Analysis of Growth Models of Japanese Quails (*Coturnix Coturnix japonica*) in Nigeria

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ABSTRACT

This study, aimed at comparing the growth curve parameters and determining the best non-linear model for Japanese quails was conducted at the Department of Animal Science, University of Ibadan, Ibadan. Two hundred and thirty-five (235) Japanese quails were purchased at day old from a reputable hatchery in Ibadan and reared in cages, after two weeks of brooding on deep litter. Body weights (g) were taken weekly from hatch till the birds were 25 weeks old. The average of the weekly body weights was fitted to four non-linear models, namely Gompertz, Logistic, Brody and Von Bertalanffy to define the growth pattern and examine the existence of differences in the growth pattern described by the models. Models were compared using Coefficients of determination (R^2), Mean square error (MSE), size of Residual standard deviation (RSD), Akaike's information criteria (AIC) and Percentage forecast error. The R^2 values were high for all models: 0.980, 0.979, 0.973 and 0.973 for Von Bertalanffy, Gompertz, Logistic and Brody, respectively. The Mean square error and Akaike's information criteria values were 65.744 and 107.449; 64.685 and 107.043; 51.363 and 101.277; 49.731 and 100.470 for the Logistic, Brody, Gompertz and Von Bertalanffy models, respectively. Residual standard deviations were 8.979, 8.539, 7.847 and 7.832 with corresponding Percentage forecast error (PCFE) values of 16.315, 11.523, 12.948 and 13.687 for the Brody, Logistic, Gompertz and Von Bertalanffy models respectively. The Von Bertalanffy model was the most suitable for explaining the growth of the Japanese quails based on these goodness of fit criteria: The highest R^2 (0.980), lowest Mean square error (49.731), Residual standard deviation (7.832) and Akaike's information criteria (100.470).

Keywords: Growth curve, non-linear models, logistic model, body weight

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INTRODUCTION

Growth is a fundamental attribute of biological systems. It is a priority trait in the poultry industry and can be defined as an increase in body size per unit time (Lawrence and Fowler, 2002). Growth is under the control of genetics and environment and can be described by the changes throughout the life accompanied by the utilisation of materials, resulting in increase in volume, size, or shape of an organism. These changes can be followed by measurements of body weight in regular intervals and summarised by mathematical equations fitted to growth curves.

Growth trend parameters are highly heritable and can be used successfully in selection studies. Modeling of growth curves is useful because it provides means for visualizing growth patterns over time, and the generated equations can be used to predict the expected weight of a group of animals at a specific age (Norris *et al*., 2007). It has been observed that animal growth follows a sigmoid pattern (S-shape) and numerous nonlinear growth equations have been developed to describe and fit the sigmoid relationship between weight and time in poultry. The nonlinear models are able to predict the shape of the growth pattern more logically than the linear ones (Hruby *et al.* 1996). The generally used models are the Logistic, Gompertz or Bertalanffy growth functions, which summarize the information into a few biologically interpretable parameters (Goliomytis *et al.,* 2003). The Gompertz growth model has been cited as the model of choice for chicken data based on its overall fit and biological meaning of model parameters (Anthony *et al.,* 1991). Growth curves of the same or different species are not necessarily best described by the same equation (Ricklefs, 1967).

Growth curves for individual quails were fitted using the Gompertz model by Akbas and Yaylak (2000). Mean estimates of growth curve parameters- asymptotic limit of weight (A), the rate of body weight gains after hatch to mature body weight (B) and maturing rate (k) for male plus female were 245, 3.399 and 0.055, respectively.

Estimates of the Gompertz growth curve in Japanese quails have been obtained with high determination coefficients ($0.9898 \geq R^2 \geq 0.9840$) in both male and female Japanese quails. This implies that the growth curves of the observed data were adequately described by the Gompertz function (Akbas and Oguz, 1998).

Earlier study by Marks (1978) reported that growth curve parameters were changed by selection for body weight in Japanese quails. Ozkan and Kocabas (2004) reported that the Logistic model gave the best fit to male and female, selected and unselected quail populations when compared with the Brody, Exponential, Gompertz and Bertalanffy models.

Generally, there are conflicting reports on the model that best describes growth of Japanese quails. Therefore, the objectives of this study were to identify models which summarize quail growth with few parameters using selected non-linear equations in relation to age and to compare growth curves of quails and identify the best growth model.

