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ASSESSMENT OF SPLINE FUNCTIONS AND NON-LINEAR MODELS FOR ESTIMATING GROWTH CURVE PARAMETERS OF FUNAAB-ALPHA CHICKENS

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ABSTRACT

The study assessed the growth of FUNAAB-Alpha chickens (FAC) using spline and non-linear functions in order to establish the most appropriate growth function(s) for FAC. Three hundred (300) day-old chickens of FAC were used for the study. They were raised intensively under a deep litter system for 20 weeks and body weight records were taken weekly with the aid of a digital scale. Spline models of different numbers of, and locations of, knots were fitted using the REG procedure of SAS® while four non-linear models (Gompertz, Logistic, Bertalanffy and Richards') were fitted using the NLIN procedure of SAS®. The estimated hatch weight (β_0) for the male and female chickens ranged from 30.77 g to 74.71 g and from 15.56 g to 38.19 g, respectively. The regression coefficients ranged from -38.47 to 47.46 and -39.40 to 40.47 for the male and female, respectively. The highest magnitudes of these coefficients were estimated at early ages (3 to 10 weeks), implying that growth rate at early stage of life might be a key response to selection for later growth performance. For non-linear models, parameter A (or asymptotic weight) for all the models ranged from 3716 g to 2050 g and 1591 g to 3330 g for male and female, respectively. The parameter (B), the scaling parameter (constant of integration), ranged from 0.7541 to 15.441. Likewise, parameter K, which is the maturity index, ranged from 0.0463 to 0.2002. The age at inflection point for FUNAAB-Alpha chickens ranged between 13.30 and 17.63 weeks for male chickens and between 14.23 and 19.94 weeks for female chickens while the corresponding body weight at inflection point ranged between 754 and 1528 g and 586 and 1261 g for male and female chickens, respectively. Based on Akaike Information Criterion and Bayesian Information Criterion as best fit model selection criteria, it was concluded that the spline models of 3 and 4 knots were the best fit linear spline models while Bertalanffy and Gompertz models were selected as the best fit non-linear models.

Key words: spline model; non-linear models; knots; growth parameters; regression coefficients

INTRODUCTION

Nigerian indigenous chickens have been characterized as hardy, good scavengers and highly adapted to the harsh, hot and humid tropical environment (Peters *et al*., 2007). These chickens are said to be flighty, good mothers and resistant to many diseases and they play an integral role in rural economy (Sonaiya and Swan, 2004). However, Nwosu and Asuquo (1985) described them as small bodied, slow growing, poor feed converters, poor layers and poor meat birds. This is as a result of long-term natural selection for fitness in the harsh tropical and disease-prevalent environment (Adebambo *et al*., 2010). These shortcomings led to the intensification of efforts towards the development of indigenous chicken breeds with improved meat and egg production through the exchange of germ plasm with established exotic breeds. For instance, the ShikaBrown breed was developed by the National Animal Production

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Research Institute (NAPRI), Ahmadu Bello University, Zaria, Nigeria (Ikanni and Annatte, 2000). Similarly, the Federal University of Agriculture, Abeokuta, Nigeria (FUNAAB) has developed the FUNAAB-Alpha breed, described as an improved, indigenous, tropically adapted and dual-purpose breed. FUNAAB-Alpha has attributes and potentials for improved meat and egg production while maintaining adaptation to the tropical environment characterized by heat stress and infectious diseases (Adebambo, 2015). Males of FUNAAB-Alpha chickens have been reported to weigh about 1.5 – 2.0 kg at 20 weeks of age while their females usually weigh between 1.2 to 1.8 kg at 18 – 21 weeks of age when they lay their first egg (Adebambo *et al*., 2018).

The characterization of poultry breeds is a key to understanding their distinctiveness, growth, production potential, management requirements and their ability to thrive under various climatic environments. The Global Plan of Action (GPA) for Animal Genetic Resources (FAO, 2007) recognizes that a better understanding of the characteristics of livestock breeds is necessary for guiding decision making in the development of breeding strategies to enhance sustainable use of animal genetic resources. Specifically, Strategic Priority Area 6 of the GPA specifically entails "Support indigenous and local production systems and associated knowledge systems of importance to the maintenance and sustainable use of animal genetic resource". Hence, there is the need for a detailed performance characterization and evaluation study on FUNAAB-Alpha chickens. One major and important trait for such evaluation is growth.

Growth can be defined as body weight gain or weight gain of body parts with age. The process of growth has often been summarized using mathematical equations fitted to growth curves and the objective of this curve fitting is to describe the course of body weight increase over time or age with mathematical parameters that are biologically interpretable (Aggrey, 2002). These parameters have a biological interpretation in terms of growth process and their values, as well as their relationships with other parameters, they provide a genetic basis for understanding growth process and for development of breeding strategies to alter or modify the trajectory of growth.

