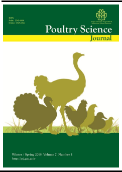

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Evaluation of Non- linear Growth Curves Models for Native Slow-growing Khazak Chickens

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Abstract

Native poultry is a valuable genetic source with high resistance against diseases providing an important subject for breeding programs. The non-linear mathematical modeling of the growth pattern may partly explain the relationship between requirements and body weight to precise feeding that plays a vital role in the animal enterprises. A study was conducted to compare five non-linear models including Gompertz, Richards, Lopez, Logistic, and Von Bertalanffy describing the growth curve of Khazak native chickens. A total of 120 Khazak chickens (male and female) were individually weighed from 0 to 29 weeks under the same condition. The models were fitted on body weight data set and then evaluated by goodness-of-fit criteria including root mean square error (RMSE), Bayesian information criterion (BIC), Akaike information criterion (AIC), and adjusted coefficient of determination (R^2_{Adj}). Based on goodness-of-fit criteria, Lopez model was the most suitable one for describing the growth curves in female and male chickens. The effect of sex was significantly important on curve parameters in all models ($P < 0.05$). The highest and lowest initial weight (W_0) parameter was estimated by Logistic and Richards models, respectively, however, the other parameters of the growth curves were higher in Lopez model compared to others. Male chickens had higher values for age (t_i), and weight (w_i) at inflection point than females. Using an appropriate model to describe the growth curve in native Khazak chickens could increase the accuracy of selection for rapid growth at early stages of age.

Introduction

Rural poultry farming is being practiced using native breeds in many developing or under developing countries because of unique responses those breeds to stress and disease (Vali, 2008). Native birds are of utmost importance products that might call to carry out selection programs to improve performance depends on different regions (Magothe *et al*., 2012; Padhi, 2016; Dessie *et al*., 2012).

Rearing native poultry may provide the valuable products and may have pivotal role in development of rural economics as the high-quality animal protein resources (Padhi, 2016) containing low fat with organic properties. Slow growth rate and egg production made those native chickens for dual purpose production (Lee, 2006; Padhi, 2016). High tolerance of native poultry against environmental issues including unstable climate, watering, and feeding is one of the positive properties of native chickens (Dessie *et al*., 2011).

The growth is a key characteristic of the animal can be defined as any change in body size per time that is influenced by either genotype or environment factors. The growth curves based on mathematical models can be used to anticipate the growth patterns in poultry species with non-linear structure, sigmoid form, and biologically justified justification parameters (Narinç *et al*., 2017). The growth curve models may provide the opportunity for practical

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commentary on the estimation of daily food needs for growth (Akbas and Oguz, 1998) and improve management plans for selection programs. The non-linear study of the growth pattern explains the relationship between requirements and body weight mathematically (Şengul and Kiraz, 2005). A number of growth models have been proposed to describe animal growth patterns. Each of these models has different mathematical advantages and/or constraints that impose the selection of appropriate model to describe the specific growth pattern (Norris *et al*., 2007).

Mignon-Grasteau and Beaumont (2000) have used four equations to describe a growth curve in particular species including Richards (chicken, turkey, quail, duck, goose) Gampartz (chicken, turkey, quail), Logistics (quail and ducks). The growth curve parameters of Japanese native chicken breeds were compared with the Gompertz model by Goto *et al*. (2010). The Gompertz model was introduced as a suitable model for describing growth curve in medium-growing chickens in a closed breeding system (Narinc *et al*., 2010), but Eleroğlu *et al*. (2014) reported Logistic model as the best model than Gompertz for describing growth curve of slow-growing chickens in the organic system.

Parameters of the growth curve could be the basis of selection in animal breeding. The Khazak breed is the prevalent small native breed in the Sistan (Sistan region, IRAN), with short legs but relatively high potential for egg production. In this region, using of native chicken preferred than industrial chickens, so improvement of this breed in term of growth by selecting for growth patterns could be useful for this region. Therefore, the current research was carried out to predict the growth pattern in Khazak chickens by different models.

Materials and Methods

Bird management

Animal handling and experimental procedures of the study was approved by the Research Animal Committee of the Rsearch Institute at University of Zabol. The research was performed on Khazak chickens raised in the Research Center of Domestic Animals (RCDA) in the University of Zabol, Zabol, Iran. A total of 120 one-day-old chicks (52 males and 68 females) were obtained from the hatchery of RCDA and then identified by wing-banded numbers. The chicks were raised together under extensive indoor production system condition. The lighting program was 24 h of light from 1 to 10 weeks, and 18 h light from 11 to 29 weeks. Data were collected up to 29th week of age when chickens reached the sexual maturity. The birds received a traditional diet containing 16% CP and 2800 kcal/kg ME throughout the experiment.

