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Modeling growth of Nigerian indigenous and tropically adapted chicken genotypes using developmental parameters

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Target Audience: *Researchers, Animal geneticist, Animal breeders and Animal nutritionist*

Abstract

The possibility of modeling growth with the aim of visualizing growth patterns over time, and generating equations that can be used to predict the expected weight of the animal at specific age could be an impetus for optimization of farmer's livelihood. The weekly body weight of 993 off-springs of seven genotypes of chicken, consisting of Nera Black-NB, White Leghorn-WL, Giriraja-GR, Naked Neck-NN, Frizzle Feather-FF, Normal Feather-NF and FUNAAB Alpha chicken-BA, were fitted to Logistic, Gompertz, Richards and Bertalanffy growth model using the procedure of NLIN (Marquart algorithm) based on Restricted Maximum Likelihood approach (ReML). The study revealed that GR chickens performed better than other genotypes, while BA had superior performance compared to the indigenous and the WL chickens. However, among the indigenous, the performance of NN chickens was best. There was a negative correlated relationship observed between asymptotic weight (A) and maturing rate (k). Gompertz model best fit the chicken data according to Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) for FF, NF, and GR while Richards model on the other hand, had better fit for NN, NB and WL. Bertalanffy model was the best for BA chicken. The study concludes that high k will produce smaller A. Furthermore, mixing of improved exotic genes with the indigenous produces improved and better adapted genotypes in BA. AIC and BIC with ReML approach presented Gompertz model with wide applicability among the indigenous chickens while Richards model fit well for the locally adapted exotic chickens.

Keywords: *Growth model; Restricted Maximum Likelihood; indigenous chickens; model best fit*

Description of Problems

Commercial poultry production is aimed at optimizing productivity through control and modification of the external conditions that may pose a threat to weight gain (1, 2). In favour of this fact, certain major adaptive genes have been found to be relevant in some indigenous breeds with respect to tropical production environment which is characterized by heat stress (3, 4). The feather distribution and feather structure are among these adaptive major genes. The frizzle and the naked neck genes in particular have been described as adaptability genes (5). These genes cause a reduction in tropical heat stress by improving the chicken's ability for convection, resulting in improved feed conversion and better performance (6). Likewise, exotic chicken genotypes in their native environment (temperate) have evolved through series of breeding and selection processes over several generations leading to better performance over the indigenous breeds. However, it has been reported that their performance is sometimes affected by environment if taken out of their native production environment (5, 7, 8). Giriraja and FUNAAB Alpha, are dual purpose breeds cut in between the indigenous and the exotic. These breeds were developed in the tropics as an improvement over the indigenous. Due to this favourable attributes, the local stock of indigenous origin has led to the development of a more productive and adaptive chicken of Nigerian origin, known as the FUNAAB-Alpha (9).

To fully understand and appreciate the comparison between and within chicken genotypes in relation to their growth pattern in diverse environment, growth models which are generally used to describe increase in body weight of an individual over time is a vital tool to describe growth (10). Growth models like the Gompertz, Richards, Logistic, Bertalanffy are considered in this study because they are robust and are the most commonly used model to define body growth in animal science (11, 12). Also, many studies have been carried out to determine the growth pattern of chickens (12, 13, 14) turkeys (14, 15) and Japanese quails (14, 16, 17) by fitting the most common non-linear growth model such as Gompertz, Logistic, Bertalanffy and Richards models to the time-body weight information.

In this study, growth and developmental data of three exotic, one crossbred and three indigenous chicken genotypes were fitted to four growth models in other to determine the model of best fit and also provide a scientific basis for the utilization of Nigerian indigenous genotypes, so also its comparability with some developed exotic breeds.

Materials and methods

Site of the experiment

This research was conducted at the Poultry Breeding Unit of the Directorate of the university farms (DUFARMS) of the Federal University of Agriculture, Abeokuta, located within latitude 7◦10‘N and a longitude 3◦2‘E of Southwestern Nigeria.

