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GROWTH DESCRIPTION OF PURE AND CROSSBRED TURKEYS USING NON-LINEAR MODELS IN HOT AND HUMID TROPICAL ENVIRONMENT

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ABSTRACT

This study was conducted to compare three non-linear growth models (Logistics, Gompertz and Von Bertalanffy) in describing the growth of 360 turkeys of three genotypes (exotic, crossbred and local). The growth curve parameters−*A*, *B* and *K* for each growth model were estimated for each turkey using the NLIN procedure (Marquart algorithm) for the Bayesian approach with a fixed-effect model. The best fit of the three models was also estimated. A comparison was done among the three models using Akaike Information Criteria (AIC) and the Bayesian Information Criteria (BIC). Pearson product-moment correlation coefficient (r), the correlation coefficient, was used to examine the linear relationship between two quantities, *A* and *K* growth model parameters. For comparison of growth models parameter predicted, the Von Bertalanffy's model predicted the smallest value in both criteria for all the male and local female turkeys, while Gompertz's growth model had the smallest predicted value in both criteria for the female exotic and female crossbred turkeys. Based on the goodness of fit using the Bayesian Model Choice Criteria (Deviance Information Criteria), Von Bertalanffy's growth model showed the best fit. However, the difference between Bertalanffy's and Gompertz's growth models is very minimal, thus, making both models suitable for modeling the growth curve of domestic turkey and to consider how this weight is attained.

Key words: turkey; non-linear growth model; logistics, Gompertz; Von Bertalanffy

INTRODUCTION

The domestic turkey (*Meleagris gallopavo*) is an important poultry species that has gain popularity in Nigeria because of its meat, which contributes to the protein need of our growing population (Ilori *et al.*, 2019; Ilori *et al.*, 2021). The available turkey populations in Nigeria include the local turkey, the exotic and their crossbreds. The Nigerian local turkey, although not as big as the locally adapted exotic Nicholas white turkey, is adapted to a wide range of climatic conditions, especially when adequately fed and reared under proper management conditions. The exotic turkey, on the other hand, are less adaptable to the tropical environment characterized by an adverse weather condition and infectious diseases (Ilori *et al.*, 2011; Agbonika & Folorunsho, 2020). Crossbred turkeys in Nigeria are usually generated as crosses using the Nigeria local turkey and exotic turkeys such as British United turkey, Nicholas white turkey and recent hybrid converter turkey. They are characterized by better

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growth performance and fitness compared to their local counterpart (Ilori *et al.*, 2010; Ilori *et al.*, 2011).

Growth is a fundamental property of any biological system depicting an increase in body size per time unit (Lawrence & Fowler, 2002; Rizzi *et al.*, 2013). It occurs in the entirety of an animal's life and is accompanied by the utilization of the materials and increased volume, size or shape of an organism (Sezer & Tarham, 2005). Genetic potential for growth and maturity period are two important parameters of growth (Ersoy *et al.*, 2005). These parameters can be predicted to estimate the time, when birds are ready for sale and contribute to poultry production profitability. The size and shape of an individual, progressively change consequent upon the differential growth of component body parts. However, most of these growth processes can not be continuously measured. Hence, mathematical functions are used to model measurements with the potential to extrapolate a non-observed intervals. Growth performance traits are very important in assessing the potential of genetic improvement and development of any livestock breed/strain. Such knowledge is essential for proper planning of breeding programmes and in adopting breeding choices/strategies. These are also essential in poultry production being fundamental attributes for assessing growth and feed efficiency as well as important parameters in economic decision making and management (Assan, 2015; Oleforuh-Okoleh *et al.*, 2017).