Data source

All chicks (52 males and 68 females) were individually weighed every week of interval until 21th wk of age, and every two weeks of interval until 29th wk of age. The body weight of males and females was measured on the same day using a sensitive, digital electronic weighing scale. Data obtained from the dead chicks were discarded from the data set. Normality of body weight data for different ages was performed with the Shapiro-test. *T*-test was used to compare the body weight differences in different ages between females and males.

Growth models

Five non- linear models (i.e., Gompertz, Richards, Lopez, Logistic, and Von Bertalanffy) were fitted to describe the growth curve based on body weight of the chickens. The models were used as follows:

Logistic: $W = \frac{W_0 W_f}{[(W_0+(W_f-W_0)\exp(-kt)]}$

Gompertz: $W = W_0 \exp\{[1-\exp(-kt)]]\ln(\frac{W_f}{W_0})\}$

Lopez: $W = (W_0\, b^k + W_f t^k)/(b^k + t^k)$

Von Bertalanffy: $W = [W_f^m - (W_f^m - W_0^m)\, exp(-kt)]^{1/m}$

Richards: $W = W_0 W_f/[W_0^m + (W_f^m - W_0^m)\exp(-kt)]^{1/m}$

where, W in all models is the body weight of bird at age t, W_0, W_f and k are initial and final (mature weight) weights, and coefficient of relative growth or maturing index, respectively. The parameter b is the age at approximately half maximum body weight, and m represents the shape parameter.

Four criteria were used for comparison of the studied models and selection of the best model to describe the growth curve in males and females (Teleken *et al*., 2017):

1) Adjusted determination coefficient, $R^2_{Adj} = 1 - \left[\left(\frac{n-1}{n-k}\right) * (1 - R^2_{model})\right]$, where n and k are the number of observation and parameters, respectively, and R^2_{model} is determination coefficient that is equal to 1-(SSE/SST). SSE and SST represent the sum of square errors and total sum of squares, respectively.

2) Root mean square error (RMSE), is root of MSE and MSE = SSE/(n-k).

3) Akaike's Information Criteria (AIC), AIC = nln(SSE/n)+2k.

4) Bayesian Information Criterion, BIC = n.ln(SSE/n) +k.ln(n).

where n, SSE, and k are the number of observations, sum square of errors, and the number of parameters, respectively.

All models were fitted on body weight data by *nlme* package of R software (Pinheiro *et al*. 2014), and the paramaters of fitted models were obtained for both male and females by function *nlsList* in the *nlme* package. The goodness of fit criteria and variance-covariance matrices of model parameters were separately calculated for each sex using of *lapply* and *sapply* function in R. F- test was used for comparison of the model parameters in males and females. The age and weight at inflection point, absolute growth rate (AGR) in the first, 15th and 29th weeks were estimated using model parameters on growth curve. After fitting the models, the predicted body weight values obtained from the models and the curves were plotted and compared with observed data.

Results

The mean (standard deviation) of body weight at different ages for female and male chickens were represented in Table 1. The males had the highest body weight at all ages except for 1 and 2 wk of age. Age increasing expanded the difference between male and females, in which body weight of males was 1.22 times more than that in females in 29 wk of age. During the first 5 weeks, the effect of sex on body weight of chickens was not significant in comparison to body weight after 7wk (P < 0.05).