MATERIALS AND METHODS

Site of The Experiment

The experiment was carried out at the Quail unit of the Teaching and Research Farm, University of Ibadan, Ibadan, Oyo State, Nigeria which lies within 7° 26' 30" North and 3° 54' 00" East within the tropical rain forest zone.

Experimental Animals, Management and Data Collection

Two hundred and thirty-five (235) Japanese quail birds were obtained at hatch from a reputable hatchery in Ibadan. Brooding was done in deep litter housing for two weeks. The litters on the floor were covered with a rough-surfaced paper during the first week to avoid damage to the feet and legs of the birds. The wire sides of the brooder house were closed with fine mesh to prevent escape of the young quails. The quail chicks were brooded at 37°C at first and the temperature was reduced to about 34°C a week after. Feed and water were placed outside the heated hovering area. Thus, the chicks were forced to venture out from under the heat and this gave them the needed exercise and accustomed them to lower temperature. The birds were fed *ad libitum* a diet containing 24% crude protein and 2,900 kcal/kg of metabolic energy. Afterwards, they were given a feed containing 20% crude protein and 2,800 kcal/kg of metabolic energy when the females came to point of lay. The birds were housed in cages with dimension of 30 x 30 x 45 cm fitted with improvised feeders and drinkers (to prevent feed wastage) at three weeks old and kept under same management condition. The gender determination of animals was completed using the colour of the chest at three weeks of age. Body weight of the quails was taken individually in grams (two decimal places) at hatch and subsequently at weekly intervals until the age of 25 weeks with the aid of a digital 2,000 g capacity weighing scale.

Statistical Analysis

Body weight of the quails were grouped based on the gender factor as male and female and gender factor was analysed with t-test for each week. But this factor was found not significant statistically ($P > 0.05$). Growth curve parameters were estimated using nonlinear procedure of Statistical Analysis System, PROC NLIN (Marquart algorithm), Version 9.2 (SAS, 2008). Models in this study were compared using Coefficients of Determination (R^2), Mean Square Error (MSE), Residual Standard Deviation (RSD), Percentage Forecast Error (PCFE) and Akaike's Information Criteria (AIC). The best growth model has the highest R^2 but the lowest MSE, RSD, PCFE and AIC (Keskin and Daskiran, 2007). The adopted growth models are presented in Table 1.

Table 1 Adopted non-linear models for describing the growth of Japanese quails

	Gompertz	Logistic	Von Bertalanffy	Brody
Parameters	$W_{(t)} = A\ e^{B\ exp-k\ t}$	$W_{(t)} = \frac{A}{1 + B\ e^{k\ t}}$	$W_{(t)} = A\ 1 - B\ e^{k\ t\ 3}$	$W_{(t)} = A\ 1 - B\ e^{k\ t}$
t	ln(B)/k	-ln(1/B)/k	ln B+ln3/K	No inflection
Y	A/e	Ax0.5	8xA/27	No inflection
U	Y / A	Y / A	Y / A	-
MW	$k\ Y$	$k\ Y/ 2$	$3k\ Y/2$	-

$W_{(t)}$ = Predicted weight (g) at age t; A = Asymptotic limit of weight (g) when age approaches infinity; B = The rate of body weight gains after hatch to mature body weight; k = maturing rate (function of the ratio of maximum growth to mature size); t = age (days); U_i = Proportion of weight at inflection point over mature weight; Y_i = Weight at point of inflection; t_i = Age at point of inflection (Soysal *et al*., 2002); MW = Maximum weight gain at point of inflection; e = base of natural logarithm (Euler's number = 2.71828)

RESULTS AND DISCUSSION

The growth curves of Japanese quails were as presented in Figure 1. From the figure, the fit lines from all models were different. All the models were found to be highly significant ($P < 0.0001$). Growth curves drawn for Logistic, Brody, Von Bertanlanffy and Gompertz growth models during several weeks after birth in the Japanese quails showed closely linear model but this linearity was altered during the later periods and the shape of growth curves sigmoidal. This is in line with the report of Yakupoglu (1999), that the values of weight and height of animals from birth to death analyzed by growth models produce shapes of growth curves which are generally straight 'S' shape that is termed as "sigmoidal curve''.