Many mathematical models have been applied to the study of growth performance in poultry research (Laird *et al*., 1965; Grossman *et al*., 1985; Aggrey, 2002). Most of these models are non-linear and fitted curves that relate the age of the bird with its weight, characterize the different phases of growth of the bird, allow the estimation of the animal's growth rate, the age at which the animal stops growing, and when it reaches sexual maturity (Galeano-Vasco *et al*., 2014).

The spline model has been suggested for the study of sigmoidal growth (Aggrey, 2002), and as an alternative to non-linear growth models. The spline linear model is a compound function consisting of a series of linear equations which meet at certain points known as knots. The spline linear regression model can be used as an alternative to high order polynomials and complicated non-linear models (Aggrey, 2002; Meyer, 2005) and can also serve as an alternative means to model complex growth processes, since it can easily be modified to accommodate more knots. Harrell (2004) suggested that linear splines could be modifiable by varying the number and position of the knots to obtain the best fit model to the dataset. Extensive information on the growth curve parameters of FAC with non-linear and spline functions will enhance making effective management and production decisions that are integral to the sustainable use of FAC as a genetic resource for income generation and poverty alleviation.

Most of the growth models available for poultry have been fitted using non-linear models. Consequently, there is a need to fit alternative growth models using spline functions so as to compare and establish model superiority for describing the growth curve of FAC. The objective of the study, therefore, was to assess the growth of FUNAAB-Alpha chickens using spline and non-linear functions in order to establish the most appropriate growth function(s) for FAC.

MATERIAL AND METHODS

Experimental location

This experiment was conducted at the Poultry Unit of the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. The farm is located at Longitude 04° 33' E and Latitude 07° 28' N at an altitude of 224 m above sea level.

Experimental birds

Three hundred (300) day-old chickens of the FUNAAB-Alpha chickens (FAC) were obtained from the Hatchery Unit of the Federal University of Agriculture, Abeokuta (FUNAAB). They were brooded for two weeks. Adequate temperature of 40 °C – 45 °C was provided during brooding using electric bulbs and gas burner as the source of heat. They were thereafter transferred to a deep litter pen at the end of the fourth week.

Management practices

The deep litter pen, containing thirty cells (each 1.5 m × 1.5 m), was made of wood and wire netting while the floor was made of concrete. The bushes around the building were cleared, the pen was properly fumigated and wood shavings were thoroughly spread on the concrete floor before the birds were transferred. Feeders and drinkers were provided for each cell in the deep litter pen. The chickens were fed starter ration containing 20 % crude protein (CP) and 2800 kcal.kg^{-1} of metabolizable energy (ME) from day old till the fifth week, after which they were fed with grower ration containing 18 % CP and 2900 kcal.kg^{-1} till the twentieth week when the experiment was terminated. Clean water was provided *ad libitum*. The feed was placed in standard and specialized feeding tray made of red colour to attract the chickens to the feed while water was provided in a standard and specialized 3.0 litre plastic drinker, placed upside down for proper water dispensation and to avoid water spillage.

Health management

Proper hygiene was ensured all the time. Biosecurity was guaranteed by barring visitors and strangers from entering the pen while a foot dip was provided at the entrance and replaced daily. Drinkers and feeders were thoroughly washed and cleaned daily while left-over feeds and water were removed in order to prevent build-up of parasites and pathogens. The litter was kept dry at all times. The chickens were vaccinated against Newcastle disease on the 10th day and other medications were administered when due, following the standard practice in poultry management.

Data collection

Each bird was wing tagged for identification and weighed weekly using a sensitive digital weighing scale (Model SF-400) with a maximum capacity of 10 kg and a sensitivity of 1 g throughout the conduct of this experiment. The bodyweight records were taken early in the morning before feeding following FAO (2012). The feather morphology (frizzle feathered or normal feathered) and feather distribution pattern (naked neck or normal neck) were also observed and recorded. The cross-tabulation of FUNAAB-Alpha chickens across sexes, feather distribution and morphology subgroups used in this study is presented in Table 1. These chickens are as shown in Plate 1 below.

Data Analysis

The raw data was first plotted to determine the appropriate locations of the knots following Aggrey (2002). Based on this preliminary step, splines of 3, 4, 5 and 6 knots corresponding to varied age ranges (in weeks) on the growth trajectory were fitted. The equations, location of the knots (age in weeks

Table 1. Distribution of FUNAAB-Alpha chickens across sexes, feather distribution and morphology sub-groups

Feather distribution/Morphology	Male	Female	Total
Normal	106	138	244
Naked neck	22	34	56
Total	128	172	300
Normal	96	127	223
Frizzled	32	45	77
Total	128	172	300

Plate 1. Naked neck, frizzled-feathered and normal feathered FUNAAB–Alpha chickens

along the trajectory) of these models are presented in Table 2. The spline functions were fitted to the body weight records using the REG procedure of SAS®.