Table 1. Body weight of Khazak chickens at different ages

Age (week)	Body weight (g)	
	female	male
0	26.32 (2.81)	26.33 (3.72)
1	38.10 (5.18)	36.50 (6.23)
2	59.84 (9.38)	59.15 (13.75)
3	92.46 (15.70)	95.97 (22.46)
4	131.95 (22.27)	140.84 (34.59)
5	174.47 (34.30)[b]	190.98 (46.56)[a]
6	201.92 (37.65)	219.36 (46.96)
7	250.26 (46.83)	268.02 (59.10)
8	302.06 (56.15)[b]	331.25 (74.13)[a]
9	361.98 (63.87)[b]	413.17 (94.54)[a]
10	412.90 (72.55)[b]	478.88 (104.38)[a]
11	461.09 (79.34)[b]	547.17 (118.24)[a]
12	503.20 (83.29)[b]	613.81 (134.50)[a]
13	549.85 (91.19)[b]	675.83 (139.57)[a]
14	601.32 (102.95)[b]	742.80 (143.52)[a]
15	618.59 (108.76)[b]	785.79 (155.93)[a]
16	652.13 (116.07)[b]	822.26 (153.64)[a]
17	687.52 (119.32)[b]	876.87 (162.64)[a]
18	703.93 (119.44)[b]	896.38 (153.86)[a]
19	725.99 (121.14)[b]	931.05 (160.80)[a]
20	756.78 (127.84)[b]	968.95 (164.20)[a]
21	789.20 (130.35)[b]	993.14 (167.39)[a]
23	848.25 (141.05)[b]	1073.27 (172.61)[a]
25	906.48 (157.07)[b]	1148.92 (186.76)[a]
27	964.51 (161.18)[b]	1189.89 (172.61)[a]
29	980.05 (162.30)[b]	1197.78 (182.46)[a]

Data presents as mean body weight and standard deviations are presented in parentheses.
The mean with different letter in each row has significant difference (P < 0.05).

Table 2 shows the model parameters for males and females in fitted models. The significant differences were observed between males and females in the model parameters (P < 0.05). Estimated initial weight (W_0) values by Lopez and Von Bertalanffy models were close to observed values in female (i.e., 26.32 g). In males, estimated W_0 by Gompertz model was close to the observed values (i.e., 26.33 g). The Logistic and Richards models resulted in overestimation and underestimation for W_0 in the models used for females and males, respectively. The estimated final weight (W_f) in Logistic model was similar to observed values, but overestimated W_0 in both male and female chickens.

The highest value of k parameter was estimated by Lopez model. The lowest estimated k parameter for males and females was found with the highest estimated W_f except for Lopez model. In the Lopez model, male chickens had the higher k and W_f parameter compared to females, whereas estimated b parameter was higher in females than that in males (Table 2). Richards and Von Bertalanffy models overestimated m parameter in females compared to males that may be translated to reach sooner the mature weight of females compared to males.

The estimated age (t_i) and weight (w_i) at inflection point of fitted models were shown in Table 3. In males and females, the highest values for t_i and w_i parameters obtained by Logistic model while the lowest values obtained by Von Bertalanffy model. In all models, the t_i and w_i for males were higher than females. Richards and Lopez models resulted in more accurate estimation of t_i and w_i than other models, and then, these accurate estimations were very close to the actual value in two sexes. However, the estimates of Lopez model had higher accuracy than Richards Model.

Table 2. Model parameters for female and male of Khazak chickens

Sex*	Model	W_0±SE	W_f±SE	k±SE	m±SE	b±SE
Female	Gomperts	37.523±3.059	1051.770±14.630	0.017±0.0005	-	-
	Logistic	71.973±3.098	954.857±9.314	0.030±0.0006	-	-
	Richards	10.761±6.187	1190.731±45.430	0.011±0.0012	0.493±0.086	-
	Lopez	22.679±7.995	1414.398±67.785	1.643±0.076	-	126.273±7.549
	Von Bertalanffy	22.704±8.257	1200.865±38.950	0.011±0.0008	0.566±0.037	-
Male	Gomperts	26.966±3.390	1285.420±19.290	0.019±0.0006	-	-
	Logistic	67.561±3.868	1171.838±12.296	0.033±0.0008	-	-
	Richards	17.096 ±7.203	1326.983±36.930	0.017±0.0016	0.177±0.111	-
	Lopez	34.793±10.130	1508.195±53.150	2.060±0.097	-	104.893±3.942
	Von Bertalanffy	35.823±10.420	1362.422±34.180	0.015±0.0010	0.401±0.031	-

W_0 (g), W_f (g), k (g per d), m and b (d) are initial weight, final (mature weight) weight, coefficient of relative growth or maturing index, the shape parameter, and the age at approximately half maximum body weight, respectively.
[*] All parameters are significantly different between sexes ($P < 0.05$).

Absolute growth rate (AGR) for 1, 15, and 29 wk are shown in Table 3. Estimated AGR values for different ages from Gompertz and Logistic models for males were higher than females, except for AGR-29. In Richard model, the AGR values were higher for females than males, except AGR-15. Estimated AGR by Lopez and Von Bertalanffy models for AGR-1 was lower for males than females, whereas AGR-15 and AGR-29 values were higher for males.