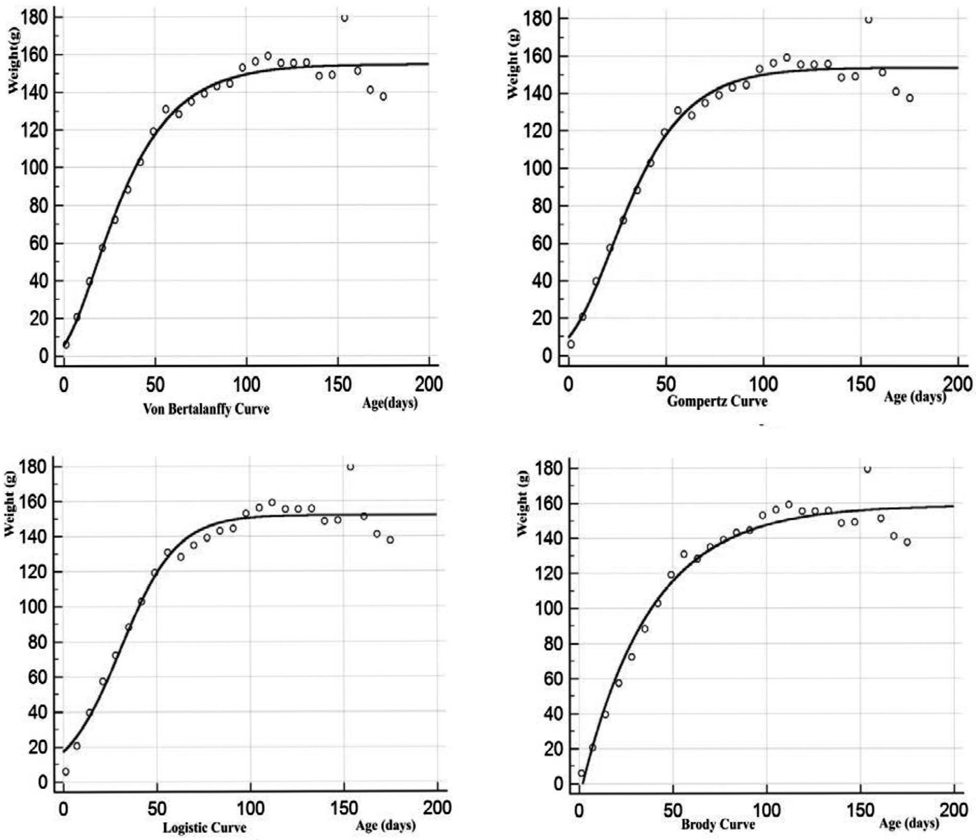

Figure 1 Growth curves describing weight-age relationship in Japanese quails

Body Weight

Observed, predicted live weight and their residuals for the growth of the quails are presented in Table 2. The predicted live weight values were positive and higher than the observed values of weight in all the models except the Brody function which had negative predicted values (-3.35 g) at day 1. Average body weight at hatch from the observed data was 6.0 g. This was slightly lower than body weight at hatch reported by El-fiky *et al.* (2006). On the other hand, predicted body weight by the Logistic and Gompertz models were higher than the body weight (8.01 g) reported by the cited author. Also, body weight at 14 days (2 weeks) was 36.59 g. This was within the range reported by Brah *et al.* (1992), who obtained body weight for 2 week-old Japanese quail. At 4 weeks, average body weight was reported to range between 88.4 and 97.9 g by Debes (2004). Body weight at 4 weeks in this study was 72.49 g while the average body weight at 6 weeks (102.94 g) was lower than body weight at 6 weeks (119.7 g) reported by Brah *et al.* (1992) but was higher than body weight of birds housed at 1:3 sex ratio by El-Fiky *et al.* (2006). Furthermore, the body weight at market weight (8 weeks) was reported by Soltan (1991) to range between 125.6 and 172.5 g. The body weight in this research at 8 weeks was 130.95 g and this was in the range reported by the author. On the contrary, 8-weeks body weight was lower than body weight reported in two local strains of quail in Egypt by El Gazar (2009). This could be due to the effect of strain on body weight of animals.