Experimental birds and management

The data used for this study were obtained from 993 offspring of seven genotypes of chicken consisting of 331 locally adapted exotic chickens (Nera Black (NB) - 133, White Leghorn (WL) - 93 and Giriraja (GR) – 105), 547 indigenous chickens (Naked Neck (NN) - 197, Frizzle Feather (FF) – 164 and Normal Feather (NF) – 186) and 115 improved indigenous chicken (FUNAAB Alpha chicken (BA) – 115). The FUNAAB Alpha chicken is a genotype developed through artificial insemination at PEARL Farm (Programme for Emerging Agricultural Research Leaders) Federal university of Agriculture Abeokuta, Ogun state. Brooding was done in a brooding cage for three weeks with adequate sanitation and vaccination so as to prevent the occurrence of diseases. After brooding, the birds were housed and reared differently according to genotypes on deep litter until twenty weeks of age. The litter materials was replaced at interval of two weeks to maintain good hygiene so as to prevent pest and infestation of diseases.

Feeds and Feeding

The birds were fed *ad libtum* with commercial feed procured from a reputable feed producer in the country. The feeds were labelled to contained 21.49% crude protein and 2816.45kcal/kg metabolizable energy for chick mash and 16.90% crude protein and 2715.35kcal/kg metabolizable for grower mash. The bird had free access to water.

Data collection

Individual weekly body weight data were measured with the aid of sensitive scale of 0.05g sensitivity with the capacity of two decimal digits.

Statistical Analysis

Data collected were fitted to the different growth curves functions according to the following model;

The nonlinear model for growth data from animal *i* is expressed as:

$BW_{ij} = f(\theta_i, t_{ij}) + e_{ij}$ $i = 1,\ldots,N$ and $j = 1,\ldots,n_i$ (18)

Where *f* is the nonlinear function relating the response variable, body weight (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*, *e* is the residuals with the assumption of $e_i \sim N(\theta, \sigma^2 I_i)$ where $\sigma^2 I_i$ is the residual variance structure for all the subjects, assuming that no covariance structure exists between the residuals of the model.

Chicken growth data were fitted to the Logistic (19), Gompertz, Richards (18) and Bertalanffy (19) growth models using the procedure of NLIN (Marquart algorithm) (22), then the arithmetic mean and standard error of arithmetic mean values of the estimates of growth curve parameters were calculated by using the procedure of MEANS in the SAS package (22) for the genotypes (NN, FF, NF, BA, NB, WL and GR) within Logistic, Gompertz, Richards and Bertalanffy according to the following growth models;

Logistic model

$BW_{ij} = A_i (1+ B_i exp\{-K_i t_{ij}\})^{-1}$

Gompertz model

$BW_{ij} = A_i exp(- B_i exp\{-K_i t_{ij}\})^{-1}$

Richards model

$BW_{ij} = A_i (1+ B_i exp\{-K_i t_{ij}\})^{(1/m)}$

Bertalanffy model

$BW_{ij} = A_i (1- B_i exp\{-K_i t_{ij}\})^{-3}$

Where

BW_{ij} = body weight of the bird at age (week) t_{ij};

A = asymptotic weight ($t_i = \infty$);

B = integration constant ($t_i = 0$);

K = maturing rate;

t = age of the bird;

m = shape parameter determining the position of the inflection point at which the auto acceleration growth phase passes into the auto retardation phase.

t_{inf} and W_{inf} which are the age and weight at the inflection point of the growth model, respectively were also estimated for each genotype using the following functions.

Logistic model $t_{inf} = -log(1/B_i)/K_i$ $W_{inf} = A_i/2$

Gompertz model

$t_{inf} = -log(B_i)/K_i$ $W_{inf} = A_i/2.7182$

Richards model $t_{inf} = -log(m/B_i)/K_i$ $W_{inf} = A_i(m+1)^{(1/m)}$

Bertalanffy model $t_{inf} = [log(B_i)+ log(3)/K_i$ $W_{inf} = 8A_i/27$

Two models selection criteria were used to determine the model that has the best fit among Logistic, Gompertz, Richards or Bertalanffy growth models.