Table 3. Estimated age (t_i), weight (wi) at inflection point and absolute growth rate (AGR) at 1, 15, and 29 weeks by different growth models

Sex	Model	t_i (d)	w_i (g)	AGR (1, g)	AGR (15 ,g)	AGR (29, g)
Female	Gomperts	70.82	386.920	2.149	5.581	1.426
	Logistic	83.56	477.430	1.097	6.535	-0.776
	Richards	54.89	300.229	3.789	5.260	2.203
	Lopez	53.41	295.009	2.841	9.422	7.849
	Von Bertalanffy	41.57	274.800	4.480	5.478	2.321
Male	Gomperts	71.15	472.880	2.470	7.348	1.426
	Logistic	84.66	585.919	1.167	8.543	-0.875
	Richards	65.30	441.467	3.116	7.334	2.105
	Lopez	62.70	413.870	1.674	14.743	12.179
	Von Bertalanffy	43.28	379.548	4.464	7.258	2.375

Table 4 shows the goodness of fit criteria for studied models in Khazak chickens. The Lopez, and Von bertalanffy models were superior than Logistic and Gompertz models in criteria for females. In comparing of criteria for Lopez, and Von Bertalnffy, Lopez model had the lowest RMSE, AIC, and BIC and highest R^2_{Adj}, thus this model was the best for describing of the growth curve in female chickens. In male chickens, the Lopez model had the lowest RMSE, and AIC and the highest R^2_{Adj} but the BIC for Gopmertz model was lower than Lopez model. However, the difference of BIC in Gompertz and Lopez model is low, thus we could prefer the Lopez model for describing growth curve in male chickens with high accuracy. The Von Bertalanffy and Lopez growth models were desirable models after the fitting for females and males. However, the estimated values of the hatching weight, inflection point for age, and weight were closer to the observed values in Lopez model.

Figures 1 and 2 illustrated the difference in fit ability of all models in female and male chickens, respectively. The predicted values by the Logistic and Gampartz models at the beginning, the middle, and the end of the curves were different from the observed values. Therefore, The Gompertz and Logistic models gave inaccurate growth curve for female and male chickens, but Lopez, Richards and Von Bertalanffy had the estimations with close similarity to the observed data.

Table 4. The goodness of fit criteria of fitting models for female and male Khazak chickens

Sex	Model	RMSE[†]	AIC[‡]	BIC[#]	R^2_{Adj}
Female	Gomperts	98.56	21170.93	21192.83	90.09
	Logistic	102.17	21297.53	21319.43	89.35
	Richards	97.82	21145.20	21172.56	90.24
	Lopez	97.68	21140.14	21167.51	90.27
	Von Bertalanffy	97.74	21142.48	21169.85	90.25
Male	Gomperts	125.01	16622.89	16643.66	90.30
	Logistic	128.14	16688.70	16709.47	89.81
	Richards	124.94	16622.39	16648.35	90.31
	Lopez	124.83	16620.25	16646.21	90.33
	Von Bertalanffy	124.91	16621.81	16647.77	90.31

[†]Root mean square error (RSME); [‡]Bayesian information criterion (BIC), [#]Akaike information criterion (AIC), and adjusted coefficient of determination (R^2Adj).

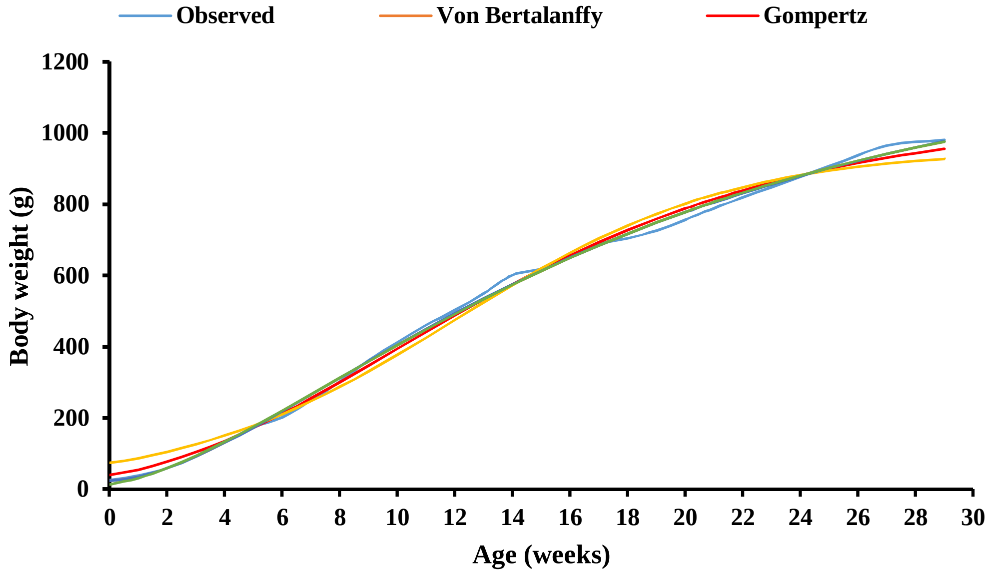

Figure 1. Estimated and predicted body weight values for female chickens during the 29 weeks.

