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Comparison of Non-linear Growth Models to Describe the Growth in Japanese Quail

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Abstract: Growth is one of the well-known features in biological creatures. The evolution of body weight during growth is of particular importance in both breeding and management. In the present study, the adequacy of 11 mathematica l functions, (Gompertz, Richards, Logistic, Bertalanffy, Brody, Negative Exponential, Morgan-Mercer Flodin and three Hyperbolastic models) used to model growth characteristics of Japanese quails were compared. For this purpose, the live-weight data obtained weekly from 499 quails were fitted to aforementioned non-linear models. The results of the analysis indicated that the Gompertz model is the most appropriate one in terms of goodness of fit criteria (R^2 = 0.99998, $\bar{R}^2$ = 0.99997, MSE = 0.318, RM = 0.03019, RSD = 0.60868, AIC = -2.010, BIC = -2.172) followed by the Richards and H3 models. Weight and age at the inflection point for Gompertz equation were calculated as 81.70 g and 14.95th day, respectively.

Key words: Growth curve, goodness of fit, Japanese quail, Non-linear regression models, breeding, Turkey

INTRODUCTION

The Japanese quail (*Coturnix coturnix japonica*) is being used as a model type in poultry breeding experiments because of having short generation interval, high fertilization efficiency and simple equipment of rearing (Narinc *et al*., 2009). In addition, raising Japanese quails for their eggs and meat is common and their economic importance is increasing gradually (Minvielle, 2004). The traits which mostly studied on quails are the ones related with their growth (Akbas and Yaylak, 2000).

Growth, a biological phenomenon, is one of the well-known features in creatures and can be described by the expression of changes on the mass and volume that occur in time on the focused feature (Akbas and Oguz, 1998). For many years, mathematical expression of the growth is being studied in agriculture, medicine and basic biological sciences. Previous researches on modeling growth in agricultural science have focused on fitting deterministic models to weekly measurements. These empirical mathematical models of growth patterns are continuous functions of time and have biologically meaningful parameters that allow interpreting the breeding and feeding strategies (Narinc *et al*., 2009).

Growth curves are useful tools representing the evolution of body weight during growth and of particular importance in both breeding and management. By using the account values such as point of inflection and growth rate, the effects of different management systems, feeding requirements and the results of breeding applications can be evaluated (Narinc *et al*., 2010).

The genetic differences which are established between strains, lines and individuals are the basis of breeding studies which are focused on improving the characteristics of growth. Growth model parameters and growth characteristics are being used in selection indexes and mixed model equations in broiler breeding. Akbas and Yaylak (2000) reported that direct selection for shape of growth curve can be applied using the growth curve parameters as simple selection criteria. Heritability estimates of growth curve parameters were moderate to high (Narinc *et al*., 2010).

The Gompertz, Richards, Logistic, Bertalanffy, Brody, Negative Exponential and Morgan-Mercer Flodin are the most common models which are used to define body growth in animal science (Knizetova *et al*., 1991; Aggrey, 2002). Hyperbolastic modelswhich were proposed by Tabatabai *et al*. (2005) have also been used in recent years.

Model fitting problems may occur between species, strains and even between lines. Therefore, available mathematical models must be compared and the optimum model must be determined for the data which are thought to be studied on. Many studies were made to identify the best model which fits to the data obtained from poultry. Balcioglu *et al*. (2009) on chukar partridges; Tzeng and Becker (1981) and Aggrey (2002) on chickens;

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Anthony *et al*. (1991) and Akbas and Oguz (1998) in quails, compared the Gompertz, Logistic and Bertalanffy models. Sengul and Kiraz (2005) compared the Gompertz, Logistic, Richards and Morgan-Mercer Flodin in their study on turkeys. Ahmadi and Mottaghitalab (2007) and Golian and Ahmadi (2008) compared Hyperbolastic models with Gompertz and Richards models with the data obtained from broiler chickens.