Mathematical functions are used in modeling growth in avian species with most being asymptotic and mechanistic (Narinc *et al.*, 2017; Durosaro *et al.*, 2021). Genetic improvement for growth performance in any livestock species or strain is based on selection for optimum performance at a specific time in their development. Mathematical models having parameters with biological interpretations are used to explain growth. Asymptotic models allow for a point, where there is no more growth, while mechanistic models predict animals through some other known theories. These models are valuable in identifying better strategies for improved livestock production including estimation of daily nutrient requirements (Pomar *et al.*, 2009), development of breeding strategies, explanation of growth pattern (Narinc *et al.*, 2017) and in selection studies. As growth rate differs in every phase of an animal's life, nonlinear models are used in estimating growth parameters instead of linear models (Ersoy *et al.*, 2005). Numerous growth equations have been developed to describe and fit the nonlinear sigmoid relationship between growth and time (Roush & Branton, 2005). Thornley & France (2007) broadly classified growth functions: (1) those that describe diminishing return behaviour; (2) those related to sigmoidal behaviour with a fixed point of inflection; and (3) those related to sigmoidal behaviour with a flexible point of inflection. Growth models describing the S-shaped (sigmoidal); asymptotic growth patterns comprise Von Bertalanffy (Von Bertalanffy, 1960), Gompertz (France & Thornley, 1984; Laird, 1964), Richards (Richards, 1959) and Logistic (Grossman *et al.*, 1985; Grossman & Bohren, 1985; Mead *et al.*, 1993) models. Several nonlinear models have been used to predict the growth patterns of many avian species. Juárez-Caratachea (2019) modelled age-weight relationship in local turkey using non-linear Gompertz, Brody, Richards, Von Bertalanffy and Logistic models in describing the growth curve. Arando *et al.* (2021) used seven non-linear growth models to evaluate growth curve of Andalusian turkey. Rivera-Toress *et al.* (2011) used mechanistic simulation model of energy and nutrient utilization in growing turkeys. Sengul & Kiraz (2005) used four non-linear models (Gompertz, Logistic, Morgan-Mercer-Flodin (MMF) and Richards) to explain the growth curve of male and female large white turkeys and to determine the best model for the turkeys, while Sogut *et al.*, (2016) used Logistic, Gompertz, Von Bertalanffy, and Gauss models to describe the growth curve of large white turkey. The description of growth curve using growth models in Nigerian turkeys is very scarce in literature. Also, no information is available on how sex dimorphism in turkey affects the growth patterns and the biological interpretation of growth parameters. These models have been used for estimation of daily nutrient requirement, development of breeding strategies, explanation of growth pattern and prediction of body weight in other poultry species. Furthermore, there is no current information on the comparison of growth models between pure local, crossbred and exotic genotypes of turkeys in the hot humid tropical environment. Therefore, this study is aimed at estimating the parameters of three mathematical nonlinear growth models (Logistics, Gompertz, and

Von Bertalanffy) of three turkey genotypes reared in the hot humid environment and also to compare the effect of sex on the growth pattern of the three genotypes of turkeys using the fixed effect model.

MATERIAL AND METHODS

Experimental Site

This experiment was conducted at the Turkey Breeding Unit of the Directorate of University Farms (DUFARMS) Federal University of Agriculture, Alabata Road, Abeokuta, Ogun State, Nigeria. The University is located on latitude N7° 14' 37" and Longitude E3° 20' 35" of the Southwestern part of Nigeria with a prevailing tropical climate with a mean annual rainfall of about 1037 mm. The mean monthly ambient temperatures range from 28 °C to 36 °C between October and March with a yearly average relative humidity of about 82 %. The University vegetation represents interphase between the tropical rainforest and the derived savannah (Ilori *et al.*, 2017; Google Map, 2021).

Source, sample size and management of experimental birds

The experimental birds were generated and selected from the parent stock being maintained at the farm and used for this experiment. The parent stock comprised of 30 local (5 males, 25 females) and 30 exotic (5 males, 25 females of Nicholas white exotic breed of turkey) birds, which were used to generate 150 local poults, 162 exotic poults and 125 crossbred poults from the two genotypes (5 male Nicholas white turkey x 25 female local). One hundred and twenty poults each of the three genotypes were selected for the study. Semen was collected from toms by the abdominal massage technique, as described by Lake (1962) with the help of two operators, who collected semen from the toms after a period of training for two weeks. The hens were then artificially inseminated with fresh undiluted semen, as described by Lake (1962). The semen collection and insemination were done twice a week in the afternoon to ensure the production of fertile eggs. Eggs from the three crosses were collected daily, identified appropriately and set in the incubator according to the mating pattern/design weekly. The poults were brooded in separate deep litter pens according to their genetic group. All poults were wing-tagged for proper identification and subjected to the same management practices throughout the experimental period of 20 weeks. Commmercial turkey feed and clean water were provided for the birds *ad libitum*. The poults were fed starters mash containing 28 % of Crude Protein (CP) from day old to 8th week, growers mash (24 % CP) from 8th to 14th week and layers mash (20 % CP) from 15th week till the end of the data collection. The birds were tagged as male or female at 8 weeks of age, when distinct physical sexual characteristics were obvious. The design of the experiment was such, that each turkey served as a replicate in the experiment. The poults were vaccinated against Marek's desease, Newcastle and infectious bronchitis diseases at day old from the hatchery. Subsequent vaccinations, including the Newcastle disease vaccine and the Fowlpox vaccine were given as at when due. Adequate sanitation was practiced to prevent oubreak of diseases. The protocol for the experiment was approved by Animal Care and Use Committee of College of Animal science and Livestock production of the Federal University of Agriculture, P.M.B. 2240, Abeokuta, Ogun State Nigeria with approval reference FUNAAB/AEWC/2019/0075.

Data Collection

Live weights of each turkey for the three genotypes were recorded every week from day old till 20 weeks of age using a measuring scale of 0.05 g sensitivity.