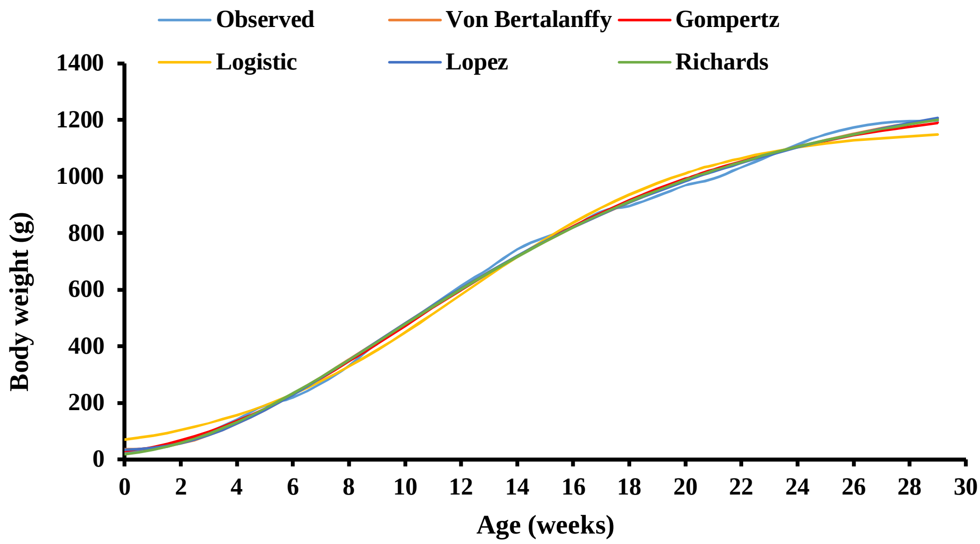

Figure 2. Estimated and predicted body weight values for male chickens during the 29 weeks.

Table 5 represents the correlation between parameters of the models for female and male chickens. Correlation between W_0 and W_f was positive and higher than 0.50 in Gomretz and Logistic models for two sexes. However, the high and negative correlation was observed between W_0 and W_f in terms of k parameter for females and males in Gomretz and Logistic. The correlation between W_0 and W_f was negative in females and males using the Lopez, Richards, and Von Bertalanffy models. The high and positive correlation was estimated in Lopez, Richards and Von Bertalanffy models for W_0 and k parameters in males and females. The values of correlation between W_0-m, W_f-k, W_f-m, W_f-b, k-b and k-m were higher than 0.65 in Lopez, Richards, and Von Bertalanffy models. The highest correlation was estimated by Lopez models between W_f and b in two sexes. The birds with the highest maturation index (k) would reach to the maturation in high ages and will have a high final body weight (W_f).

Table 5. Correlation between model parameters in females and males Khazak chickens

Sex	Model	r_{W0-Wf}	r_{W0-k}	r_{W0-m}	r_{Wf-k}	r_{Wf-m}	r_{k-m}
Female	Gomperts	0.64	-0.89	-	-0.89	-	-
	Logistic	0.54	-0.92	-	-0.74	-	-
	Richards	-0.58	0.71	0.89	-0.96	-0.84	0.94
	Von Bertalanffy	-0.43	0.55	-0.73	-0.96	0.84	-0.95
Male	Gomperts	0.65	-0.90	-	-0.87	-	-
	Logistic	0.53	-0.93	-	-0.71	-	-
	Richards	-0.54	0.72	0.90	-0.93	-0.80	0.94
	Von Bertalanffy	-0.37	0.51	-0.68	-0.94	0.80	-0.95
Sex	Model	r_{W0-Wf}	r_{W0-k}	r_{W0-b}	r_{Wf-k}	r_{Wf-b}	r_{k-b}
Female	Lopez	-0.52	0.70	-0.43	-0.93	0.99	-0.90
Male	Lopez	-0.46	0.65	-0.27	-0.91	0.97	-0.83

Discussion

The effect of sexual dimorphism on body weight has been reported for chickens with fast-growing (Santos *et al*., 2005; Dourado *et al*., 2009; Tompić *et al*., 2011), slow–growing chickens (Narinc *et al*., 2010; Eleroğlu *et al*., 2014), and medium-growing chickens (Michalczuk *et al*., 2016). These studies demonstrated that males were significantly heavier than females in agreement our results in the present study.