Four classical non-linear growth models including von Bertalanffy, Gompertz, Logistic and Richards' models were also fitted to the body weight records using PROC NLIN of SAS®. Parameter estimates of these non-linear models were thereafter compared with the fitted spline functions. These non-linear models were fitted using the NLIN procedure of SAS® using Marquardt iterative option (Marquardt, 1963)

Table 2. Equations for the spline functions

Spline model	Number of knots	Location of knots (age in weeks)	Equation of the model
SP3	3	4, 10, 16	$W_t = W_0 + b_1 t + b_2 (t - 4) + b_3 (t - 10) + b_4 (t - 16) + e$
SP4	4	4, 8, 12, 16	$W_t = W_0 + b_1 t + b_2 (t - 4) + b_3 (t - 8) + b_4 (t - 12) + b_5 (t - 16) + e$
SP5	5	4, 7, 10, 14, 18	$W_t = W_0 + b_1 t + b_2 (t - 4) + b_3 (t - 7) + b_4 (t - 10) + b_5 (t - 14) + b_6 (t - 18) + e$
SP6	6	3, 6, 9, 12, 15, 18	$W_t = W_0 + b_1 t + b_2 (t - 3) + b_3 (t - 6) + b_4 (t - 9) + b_5 (t - 12) + b_6 (t - 15) + b_7 (t - 18) + e$

Where W_t = body weight at time t; W_0 is the intercept of the model (body weight at hatch); $b_1 \ldots b_7$ are the regression coefficients (growth rates of the specified periods that constitute the entire spline); and e is the residual error.

Table 3. Non-linear growth model equations

Model	Equation	Inflection time	Inflection point	Relative growth rate
Gompertz	$W_t = A*exp\,(-B*exp\,(-k*t))$	$^{A}/_{e}$	$\ln\ ^{(B)}/_{k}$	$k\,(\frac{A-W_{(t)}}{A})$
Logistic	$W_t = \frac{A}{1 + B*exp\,(-k*t)}$	$^{A}/_{2}$	$\ln\ ^{(B)}/_{k}$	$k*\log\,(\frac{A}{W_{(t)}})$
Bertalanffy	$W_t = A\,(1 - B*e^{-k*t})^3$	$^{8}/_{27}\ (A)$	$\frac{1}{k}\ ln.3\ (B)$	$3k\,[(\frac{A}{W_{(t)}})^{1/3} - 1]$
Richards'	$1 + B*exp\,(-k*t)^{1/d}$	$^{A}/_{(d+1)}{}^{1/d}$	$\frac{1}{k} * ln\ \lvert d/B \rvert$	$dk\,[(\frac{A}{W_{(t)}})^{1/d} - 1]$

Where W_t = body weight at t weeks of age; t = bird's age in weeks; A = asymptotic weight or mature weight; B = scaling parameter (constant of integration); k = maturity index; d = shape parameter for Richards' model which allows a variable point of inflection.

according to the equations presented in Table 3. The most appropriate model(s) was/were selected using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) following Kaps and Lamberson (2004). According to these authors, a model with the lowest AIC and BIC values represent the best fit model.

RESULTS

The least squares means and standard error of body weight of FUNAAB-Alpha chickens raised under a deep litter system from hatch till the birds were 20 weeks old are shown in Table 4. The body weight of the male and female chickens were similar at hatch ($P > 0.05$). However, from hatch, the males were heavier than the female chickens across different ages ($P < 0.05$). The difference in their body weight increased linearly from hatch till the 20th week of age and reaching two peaks at 16th and 18th week of age.

The estimated hatch weights and regression coefficients for FUNAAB-Alpha chickens using spline functions of 3 (SP3), 4 (SP4), 5 (SP5) and 6 (SP6) knots are presented in Table 5. For both sexes, SP3 estimated the highest hatch weight while SP6 estimated the least values. The regression coefficients ranged from -38.47 to 47.46 for male chickens, while it ranged from -39.40 to 40.47 for female chickens. Highest magnitudes of these coefficients were estimated at early ages.

Table 4. Least squares means for body weight of FUNAAB-Alpha Chickens raised under a deep litter system from day old to 20 weeks of age

Age (weeks)	LSM (g) ± SE (male)	LSM (g) ± SE (female)
Day old	33.40 ± 3.45	31.25 ± 1.28
2	126.80 ± 4.06^{a}	118.07 ± 3.95^{b}
4	296.65 ± 10.81^{a}	254.27 ± 10.28^{b}
6	408.05 ± 14.12^{a}	321.76 ± 14.23^{b}
8	606.10 ± 18.25^{a}	418.70 ± 21.35^{b}
10	805.29 ± 21.60^{a}	568.23 ± 26.30^{b}
12	901.65 ± 23.66^{a}	665.19 ± 30.28^{b}
14	1305.41 ± 33.62^{a}	853.65 ± 36.44^{b}
16	1509.78 ± 39.89^{a}	953.86 ± 43.05^{b}
18	1669.22 ± 42.03^{a}	1129.33 ± 48.78^{b}
20	1894.80 ± 45.95^{a}	1321.71 ± 52.43^{b}

LSM = least squares means, SE = standard error of the means.
^{ab}Means within the same column having different superscript are significantly different ($P < 0.05$).