Akaike Information Criteria (AIC) = $-2f(\theta) + 2d$ and the

Bayesian Information Criteria (BIC) = $-2f(\theta) + d\ln(N_e)$

where

$f(\theta)$ = the maximum value of the (possibly restricted) log likelihood,

θ = vector of parameter estimates,

d = dimension of the model, and

N_e = number of effective observations

The AIC and BIC were estimated running the procedure of NLMIXED with the ML method available in the SAS package (22) for Logistic, Gompertz, Richards and Bertalanffy growth models. The AIC and BIC values analytically measure how well different models fit the data. AIC and BIC equations indicate that AIC and BIC reward descriptive accuracy via the maximum likelihood by penalizing lack of parsimony according to the number of free parameters. Therefore, the lowest values of AIC and BIC determine the better-fit growth model among Logistic, Gompertz, Richards or Bertalanffy growth models for the observed data.

The Pearson product-moment correlation coefficient (r), simply called the correlation coefficient, was used to examine the linear relationship between A and k growth model parameters. The correlation coefficient between A and k parameters from Logistic, Gompertz, Richards and Bertalanffy growth models are written:

$r_{Ak} = \sum(A- \bar{A})(k- \check{k})/\sqrt{\{\sum(A- \bar{A})^2\sum(k- \check{k})^2\}}$ $i = 1,\ldots,N$

Where

$\bar{A}$ and $\check{k}$ are the arithmetic means for the estimates of A and k parameters, respectively and was estimated by using the procedure of

CORR available in the SAS package (22). 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

The means and standard error (±SE) for the parameters estimated from the growth model of Logistic function based on Restricted Maximum Likelihood are shown in Tables 1 as a basis for the comparison between the genotypes. Mean (±SE) for the asymptotic weight (*A*), an estimation of the mature weight, was highest in GR (2056.55g) followed by NB 1561.83g while NF had the lowest value of 1124.98g. However, among the indigenous chickens, NN had the highest *A* followed by FF. The BA was heavier than the indigenous chickens (NN, FF and NF) and WL. The integration constant (*B*) (i.e. weight at t=0) was highest in the FF (20.81g) compared to other genotypes while among the exotic genotypes, NB (19.92g) recorded the highest *B*. The maturing rate (*k)* ranged between 0.22 and 0.26. The highest value of *k* was obtained in FF (0.26) followed by GR (0.25) while the lowest was recorded in NB. The time taken to reach the inflection point, t_{inf}, was highest in NB (13.93 weeks) followed by BA with 13.08 weeks while NF recorded the shortest age at inflection. Among the indigenous chickens, NN took longer time to reach the inflection point. Furthermore, weight at the point of inflection, W_{inf}, was heaviest in GR (1028.28g) followed by NB. The BA had the heaviest W_{inf} compared to the indigenous chickens and WL. The lowest W_{inf} among the indigenous genotypes was recorded in NF while the highest was recorded in NN (615.65g).

Table 2 presented the parameters estimates for Gompertz growth model. From the table, it could be observed that the W_{inf} and *A* was highest in GR (1003.00g and 2726.33g respectively) while FF had the highest *B* and *k* value (4.03g and 0.13 respectively). The BA chicken performed better than the indigenous chickens and WL with respect to *A*, t_{inf} and W_{inf} . The lowest value for all the parameters was observed in the NF except in *k* (0.12) where the lowest value of 0.11 was obtained in WL. The NN performed relatively better among the indigenous chickens.