Logistic model highly underestimated W_0 of CCGP chickens (Michalczuk *et al*., 2016) that was similar to our result in the present study. Similarly, the mature weight (W_f) parameter for male chickens has been estimated higher than females (Santos *et al*., 2005; Dourado *et al*., 2009; Narinc *et al*., 2010). Teleken *et al*. (2017) reported that m parameter in females was lower than males using the Richards and Von Bertalanffy model, proving our finding in the present study. Most recently, the highest and lowest estimations of W_0 have been reported by the use of Logistic and Richards models, respectively (Masoudi and Azarfar, 2017). The inverse association between W_f and k parameters (Adenaike *et al*., 2017) showed that early maturing in livestock led to slow rate of growth in the first weeks of age. The difference between W_f and k parameters in males and females was observed in Japanese native chickens using Gompertz model in which males had the higher W_f and k values than females (Cooper, 2005; Goto *et al*., 2010).

The range of maturation index for slow–growing broilers (N'Dri *et al*., 2006) was in agreement with our findings. Aggrey (2002) reported a higher maturation index value for males using the Logistic model that similar our results in present study. Similarly, the higher maturation index was estimated by Logistic model in comparison to the Gompertz model by Narinc *et al*. (2010).

Narinc *et al*. (2010) reported higher inflection point for age in males than female, which was in agreement with our results, but inversely the present result, the highest weight at inflection point was reported for turkey medium-growing females. The difference between sexes in terms of t_i values reported by Cooper (2005) and Goto *et al*. (2010) that all of males had the highest t_i value. Overally, the range of ti in growing chickens was reported to be from 41 to 48 d among different studies (Santos *et al*., 2005; Dourado *et al*., 2009; Narinc *et al*., 2010). The range in our study was from 41.57 to 84.66, that was higher than other studies.

The t_i values obtained in this study were found to be higher than those of reported by others for slow-growing chickens reared in alternative systems. However, N'Dri *et al*. (2006) investigated estimated t_i value as 48.90 d of age for females and males in slow-growing chickens, which was in contrast to our findings. Our estimations of t_i were found to be similar to the values reported for inbred lines and local genotypes (Yang *et al*., 2004; Norris *et al*., 2007). The age and weight at inflection point ranged for three indigenous chickens of China from 7.38 to 8.96 weeks and 718.026 to 1198.843 g, respectively (Zhao *et al*., 2015), that was in agrrement with our estimations. Regarding different studies, it has been shown that males had the lowest age at inflection point than females in Ross 308 (Tompić *et al*., 2011). The male chickens of Jinghai chickens reached to the inflection point at higher age than that of the females (Yang *et al*., 2004) that is similar to the results of the present study.

The males had higher w_i and growth rate values than females in the present study that were in agreement with others (Santos *et al*., 2005; Dourado *et al*., 2009; Narinc *et al*., 2010). The males showed the highest growth potential, in which the growth rate was increased in 15 wk of age. Eleroğlu *et al*. (2014) reported similar trend for Slow–growing GB–JA and S757 chickens. The average daily gain of Italy local males and female chickens was reported to be 14.43 to 16.89 and 11.35 to 13.89 g/d, respectively (Rizzi *et al*., 2013).

Based on high R^2 and low MSE, Gompertz and Von Bertalanffy models were reported to be the best models for describing growth of Korean native chicken (KNC). Moreover, the Von Bertalanffy model was the best model to describe the growth in KNC compared to Gompertz model (Manjula *et al*., 2016). Logistic model was fitted for growth curves of slow–growing chicken in organic system very well (Eleroğlu *et al*., 2014). The Richards model was introduced the best model for describing the growth trend in Ross 308 and no significant difference was observed between Richards, Gompertz and Logistic models (Tompić *et al*., 2011). Teleken *et al*. (2017) and Michalczuk *et al*. (2016) studied the growth curve in Athens-Canadian chickens and Poland medium–growing chickens under semi-confined condition, respectively. The Gompertz model was obtained the best estimations for describing growth curve in those breeds.

