COMPARISON OF GOMPERTZ, LOGISTIC AND RICHARDS GROWTH MODELS FOR DESCRIBING GROWTH CURVES OF DOMESTIC PIGEON SQUABS (*COLUMBA LIVIA*) IN MAIDUGURI, BORNO STATE, NIGERIA.

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ABSTRACT

This research was carried out to describe the growth patterns of male and female domestic pigeon squabs and determine the most suitable model. Body Weight data from hatch to 30 days of age and 3 nonlinear mathematical functions (Richards, Gompertz, and Logistic) were used to estimate growth patterns of the pigeon squabs. In general, male squabs are significantly (P<0.05) heavier than females at all ages, an indication that there is sexual dimorphism in pigeons at the early ages. The Gompertz recorded highest asymptotic weights (317.25 and 314.87 g) for both male and female squabs while the Richard had the least (311.10 and 303.63 g). However, the asymptotic weights estimated by both Logistics and Richards models were very close for both males (312.89 and 311.10 g) and females (305.45 and 303.63 g). This might imply that both models will have almost the same level of accuracy in predicting the weight of squabs. Comparing the models by Akaike's Information Criterion (AIC) values and Mean Square Error (MSE) showed that all the models have similar values with Gompertz (9007.4 and 8122.4) had the highest values for males compared to the Richards (9005.5 and 8098.4) and Logistic (9003.6 and 8091.8) models. A similar trend was observed for females. Though, the R^2 values (>0.80) showed that Richards model adequately described the growth of pigeon squabs, the results confirmed that the Richards model was more suitable, followed by the Logistic and Gompertz models based on AIC and MSE.

Key words: Pigeon, Growth models, Squabs, Parameters, Sigmoid curve

INTRODUCTION

Growth is a fundamental property of biological systems and it can be defined as an increase in body size per time unit (Lawrence and fowler, 2002). The lifetime interrelation between and among individuals inherent impulse to grow and mature in all body parts and the environment is the growth model. Growth curve functions are the most adequate means for describing the growth pattern of body weight or body parts, because they summarize the information into a few parameters that may be interpreted biologically (Goliomytis *et al*., 2003).There are several mathematical expressions that have been used to describe animal growth. Most of these mathematical functions are either three or four parameter non-linear exponential equations, with an inflection point coinciding with the time of maximum growth rate and are asymptotic to the mature size of the animal being described. Growth functions are generally classified in to three categories i.e. those that describe diminishing returns behaviour (monomolecular), sigmoid behaviour with a fixed point of inflexion (e.g. Logistic, Gompertz, Schumacher), and sigmoidal behaviour with a flexible point of inflexion (e.g. Von Bertalanffy, Richards, Lopez (Thornley and France, 2007). However, to examine the accuracy of the model used, the fitting criteria usually entail coefficient of determination (R^2) and standard error of prediction (Raji *et al.,* 2014). Thus, there is dearth of information on which model best fit to describe growth of pigeon squabs. Therefore, this study was designed to determine the best model for describing the growth of squabs raised in Maiduguri, Borno of Nigeria.

MATERIALS AND METHODS

The study was conducted at the Poultry and Livestock Teaching and Research Farm of the Department of Animal Production Technology Ramat Polytechnic, Maiduguri, Borno State, Nigeria. Maiduguri the capital city of Borno State is located at latitude 11^0 51'North and longitude 13^0 05' East and at an altitude of 354 m above sea level. Maiduguri has very short duration of rainy season with about 645.9 mm/annum and a long dry season (MCN, 2018). The ambient temperature of 20^o C to as 44^o C. Relative humidity is

45% which usually lowers to about 5%. Day length is 11 to 12 hours (MCN, 2018). A total of 76 pairs of parent's pigeon were used to produce 228 squabs for the experiment. The parent pigeons of breeding age were housed in wooden cage attached externally to the walls in monogamous pairs in an intensive system. They were fed with seeds and grains, varying from wheat, millet, sorghum to crushed groundnut, two times daily. Clean drinking water was provided *ad-libitum.* Using a 5000 g digital sensitive weighing scale, body weights data was collected from hatch to 30 days at intervals of 3 days. The data were analyzed using the general linear model of SPSS 11.0. Significant means was separated using the Duncan's multiple range tests.

