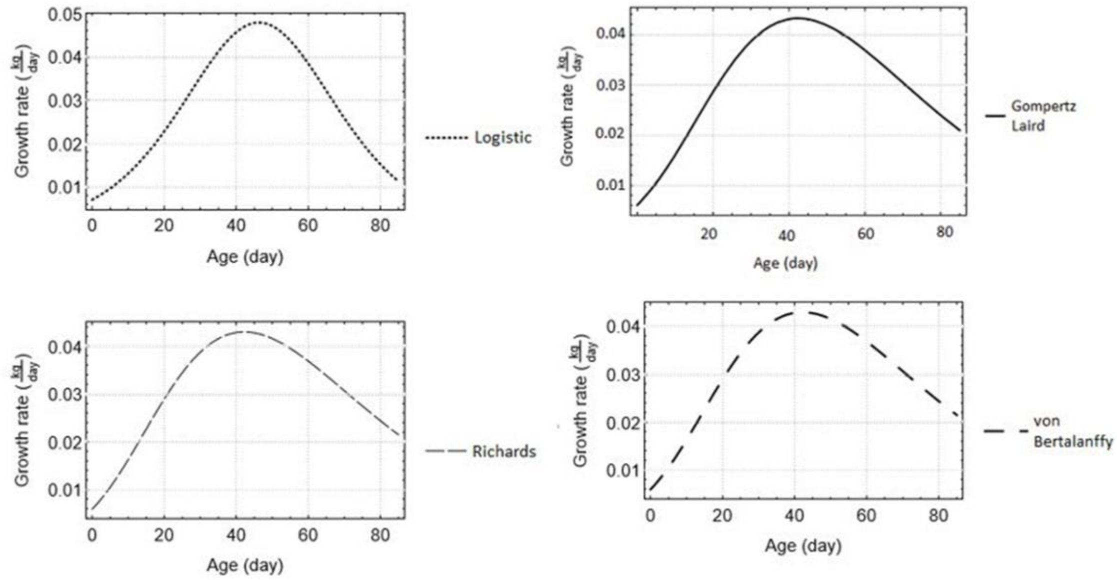

Figure 5. Logistic, Gompertz-Laird, Richards, and von Bertalanffy growth rate curves in F_2 female chickens.

fitness were higher than 0.97. The difference between models for R^2, adjusted R^2, and RMSE were not significant, but the difference among sexes was significant ($P< 0.001$).

In this research, Logistic as the non-flexible three-parameter model, Gompertz-Laird as the flexible three-parameter model, and Richards and von Bertalanffy as flexible four-parameter models were compared to select the best growth model by some model selection criteria like AIC, AICc, and BIC. The Gompertz-Laird model takes the minimum value of each criterion into account (Table 9).

DISCUSSION

This study showed that, in comparison to other studies, crossbreed chickens of Arian line and Urmia are medium-growing birds