Table 5. Estimated coefficients for spline regression model parameters of FUNAAB-Alpha chickens raised under a deep litter system

	Male				Female			
Parameters	SP3	SP4	SP5	SP6	SP3	SP4	SP5	SP6
Hatchweight (β_0)	74.71	52.32	68.45	30.77	34.40	29.57	38.19	15.56
β_1	47.46	38.01	33.39	39.50	36.68	35.34	40.22	31.90
β_2	-38.39	35.07	35.52	33.52	-29.05	31.85	28.47	37.84
β_3	-21.81	-30.49	-38.47	-29.13	-24.35	-23.84	-27.88	-18.83
β_4	23.91	-28.60	-15.80	-23.00	19.33	-21.56	-29.14	-19.40
β_5		25.89	-29.44	-21.38		28.72	-24.35	-19.89
β_6			29.43	22.78			18.77	24.28
β_7				19.51				15.23

Table 6 showed the estimated growth model parameters for male and female FUNAAB-Alpha chickens using Gompertz, Logistic, Bertalanffy and Richards' growth functions. For all the models, parameter (A), which is the asymptotic weight (or maximum stationary weight), ranged from 2050.8 g to 3716.6 g for the male and from 1591.7 g to 3330 g for the female chicken respectively. Parameter (B), the scaling parameter (constant of integration) ranged from 0.7541 g to 15.441 g. Likewise, parameter K, which is the maturity index ranged from 0.0463 g to 0.2002 g. The Bertalanffy model estimated the highest asymptotic weight while the Logistic model estimated the least.

Table 7 showed the body weight and age at inflection point for FUNAAB-Alpha chickens as estimated by Gompertz, Logistic, Bertalanffy and Richards' models. For all the models fitted, age at inflection point for FUNAAB-Alpha chickens ranged between 13.30 and 17.63 weeks for male chickens and 14.23 to 19.94 weeks for female chickens. The corresponding body weight at inflection point ranged between 754 and 1528 g and 586 and 1261 g for male and female chickens respectively. For both

Table 6. Estimates of growth model parameters for FUNAAB-Alpha chickens

	Male			
Model	A	B	K	D
Gompertz	3056.3 ± 462.7	3.5503 ± 0.1046	0.0860 ± 0.011	-
Logistic	2050.8 ± 178.5	15.441 ± 1.4930	0.2002 ± 0.0178	-
Bertalanffy	3716.6 ± 951.3	0.7541 ± 0.0116	0.0463 ± 0.00923	-
Richards'	3056.2 ± 462.5	2.521 ± 0.153	0.150 ± 0.0111	0.343 ± 0.0367
	Female			
Gompertz	2521.0 ± 362.0	3.5813 ± 0.0859	0.080 ± 0.0091	-
Logistic	1591.7 ± 118.4	15.7189 ± 1.1851	0.1964 ± 0.0140	-
Bertalanffy	3330.6 ± 1262.7	0.7672 ± 0.0124	0.0417 ± 0.00889	-
Richards'	2520.9 ± 361.9	2.852 ± 0.964	0.147 ± 0.0190	0.352 ± 0.0224

Where A, B, K and D represent the asymptotic weight, the scaling parameter, maturity index and the shape parameter (for Richards' model) respectively.

Table 7. Body weight (g) and age (weeks) at inflection point

	Male		Female	
Model	T (weeks)	W (g)	T (weeks)	W (g)
Gompertz	14.73	1528	15.95	1261
Logistic	13.67	754	14.03	586
Bertalanffy	17.63	1101	19.94	987
Richards'	13.30	1294	14.23	1070

Where T is the age (weeks) and W is the body weight (g) at inflection point.

Table 8. Best fit model selection criteria using Goodness-of-Fit tests

	Male		Female	
Model	AIC	BIC	AIC	BIC
SP3	46.735	55.221	44.138	54.343
SP4	50.167	61.256	43.867	54.201
SP5	49.204	59.544	45.867	56.425
SP6	54.660	65.298	46.623	57.188
Gompertz	50.42	61.528	44.460	55.102
Logistic	53.23	64.488	47.10	58.342
Bertalanffy	49.42	60.122	44.21	54.154
Richards'	50.42	61.778	46.76	57.813

Where AIC and BIC are Akaike Information Criterion and Bayesian Information Criterion respectively.

sexes, the Gompertz model estimated the highest body weight at inflection while the Logistic model estimated the least. Similarly, the Richards' model predicted the earliest age at inflection point while the Bertalanffy model estimated the latest age at inflection. For all the models, males had higher body weight at inflection than females. However, the females had higher ages at inflection point than the corresponding males for all the models.