Statistical Analysis

The nonlinear model for growth data using REML approach for animal i can be expressed as:

$BW_{ij} = f(\theta_i, t_{ij}) + e_{ij}$ $\quad$ $i = 1, N$ and $j = 1, n_i$

where − f is the nonlinear function relating the response variable (BW_{ij}) to time (t_{ij}), θ_i is a vector including the parameters of the non-linear function, N is the number of animals and n_i is the number of measurements taken from animal i.

Turkey growth data were fitted to the Logistic, Gompertz, (Gompertz, 1825) and Von Bertalanffy (Von Bertalanffy, 1957) growth models including fixed parameters A, B and K as described in Table 1.

Table 1. Predicted body weight of turkeys using three non-linear models

Model	$BW_{ij} = f(\theta_i, t_{ij}) + e_{ij}$	t_{inf}	W_{inf}
Logistic	$BW_{ij} = A_i\,(1 + B_i \exp\{-K_i\, t_{ij}\})^{-1} + e_{ij}$	$-\frac{\log\left(\frac{1}{B_i}\right)}{K_i}$	$\frac{A_i}{2}$
Gompertz	$BW_{ij} = A_i\, exp\,\{-B_i \exp\{-K_i\, t_{ij}\}\} + e_{ij}$	$-\frac{\log(B_i)}{K_i}$	$\frac{A_i}{2.7182}$
Von Bertalanffy	$BW_{ij} = A_i\,(1 - B_i \exp\{-K_i\, t_{ij}\})^3 + e_{ij}$	$\frac{\log(B_i) + \log(3)}{K_i}$	$\frac{8A_i}{27}$

In these models, BW_{ij} is the body weight of turkey at age (week) t_{ij}; A is the asymptotic weight or an estimation of mature weight as age approaches infinity ($t_i \rightarrow \infty$); B is the integration constant defining the degree of maturity at $t_i = 0$; K is the rate of maturing and refers to growth rate relative to mature weight. e_i is the residuals with the assumption of $e_i \sim N(0,\sigma^2 I_i)$ where $\sigma^2 I_i$ is the residual variance structure for all subjects, assuming that no covariance structure exists between the residuals of the model. t_{inf} and W_{inf} are the age and weight at the inflection point of the growth model, respectively. Growth curve parameters; asymptotic weight (A), integration constant (B) and rate of maturing (K) for Logistic, Gompertz or Von Bertalanffy growth models were estimated for each turkey using the procedure of NLIN (Marquart algorithm) (SAS, 2000). The age and weight at the inflection point (t_{inf} and W_{inf}) for each turkey were calculated using estimated growth curve parameters. Then, the arithmetic means, standard error of arithmetic mean, minimum and maximum values of the estimates of growth curve parameters, and the age and weight at the inflection point (t_{inf} and W_{inf}) were calculated using the procedure of MEANS/ANOVA in the same SAS package for sex and genotype of sire within the growth models. Comparisons between Logistic, Gompertz or Von Bertalanffy growth models were carried out using the Akaike Information Criteria (AIC) and the Bayesian Information Criteria (BIC). The AIC and BIC were calculated by running the procedure of NLMIXED with the ML method available in the SAS package (SAS, 2000) for each growth model. The Pearson product-moment correlation coefficient (r), simply called the correlation coefficient, was used to examine the linear relationship between two quantities, such as the A and K growth model parameters. The Pearson correlation is defined between -1 and +1 ($-1 \leq r \leq 1$), where -1 indicates a perfect decreasing (negative) linear relationship, +1 indicates a perfect positive (increasing) linear relationship, and some values between -1 and +1 in all other cases indicate the degree of linear dependence between the A and K parameters.

RESULTS

Effect of a genotype and sex on parameter estimates of Logistic growth model based on Fixed Effect Model

The mean and standard error of parameter estimates for the Logistic growth curve fitted for genotype and sex based on the Fixed Effect Model are shown in Table 2.

The local turkey female had the lowest asymptotic weight A (2541.6 g), B (16.4338 g), and W_{inf} (1270.8 g) while the exotic male had the highest A (4744.5 g), K (0.284670 g) and W_{inf} (2372.2 g). The female crossbred had the highest age at inflection point followed by the male crossbred, while the least was observed in male exotic turkeys. Figures 1 and 2 (annex) showed the predicted growth curve from estimated body weight using the Logistic growth model on the three genotypes of turkey for both males and females. In Figure 1, the male exotic turkey had a higher growth rate from onset to the end

Table 2. Estimated mean and standard error for the Logistic growth model parameters fitted for genotype and sex based on the Fixed Effect Model