Table 2 Observed and Predicted body weight and residual values for non-linear models for Japanese quails

Age (d)	Weight (g)	Logistic		Gompertz		Brody		Bertalanffy	
		Pred.(g)	Res	Pred.(g)	Res	Pred.(g)	Res	Pred.(g)	Res
1	6.00	18.48	-12.48	11.07	-5.07	-3.35	9.35	7.24	-1.24
7	20.78	25.99	-5.21	21.10	-0.32	20.92	-0.14	19.19	1.59
14	39.59	37.56	2.03	36.77	2.82	44.67	-5.08	37.35	2.24
21	57.51	52.17	5.34	54.86	2.65	64.32	-6.81	56.79	0.72
28	72.49	69.03	3.46	73.19	-0.70	80.59	-8.10	75.20	-2.71
35	88.39	86.62	1.77	90.08	-1.69	94.05	-5.66	91.42	-3.03
42	102.94	103.12	-0.18	104.61	-1.67	105.18	-2.24	105.05	-2.11
49	119.20	117.15	2.05	116.52	2.68	114.40	4.80	116.16	3.04
56	130.95	128.09	2.86	125.92	5.03	122.02	8.93	125.02	5.93
63	128.26	136.08	-7.82	133.16	-4.90	128.33	-0.07	131.97	-3.71
70	135.02	141.63	-6.61	138.64	-3.62	133.56	1.46	137.38	-2.36
77	139.15	145.35	-6.20	142.72	-3.57	137.88	1.27	141.54	-2.39
84	143.15	147.79	-4.64	145.73	-2.58	141.45	1.70	144.73	-1.58
91	144.66	149.37	-4.71	147.95	-3.29	144.41	0.25	147.16	-2.50
98	153.08	150.37	2.71	149.56	3.52	146.86	6.22	149.00	4.08
105	156.36	151.01	5.35	150.73	5.63	148.89	7.47	150.40	5.96
112	159.32	151.42	7.90	151.58	7.74	150.56	8.76	151.46	7.86
119	155.42	151.67	3.75	152.20	3.22	151.95	3.47	152.27	3.15
126	155.57	151.83	3.74	152.65	2.92	153.10	2.47	152.87	2.70
133	155.85	151.93	3.92	152.97	2.88	154.05	1.80	153.33	2.52
140	148.51	152.00	-3.49	153.20	-4.69	154.84	-6.33	153.67	-5.16
147	149.23	152.04	-2.81	153.37	-4.14	155.49	-6.26	153.93	-4.70
154	179.47	152.06	27.41	153.49	25.98	156.02	23.45	154.12	25.35
161	151.12	152.08	-0.96	153.57	-2.45	156.47	-5.35	154.27	-3.15
168	141.08	152.09	-11.01	153.64	-12.56	156.84	-15.76	154.38	-13.30
175	137.54	152.10	-14.56	153.68	-16.14	157.14	-19.60	154.47	-16.93

d = days; g = grams; Pred. = predicted weight; Res. = Residual value

Parameter Estimate and Correlation of Growth Parameters

Table 3 shows the parameter estimates and standard errors of the growth models. The asymptotic limit of weight, parameter A, was highest in the Brody model (161.4). The estimates for the parameter A were 153.4, 155.4 and 156.6 for Logistic, Gompertz and Von Bertanlanffy models respectively. Based on asymptotic weight, the Brody ranked first, followed by the Von Bertalanffy and Gompertz models. The highest estimates of B (integration constant related to hatch weight) (7.543) and maturing rate, k (0.065) parameters were found for the Logistic model. Brody and Von Bertalanffy models had k parameter estimates of 0.026 and 0.039, respectively.

Table 3 Parameter estimates and standard errors of growth models fitted for Japanese quails

Models	A (g)	B	k	Y_i (g)	T_i (d)	U_i (g)	MWI (g)
Gompertz	155.40 ± 2.333	2.705 ± 0.281	0.045 ± 0.003	57.17	22.15	0.367	2.5727
Logistic	153.40 ± 2.368	7.543 ± 1.506	0.065 ± 0.006	76.70	31.09	0.500	2.7144
Bertalanffy	156.60 ± 2.447	0.656 ± 0.053	0.039 ± 0.003	46.40	17.32	0.296	2.4628
Brody	161.40 ± 3.543	1.041 ± 0.040	0.026 ± 0.002	No inflection	No inflection	-	-