Goodness-of-fit tests for spline models as well as for the non-linear models (Gompertz, Logistic, Bertalanffy and Richards') are presented in Table 8. These included the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The lower the values of AIC and BIC, the better fit is the data (Kaps and Lamberson, 2004). For the male, SP3 had the lowest AIC and BIC and was adjudged the best fit model followed by SP5, SP4 and SP6 in that order. For the female, SP3 and SP4 had the lowest AIC and BIC values and were selected as the best fit model followed by SP6 and SP5 in that order.

Table 9 showed the correlation coefficients among model parameters. High and negative correlation coefficients ($r < -0.90$) were observed between parameters A (asymptotic weight) and K (maturity index), both male and female, for all the models. Between parameters B and K, there was high positive correlation for the Logistic and Richards' models, for both male and female. For the Gompertz model, negative correlation was observed for the male while positive correlation was observed for the female. The correlation coefficients between parameter A (asymptotic weight) and B (constant of integration), ranged from -0.933 to 0.735 for all models. For the Richards' model, both male and female, there was a highly negative correlation ($r < -0.90$) between these parameters,

Table 9. Correlation coefficients among model parameters for nonlinear models

Male				Female			
Gompertz	Logistic	Bertalanffy	Richards'	Gompertz	Logistic	Bertalanffy	Richards'
Parameter A and B							
0.00266	-0.176	0.406	-0.918	0.263	-0.106	0.735	-0.933
Parameter A and K							
-0.981	-0.915	-0.993	-0.981	0.982	-0.918	-0.995	-0.983
Parameter B and K							
-0.181	0.533	0.309	0.962	0.0931	0.467	-0.669	0.986

A = asymptotic weight or mature weight; B = scaling parameter (constant of integration); and k = maturity index

which indicated that chickens with higher constant of integration had lower asymptotic weight and vice-versa. Positive correlation was observed between these parameters based on Bertalanffy model which implied that high asymptotic weight is associated with higher values of the constant of integration.

Figures 1 and 2 show graphical representations of growth rate of male and female FUNAAB-Alpha chickens, respectively, as predicted by spline functions of 6 (SP6), 5 (SP5), 4 (SP4) and 3 (SP3) knots. The growth curves of the male and female chickens by the non-linear models are depicted in Figures 3 and 4. Generally, body weight increased with age but at different rates as predicted by different spline functions. There are overlaps in the growth rates predicted by these functions from hatch till about 4th to 6th week for most cases. For the male FUNAAB-Alpha chickens, such overlaps were obvious between SP4, SP5 and SP6 from hatch till the 14th week before the growth rate of the SP5 became higher than the rest. The growth rate predicted by the 3-knot function (SP3) was found to be lowest. For the female FUNAAB-Alpha chickens, the growth rate predicted by the SP5

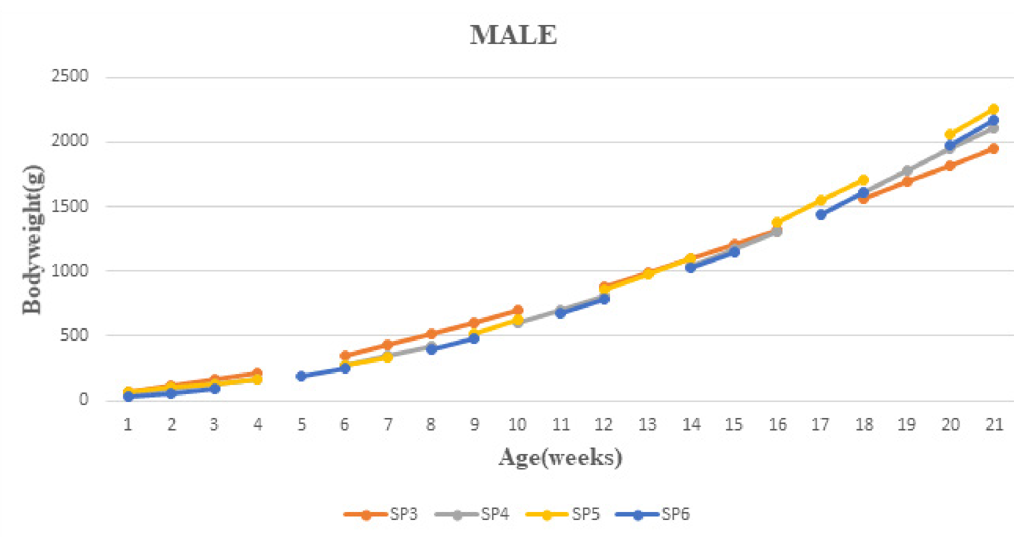

Figure 1. Growth curve of FAC as predicted by spline models (male chickens)