Table 1: Means (±SE) for growth curve parameters using Logistic growth model

	Growth curve parameters				
Factors	*A(g)*	*B(g)*	*k*	t_{inf} *(weeks)*	W_{inf} *(g)*
Genotype					
Indigenous chickens					
NN	1231.28 ±22.25	19.72 ±0.43	0.24 ±0.3x10^{-2}	12.18 ±0.13	615.65 ±11.08
FF	1202.43 ±29.15	20.81 ±0.53	0.26 ±0.5x10^{-2}	11.73 ±0.28	601.20 ±14.58
NF	1124.98 ±24.80	17.10 ±0.57	0.24 ±0.3x10^{-2}	11.53 ±0.15	562.48 ±12.40
Crossbred chicken					
BA	1376.95 ±54.03	19.30 ±0.56	0.23 ±0.3x10^{-2}	13.08 ±0.20	688.45 ±27.00
Locally adapted exotic chicken					
NB	1561.83 ±50.28	19.92 ±0.70	0.22 ±0.5x10^{-2}	13.93 ±0.38	780.93 ±25.13
WL	1250.75 ±35.08	18.06 ±0.50	0.23 ±0.4x10^{-2}	12.33 ±0.23	625.40 ±17.55
GR	2056.55 ±91.08	19.00 ±0.73	0.25 ±0.7x10^{-2}	12.00 ±0.33	1028.28 ±45.53

A=Asymptotic weight, *B*=Integration constant, *k*=maturing rate,
t_{inf}=Age at inflection point, W_{inf}=Weight at inflection point
NN=Naked Neck, FF=Frizzle Feathered, NF=Normal Feathered, BA=FUNAAB Alpha, NB=Nera Black, WL=White Leghorn and GR=Giriraja

Table 2: Means (±SE) for growth curve parameters using Gompertz growth model

Factors	Growth curve parameters				
	A(g)	*B(g)*	*k*	t_{inf} *(weeks)*	W_{inf} *(g)*
Genotype					
Indigenous chickens					
NN	1626.88 ±41.55	3.92 ±0.04	0.12 ±0.24x10^{-2}	11.90 ±0.23	598.50 ±15.30
FF	1562.30 ±67.03	4.03 ±0.04	0.13 ±0.42x10^{-2}	11.28 ±0.40	574.75 ±24.65
NF	1446.13 ±46.48	3.68 ±0.05	0.12 ±0.24x10^{-2}	11.00 ±0.25	532.00 ±17.10
Crossbred chicken					
BA	1981.18 ±106.38	3.86 ±0.05	0.10 ±0.22x10^{-2}	13.53 ±0.35	728.85 ±39.13
Locally adapted exotic chickens					
NB	2431.65 ±148.18	3.90 ±0.04	0.09 ±0.39x10^{-2}	15.25 ±0.75	894.60 ±54.53
WL	1739.60 ±76.65	3.76 ±0.04	0.11 ±0.28x10^{-2}	12.33 ±0.35	639.95 ±28.20
GR	2726.33 ±149.98	3.88 ±0.07	0.12 ±0.58x10^{-2}	11.88 ±0.48	1003.00 ±55.15

A=Asymptotic weight, *B*=Integration constant, *k*=maturing rate,
t_{inf}=Age at inflection point, W_{inf}=Weight at inflection point
NN=Naked Neck, FF=Frizzle Feathered, NF=Normal Feathered, BA=FUNAAB Alpha, NB=Nera Black, WL=White Leghorn and GR=Giriraja

Table 3 shows the parameter estimates of Richards growth model predicted for all the genotypes. The model predicted the highest estimated means of 2716.43g and 1005.70g for *A* and W_{inf} respectively in GR compared to the other genotypes. Parameter estimates obtained in *B* and *k* was highest in FF when compared to the locally adapted exotic chickens, the indigenous chickens (NN and NF) and the BA chicken. The NB had the highest estimated mean (15.33 ±0.75) for t_{inf} with lowest *k* (0.10) similar to the BA. The result showed that despite the lower *k* recorded for the BA chicken compared to the indigenous (NN, FF and NF) chickens, it was still able to achieve higher *A* (1974.63g) and W_{inf} (728.95).