Growth Models

Parameters of growth were estimated using Gompertz, Richard's and logistic growth curve functions in the SAS NLIN procedure (2004). To determine the fit of the growth curves, an R^2 value, inflection point and asymptotic weight were computed.

Table 1: Models used for describing growth of domestic pigeon squabs

Model name	Equation
Gompertz	$Y_t = a * Exp(-Exp(-b * (weeks - c)))$
Logistic	Y = a/(1+Exp(b-c*X))
Richard's	Y = a/(1+Exp(b-c*X))^(1/d)

From the equations in Table 1, Y is the body weight (g) of birds at x days of age; a, b and c are model parameters where "a" is asymptotic weight when time goes to infinity, when adult weight is not reached. "b" is a scaling parameter (constant of integration), which is related with initial values of Y, and "c" is relative growth rate. "d" is the shape parameter connecting inflection point in Richards's growth function. The Gompertz and Logistic models have 3 parameters in their equations, with fixed inflection points. The 4- parameter Richards function was developed as an advancement of the logistic and the Gompertz functions and has a flexible point of inflection. The models were fitted to each squab growth data with the Levenberg-Marquardt iteration method using the nonlinear regression procedure of Statistix 9.0 software. Goodness of fit for the models was determined by the coefficient of determination (R^2) and the models were compared by using Mean Square Error (MSE), and Akaike's Information Criterion.

RESULTS AND DISCUSSION

The means and standard errors of body weights of pigeon squabs by sex are shown in Table 2. The body weights ranged from 14.327 g at day old to 346.69 g at day 30.This result is in agreement with the findings of Zannah *et al.* (2021) who reported that the mean body weight of pigeon squabs at day old to 30 days ranged from 15.51 g to 363.60 g. Aliyu *et al.* (2017) also reported that the mean body weight of pigeon squabs at day old and 27 days were 15.19 g and 376.60 g. It is evident that the mean body weights of pigeon squabs remarkably increased as the squabs advanced in age up to 18 days and begin to slow down gradually thereafter. Males were significantly (P<0.05) heavier in body weights than females at all ages. This may indicate that there is sexual dimorphism in pigeons at the early ages. The result of this study is in line with Aliyu *et al.* (2017) who reported that male squabs to be significantly heavier (p<0.05) than their female counterparts at all ages. Bhowmik *et al.* (2014) also reported that male were significantly (P<0.01) heavier than females in all age groups.

The Gompertz, Logistics and Richards models were used to assess growth pattern of pigeons. The fitted parameters and goodness of fit criteria for the growth models by sex of the squabs are presented in Table 3. The Gompertz consistently recorded the highest asymptotic weights (317.25 g) for male and (314.87 g) for female squabs while the Richard had the least (311.10) for male and (303.63 g) for female squabs. The asymptotic weights of male and female squabs did not vary very much, those of males appeared to be higher for all the models. Similarly, the asymptote weights estimated by both Logistics and Richards models were very close for both males (312.89 and 311.10 g) and females (305.45 and 303.63 g). Asymptotic body weights predicted by the Richards model for both males and females were comparable with that of Logistics model. This might imply that both models will have almost the same level of accuracy in predicting the weight of squabs. Raji *et al.* (2017) recorded the highest asymptotic weights

(342.54 vs 340.58 g) for both male and female squabs with Gompertz model. Gao *et al.* (2016) reported higher asymptotic weights (507.72 and 494.41g) as predicted by the Gompertz and Logistic models, respectively in pigeons. Xiang and Wang (2000) also reported higher asymptote weight (514.9 g) in pigeons. The higher weight obtained by the authors could be due to the fact that this type of bird had the higher growth rate than other type of birds or as a results of the difference of duration in which birds were kept. The values estimated for parameter c (maturity index) were higher in Richard (0.3534 and 0.2449), than Logistics (0.2812 and 0.1780) and Gompertz (0.1945 and 0.1474) for males and females. There were difference between sexes, this may support the point that sexual dimorphism might exist among pigeon squabs. This contradict the findings of Raji *et al.* (2017) who reported that no sexual dimorphism at early stage of pigeon squabs. Similarly, the highest d parameter (shape or curve parameter) value was recorded for male (1.8049) and lowest for female (1.3508) estimated by the Richards model. For the model selection criteria, the R^2 values for the Gompertz, Logistic and Richards were 0.5695, 0.7870 and 0.8582 for male and 0.4944, 0.7484 and 0.8321 for female respectively. The Richards model had the highest coefficient of determination (R^2) value in both sex while Gompertz had the least. Similarly, the highest MSE (Mean Square Error) and AIC (Akaikes Information Criterion) values was recorded with Richards model. Mignon-Grasteau *et al.* (1999) reported that Richards had the highest number of iterations. Mohammed (2015) also reported a lower MSE for the Gompertz when the author compared the Gompertz, Logistics and Von Bertanlaffy Models for describing growth of broilers.