		Growth Curve Parameters				
Sex	Genotype	*A*	*B*	*K*	t_{inf}	W_{inf}
Male	Local	3365.7 ± 72.6	22.0715 ± 1.6120	0.275096 ± 0.007119	11.3 ± 0.2	1682.8 ± 36.3
Male	Exotic	4744.5 ± 63.3	19.9329 ± 1.1258	0.284670 ± 0.005311	10.5 ± 0.2	2372.2 ± 31.7
Male	Cross	4029.5 ± 152.7	20.9130 ± 1.0510	0.237521 ± 0.007996	13.0 ± 0.5	2014.7 ± 76.3
Female	Local	2541.6 ± 57.5	16.4338 ± 0.6774	0.258756 ± 0.005219	10.8 ± 0.2	1270.8 ± 28.8
Female	Exotic	4636.9 ± 129.2	23.2705 ± 1.9117	0.268468 ± 0.008408	11.7 ± 0.4	2318.4 ± 64.6
Female	Cross	3806.7 ± 133.0	25.3976 ± 1.2959	0.245381 ± 0.008673	13.3 ± 0.5	1903.3 ± 66.5

A = Asymptotic weight, *B* = Integration constant, *K* = Maturing rate, t_{inf} = Age at inflection point, W_{inf} = Weight at inflection point

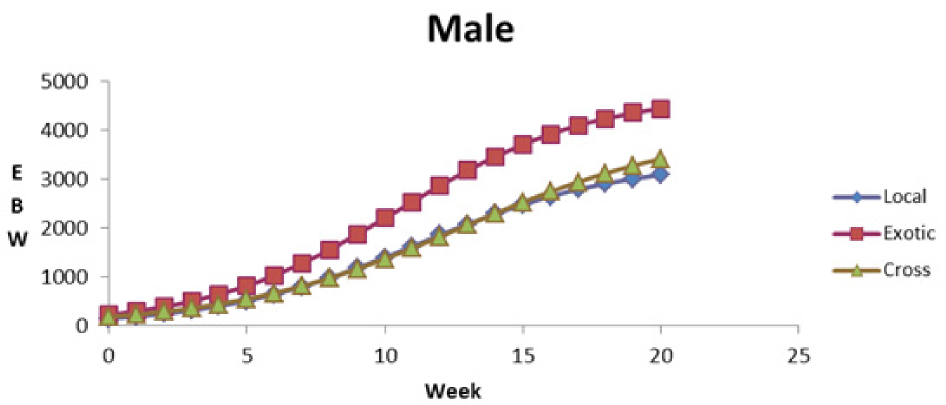

Figure 1. Predicted growth curve of male turkeys selected for 20 week body weight using Logistic growth model based on Fixed Effect Model

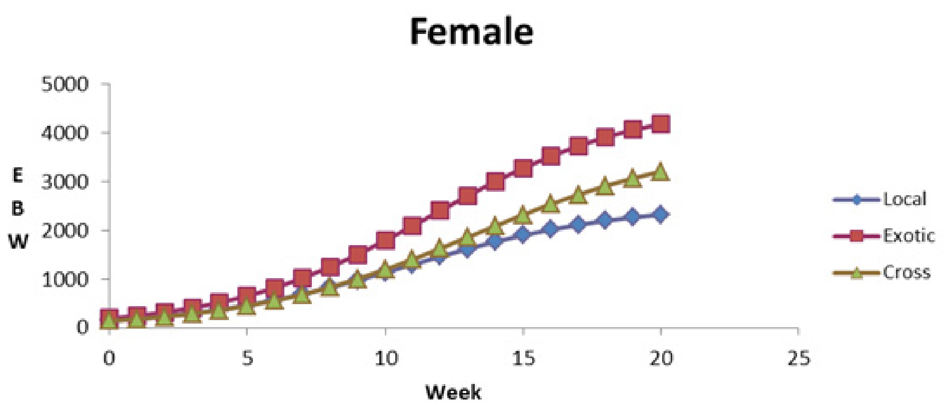

Figure 2. Predicted growth curve of female turkeys selected for 20 week body weight using Logistic growth model based on Fixed Effect Model

and also had the highest estimated 20-week bodyweight. The crossbred and local males had a similar growth rate from $t = 0$ until the 18th week, when the crossbred slightly performed better than the local with 100 g. The growth curve for the female genotype (Figure 2) shows that all the genotypes started similarly ($t = 0$) until the 5th week, when growth variation was obvious between genotypes. As revealed from the figure, the exotic females were different from the other genotypes with superior estimated body weight at 20-week.

Effect of a genotype and sex on parameter estimates of Gompertz growth model based on Fixed Effect Model

The estimated mean and standard error of parameter estimates for the Gompertz growth curve fitted for genotype and sex based on the Fixed Effect Model are shown in Table 3.