Table 3: Means (±SE) for growth curve parameters using Richards growth model

Factors	Growth curve parameters				
	A(g)	*B(g)*	*k*	t_{inf} *(weeks)*	W_{inf} *(g)*
Genotype					
Indigenous chickens					
NN	1618.80 ±42.95	0.12 ±0.05	0.12 ±0.33x10^{-2}	11.90 ±0.23	599.50 ±15.10
FF	1531.20 ±68.83	0.96 ±0.33	0.14 ±0.68x10^{-2}	11.30 ±0.38	576.73 ±23.95
NF	1433.88 ±45.33	0.10 ±0.05	0.12 ±0.26x10^{-2}	10.98 ±0.25	530.88 ±16.65
Crossbred chicken					
BA	1974.63 ±107.28	0.10 ±0.07	0.10 ±0.29x10^{-2}	13.53 ±0.38	728.95 ±39.10
Locally adapted exotic chickens					
NB	2444.68 ±149.95	0.18 ±0.12	0.10 ±0.40x10^{-2}	15.33 ±0.75	903.38 ±56.48
WL	1734.40 ±78.20	0.05 ±0.02	0.11 ±0.33x10^{-2}	12.35 ±0.35	640.18 ±28.03
GR	2716.43 ±158.63	0.28 ±0.28	0.12 ±0.93x10^{-2}	11.90 ±0.45	1005.70 ±52.83

A=Asymptotic weight, *B*=Integration constant, *k*=maturing rate,
t_{inf}=Age at inflection point, W_{inf}=Weight at inflection point
NN=Naked Neck, FF=Frizzle Feathered, NF=Normal Feathered, BA=FUNAAB Alpha, NB=Nera Black, WL=White Leghorn and GR=Giriraja

Table 4 presented the estimated model parameters for Bertalanffy growth model as predicted for all the genotypes. The model predicted the highest value for NB in *A*, t_{inf} and W_{inf} (4723.45g, 20.18 weeks and 1399.55g respectively) and the lowest *k*. The lowest predicted means value obtained in all the parameters was observed in NF i.e. *A*, *B*, t_{inf} and W_{inf} (1901.35g, 0.77g, 11.40 weeks and 563.38g respectively) except in *k* where it obtained the highest value alongside FF and GR. The BA was better than the indigenous chickens (NN, FF and NF) and WL with respect to *A* (3041.13g), t_{inf} (15.63 weeks) and W_{inf} (901.08g). However, among the indigenous chickens, FF followed by NN had better *A*, t_{inf} and W_{inf}.

Table 4: Means (±SE) for growth curve parameters using Bertalanffy model

	Growth curve parameters				
Factors	*A(g)*	*B(g)*	*K*	t_{inf} *(weeks)*	W_{inf} *(g)*
Genotype					
Indigenous chickens					
NN	2172.83 ±88.78	0.80 ±0.00	0.07 ±0.22x10^{-2}	12.58 ±0.38	643.80 ±26.33
FF	2067.50 ±146.65	0.81 ±0.00	0.08 ±0.42x10^{-2}	11.78 ±0.65	612.58 ±43.48
NF	1901.35 ±111.70	0.77 ±0.01	0.08 ±0.23x10^{-2}	11.40 ±0.53	563.38 ±33.13
Crossbred chicken					
BA	3041.13 ±258.38	0.79 ±0.01	0.06 ±0.20x10^{-2}	15.63 ±0.73	901.08 ±76.55
Locally adapted exotic chickens					
NB	4723.45 ±636.23	0.79 ±0.01	0.05 ±0.37x10^{-2}	20.18 ±1.85	1399.55 ±188.53
WL	2614.38 ±225.08	0.78 ±0.00	0.07 ±0.27x10^{-2}	13.80 ±0.70	774.63 ±66.70
GR	3697.08 ±273.38	0.79 ±0.01	0.08 ±0.54x10^{-2}	12.80 ±0.78	1095.45 ±81.00

A=Asymptotic weight, *B*=Integration constant, *k*=maturing rate,
t_{inf}=Age at inflection point, W_{inf}=Weight at inflection point
NN=Naked Neck, FF=Frizzle Feathered, NF=Normal Feathered, BA=FUNAAB Alpha, NB=Nera Black, WL=White Leghorn and GR=Giriraja

Both Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) were used to examine the better fit model for modeling growth curve parameters in all the genotypes as shown in Table 5. The result showed that Gompertz growth model had the smallest predicted value for both AIC and BIC with respect to the indigenous chickens (FF and NF) and GR. The difference between Bertalanffy and Gompertz was less than 6 thus making it fit also in modeling growth curve of NF. Richards growth model however, only showed best fit for fitting growth curve in NN and locally adapted exotic chickens (NB and WL). Bartalanffy growth model on the other hand, had the best fit for modeling growth curve in the BA (AIC=6865.50 and BIC=6882.50).