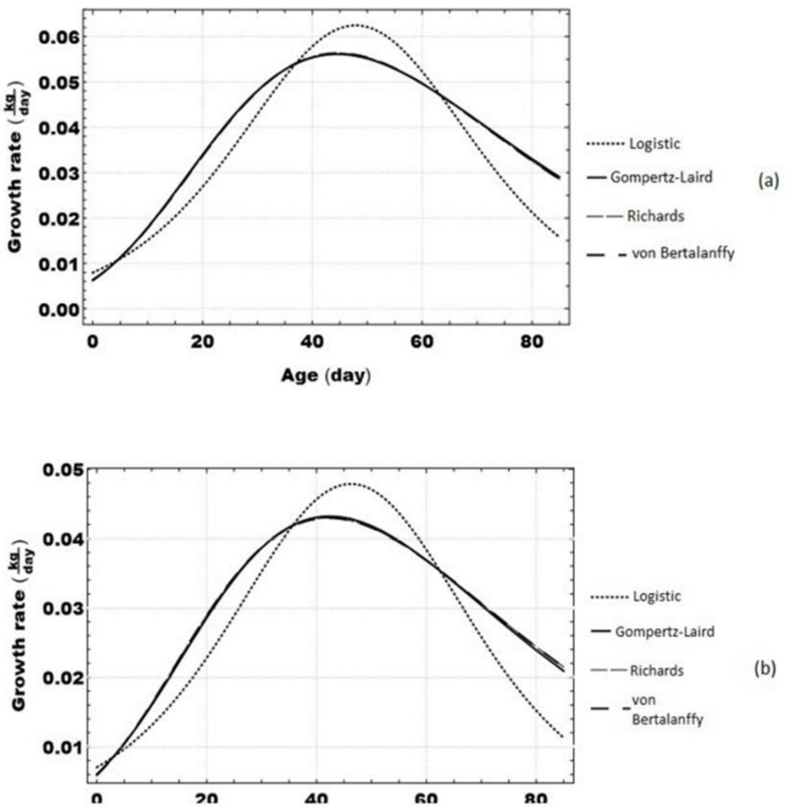

Figure 6. Comparison of growth rate curves of Logistic, Gompertz-Laird, Richards, and von Bertalanffy; in males (a) and females (b).

Table 8. Numerical statistical indices, R^2, adjusted R^2, root mean squared error (RMSE) for different models.

Model	Sex	R^2	adjusted R^2	RMSE
Gompertz Laird	Male	0.978606	0.978565	0.265377
	Female	0.981378	0.981352	0.197203
Logistic	Male	0.977875	0.977833	0.269873
	Female	0.980467	0.980439	0.201972
Richards	Male	0.978607	0.978552	0.265457
	Female	0.981381	0.981345	0.197236
von Bertalanffy	Male	0.978607	0.978552	0.265457
	Female	0.981381	0.981345	0.197236

(Marcato *et al.*, 2008; Narinc *et al.*, 2010; Rizzi *et al.*, 2013). Other reports in this strain for growth traits (Emrani *et al.*, 2017), meat production and quality (Emamgholi-Begli *et al.*, 2017), cell-mediated immune response (Raeesi *et al.*, 2017), immune system performance (Maghsoudi *et al.*, 2017) and metabolic traits (Javanrouh-Aliabad *et al.*, 2018), revealed that this population has the ability to breed in free-range condition. To follow up the operational objectives on this population, the best growth curve fitted to population structure, environmental conditions, etc. should be evaluated to select the parents with the best growth pattern. The males'

Table 9. Statistical criteria, AIC, AICc, and BIC for different functions. [a]

Model	Sex	AIC	AICc	BIC
Gompertz Laird	Male	**292.535**	**292.871**	**313.937**
	Female	**-853.425**	**-853.178**	**-830.83**
Logistic	Male	344.847	345.183	366.249
	Female	-753.163	-752.916	-730.568
Richards	Male	294.463	295.044	321.216
	Female	-851.719	-851.293	-823.475
Van Bertalanffy	Male	294.463	295.044	321.216
	Female	-851.719	-851.719	-823.475

[a] The bold items indicated that Gompertz-Laird model takes the minimum value of each criterion into account.

weight was higher than females weight. However, some studies reported a higher weight for females, but the outcomes of some similar studies also are consistent with this finding (Aggrey, 2002; Tompić *et al.*, 2011).

In Gompertz-Laird model, Standard Error (SE) is low, which means the model could predict the parameters with less error than the other models. Due to the low SE of initial weight in Gompertz-Laird model, the estimated initial average Weight (W_0) in this model is close to the observed initial average weight. Rizzi *et al.,* (2013) and Zhao *et al.*, (2015) showed that the Gompertz W_0 values were close to the observed initial average weight. Since the Logistic model overestimates the initial weight and underestimates the final weight, the Logistic W_f values were lower than the other models and the W_0 values were higher than the other models.

As noted previously, the Richards equation is not able to estimate appropriate mature weight when body weight is not recorded after 90 days of age. Although the final weight in Gompertz-Laird is higher than the Richards, but SE in the Richards is higher than the Gompertz-Laird model.

The inflection point of male birds was significantly higher than female birds ($P< 0.01$). Occasionally, male chicks reached the inflection point at a later age than the females. These findings are in agreement with the results of other studies (Aggrey, 2002; Porter *et al.,* 2010; Rizzi *et al.*, 2013; Selvaggi *et al.,* 2015). The age and weight at the inflection point were approximately similar in Gompertz-Laird, Richards, and von Bertalanffy models, which indicated that the growth pattern in these models was the same (Table 6, Figure 3); therefor, their growth curves were matched on each other. Age and weight at the inflection point are different between the females and males in all models, exhibiting different growth trends in both sexes. The position of the inflection point strongly influences the growth rate constant value and mature weight. Several studies revealed a higher weight and age at the inflection point that leads to higher final weight (Aggrey, 2002; Norris *et al.,* 2007; Rizzi *et al.,* 2013; Selvaggi *et al.*, 2015).