The purpose of this study is to compare the nonlinear regression models which are used to determine the age-related changes on body weight in Japanese quails and to identify the most appropriate model for the data.

MATERIALS AND METHODS

Experimentation: This study was conducted at The Poultry Breeding Unit, Animal Science Department, Faculty of Agriculture, Akdeniz University, Turkey. Weekly data on live weight of Japanese quail from 499 progenies belonging to 20 sires and 60 dam formed the basis of this study. Hatched chicks were immediately pedigree wing-banded and weighed before being moved to heated (35°C) battery brooders. Chicks were raised in quail battery brooders until three weeks of age. Then, the quails were moved from the battery brooders to individual growing cages (25 cm deep, 21 cm wide, height 25 cm height) at 3 week of age. Lighting schedule of 24 h lighting for the first 3 weeks and then 23:1 h light:dark cycle was applied. The birds were fed on starter diets of 3000 kcal kg^{-1} of metabolizable energy kg^{-1} and 24% of crude protein for the first 21 days and thereafter 22% crude protein and 2800 kcal kg^{-1} metabolic energy grower diet between 21 and 42 days of age. Quails were allowed to access *ad libitum* to feed and water. The growth data were obtained from 499 quails which were alive at the end of the 6th week of age. Live weights were recorded weekly. The live weight data obtained weekly from 499 quails which were alive at the end of the 6th week weighed with a 0.1 g sensitive electronic scale.

Growth models: In this study, Morgan-Mercer Flodin, Negative Exponential, Brody, Gompertz, Logistic, Von Bertalanffy, Richards and three Hyperbolastic models (H1, H2, H3) were fitted to the measurements of live weights related with age via NLIN procedure by using Marquardt algorithm of SAS software (SAS Institute, 2005). The model expressions are shown in Table 1. In all models, w_t is the body weight at age t, β_0 is the asymptotic or maximum growth response, β_1 is a scale parameter related to initial weight (hatching weight), β_2 is the intrinsic growth rate, β_3 is the shape parameter and β_4 is the parameter for Hyperbolastic 1 and Hyperbolastic 3 (Yang *et al*., 2006; Narinc *et al*., 2010).

After the models are fitted to the data, researchers need to know how accurately each model describes the data. There are several statistics used to determine the goodness of fit. Coefficient of determination (R^2) and adjusted coefficient of determination R^2 are the most common ones being used to compare the performances of the estimated models. To use other model selection criteria as well will bring more accurate selections. In this respect, the models fitted to the data were compared by using goodness of fit statistics listed below:

Table 1: Growth curve model expressions

Models	Expression
Morgan-Mercer Flodin	$w_t = (\beta_0\beta_1 + \beta_2 t^{\beta 3})(\beta_1 + t^{\beta 3})$
Negatif exponential	$w_t = \beta_0 (1\text{-}\exp(-\beta_2 t)))$
Brody	$w_t = \beta_0 (1-\beta_1 \exp(-\beta_2 t))$
Gompertz	$w_t = \beta_0 \exp(-\beta_1 \exp(-\beta_2 t))$
Logistc	$w_t = \beta_0/(1 + \beta_1 \exp(-\beta_2 t))$
Von Bertalanffy	$w_t = \beta_0^{1-\beta 3}-\beta_1 \exp[(-\beta_2 t)^{1/1-\beta 3}]$
Richards	$w_t = \beta_0/(1 + \beta_1 \exp(-\beta_2 t))^{1/\beta 3}$
Hyperbolastic 1	$w_t = \beta_0 (1 + \beta_1 \exp(-\beta_0\beta_2 t-\beta_4 \text{arcsinh}(t)))$
Hyperbolastic 2	$w_t = \beta_0/(1 + \beta_1 \text{arcsinh}(\exp(-\beta_0\beta_2 t^{\beta 3})))$
Hyperbolastic 3	$w_t = \beta_0-\beta_1(\exp(-\beta_2 t^{\beta 3} - \text{arcsinh}(\beta_4 t)))$