The Gompertz models with high R^2 were selected as the best models for describing of growth in Nigerian native chickens (Adenaike *et al*., 2017), South Africa Venda and Naked Neck chickens (Norris *et al*., 2007) and slow-growing chickens in China (Zhao *et al*., 2015). Yang *et al*. (2004) compared three growth models including Logistic, Gompertz, and Von Bertalanffy for body weight data of Jinghai yellow chickens, and Von Bertalanffy model gave the best fit for describing growth curve in this breed.

In the present study, the Logistic model overestimated the initial body weight for female and male chickens. It is reported that models that have difference between predicted and actual body weight at short interval are better than models with deviations at longer times (Adenaike *et al*., 2017).

An approximate correlation matrix of Gompertz parameters was reported high and negative between W_0 to k (i.e., -0.94), W_f to k (i.e., -0.96), and high and positive (i.e., 0.83) between W_0 to W_f (Masoudi and Azarfar, 2017). The correlation between $\beta 0$- $\beta 1$ and $\beta 0$- $\beta 2$ was found to be negative, but positive for $\beta 1$-$\beta 2$ in Von Bertalanffy, Gompertz and Logistic (Narinc et al. 2010). The high negative correlation coefficients observed between $\beta 0$ and $\beta 2$ parameters in Gompertz, Logistic, and Von Bertalanffy models (Yaylak, 2000; Narinc *et al*., 2010) confirm our results.

Conclusion

In this study, five non-linear models were used for describing the growth curve in Khazak chickens reared in the tropic region of Iran, Sistan. All goodness of fit criteria that was used for model comparison suggested that the growth data of slow-growing Khazak chickens reared under tropics would give the most accurate estimations using the Lopez model. The significant difference in model parameters was observed between females and males, so that males had the highest initial and final weight, age and weight at inflection point and growth rates than those in females. Using the Lopez model for females and males of Khazak chickens could be useful to predict the important biological traits.

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References

Adenaike A, Akpan U, Udoh JE, Wheto M, Durosaro SO, Sanda AJ & Ikeobi CON. 2017. Comparative evaluation of growth functions in three broiler strains of Nigerian chickens. Pertanika Journal of Tropical Agricultural Science , 40: 611-620.

Aggrey S. 2002. Comparison of three nonlinear and spline regression models for describing chicken growth curves. Poultry Science, 81: 1782-1788. DOI: 10.1093/ps/81.12.1782

Akbas Y & Oguz I. 1998. Growth curve parameters of lines of Japanese quail (*Coturnix coturnix japonica*), unselected and selected for four-week body weight. Archiv fuer Gefluegelkunde, 62: 104-109.

Cooper RG. 2005. Growth in the ostrich (*Struthio camelus* var. *domesticus*). Animal Science Journal, 76: 1-4. DOI: 10.1111/j.1740-0929.2005.00230.x

Dessie T, Dana N, Ayalew W & Hanotte O. 2012. Current state of knowledge on indigenous chicken genetic resources of the tropics: domestication, distribution and documentation of information on the genetic resources. World's Poultry Science Journal, 68: 11-20. DOI: 10.1017/s0043933912000025

Dessie T, Taye T, Dana N, Ayalew W & Hanotte O. 2011. Current state of knowledge on phenotypic characteristics of indigenous chickens in the tropics.

World's Poultry Science Journal, 67: 507-516. DOI: 10.1017/s0043933911000559

Dourado LRB, Sakomura NK, Nascimento DCN, Dorigam JC, Marcato SM & Fernandes JBK. 2009. Growth and performance of naked neck broiler reared in free-range system. Ciência e Agrotecnologia, 33: 875-881.

Eleroğlu H, Yıldırım A, Şekeroğlu A, Çoksöyler FN & Duman M. 2014. Comparison of growth curves by growth models in slow-growing chicken genotypes raised the organic system. International Journal of Agriculture and Biology, 16: 529-535.

Goto T, Goto N, Shiraishi JI, Bungo T & Tsudzuki M. 2010. Comparison of growth curves of four breeds of Japanese native chicken, Onaga-dori, Tosa-jidori, Ukokkei and Hinai-dori. Journal of Animal and Veterinary Advances, 9: 1362-1365. DOI: 10.3923/javaa.2010.1362.1365

Lee Y. 2006. Taiwan country chicken: a slow growth breed for eating quality. In: Symposium, 2006 Scientific Cooperation in Agriculture between Council of Agriculture (Taiwan, ROC) and Institut National de Recherche Agronomique (France). pages, 121-132.