A = Asymptotic limit of weight (g) as weight approaches infinity; B = Integration constant, related to hatch weight; k = Rate of maturity; Y_i = Weight (g) at point of inflection; t_i = Age (d) at point of inflection; U_i = Ratio of body weight at point of inflection to mature body weight (g); MWI = Maximum weight (g) gain at point of inflection; g = grams; d = days

The correlations between growth model parameters (A, B and k) of the different models were considered and presented in Table 4. Correlations among the parameters AB of all the models were found to be negative. Negative correlation among parameters Ak was also obtained for all the models, whereas Bk correlation was found to be positive. The highest positive correlation for growth parameter (0.87) was calculated for the Logistic model and this was obtained for the association between parameter B and k, while the strongest negative correlation for the parameters was obtained for the Brody model (Ak = -0.80). Strong positive correlations were also obtained for the Gompertz and Bertalanffy models for the association between B and k. The lowest negative correlation was calculated for the association between parameters A and B and this was obtained for the Logistic model. Brody model gave the lowest positive correlation and this was obtained for the association between parameters B and k.

Table 4 Approximate correlation of growth parameter estimates

Models	AB	AK	BK
Logistic	-0.19	-0.44	0.87
Gompertz	-0.29	-0.58	0.83
Brody	-0.36	-0.80	0.66
Von Bertalanffy	-0.33	-0.64	0.81

A = Asymptotic limit of weight as it approaches infinity; B = Integration constant related to hatch weight; K = Rate of maturity

Parameter k determines the rate or earliness of maturity. A large k value indicates early maturity for the birds while a small k value indicates late maturity. Logistic model predicted the highest k value (0.065) and it implies that the quails would come to maturity earlier than what was predicted by the other models. The values of the k parameter obtained for the Brody, Logistic, Bertalanffy and Gompertz models in this study were similar to the values observed in quails by Narinc *et al.* (2010). Akbas and Oguz (1998) reported k parameter as minimum of 0.046 and maximum 0.132 for Gompertz, Logistic and Bertalanffy models. The same parameter was detected as minimum of 0.04 and maximum of 0.10 for Gompertz, Bertalanffy and Logistic models (Ozkan and Kocabas, 2004). The k parameter of this study was in the same range with the reports of earlier authors.

Parameter A gives an idea of the mature weight predicted by each model. In this study, the highest A value was predicted by the Brody model (161.4). This is attainable by quails that can grow up to a live weight of 250 g. This study was in line with Akbas and Yaylak (2000) and Kizilkaya *et al*. (2005) who reported a negative correlation between parameters A and k for Japanese quails. All the models used in the study gave a negative correlation between parameters A and k, with Brody model giving the highest negative correlation. The high negative correlation coefficients detected between A and k parameters in the present study demonstrate that the achievement of the estimated mature weight will take place at a farther period than the age when measurements were performed. The correlation coefficients determined in the study were found to be concordant with various studies that examined growth in poultry with the Gompertz model (Akbas and Yaylak, 2000).

In the present study, the largest value of the A parameter was observed under the Brody model and may indicate possible overestimation of mature weight by this model because of an absence of an inflection point. The standard errors for the A parameter values estimated under this model were also large. The Brody model may also be used to describe the data though the major shortcoming stems from the biased estimate of the A parameter with its large standard error.

The data set was not too large and thus did not pose computing difficulties under all models, but there was less iteration observed for convergence under the Gompertz model compared to other models. Among the models, the best values in terms of choosing model criterion, standard error were observed in the Gompertz model. This is in agreement with Cetin *et al.* (2000) who compared growth models of partridges. The biological importance of high negative correlation observed between mature weight (asymptotic weight) and growth rate (k) indicated that chicks that grew faster did not attain a large mature weight compared to those that mature more slowly in early life. This negative correlation may pose a challenge if the objective in an improvement program is to increase the rate of growth as this would result in lower mature weights.

Parameter B in this study was 2.705, which was lower than B parameter in selected Japanese quails with B parameter of 3.399 when growth of the birds was modelled with Gompertz model (Akbas and Yaylak, 2000). This supports the report that growth model parameters could be changed by selection (Marks, 1978).