$$\text{Coefficient of determination } (R^2) = 1\text{-}(SSE/SST)$$

Where:
SSE = Sum of square of errors
SST = Total sum of squares

Adjusted determination coefficient

$$(R2) = R2\text{-}|(k\text{-}1/n\text{-}k)(1\text{-}R2)$$

Where:
n = The number of observations
k = The number of parameters

$$\text{Mean Square Error (MSE)} = SSE/(n\text{-}k)$$

Where:
n = The number of observations
SSE = Sum of square of errors
k = The number of parameters

Akaike's Information Criteria (AIC) = n.ln(SSE/n)+2k, where n; the number of observations, SSE; Sum of square of errors, k; the number of parameters (Akaike, 1974).

Schwarz Bayesian information criterion (SBC or BIC) n.ln(SSE/n)+k.ln(n), where n; the number of observations, SSE; sum of square of errors, k; the number of parameters (Schwarz, 1978).

RESULTS AND DISCUSSION

Results of estimated parameter values for all models and the goodness of fit criteria are shown in Table 2 and 3. Determination coefficients for Logistic, Von Bertalanffy, Richards, Negative Exponential, Brody, Gompertz, MMF, H1, H2 and H3 are 0.99918, 0.99968, 0.99998, 0.99790, 0.99031, 0.99998, 0.99986, 0.99966, 0.99979

Table 2: Growth curve parameters

Model	β_0	β_1	β_2	β_3	β_4
Logistic	201.9±5.98	12.82±2.09	0.139±0.01	-	-
Von bertalanffy	247.3±23.75	7.98±0.70	0.054±0.04	0.585±0.02	-
Richards	222.0±3.19	0.01±0.23	0.080±0.01	0.003±0.07	-
Negative exponential	471.0±144.00	-	0.014±0.01	-	-
Brody	492.7±246.70	0.99±0.01	0.013±0.01	-	-
Gompertz	222.1±1.58	3.31±0.04	0.080±0.01	-	-
Morgan-Mercer flodin	266.9±8.59	0.01±0.01	8.564±1.29	-1.870±0.08	-
Hyperbolastic 1	208.9±5.70	33.64±2.09	0.001±0.00	-	0.303±0.05
Hyperbolastic 2	215.0±6.02	38.68±3.11	0.002±0.00	0.695±0.03	-
Hyperbolastic 3	220.0±3.71	211.65±9.09	0.009±0.00	1.515±0.11	-0.007±0.01

Table 3: Predictions and residuals of growth curve models

Observed		Logistic		Bertalanffy		Richards		Negative exponential		Brody	
Age	Weight	P	R	P	R	P	R	P	R	P	R
0	8.67	14.61	-5.94	4.34	4.34	8.12	0.55	6.34	2.33	1.26	7.42
7	32.93	34.50	-1.57	34.78	-1.85	33.52	-0.59	42.63	-9.71	43.12	-10.19
14	75.40	71.18	4.23	77.74	-2.34	75.45	-0.05	81.4	-6.00	81.41	-6.01
21	120.72	119.11	1.61	119.27	1.45	119.93	0.79	116.67	4.06	116.45	4.28
28	155.92	159.87	-3.94	153.85	2.07	156.25	-0.32	148.74	7.18	148.5	7.43
35	180.97	183.65	-2.68	180.54	0.43	181.7	-0.73	177.91	3.06	177.82	3.15
42	198.57	194.61	3.97	200.27	-1.69	198.03	0.54	204.44	-5.86	204.64	-6.07
Goodness of fit criteria											
R^2		0.99918		0.99968		0.99998		0.99790		0.99031	
Adj. R^2		0.99877		0.99937		0.99996		0.99748		0.98546	
MSE		13.81434		5.30767		0.31834		35.34312		45.01412	
Res. Mean		-0.61939		0.34264		0.02782		-0.70568		0.00000	
Res. SD		3.95772		2.46055		0.60862		6.37632		7.24704	
AIC		24.37812		19.68300		-0.01401		28.95601		32.64900	
BIC		24.21543		19.46700		-0.23120		28.84712		32.48700	