Magothe T, Okeno T, Muhuyi W & Kahi A. 2012. Indigenous chicken production in Kenya: I. Current status. World's Poultry Science Journal, 68: 119-132. DOI: 10.1017/s0043933912000128

Manjula P, Park HB, Yoo J, Wickramasuriya S, Seo DW, Choi NR, Kim CD, Kang BS, Oh KS & Sohn SH. 2016. Comparative study on growth patterns of 25 commercial strains of Korean native chicken. Korean Journal of Poultry Science, 43: 1-14. DOI: 10.5536/kjps.2016.43.1.1

Masoudi A & Azarfar A. 2017. Comparison of nonlinear models describing growth curves of broiler chickens fed on different levels of corn bran. International Journal of Avian and Wildlife Biology, 2: 1-7. DOI: 10.15406/ijawb.2017.02.00012

Michalczuk M, Damaziak K & Goryl A. 2016. Sigmoid models for the growth curves in medium-growing meat type chickens, raised under semi-confined conditions. Annals of Animal Science, 16: 65-77. DOI: 10.1515/aoas-2015-0061

Mignon-Grasteau S & Beaumont C. 2000. Growth curves in birds. Productions Animales, 13: 337-348.

N'dri A, Mignon-Grasteau S, Sellier N, Tixier-Boichard M & Beaumont C. 2006. Genetic relationships between feed conversion ratio, growth curve and body composition in slow-growing chickens. British Poultry Science, 47: 273-280. DOI: 10.1080/00071660600753664

Narinc D, Aksoy T, Karaman E & Ilaslan Curek D. 2010. Analysis of fitting growth models in medium growing chicken raised indoor system. Trends in Animal and Veterinary Sciences, 1: 12-18.

Narinç D, Narinc NÖ & Aygün A. 2017. Growth curve analyses in poultry science. World's Poultry Science Journal, 73: 395-408. DOI: 10.1017/s0043933916001082

Norris D, Ngambi JW, Benyi K, Makgahlele ML, Shimelis HA & Nesamvuni EA. 2007. Analysis of growth curves of indigenous male Venda and Naked Neck chickens. South African Journal of Animal Science, 37: 21-26.

Padhi MK. 2016. Importance of indigenous breeds of chicken for rural economy and their improvements for higher production performance, Scientifica, 1-9. DOI: 10.1155/2016/2604685

Pinheiro J, Bates D, DebRoy S & Sarkar D. 2014. R Core Team, nlme: linear and nonlinear mixed effects models. R package version 3.1-117. Web. http://CRAN. R-project. org/package= nlme. Accessed on June 1. 2018

Rizzi C, Contiero B & Cassandro M. 2013. Growth patterns of Italian local chicken populations. Poultry Science, 92: 2226-2235. DOI: 10.3382/ps.2012-02825

Santos A, Sakomura N, Freitas E, Fortes C & Carrilho E. 2005. Comparison of free range broiler chicken strains raised in confined or semi-confined systems. Revista Brasileira de Ciência Avícola, 7: 85-92. DOI: 10.1590/s1516-635x2005000200004

Şengul T & Kiraz S. 2005. Non-linear models for growth curves in large white turkeys. Turkish Journal of Veterinary and Animal Sciences, 29: 331-337.

Teleken JT, Galvão AC & Robazza WDS. 2017. Comparing non-linear mathematical models to describe growth of different animals, Acta Scientiarum. Animal Sciences, 39: 73-81.

Tompić T, Dobša J, Legen S, Tompić N & Medić H. 2011. Modeling the growth pattern of in-season and off-season Ross 308 broiler breeder flocks. Poultry Science, 90: 2879-2887. DOI: 10.3382/ps.2010-01301

Vali N. 2008. Indigenous chicken production in Iran: a review. Pakistan journal of biological Sciences, 11: 2525. DOI: 10.3923/pjbs.2008.2525.2531

Yang H, Xv Q & Dai G. 2004. Analysis on three kinds of growth curve in avian. Chinese Poultry Science, 8: 164-166.

Yaylak E. 2000. Heritability estimates of growth curve parameters and genetic correlations between the growth curve parameters and weights at different age of Japanese quail. Archiv für Geflügelkunde, 64: 141-146.

Zhao Z, Li S, Huang H, Li C, Wang Q & Xue L. 2015. Comparative study on growth and developmental model of indigenous chicken breeds in China. Open Journal of Animal Sciences, 5: 219- 223. DOI: 10.4236/ojas.2015.52024