Average and maximum of GR in Gompertz-Laird, Richards and von Bertalanffy models were exactly similar; their growth rate curves completely matched each other. The peaks of Gompertz-Laird, Richards and von Bertalanffy growth rate curves were earlier and lower than the peak of Logistic growth rate because of lower age at the inflection point and maximum GR in these three models, and higher age at the inflection point and maximum GR in Logistic model.

Mature weight highly correlated with rapid early growth rate ($r> 0.5$) (Hunton, 1995). This research showed higher mature weight in males than females, hence the average GR and maximum GR in males should be higher than females, concordant to others (Topal and Bolukbasi, 2008; Darmani-Kuhi *et al.,* 2010; Moharrery and Mirzaei, 2014).

[DOR: 20.1001.1.16807073.2020.22.6.18.4]

The shape parameter (n) varied in male and female chicks, which leads to the difference in their growth trend. Different values of age and weight at the inflection point in our research confirm this difference. The shape parameter is used to study theeffects of environmental stress on growth because it is more likely to change in response to environmental stress than is either the mature weight or growth rate. Growth models with fixed shapes may not contribute to the understanding of the effects of environmental changes on growth (Brisbin *et al.*, 1987). The 'L' parameter in Gompertz-Laird model is considered for instantaneous growth rate. In our finding, 'L' value in males was higher than females. The growth rate in males was higher than the females, thus the instantaneous growth rate in males is higher than females.

The calculated R^2 and adjusted R^2 were more than 0.97, which showed that the growth curves could be fitted by all 4 nonlinear curves models. In another study on broiler chickens, these indices were reported above 0.99 (Zhao *et al.*, 2015). Rizzi *et al.* (2013) reported these indexes above 0.97. Although R^2 is often used, it is well to remember that R^2 does not represent a good metric of model performance for nonlinear models, it is just an overall measure of fit. In spite of that, the difference between R^2 and adjusted R^2 values in all tested models was not significant; to deeply evaluate the best fit, RMSE is calculated. The RMSE values in all models were not significant, too.

It is necessary to select a simple equation with several parameters that can provide a better description of weight-age data (Ricklefs, 1985). The Gompertz-Laird model takes into account the minimum value of each criterion. The original Gompertz equation is a function of the mature weight (Barbato, 1991). In addition, weight at the inflection point in this model is dependent on mature weight, whereas, broilers rarely reach their mature weight because they are usually slaughtered at 42 days of age. Richards model is attractive and flexible, but due to the problems mentioned previously, it does not fit very well. The Laird form of Gompertz model, that has a variable inflection point and is not the function of the mature weight, is a special type of flexible Richards model without problems of Gompertz and Richards models. Therefore, Gompertz-Laird model is the best model for studying the growth pattern of broiler chickens in crossbreeds of Arian and Urmia chicks.

Aggrey (2002) compared three nonlinear models (Gompertz-Laird, Richards, and Logistic) and a spline linear regression model in a randomized population of broiler chicks based on R^2 criterion and found that Gompertz-Laird was a more appropriate model for describing the growth curve. Other authors also have reported that the Gompertz curve is the best suited to describe the growth of broiler chickens. Rizzi *et al.* (2013) compared three nonlinear models (Gompertz, Logistic and Richards) in the Italian broiler chickens based on the R^2 and RMSE indices and confirmed the results using F test. They found that the Gompertz model was more appropriate. Norris *et al.* (2007) also compared the Gompertz, Logistic, and Richards models in two broiler breeds through the R^2 index, and suggested the Gompertz model as a superior model. By comparing three nonlinear models (Gompertz, Logistic and Richards) in the study by Selvaggi *et al.* (2015) on Italian chicken breed, Gompertz model was chosen as the appropriate model based on R^2, adjusted R^2, and RMSE indices and the AIC criteria. Zhao *et al.* (2015) compared three Gompertz, Logistic, and von Bertalanffy models in broiler chicks of the three Chinese breeds through the R^2 index and selected the Gompertz as the superior model.