Observed		Gompertz		Morgan-Mercer flodin		Hyperbolastic 1		Hyperbolastic 2		Hyperbolastic 3	
Age	Weight	P	R	P	R	P	R	P	R	P	R
0	8.67	8.09	0.58	9.22	-0.55	8.67	0.00	12.22	-3.55	9.00	-0.33
7	32.93	33.52	-0.60	31.58	1.35	36.14	-3.21	34.65	-1.73	32.42	0.51
14	75.40	75.46	-0.06	76.73	-1.33	74.02	1.39	74.21	1.19	76.25	-0.85
21	120.72	119.93	0.79	120.64	0.08	118.8	1.92	119.43	1.29	120.05	0.67
28	155.92	156.23	-0.31	155.25	0.67	157.5	-1.57	157.23	-1.31	155.81	0.12
35	180.97	181.69	-0.73	180.68	0.29	182.87	-1.90	182.4	-1.43	181.52	-0.55
42	198.57	198.05	0.53	199.09	-0.51	196.72	1.86	197.11	1.47	198.32	0.26
Goodness of fit criteria											
R^2		0.99998		0.99986		0.99966		0.99979		0.99998	
Adj. R^2		0.99997		0.99971		0.99933		0.99958		0.99995	
MSE		0.31801		0.66817		5.66221		3.50823		0.27501	
Res. Mean		0.03019		0.00014		-0.21743		-0.57929		-0.02557	
Res. SD		0.60868		0.88273		2.04713		1.92367		0.56515	
AIC		-2.01020		5.17512		20.13610		16.78550		0.95223	
BIC		-2.17212		4.95901		19.92230		16.56870		0.68243	

and 0.99998, respectively. Adjusted determination coefficients R^2 the same models are 0.99877, 0.99937, 0.99996, 0.99748, 0.98546, 0.99997, 0.99971, 0.99933, 0.99958 and 0.99995, respectively. Determination and adjusted determination coefficients obtained from Gompertz, Richards and H3 were the highest. When the models ranked according to the goodness of fit by MSE, H3 model (MSE = 0.275) shows the lowest value, followed by Gompertz (MSE = 0.318), Richards (MSE = 0.318). MMF (MSE = 0.668), H2 (MSE = 3.508), Von Bertalanffy (MSE = 5.307), H1 (MSE = 5.662), Logistic (MSE = 13.810), Negative Exponential (MSE = 35.343) and Brody (MSE = 45.014). In terms of Residual Means (RM) and Residual Standard Deviations (RSD), Richards (RM = 0.02780, RSD = 0.60862) and Gompertz (RM = 0.03019, RSD = 0.60868) provide the best fit to the measured data set. Gompert model shows the minimum AIC and BIC values (AIC = -2.010, BIC = -2.172), followed by Richards (AIC = -0.014, BIC = -0.230), H3 (AIC = 0.952, BIC = 0.682), MMF (AIC = 5.175, BIC = 4.959), H2 (AIC = 16.785, BIC = 16.568), Bertalanffy (AIC = 19.683, BIC = 19.467), H1 (AIC = 20.136, BIC = 19.920), Logistic (AIC = 24.378, BIC = 24.215), Negative Exponential (AIC = 28.956, BIC = 28.847) and Brody (AIC = 32.649, BIC = 32.487). All growth models were powerful to describe the data obtained from Japanese quails (Fig. 1). Actual (weight) and estimated (P) weekly body weights belonging to different