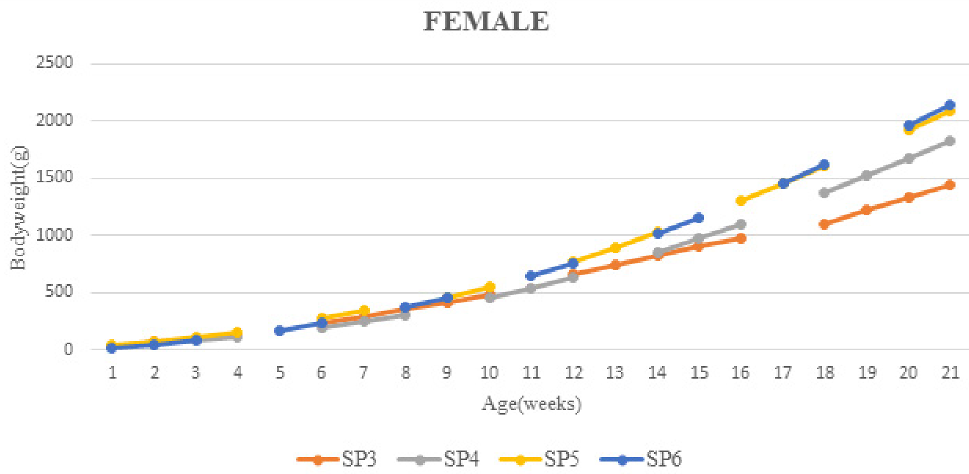

Figure 2. Growth curves of FAC as predicted by spline models (female chickens)

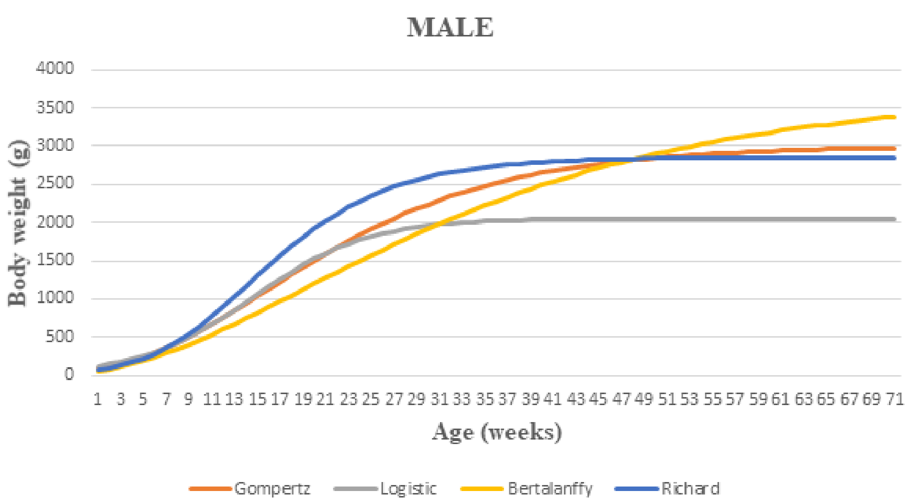

Figure 3. Growth curves for FAC (male chickens) predicted by Richards', Gompertz, Logistic and Bertalanffy models

and SP6 functions were similar and higher and higher than the growth rate predicted by SP3 which was observed to be the lowest.

Relative growth rate (RGR) of FAC across sex, as estimated by Gompertz, Logistic, Bertalanffy and Richards' models are presented in Figures 5 (a-d).The RGR represent chickens' growth rate relative to body size at various ages. Based on all non-linear models fitted, the initial relative growth rate was observed to be maximum at the first week, and decreased steadily till the curve flattens out, indicating that RGR was almost zero after the point of inflection had been reached. Further, the RGR decreased at a lower rate from 0 to 8 weeks of age, while the rate of decrease was rapid after the inflection point was reached.

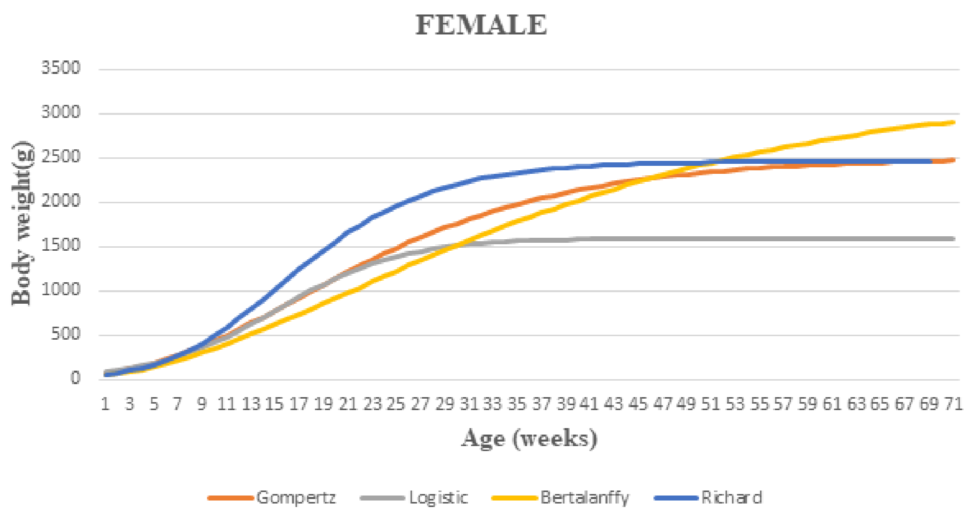

Figure 4. Growth curves for FAC (female chickens) predicted by Richards', Gompertz, Logistic and Bertalanffy growth models