The lowest mean for asymptotic weight, integration constant and weight at inflection point were observed in female local turkeys. However, its maturing rate was similar to that of female exotic

Table 3. Estimated mean and standard error for the Gompertz's growth model parameters fitted for genotype and sex based on the Fixed Effect Model

		Growth Curve Parameters				
Sex	Genotype	*A*	*B*	*K*	t_{inf}	W_{inf}
Male	Local	4178.9 ± 138.7	4.2807 ± 0.1473	0.144879 ± 0.005291	10.5 ± 0.3	1537.4 ± 51.0
Male	Exotic	5499.3 ± 105.5	4.1433 ± 0.1118	0.154660 ± 0.003827	9.2 ± 0.2	2023.1 ± 38.8
Male	Cross	5378.1 ± 363.3	4.0141 ± 0.0848	0.115228 ± 0.005578	12.7 ± 0.8	1978.5 ± 133.7
Female	Local	3046.4 ± 92.1	3.7213 ± 0.0688	0.139727 ± 0.003644	9.7 ± 0.3	1120.7 ± 33.9
Female	Exotic	5844.2 ± 311.7	4.2831 ± 0.1499	0.134778 ± 0.007458	11.0 ± 0.7	2150.0 ± 114.7
Female	Cross	5183.7 ± 252.1	4.3163 ± 0.0929	0.114477 ± 0.005893	13.2 ± 0.6	1907.0 ± 92.7

A = Asymptotic weight, *B* = Integration constant, *K* = Maturing rate, t_{inf} = Age at inflection point, W_{inf} = Weight at inflection point

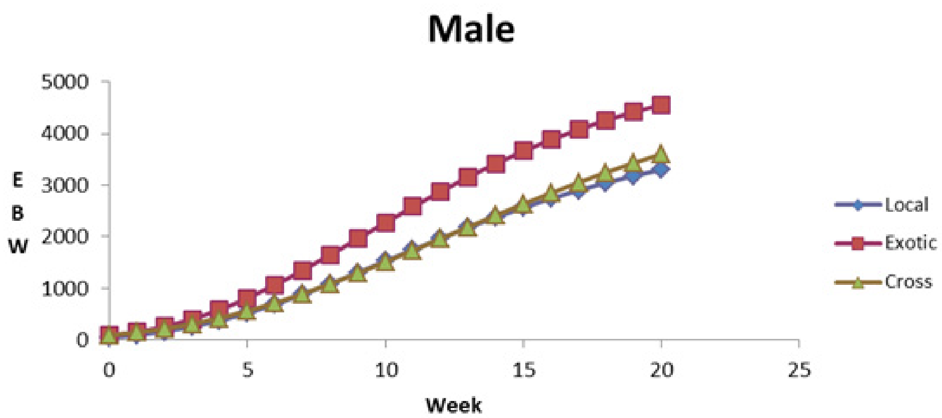

Figure 3. Predicted growth curve of male turkeys selected for 20 week body weight using Gompertz's growth model based on Fixed Effect Model

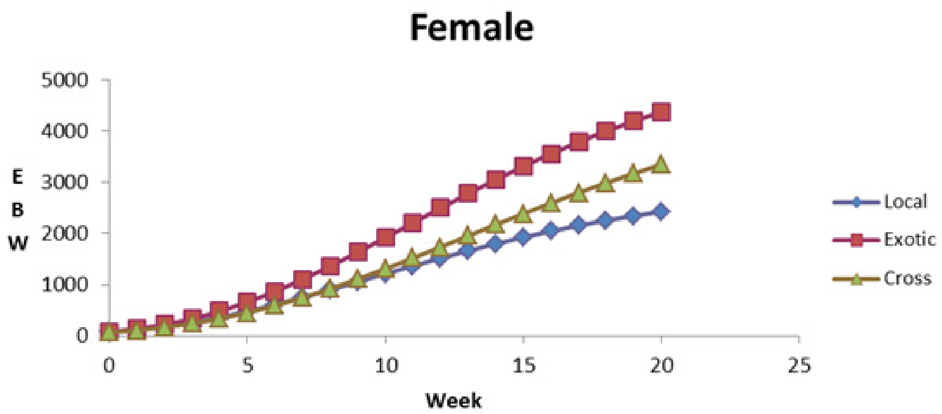

Figure 4. Predicted growth curve of female turkeys selected for 20 week body weight using Gompertz's growth model based on Fixed Effect Model

turkeys and higher than that of male and female crossbred turkeys. The highest value of A and W_{inf} was obtained in female exotic turkeys. The maturing rate ranged from lowest in female crossbred turkey to highest in male exotic turkey. The age at the inflection point was lowest in male exotic turkeys and highest in female crossbred turkeys. Figures 3 and 4 (annex) show the growth curve of male and female turkeys selected for 20-week bodyweight, as predicted by the Gompertz growth model based on the Fixed Effect Model. In Figure 3, the male exotic turkey had the best growth rate from the beginning to the end with an estimated 20-week bodyweight of 4800 g, while the lowest estimated body weight at 20-week was observed in the male local turkey. In Figure 4, the lowest estimated body weight at 20-week was recorded in the female local turkey. The exotic female, on the other hand, had the best growth rate with the best estimated body weight at the end of the experiment.