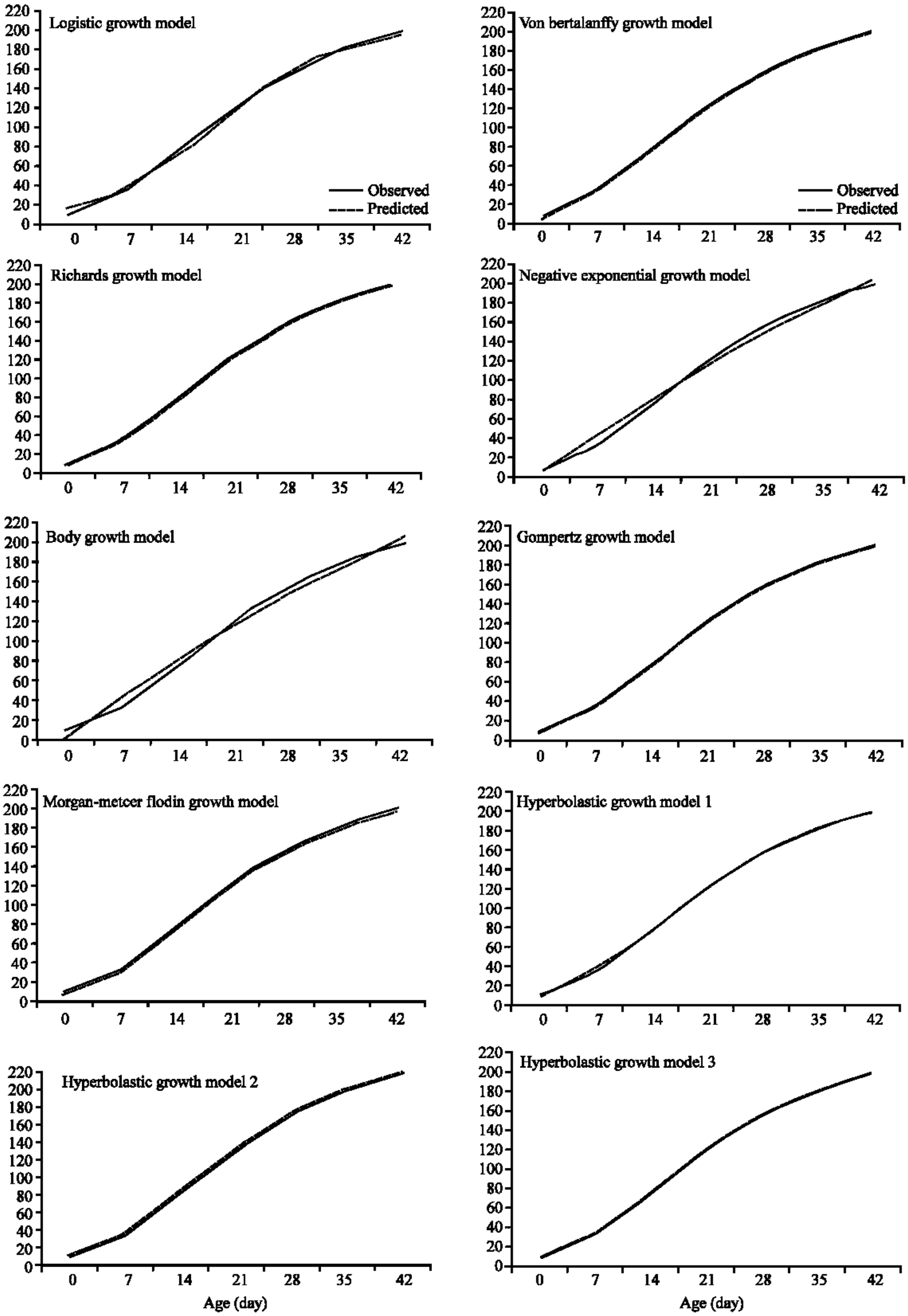

Fig. 1: Fitted growth curves

models are shown in Table 3. The overall goodness of fit statistics have shown that the Gompertz model has the best fitting to the data set and also Richards and H3 models have shown higher accuracy. These results are in good agreement with Tzeng and Becker (1981), Ricklefs (1985), Anthony *et al*., (1991) and Akbas and Oguz (1998) who reported that the Gompertz equation is the best fit for galliformes. In addition, Brisbin *et al.* (1986), Knizetova *et al*. (1991) and Sezer and Tarhan (2005) successfully fitted Richards model to the growth data which were collected from poultry. Ahmadi and Mottaghitalab (2007) on Athens-Canadian and Golian and Ahmadi (2008) on broiler chickens fitted the data to Hyperbolastic models whose theoretical base has been revealed in recent years (Tabatabai *et al*., 2005). Their results, similar with the present study, provide that H3 model has the best fit to the data set compared to H1 and H2. There are studies carried out to compare Logistic, Von Bertalanffy and MMF with other growth models by using data obtained from poultry. Brody and Negative Exponential models which show the worst goodness of fit values have been frequently used in ruminant animal's growth data in previous studies. This may be caused by the fact that ruminant animals could reach the mature weight after a long time period than galliformes.

Estimated model parameters and standard errors obtained with Logistic, Bertalanffy, Richards, Negative Exponential, Brody, Gompertz, MMF, H1, H2 and H3 models are shown in Table 2. Asymptotic weight parameters for Gompertz, Richards and H3 models are estimated as 220.10, 222.00 and 220.00, respectively. The results are higher than those reported by Anthony *at al.* (1991) whereas in agreement with those (203.5-244.4) reported by Akbas and Oguz (1998). Asymptotic weight parameter represents the maximum growth response for animals and there are some differences between estimated asymptotic weight parameters for the models used in this study. Asymptotic weight is directly related with genotypic and environmental effects. Hence, it is expected to observe different asymptotic weight parameters for quails fed in different environments and have different genotypes. β_1 parameter of Gompertz equation