Topal and Bolukbasi (2008) compared the models of Gompertz, Logistic, von Bertalanffy, Morgan, and Weibull in Ross broiler chicks based on the R^2, MSE, MAE, MAPE, and WAPE. They introduced the Weibull, Morgan and Gompertz models as appropriate models.

Also, some studies have reported the Richards model as the top model. By comparing the Gompertz, von Bertalanffy, Richards, Lopez, Frans and Logistic models in a broiler and laying broiler chicks based on the RSS indicator, the Richards model was suggested as a more suitable model for describing the growth pattern (Darmani-Kuhi *et al.,* 2003). Tompić *et al.* (2011) compared the Richards, Gompertz, and Logistic models of Ross broiler chicks with R^2, and Richards was introduced as the appropriate model for the growth pattern.

Some researchers confirmed von Bertalanffy's superiority (Yang *et al.,* 2006). Another research compared the low-growth chickens using Logistic and Gompertz models based on the R^2, MSE, RSD, and AIC indices (Eleroglu *et al.,* 2014). They used the Chi-square test for confirming that and subsequently introduced the Logistic model as the superior model .

Moharrery and Mirzaei (2014) also concluded that Gompertz and Logistic models were not suitable models for examining the growth pattern in chickens by comparing Gompertz, Logistic, Richards, Lopez, and Weibull models based on R^2 and RSS in broiler chicks.

Until now, many models have been used to evaluate the growth curve in poultry. It is noteworthy that implementation of these models depends on many factors such as breed or population structure, sex of birds, nutrition, environmental conditions, sampling, and statistical methods. This study developed four nonlinear models on a crossbreed population. Results showed that the Gompertz-Laird was a superior model compared to the other three models. Therefore, the Gompertz-Laird model is suggested for studying the growth curve and other complementary studies in this population.

CONCLUSIONS

The estimated initial average Weight (W_0) in Gompertz-Laird model was close to the observed initial average weight. The instantaneous growth rate of the Gompertz-Laird model in males was higher than the females. The Gompertz-Laird model, a nonlinear flexible three-parameter model, predicts growth parameters better than other nonflexible and flexible studied models in crosses of Arian and Urmia chicks.

REFERENCES

1. Aggrey, S. E. 2002. Comparison of Three Nonlinear and Spline Regression Models for Describing Chicken Growth Curves. *Poult. Sci.,* **81**: 1782-1788.
2. Archontoulis, S. V. and Miguez, F. E. 2015. Nonlinear Regression Models and Applications in Agricultural Research. *Agron. J.,* **107:** 786-798.
3. Barbato, G. F. 1991. Genetic Architecture of Growth Curve Parameters in Chickens. *Theor. Appl. Genet.,* **83:** 24-32.
4. Brisbin, I. L., Collins, C. T., White, G. C. and Mccallum, D. A. 1987. A New Paradigm for the Analysis and Interpretation of Growth Data: The Shape of Things to Come. *Auk.,* **104:** 552-554.
5. Brun, F., Wallach, D., Makowski, D. and Jones, J. W. 2006. Working with Dynamic Crop Models: Evaluation, Analysis, Parameterization, and Applications. Elsevier, Masterdam, Boston.
6. Burnham, K.P. 2002. Information and Likelihood Theory: A Basis for Model Selection and Inference. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. Springer, New York.
7. Darmani-Kuhi, H., Kebreab, E., Lopez, S. and France, J. 2003. An Evaluation of Different Growth Functions for Describing the Profile of Live Weight with Time (Age) in Meat and Egg Strains of Chicken. *Poult. Sci.,* **82:** 1536-1543.
8. Darmani-Kuhi, H. D., Porter, T., López, S., Kebreab, E., Strathe, A. B., Dumas, A., Dijkstra, J. and France, J. 2010. A Review of Mathematical Functions for the Analysis of Growth in Poultry. *Worlds Poult. Sci. J.,* **66:** 227-240.
9. Eleroglu, H., Yildirim, A., Sekeroglu, A., Coksoyler, F. N. and Duman, M. 2014. Comparison of Growth Curves by Growth Models in Slow-Growing Chicken Genotypes

[DOR: 20.1001.1.16807073.2020.22.6.18.4]