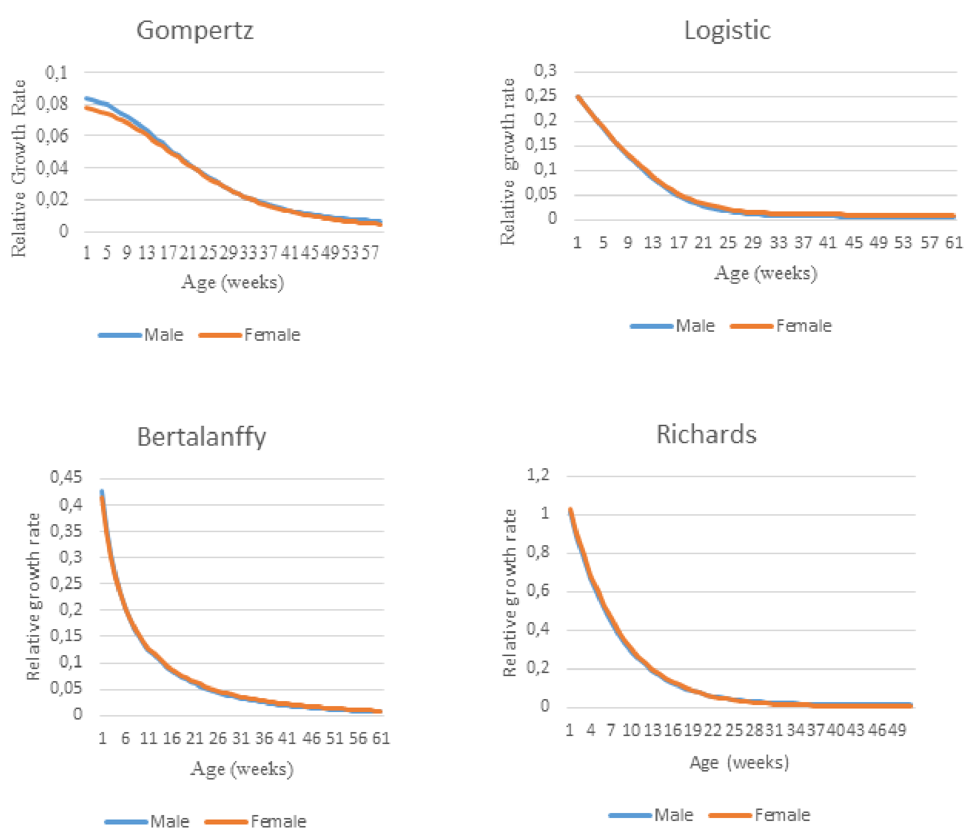

Figure 5 (a-d). Relative growth rate for FUNAAB-Alpha chickens raised under a deep litter system based on Gompertz, Logistic, Bertalanffy and Richards' model

DISCUSSION

Weight at hatch obtained in this study are higher than 29.00 ± 1.0 g and 23 ± 1.6 g and 24 ± 0.8 g and 25.6 ± 0.7 g for male and female, respectively, as reported by Adedokun and Sonaiya (2001) for some indigenous chickens of Nigeria in derived savanna and rainforest agro-ecological zone of Nigeria, respectively. The higher hatch weight obtained in this study could be attributed to the fact that FUNAAB-Alpha chickens have been improved genetically as they have undergone selection over many generations for improved growth performance (Adebambo *et al*., 2018). The body weight at maturity (20th week) obtained in this study for the male was lower than an average of 2.10 kg reported by Adebambo *et al*. (2018) for improved FUNAAB-Alpha breeds that were reared across 5 agro-ecological zones of Nigeria under the African Chicken Genetic Gain Programme (www.africacgg.net). However, the body weight obtained in this study at 4th, 8th, 12th and 16th week of age were similar to 287.13 ± 6.17 g, 844.30 ± 21.84 g, 1158.15 ± 25.71 g, and 1587.93 ± 40.00 g, respectively, reported by Oleforuh-Okoleh *et al*., (2017) for FUNAAB-Alpha.