Effect of a genotype and sex on parameter estimates of Bertalanffy growth model based on Fixed Effect Model

Table 4 presents the estimated means and standard error of parameter estimates for the Von Bertalanffy growth curve fitted for genotype and sex based on the Fixed Effect Model.

Table 4. Estimated mean and standard error for the Von Bertalanffy's growth model parameters fitted for genotype and sex based on the Fixed Effect Model

		Growth Curve Parameters				
Sex	Genotype	A	B	K	t_{inf}	W_{inf}
Male	Local	5222.2 ± 271.2	0.8515 ± 0.0141	0.099325 ± 0.004422	10.5 ± 0.4	1547.3 ± 80.4
Male	Exotic	6217.2 ± 160.3	0.8467 ± 0.0163	0.109814 ± 0.003582	8.5 ± 0.2	1842.1 ± 47.5
Male	Cross	6763.1 ± 426.4	0.8063 ± 0.0097	0.074026 ± 0.004764	12.9 ± 0.9	2003.9 ± 126.3
Female	Local	3598.2 ± 145.3	0.7849 ± 0.0099	0.098305 ± 0.003309	9.2 ± 0.3	1066.1 ± 43.0
Female	Exotic	7334.7 ± 654.3	0.8487 ± 0.0187	0.088949 ± 0.007366	11.1 ± 1.0	2173.2 ± 193.9
Female	Cross	7599.6 ± 642.6	0.8417 ± 0.0107	0.068102 ± 0.005308	14.9 ± 1.1	2251.7 ± 190.4

A = Asymptotic weight, B = Integration constant, K = Maturing rate, t_{inf} = Age at inflection point, W_{inf} = Weight at inflection point

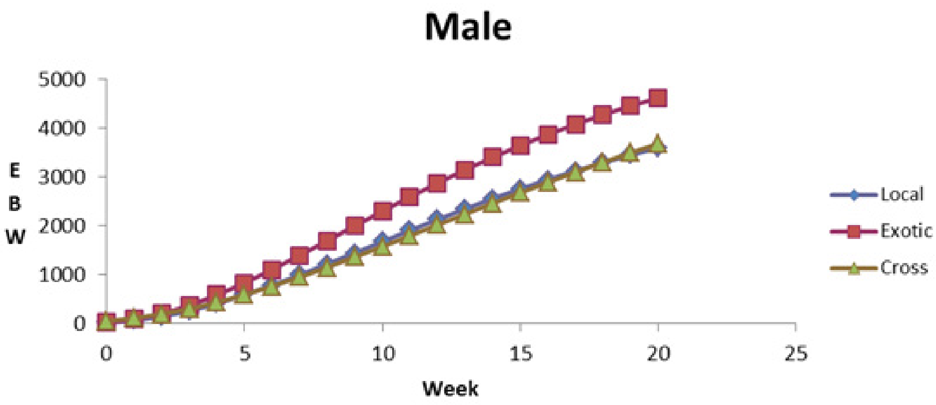

Figure 5. Predicted growth curve of male turkeys selected for 20 week body weight using Von Bertalanffy's growth model based on Fixed Effect Model

The female crossbred turkey had the highest value for *A* (7599 g), t_{inf} (14.9 weeks) and W_{inf} (2251.7 g) and are more than double the lowest means obtained for the local female turkey (A = 3598.2 g and W_{inf} = 1066.1 g). The age at the inflection point was lowest in male exotic turkeys and highest in female crossbred turkeys. The highest integration constant was observed in male local turkey followed by the female exotic and then the female local turkey. The least maturing rate was observed in female crossbred turkeys and the highest obtained in the male exotic turkey. Figures 5 and 6 (annex) show the predicted growth curve of male and female turkey genotypes using the Von Bertalanffy growth model based on the Fixed Effect Model. The exotic male turkey had the highest growth rate with the highest estimated 20-week body weight, while the same growth rate and estimated body weight at 20-week was recorded for both local and crossbred male turkey. Different growth rate was obtained for the three female genotypes (Figure 6), with the exotic female having the best growth rate, which culminated in the highest estimated body weight of 4300 g, while the least (2400 g) was obtained in the female local turkey.

Comparison of models for best fit based on Fixed Effect Model

Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) used to select the better fit model used in modeling the growth curve for males and females of the three turkey genotypes are shown in Table 5.