Point of Inflection (POI)

The Brody model is one that naturally has no point of inflection (POI) even if the data is one that should have a point of inflection. In this study, body weight at POI (Y_i) and approximate age at POI (t_i) were 57.17g and 22.15 days, 76.70 g and 31.09 days, 46.40 g and 17.32 days for the Gompertz, Logistic and Von Bertalanffy models, respectively. Also, the Maximum Weight Gain (MWG) at POI for the Gompertz, Logistic, Von Bertalanffy were 2.5727, 2.7144 and 2.4928 g, respectively with corresponding proportion of weight at POI over mature weight (U_i) of 0.367, 0.500 and 0.296.

The point of inflection (POI) at which the growth rate is maximum, gives an estimate of age and weight at puberty. The rate of growth begins to decline at this point. In this study, body weight at POI (Y_i) and approximate age at POI (t_i) were 57.17 g and 22.15 days, 76.70 and 31.09 days, 46.40 g and 17.32 days for the Gompertz, Logistic and Von Bertalanffy models, respectively. Also, the Maximum Weight Gain (MWG) at POI for the Gompertz, Logistic, Von Bertalanffy were

2.5727, 2.7144 and 2.4928 g, respectively with corresponding proportion of weight at POI over mature weight (U_i) of 0.367, 0.500 and 0.296. The result of the weight at point of inflection showed that the point of inflection of the growth of the Japanese quails, as predicted by the models were 36.7%, 50% and 29.6%. Also, the Japanese quails were predicted to come to puberty at approximately 17, 22 and 31 days of age by the Von Bertalanffy, Gompertz and Logistic models, respectively.

Fitness of Models

Models that gave the highest Coefficient of determination values (R^2) have been accepted as best fitting model (Topal *et al.,* 2004). In addition, models that gave the lowest Mean Square Error (MSE), Residual Standard Deviation (RSD) and Percentage Forecast Error (PCFE) and Akaike's Information Criteria (AIC) values have also been accepted as the best fitting for the set of data (Keskin and Daskiran, 2007). The Coefficient of determination (R^2), Mean Square Error (MSE), Percentage Forecast Error (PCFE), Residual Standard Deviation (RSD) and Akaike's Information Criteria (AIC) values are presented in Table 5

Table 5 Goodness of fit statistics and approximate correlation of growth parameter estimates

Fitness Criterial	Logistic	Gompertz	Brody	Bertalanffy
R^2	0.973	0.979	0.973	0.980
MSE	65.744	51.363	64.685	49.731
PCFE	11.523	12.948	16.315	13.687
RSD	8.539	7.847	8.979	7.832
AIC	107.449	101.277	107.043	100.470
AB	-0.190	-0.29	-0.36	-0.33
AK	-0.44	-0.58	-0.80	-0.64
BK	0.87	0.83	0.66	0.81

R^2 = Coefficient of determination; MSE = Mean Square Error; PCFE = Percentage Forecast Error; RSD = Residual Standard Deviation; AIC = Akaike's Information Criteria; A = Asymptotic limit of weight (g) as weight approaches infinity; B = Integration constant, related to hatch weight; k = Rate of maturity

Coefficient of Determination (R^2)

Coefficient of determination is a measure of the total variation accounted for by the explanatory variable (age) of the Japanese quails. The estimates of the Von Bertalanffy, Gompertz, Brody and Logistic growth curves were obtained with high determination coefficients (R^2) of 0.980, 0.979, 0.973 and 0.9723 respectively. This implies that the growth curves of the observed data of Japanese quail were adequately described by these growth functions. This is in agreement with Akbas and Oguz (1998). Also, Aggrey (2002) and Norris *et al.* (2007) also found high R^2 values in a study of growth in broilers using Gompertz and Bertalanffy growth models. In general, based on R^2 values alone, all models seemed to be appropriate to explain significant relationship to describe the association between age and live weight. Knizetova *et al.* (1995) found similar result of R^2 larger than 0.9 by using the models outlined in this study or different models. This research had slightly lower values of R^2 for the Logistic and Gompertz models than what was reported for *ad libitum* fed broilers by Stephan *et al.* (1987). They R^2 values were found to be 0.979 and 0.980 for the Logistic and Gompertz models, respectively. Also, Knizetova *et al.* (1994) obtained R^2 value of 0.9994 in ducks and

0.9901 in geese which was higher than the highest R^2 value (0.980) obtained in this study. This could be due to species differences. Sengul and Kiraz (2005) found high Coefficients of determination for Gompertz and Logistic in a study of growth curves in turkeys. Akbas and Oguz (1998) reported that R^2 value calculated for Gompertz model from selected line of Japanese quail was 0.9898. The R^2 in this present research was slightly lower and this could be due to the effect of selection. In this study, all the models except the Logistic model had higher coefficient of determination for the Japanese quails than what was obtained by Eser *et al.* (2012).