Raised the Organic System. *Int. J. Agric. Biol.*, **16:** 529-535.
10. Emamgholi-Begli, H., Torshizi, R. V., Masoudi, A., Ehsani, A. and Jensen, J. 2017. Relationship between Residual Feed Intake and Carcass Composition, Meat Quality and Size of Small Intestine in a Population of F2 Chickens. *Livest. Sci.*, **205:** 10-15.
11. Emrani, H., Torshizi, R. V., Masoudi, A. A. and Ehsani, A. 2017. Identification of New Loci for Body Weight Traits in F2 Chicken Population Using Genome-Wide Association Study. *Livest. Sci.*, **206:** 125-131.
12. Forni, S., Piles, M., Blasco, A., Varona, L., Oliveira, H. N., Lôbo, R. B. and Albuquerque, L. G. 2009. Comparison of Different Nonlinear Functions to Describe Nelore Cattle Growth. *J. Anim. Sci.*, **87**: 496-506.
13. France, J., Dijkstra, J. and Dhanoa, M. S. 1996. Growth Functions and Their Application in Animal Science. *Ann. Zootech.*, VOL?? 165-174.
14. Hunton, P. 1995. *Egg Production, Processing and Marketing.* Elsevier, Tokyo, Japan.
15. Hyankova, L., Knížetová, H., Dědková, L. and Hort, J. 2001. Divergent Selection for Shape of Growth Curve in Japanese Quail. 1. Responses in Growth Parameters and Food Conversion. *Br. Poult. Sci.*, **42:** 583-589.
16. Javanrouh-Aliabad, A., Vaez Torshizi, R., Masoudi, A. and Ehsani, A. 2018. Identification of Candidate Genes for Blood Metabolites in Iranian Chickens Using a Genome-Wide Association Study. *Br. Poult. Sci.*, **59:** 381-388.
17. Lewis, F., Butler, A. and Gilbert, L. 2011. A Unified Approach to Model Selection Using the Likelihood Ratio Test. *Methods Ecol.*, **2:** 155-162.
18. Maghsoudi, A., Torshizi, R. V., Masoudi, A., Karimi, T. M. and Mohammadhassan, Z. 2017. Comparison of Immune System Performance in Arian, Western Azerbaijan Native Fowl, Their Crosses and Ross Strain. *Anim. Prod.*, VOL?? 265-280
19. Marcato, S. M., Sakomura, N. K., Munari, D. P., Fernandes, J. B. K., Kawauchi, I. M. and Bonato, M. A. 2008. Growth and Body Nutrient Deposition of Two Broiler Commercial Genetic Lines. *Braz. J. Poul. Sci.*, **10:** 117-123.
20. Moharrery, A. and Mirzaei, M. 2014. Growth Characteristics of Commercial Broiler and Native Chickens as Predicted by Different Growth Functions. *J. Anim. Feed Sci.*, VOL??? 663, 127.
21. Narinc, D., Aksoy, T., Karaman, E. and Ilaslan Curek, D. 2010. Analysis of Fitting Growth Models in Medium Growing Chicken Raised Indoor System. *Trend. Anim. Vet. Sci.*, **1:** 12-18.
22. Narinc, D., Karaman, E., Aksoy, T. and Firat, M. Z. 2014. Genetic Parameter Estimates of Growth Curve and Reproduction Traits in Japanese Quail. *Poult. Sci.*, **93:** 24–30
23. Narinc, D., Narinc, N. O. and Aygun, A. 2017. Growth Curve Analyses in Poultry Science. *Worlds Poult. Sci. J.*, **73:** 395-407.
24. Norris, D., Ngambi, J. W., Benyi, K., Makgahlele, M. L., Shimelis, H. A. and Nesamvuni, E. A. 2007. Analysis of Growth Curves of Indigenous Male Venda and Naked Neck chickens. *S.* Afr. **37:** 21-26.
25. Porter, T., Kebreab, E., Darmani-Kuhi, H., Lopez, S., Strathe, A. B. and France, J. 2010. Flexible Alternatives to the Gompertz Equation for Describing Growth with Age in Turkey Hens. *Poult. Sci.*, **89**: 371-378.
26. Raeesi, V., Ehsani, A., Torshizi, R. V., Sargolzaei, M., Masoudi, A. and Dideban, R. 2017. Genome-Wide Association Study of Cell-Mediated Immune Response in Chicken. *J. Anim. Breed. Genet.*, **134:** 405-411.
27. Ricklefs, R. E. 1985. Modification of Growth and Development of Muscles of Poultry. *Poult. Sci.*, **64:** 1563-1576.
28. Ritz, C. and Streibig, J.C. 2008. *Nonlinear Regression with R.* Springer, New York.
29. Rizzi, C., Contiero, B. and Cassandro, M. 2013. Growth Patterns of Italian Local Chicken Populations. *Poult. Sci.*, **92:** 2226-2235.
30. Selvaggi, M., Laudadio, V., Dario, C. and Tufarelli, V. 2015. Modelling Growth Curves in a Nondescript Italian Chicken Breed: An Opportunity to Improve Genetic and Feeding Strategies. *Poult. Sci.*, VOL?? 288-294.
31. Tompić, T., Dobša, J., Legen, S., Tompić, N. and Medić, H. 2011. Modeling the Growth Pattern of in-Season and off-Season Ross 308 Broiler Breeder Flocks. *Poult. Sci.*, **90**: 2879-2887.
32. Topal, M. and Bolukbasi, Ş. C. 2008. Comparison of Nonlinear Growth Curve Models in Broiler Chickens. *J. Appl. Anim.*, **34:** 149-152.
33. Yang, Y., Mekki, D. M., Lv, S. J., Wang, L. Y., Yu, J. H. and Wang, J. Y. 2006. Analysis of Fitting Growth Models in Jinghai Mixed-