It was observed that the Von Bertalanffy growth model had the smallest predicted value

Table 5. Criteria of choice for the three growth models

		Logistic		Gompertz		Von Bertalanffy	
Sex	Genotype	AIC	BIC	AIC	BIC	AIC	BIC
Male	Local	19992	20014	19835	19856	19804	19825
Male	Exotic	2773	2787	2638	2651	2600	2613
Male	Cross	6437	6454	5974	5991	5838	5854
Female	Local	16925	16946	16763	16783	16717	16737
Female	Exotic	2557	2570	2507	2520	2556	2569
Female	Cross	5314	5330	4896	4912	4903	4919

Model choice criteria (Smallest value indicates the better-fitted model) in both criteria for all the male and local female turkeys, while the Gompertz growth model had the smallest predicted value in both criteria for the female exotic and female crossbred turkeys. However, the difference between Von Bertalanffy's and Gompertz's growth models is very minimal, thus, making both models suitable for modeling the growth curve of domestic turkey.

Correlation between asymptotic weight A and maturing rate k within the three growth models

Pearson correlation between asymptotic weight A and maturing rate K for all three growth models used is shown in Table 6.

Negative correlations existed between asymptotic weights and maturing rates for all the genotypes and sex considered. The highest negative correlation was recorded in female exotic turkeys (-0.866, -0.985, -0.967) for Logistic, Gompertz and Von Bartalanffy, respectively. The lowest negative correlation was observed in male exotic turkey for Logistic and Gompertz models, while the least was obtained in male local turkey for Von Bertalanffy's growth model.

DISCUSSION

The fixed effect model is a statistical approach, where the model parameters are non-random quantities with fixed effect population mean using Logistic, Gompertz and Von Bertalanffy. The Von Bertalanffy's model predicted the highest asymptotic final weight in two sexes of the three turkey genotypes. This prediction is followed by that of Gompertz, while the least asymptotic final weight was observed in Logistic. Like the case of mixed models, the fixed effect model also gives a good prediction and fits the data adequately, which corroborates other studies in different species including cattle (Berry *et al.*, 2005) and sheep (Gbangboche *et al.*, 2008). However, little difference existed between both models in fit statistics in the exploratory dataset. Also, when their ability to predict future animal live weight in the forward prediction dataset was considered, the ability of the mixed model equations was in all cases superior to the fixed effect models for the same criteria. Mixed model equations account for the population mean but also the individual animal deviations from that mean, thereby potentially accounting for more of the variance compared to the fixed-effect models. The superiority of mixed models is particularly important, when the growth rate is starting to plateau. The fixed terms use data on contemporaries to model this plateauing effect. This influences the predicted future growth trajectory of animals without sufficient data to inform the algorithm that their growth rate is, or will soon start to slow down (Coyne *et al.*, 2015). The growth rate (*B*), which is the proportion of the asymptotic mature weight to be gained after birth, was higher in the Logistic model for all the genotypes, while the least integration constant was observed in the Von Bertalanffy's model. This, however, was adduced to the fact that the Logistic model predicts 50 % of the asymptotic final weight at the inflection point, which could be realized by higher initial weight (Ozoje *et al.*, 2007; Zhao *et al.*, 2015). The maturing rate (*K*) was also higher in the Logistic model and lowest in the Von Bertalanffy's model for all genotypes in the different sexes. To achieve the 50 % growth before inflection, as observed in this model,

Table 6. Pearson correlation between *A* and *K* parameters within each model

		Logistic		Gompertz		Von Bertalanffy	
Sex	Genotype	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
Male	Local	-0.686	0.0001	-0.775	0.0001	-0.792	0.0001
Male	Exotic	-0.360	0.3073	-0.715	0.02	-0.844	0.0001
Male	Cross	-0.761	0.0001	-0.761	0.0001	-0.866	0.0001
Female	Local	-0.457	0.0002	-0.717	0.0001	-0.800	0.0001
Female	Exotic	-0.866	0.0025	-0.985	0.0001	-0.967	0.0001
Female	Cross	-0.727	0.0004	-0.895	0.0001	-0.907	0.0001

it is assumed that maturing rate will be high and may subsequently lead to a smaller mature weight. For the age at inflection, the Von Bertalanffy predicted fairly lowest and the longest growing period compared to other models, which could be ascribed to the fact that the animals, that are generally heavier at maturity, tend to take longer growing period to mature (Taylor and Fitzhugh, 1971). The longer growing period, used by the crossbred turkey male and females compared to the other genotypes and their sexes, could be attributed to the effect of crossbreeding on their maturing rate. There is a relationship between the asymptotic weight and the weight at inflection based on the time taken to reach the inflection point. There are few differences between models regarding weight at inflection. The fairly higher weight at inflection was observed using the Logistic model, while the least was observed in the Gompertz's model, even though the Von Bertalanffy had the highest asymptotic weight and took a longer period to reach the point of inflection. Abe (2016) observed the highest weight at inflection with a longer period to reach the inflection point in chicken and suggested, that the longer period to reach inflection point could be the reason for the better weight at inflection. The exotic turkey male had the highest weight at inflection using the Logistic function while the least was observed in the local turkey female. The crossbred turkey female had the highest weight at inflection using the Von Bertalanffy, while the least was also observed in the local turkey female.