Table 6 shows the pearson's correlation between *A* and *k* for all the growth models considered. Negative correlation was observed between *A* and *k* for all the genotypes in all the models considered. The highest negative correlation was recorded in FF chicken (-0.84, -0.93 and -0.92) for Logistics, Gompertz and Bertalanffy respectively while Richards recorded the highest in WL (-0.88). Lowest negative correlation was estimated for Gompertz and Bertalanffy in NF chicken, Logistic in NN chicken and Richards in crossbred chicken.

Table 5. AIC and BIC values for models for Best fit

	Logistic		Gompertz		Richards		Bertalanffy	
Factors	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
Genotype								
Indigenous chickens								
NN	11570.50	11590.00	11481.50	11501.00	11458.50	11482.50	11633.00	11652.00
FF	9060.75	9078.75	8910.25	8928.50	8916.00	8933.50	8924.25	8941.75
NF	11693.50	11712.00	11633.00	11651.00	11817.50	11840.75	11638.50	11657.25
Crossbred chicken								
BA	6990.00	7007.00	6910.00	6927.00	6904.75	6926.25	6865.50	6882.50
Locally adapted exotic chickens								
NB	8185.25	8203.00	7944.75	7964.00	7899.75	7921.75	7946.75	7964.00
WL	5413.50	5430.00	5259.50	5275.75	5234.50	5255.25	5301.75	5317.75
GR	7405.00	7420.00	7245.50	7260.75	7391.25	7409.75	7361.75	7377.25

AIC=Akaike Information criteria, BIC=Bayesian Information Criteria
NN=Naked Neck, FF=Frizzle Feathered, NF=Normal Feathered, BA=FUNAAB Alpha, NB=Nera Black, WL=White Leghorn and GR=Giriraja

Table 6. Pearson's correlation between parameter *A* and *k*

	Logistic		Gompertz		Richards		Bertalanffy	
Factors	r	p-value	R	p-value	r	p-value	R	p-value
Genotype								
Indigenous chickens								
NN	-0.54	0.09	-0.77	0.00	-0.75	0.00	-0.84	0.00
FF	-0.84	0.00	-0.93	0.00	-0.83	0.00	-0.92	0.00
NF	-0.63	0.04	-0.62	0.21	-0.59	0.21	-0.67	0.08
Crossbred chicken								
BA	-0.79	0.00	-0.87	0.00	-0.46	0.00	-0.88	0.00
Locally adapted exotic chickens								
NB	-0.70	0.00	-0.90	0.00	-0.82	0.00	-0.88	0.00
WL	-0.74	0.02	-0.84	0.00	-0.88	0.00	-0.84	0.00
GR	-0.46	0.21	-0.64	0.21	-0.63	0.21	-0.75	0.16

r = correlation coefficient
NN=Naked Neck, FF=Frizzle Feathered, NF=Normal Feathered, BA=FUNAAB Alpha, NB=Nera Black, WL=White Leghorn and GR=Giriraja