The coefficients of correlation among parameters of the different models are presented in Table 5. The correlations between b and c, b and d and, c and d were high and positive while a and b, a and c and a and d were negative for all models. The correlation among parameters indicates that heavier birds are less precocious due to the antagonism between parameters a and c. Mignon-Grasteau *et al.* (1999) reported that there is a pronounced correlation among the growth parameters estimated from growth models. Mohammed (2015) also made similar observation.

Table 2: Mean ± Standard error of Body Weights (g) at Different Ages by Sex in Pigeon Squabs

Age (Days)	Overall Mean	Male	Female
0	14.327	14.337 ± 0.39[a]	13.92 ± 0.37[b]
3	58.923	61.928 ± 1.97[a]	55.92 ± 1.89[b]
7	119.47	125.52 ± 4.15[a]	113.42 ± 3.98[b]
10	178.85	187.37 ± 5.77[a]	170.33 ± 5.54[b]
14	234.37	243.79 ± 7.38[a]	224.96 ± 7.08[b]
18	268.04	275.28 ± 8.80[a]	260.81 ± 8.44[b]
21	286.90	295.01 ± 8.08[a]	278.76 ± 7.75[b]
24	307.99	315.51 ± 8.19[a]	300.48 ± 7.86[b]
27	324.88	330.53 ± 7.91[a]	319.27 ± 7.59[b]
30	346.69	352.17 ± 7.59[a]	341.21 ± 7.28[b]

ab= means within the row bearing different superscripts are statistically significant ($p<0.05$).

Table 3: Parameter estimates and goodness of fit criteria for the different models by sex

Parameter	Gompertz		Logistics		Richard	
	Male	Female	Male	Female	Male	Female
A	317.25	314.87	312.89	305.45	311.10	303.63
B	0.8779	0.6609	1.9140	1.5591	3.3944	2.1937
C	0.1945	0.1474	0.2812	0.1780	0.3534	0.2449
D	-	-	-	-	1.8049	1.3508
R^2	0.5695	0.4944	0.7870	0.7484	0.8582	0.8321
MSE	7192.0	8122.4	7116.8	8091.8	7112.1	8098.4
AIC	8885.8	9007.4	8875.2	9003.6	8875.6	9005.5

a =Asymptote weight, b = Scale parameter (constant), c =Relative growth rate, d = Shape parameter R^2 = Coefficient of determination, MSE =Mean Square Error and AIC = Akaike's Information Criterion

Table 4: Correlation coefficients of the model parameters by sex

Parameter	Gompertz		Logistics		Richard	
	Female	Male	Female	Male	Female	Male
Rab	- 0.2808	-0.2885	-0.2157	-0.1959	-.6468	-0.4905
Rac	-0.7863	-0.6612	-0.6248	-0.4939	-0.7364	-0.5591
Rad	-	-	-	-	-0.6356	-0.4791
Rbc	0.6830	0.7759	0.7818	0.8459	0.9757	0.9826
Rbd	-	-	-	-	0.9952	0.9912
Rcd	-	-	-	-	0.9577	0.9578

a =Asymptote weight, b = Scale parameter (constant), c =Relative growth rate, d = Shape parameter
r = correlation

CONCLUSION

The study reveals that all the models (Gompertz, Logistic and Richards) gave a suitable fit to the growth data and can be used to describe growth of squabs but the Logistic and Richards gave a better fit to the data. Furthermore, the predicted growth curves did not deviate substantially from the actual live body weights at the different ages. Thus, the shape of the predicted growth curves was typically sigmoid for both male and female squabs. However, use of other models apart from Gompertz, Logistic and Richards to identify the best model that fit their pattern of growth is recommended.

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