Using the fixed effect model, the exotic turkey male had the highest asymptotic final weight and weight at the inflection point compared to the other genotypes in the Logistic model. The longer time taken by the crossbred and especially the females to reach the inflection point may have contributed to their superior weight at the point of inflection compared to the local turkey. This may also be due to the effect of crossbreeding on the growth performance of this turkey. Sexual dimorphism was only in favour of males in the Logistic model, while females were favoured at weight at inflection for both Gompertz's and Von Bertalanffy's models. Differences in weight between sexes have also been reported in Japanese quail (Kizilkaya *et al.*, 2004).

From all the growth curves, using the fixed effect model, exotic turkey males and females had the highest estimated body weight at 20 weeks followed by the crossbred turkey, while the least was estimated in the local turkey. However, only the Von Bertalanffy's model estimated the same body weight for both female crossbred and local turkeys. This superiority of exotic turkey, as stated earlier, has been the effect of selection over many generations for improved performance (Ilori *et al.*, 2010).

The result of the study for the model with the lowest values (Galeano-Vasco *et al.*, 2014), as predicted by AIC and BIC, showed that the Von Bertalanffy's growth model had the smallest predicted value in both criteria and the best fit for all the turkey males and local turkey females while Gompertz´s growth model had the best fit for the female exotic and female crossbred turkeys. However, the difference between Von Bertalanffy's and Gompertz's growth models is minimal, thus, making them fit for modeling the growth curve of domestic turkey. Sogut *et al.* (2016) and Segura-Correa *et al.* (2017) had reported Von Bertalanffy's as the best model for fitting the growth curve of turkey. Gompertz was also considered as a model of choice with the best fit especially in chicken (Galeano-Vasco & Cerón-Muñoz, 2013; Abe, 2016). The disparity in the different models for body weight prediction maybe attributed to variations in the maturing patterns of the different genotypes.

According to Carrijo and Duarte (1999), negative correlations existed between *A* and *K*, which is an inverse relationship such that animals with heavier average asymptotic weight had the lowest values of *K*. There are negative correlations existed between asymptotic weights and maturing rates for all the genotypes and sex considered. The highest negative correlation was recorded in female exotic turkeys for Logistic, Gompertz and Bartalanffy respectively. The lowest negative correlation was observed in male exotic turkey for Logistic's and Gompertz's models, while the least was obtained in local turkey male for the Von Bertalanffy's growth model. The highest negative correlation, as observed in the female crossbred turkey, could be attributed to the fact that the alleles responsible for the growth rate in this population are not yet fixed and are still segregating, which might facilitate a longer period to reach an inflection point in this genotype. Similar trends have been adduced to the fact that early maturing animals tend to attain smaller mature weight, while high mature weight is related to a long growing period

(Kizilkaya *et al.*, 2006). Previous studies (Mignon-Grasteau, 1999; Lewis *et al.*, 2002) have exploited fixed effect models for the development of growth curves in a range of species. Gossett *et al.* (2007) reported that the mixed model equations, when incorporated into the Gompertz growth function, were the best type of models to model the growth curve of premature human infants. Therefore, the results of the present study indicate that mixed model equations should also be considered in the implementation of growth curves.

CONCLUSION

Our study, using AIC and BIC in the fixed effect model, shows that the Von Bertalanffy's growth model had the smallest predicted value in both criteria and the best fit for all the male turkeys and local female turkey, while the Gompertz's growth model had the best fit for the female exotic and female crossbred turkeys. However, the difference between Von Bertalanffy's and Gompertz's growth models is very minimal, thus, making them fit for modeling the growth curve of domestic turkey. The fixed effect model using the Von Bertalanffy's growth model well described the turkey data set for asymptotic final weight. The negative correlation between *A* and *K* showed that early maturing turkey will attain smaller weight or lighter asymptotic weight and associated with a high inflection point. Optimization of profitability of commercial poultry production depends on careful consideration of the growth curve and the parameters of the growth curve.

AUTHOR CONTRIBUTIONS

Conceptualization: Ozoje, M. O., Peters, S. O., Ilori, B. M.

Methodology: Peters, S. O., Ilori, B. M., Durosaro, S. O.

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All authors have read and agreed to the published version of the manuscript.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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