Mean Square Error (MSE)

Calculated MSE ranged from 49.731 to 65.744, with the Logistic model giving the highest MSE value of 65.744 and the lowest MSE value of 49.731 was obtained from the Von Bertalanffy model. The Brody model gave a calculated MSE value of 65.685, which was second to the Logistics MSE value. The Gompertz model gave a calculated MSE value of 51.363. According to the MSE, the best fit was provided by the Bertalanffy model. This result of this study was different from the studies reporting that the Gompertz growth curve model is the most concordant model for poultry species (Santos *et al.,* 2005). Also, the smallest value was obtained from the Von Bertalanffy model. This contradicts the study by Eser *et al*. (2012), who obtained the lowest MSE value for the Logistic model which made the model the best fit for their set of data. This work also contradicts the result of Eser *et al.* (2012) who studied the weight-age relationship with Brody, Gompertz, Logistic and Bertalanffy models for 8 weeks and found the Logistic model as the best fit model for body weight-age in Japanese quail. Perhaps the weight of the birds would have been better described by other models if the study extended beyond 8 weeks.

Residual Standard Deviation (RSD)

The Residual Standard Deviation (RSD) was also presented as one of the criteria for comparing growth model of animals. The RSD values ranged from 7.832 for Von Bertalanffy model to 8.979 for Brody. The Logistic and Gompertz models had values of 8.539 and 7.847 respectively. Comparing the models based on the RSD values puts Bertalanffy ahead of the other models, followed by the Gompertz model. Brody model is less fit for the set of data by giving the highest RSD value.

The Residual standard deviation values were calculated and the lowest value was obtained from the Bertalanffy model. On the contrary, Eser *et al.* (2012) obtained the lowest value for the Logistic model. They also obtained lower values of RSD for all the models compared to what was obtained in this study.

Akaike's Information Criteria (AIC)

Akaike's Information Criteria (AIC) values were 107.449, 107.043, 101.277 and 100.470 for Logistic, Brody, Gompertz and Von Bertalanffy models, respectively. Brody's AIC value was closer to Logistic's value than it was to the Gompertz value, which was second in rank to the Von Bertalanffy's AIC value. Ranking of the models based on AIC, the Von Bertalanffy model gave the smallest value of 100.470 and this made it better than the rest. Logistic model had the highest value (107.449) for AIC and the lowest value was calculated for the Von Bertalanffy model. This contradicts the result of Eser *et al.* (2012) who calculated the lowest value for the Logistic model. This could be as a result of differences in sample size.

The model with the lowest PCFE value has been chosen as the best in earlier research on animal growth model comparison. The PCFE value ranged from 11.523 (Logistic model) to 16.315 (Brody models). The calculated PCFE values for the Bertalanffy and Gompertz models were 13.687 and 12.948 respectively. The smaller the PCFE, the better fit is the model. Logistic model is better fit for describing the growth of the animals in this study, followed by the Gompertz, Bertalanffy and Brody models based on the PCFE values.

Overall comparison of all the models using the four criteria showed that the Von Bertalanffy model had the best fit for the growth of Japanese quail by having the highest R^2 value of 0.980 and lowest MSE, RSD, and AIC values of 49.731, 7.832 and 100.470, respectively. This was followed by the Gompertz, Logistic and the Brody model. The Von Bertalanffy can then be used for predicting live weight at later ages from early partial live weight data.

CONCLUSION

The Von Bertalanffy model was the most suitable for explaining the growth of the Japanese quails based on these goodness of fit criteria: The highest R^2 (0.980), lowest Mean square error (49.731), Residual standard deviation (7.832) and Akaike's information criteria (100.470).

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