Sex Yellow Chicken. *Int. J. Poult. Sci.*, **5**: 517-521.

34. Zhao, Z., Li, S., Huang, H., Li, C., Wang, Q. and Xue, L. 2015. Comparative Study on Growth and Developmental Model of Indigenous Chicken Breeds in China. *Open J. Anim. Sci.*, **5**: 219.
35. Zucchini, W. 2000. An Introduction to Model Selection. *J. Math. Psychol*., **44**: 41-61.

توصیف الگوی رشد در جمعیت آمیخته مرغ گوشتی بومی و لاین تجاری

ر. سیفی مورودی، س. انصاری مهیاری، ر. واعظ ترشیزی، و ح. احمدی

چکیده

در این مطالعه، چهار مدل غیرخطی شامل لجستیک، گومپرتز-لیرد، ریچاردز و ون‌برتالانفی به منظور دستیابی به بهترین پیش بینی پارامترهای رشد که توصیف کننده منحنی رشد در جمعیت مرغ آمیخته است، مقایسه شدند. داده های رشد (شامل وزن هفتگی پرنده از بدو تولد تا سن ۸۴ روزگی) از ۳۰۳ پرنده نسل دوم (۱۷۴ پرنده ماده و ۱۲۹ پرنده نر) حاصل آمیزش مرغ گوشتی لاین آرین (لاین B) و مرغ بومی ارومیه جمع آوری شد. از معیارهای آماری مانند آکائیک، آکائیک سی و روش بیزین، برای یافتن بهترین مدل استفاده شد. نتایج نشان داد که مقادیر برآورد شده وزن اولیه (W_0) و وزن نهایی (W_f) در نرها به طور معنی داری (P < ۰/۰۱) بالاتر از پرندگان ماده در همه مدلها بود. متوسط وزن اولیه محاسبه شده توسط مدل گومپرتز-لیرد (۰/۰۳۸ کیلوگرم) به میانگین وزن اولیه مشاهده شده (۰/۰۴۴ کیلوگرم) نزدیکتر بود. صرف نظر از جنسیت پرندگان، سن (t_i) و وزن (W_i) در نقطه عطف در مدل های گومپرتز-لیرد، ریچاردز و ون برتالانفی تقریباً یکسان بوده و این نشان می دهد که الگوهای رشد توصیف شده توسط این مدل ها مشابه هستند. در حالیکه، مقادیر مختلف t_i و W_i بین نر و ماده‌ها در هر چهار مدل، الگوی رشد متفاوت در نرها و ماده‌ها را نشان می دهد. با توجه به مقدار بالای ۹۷ درصد که توسط شاخص های R^2 و $adj\ R^2$ محاسبه شده است، هر چهار مدل غیر خطی توانایی توصیف داده های رشد را دارند. با این حال، براساس معیارهای انتخابی آکائیک، آکائیک سی و روش بیزین، مدل گومپرتز-لیرد عملکرد بهتری را نشان داد، بنابراین به عنوان بهترین مدل برای تجزیه و تحلیل الگوی رشد در جمعیت آمیخته مورد بررسی پیشنهاد می شود.