describes the rate or earliness of maturity. The estimated value of β_1 parameter is 3.3124 and this value is similar to the values (3.399-4.100) reported for quails by Akbas and Yaylak (2000), Akbas and Oguz (1998) and Balcioglu *et al*. (2005) for Gompertz model. Value of β_2 parameter is 0.0801 in Gompertz model. This value is higher than the values (0.046-0.070) reported for quails by Akbas and Yaylak (2000), Akbas and Oguz (1998) and Balcioglu *et al*. (2005). The smaller estimation of β_2 value indicates longer periods of growth and higher mature weight on the contrary, high β_2 parameter indicates early maturing and smaller mature weights. Weight and age at the inflection point for Gompertz equation were calculated as 81.70 g and 14.95th day (β_0/e and ln(β_1)/β_2), respectively. Akbas and Yaylak (2000), Akbas and Oguz (1998) and Balcioglu *et al*. (2005) reported the inflection point of weights in the range of 74.85-89.89 g and the age at the inflection point in the range of 18.74-21.22 day by Gompertz model for quails.

The Logistic, Bertalanffy, Richards, Negative Exponential, Brody, Gompertz, MMF, H1, H2 and H3 models were used to assess growth patterns of the Japanese quail. The overall calculated statistic values showed that the Gompertz model provides higher accuracy of fitness to the growth data, followed by the Richards and H3 models. Gompertz model provides a better description of growth curve of quail summarizing age-weight data with the biologically meaningful parameters. The Richards model as well as H3 model which have four and five parameters respectively are more flexible than the Gompertz model.

CONCLUSION

The comparison of 11 growth models in terms of the goodness of fit criteria revealed that three-parameter Gompertz-model is the most appropriate model for describing the age-ralated changes of body weight in Japanese quails. However it requires special attention to characterize the growth patterns of animals in different environmental conditions or from different lines and the like. Thus, it is concluded that we need further study to examine the most appropriate model, in which the growth model parameters and growth characteristics used in order to bring more accurate results for breeding and management purposes.

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