Discussion

Mathematical models are used to explain or study the effects and contributions of different components in a system so as to make a prediction about the likelihood of an event or outcome (23) and deduce a conclusion on the influence of fixed effect on population mean. The predictions obtained in Bertalanffy, despite achieving 30% of its final asymptotic weight at the inflection point, recorded the highest W_{inf} for all the genotypes and subsequent heaviest asymptotic weight. Furthermore, the predictions obtained from Gompertz and Richards models were relatively similar while Logistic model was inferior. This justifies the fact that while Logistic achieved 50% of its final asymptotic weight at the inflection point, Gompertz and Richards are just 37% (24, 25, 26) at the same point. This means that weight attained at inflection point, which is the peak of the growth curve, is an indication of what the final weight of the chickens will be. It further showed that weight gain after the point of inflection will be increasing at a reducing rate. As already established between the models, GR, a dual purpose chicken which thrives well under varying climate (27) produced the highest mature weight, reach the peak faster than most genotypes. The BA chickens on the other hand exhibited the power of hybrid vigour by producing more weight than the indigenous chickens. Similarly, heavier *A* was observed for NN and FF chickens due to improved heat conduction found in them (3, 28) which positively improves protein deposition (29).

The highest integration constant (*B)*, which is the initial weight at t=0, predicted by logistic model for all the genotypes is an indication that the model will reach a declining growing phase faster than other model. This can also account for the higher weight (50%) achieved at inflection point penultimate to the asymptotic final weight (L_∞) compared to other models. The weight at zero age as predicted in Richards model was the lowest after Bertalanffy and Gompertz models. (30) also reported that the size of *B* indicated the proportion of the asymptotic mature weight to be gained after birth. The highest value of *B* obtained in FF chicken among the genotypes did not translate to much weight gain either at the W_{inf} or on the *A*. However, the lowest value observed in WL produced the lowest final weight.

The *k* which defines the ratio of maximum growth rate relative to mature weight (maturing rate index) (18) was highest in Logistic growth model and lowest in Bertalanffy for all the genotypes and in line with the findings of this study with respect to similar result obtained for Gompertz and Richards, (31) and (32) in their work with chickens also reported that Gompertz and Richards recorded similar parameter estimate values for *k*. To achieve the 50% growth before inflection point in Logistic model, it is assumed that maturing rate will be high leading to smaller mature weight. According to (32), high maturing rate imply shorter periods of growth (early maturity) and lower mature weight. This explains the least values of maturing rate obtained in Bertalanffy model and the subsequent high asymptotic weight recorded for all the genotypes.

There was no marked difference between the models in terms of age at inflection point for all the genotypes. However, Bertalanffy predicted fairly longer growing period compare to other models. The relationship between the asymptotic weight and the weight at inflection has a lot of bearing on the time taken to reach inflection point. The longer time taken for the BA chickens to reach inflection point may have contributed to the superior weight difference at the inflection point and at the asymptotic level over the indigenous and WL chickens. This is because the latter the inflection point is reached the more weight gained and the higher the asymptotic weight. (33) also reported direct relationship between age and weight at inflection point. However, among the indigenous across the models, NN followed by FF chicken were observed to grow for a longer time and achieve the highest weight at the inflection point.

The result of the study with respect to the model with the lowest value as predicted by AIC and BIC showed that Gompertz growth model had the best fit for FF, NF and GR chicken. Similar result was reported by (34), (35) and (36) that Gompertz function was more appropriate to describe the growth curve in chickens. The results further showed that Richards growth model had the best fit for NN, NB and WL chickens. (37) in their study, reported that Richards was better than Gompertz but with more parameters in the model while Bartanlaffy growth model had the best fit for modeling growth curve in the crossbred chickens.

Negative correlation that existed between *A* and *k* in this study was an indication that early maturing chicken will tends to attain smaller mature weight, and likewise showed that high mature weight is strongly related with long growth period and/or chicken with lighter asymptotic weight reached that weight at a younger age. Similar findings were also reported by (38) and (11).

Conclusion and Applications

The study showed that:

1. The pattern of growth and development of the genotypes varies as predicted by the growth models and different models better fit to describe the growth of different genotype. Richards model under AIC best fit NN, NB and WL while Gompertz best fit FF, NF and GR. Bertalanffy best fit BA.
2. The improved indigenous chicken (BA) performed better with all the models than the indigenous chicken and even than some locally adapted exotic breed like WL.
3. There is an opportunity of optimizing the model of choice for selective breeding with respect to the genotypes involve in the selection process.

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