The hatch weight predicted by SP3 for the male (74.71 g) was higher than 32.80 g reported by Aggrey (2002) who fitted linear splines of 3 knots at 6, 18 and 113 days of age to describe the growth patterns of Athens-Canadian chickens. This could possibly be due to the differences in the location of the knots utilized. The value of 33.60 g obtained by Aggrey (2002) for female chickens was however, similar to 34.40 g obtained in this study. The range of linear regression coefficients obtained were also much higher than the range of 5.70 to 17.90 reported by Aggrey (2002). An important factor that may hinder direct comparison of the values of regression coefficients is the fact that the locations of the knots utilized in these studies are different, and may be data-specific. The knots were placed at specific locations based on observed growth patterns obtained from preliminary analysis of the data. Highest growth rates for all the spline models were predicted for the first 3 to 10 weeks of growth. This is in agreement with the report of Aggrey (2002) that the highest growth rate was attained between days 18 and 113 for the female chickens, while for the male chickens it was from hatch to day 6. Therefore, growth rate at early stage of life may be an indicator trait for growth performance later in life. Hence, breeding strategies to improve the growth performance of meat-type chickens may focus on the first few weeks after hatching. Further research is needed to clarify this point.

The asymptotic weight estimated in this study by the Gompertz model was consistent with the findings of Zhao *et al*. (2015) and Al-Samarai (2015) on some improved indigenous chickens of China and meat-type chickens of Iraq respectively. However, lower values were obtained by Aggrey (2002), Osei-Amponsah *et al*. (2014) and Ngeno *et al*. (2010) for Athens-Canadian chickens and local chickens in Ghana and Kenya, respectively. The values of parameter A (or asymptotic weight) obtained for Logistic model is consistent with the values reported by Aggrey (2002) and Al-Samarai (2015) but lower than the values reported by Eleroglu *et al*. (2014) for Turkish indigenous chickens. Further, estimates of Parameter A (asymptotic weight) obtained in this study for Richards' model are consistent with the findings of Aggrey (2002) but higher than those reported by Rizzi *et al*. (2013) and Osei-Amponsah *et al*. (2014) for chickens in Italy and Ghana respectively. Variations in the asymptotic weight of these chickens could be attributable to a combination of factors including genetic differences, system of management, the prevailing climatic conditions of the environment in which these chickens were raised, as well as various possible interactions among these factors, which would ultimately influence the growth trajectory.

Overall, there seem to be a better fit to the data as the number of knots reduces. Stone (1986) concluded that fewer knots should be used unless the sample size is large enough and there is a theoretical background to assume that the relationship being studied changes rapidly over time. For both sexes, the Bertalanffy model had the lowest AIC and BIC as goodness-of-fit criteria, and was adjudged the best fit model. This was followed by the Gompertz, Richards' and Logistic models in that order. This was in agreement with the conclusions of several authors [Aworetan and Oseni, (2018), Eleroglu *et al*., (2014), Ngeno *et al*., (2010) and Osei-Amponsah *et al*. (2014)] who reported Bertalanffy as the best fit non-linear model for evaluating the growth of indigenous chickens of Nigeria, Turkey, Kenya and Ghana, respectively. The lesser fit or inadequacy of Richards' model observed in this study might be due to the extra parameter in the model, for which it was penalized by the model selection criteria. Meng *et al*., (1997) reported that the Richards' model was inadequate in providing good fit to data patterns and observations. Aggrey (2002) suggested that the addition of the fourth parameter in the Richards' model may represent an over-parameterization of the growth model.

The high negative correlation coefficients between parameters A and K indicated that the higher the value of the maturity index, the lower is the value of the asymptotic weight. This might be due to the fact that chickens with higher maturity index reached the point of inflection faster as observed with the Logistic model with the highest maturity index value. As noted by Aggrey (2002), the position of the inflection point strongly influences the growth rate and the mature body weight, meaning that the faster the inflection point was reached the lower the value of the mature body weight. This is in agreement with the findings of Al-Samarai (2015) and Ngeno *et al*. (2010) who reported pronounced negative correlation coefficients between parameters A and K.

The relative growth rate patterns estimated by the non-linear models were in consonance with the findings of Eleroglu *et al*., (2014) that asserted that the relative growth rate was always highest at day old and decreased steadily until maturity. Further, there were no disparities in the relative growth rates estimated irrespective of feather morphology and distribution patterns of FAC, indicating that the manifestations of feather-reducing genes of frizzling and naked neck did not significantly influence relative growth rate.

CONCLUSION

This study generated regression coefficients to describe growth performance of FUNAAB-Alpha chickens using 3, 4, 5 and 6 knots. These coefficients can serve as specific breed descriptors for FUNAAB-Alpha chickens during selection and performance testing, or as part of a breed characterization process. The highest value of regression coefficients were estimated for the period of 3-10 weeks implying that growth rate at early stage of life might be a key response to selection for later growth performance and that selection for improved body weight could be done at these ages for further breeding of the breed. Spline models with 3 and 4 knots were found to be the best fit spline models for describing the growth trajectories of FUNAAB-Alpha chickens. Further, Bertalanffy and Gompertz models were found to be the best fit non-linear models for describing the growth performance of FUNAAB-Alpha chickens.

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