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Assessment of spline functions for estimating growth curve parameters of FUNAAB-Alpha chickens

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Abstract

The objective of this study was to fit four spline linear regression models to describe the growth of FUNAAB-Alpha Chickens (FAC). Body weight records of 300 FAC raised from day old till the 20^{th} week were used to fit spline models of 3 (SP3), 4 (SP4), 5 (SP5) and 6 knots (SP6) using the REG procedure of SAS®. The data were first plotted to determine the most appropriate location of knots and they were placed at 4^{th}, 10^{th} and 16^{th} week of age for SP3; 4^{th}, 8^{th}, 12^{th} and 16^{th} week for SP4; 4^{th}, 7^{th}, 10^{th}, 14^{th} and 18^{th} week for SP5 and 3^{rd}, 6^{th}, 9^{th}, 12^{th}, 15^{th} and 18^{th} week for SP6, respectively. The hatch weight predicted by SP3 was observed to be highest while SP6 predicted the lowest hatch weight for male and female FAC. Regression coefficients ranged from -38.47 to 47.46 and -39.40 to 40.47 for the male and female, respectively. For all the models, the highest magnitude of these coefficients were estimated at early ages after hatching (at 3 to 10 weeks of age). Based on Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC) as the goodness-of-fit selection criteria, SP3 had the lowest value for AIC and BIC for male FAC while SP4 had the lowest value of AIC and BIC for the female FAC. It was concluded that spline models of lower knots (SP3 and SP4) were the best fit to describe the growth of male and female FAC respectively, and that growth rate at early stages of life of FAC may be good predictors of later growth performance.

Keywords: Spline models, FAC, Knots, hatch weight, Akaike Information criterion.

Introduction

Mechanical splines refer to a set of instruments once used to draw smooth curves through data points (Kaya, 2014). The usage of these mechanical splines involved the placement of pins at selected points along a curve in a design, and then the spline was bent so that it touched each of these pins. With this construction, the spline interpolates the curve at these pins and could be used to reproduce the curve in other drawings. Locations of the pins are called knots (Aggrey, 2002). It was through this analogy that a mathematical function was derived for breaking complex relationships between two variables into fragments that describe such relationship with higher precision. Mathematically, a spline function consists of polynomial pieces on sub-intervals joined together with certain continuity conditions at various positions known as knots or junctions. It is a regression model that is fast gaining wide attention in statistical modeling due to its flexibility, good statistical interpretation, amenability to data that have no particular pattern, and very useful for modeling data that have changed patterns in sub-intervals (Budiantara and Purnomo, 2011) and is a straightforward extension of the parametric, linear regression (Meyer, 2005). The shape of the curve defined by the spline can be easily changed by adjusting the location of the knots. Aggrey (2002) and Meyer (2005) have suggested that the spline linear regression models can be used as alternative to high order polynomials, and to complex and complicated non-linear models. Spline models have been suggested for evaluating sigmoidal growth (Aggrey, 2002), and as alternatives to non-linear growth models.

FUNAAB – Alpha chickens (FAC) have been described as multi-coloured breed of chickens developed for the rural poor under the village scavenging system (Adebambo *et al.,* 2018). They are described as improved, indigenous, tropically adapted and dual-purpose breed developed through crossbreeding and intensive selection over twelve generations for improved meat and egg production without sacrificing adaptation to the tropical environment characterized with heat stress and infectious diseases (Adebambo, 2015). According to Adebambo (2015), the development of FAC started in 1994 with initial characterization of indigenous genetic materials sourced all over southwestern Nigeria. These included the frizzled feathered, naked neck, normal feathered and the dwarf skeletal variants. These selected indigenous chickens were then crossed with Giriraja, an improved breed native to India. The crossbred chickens were thereafter backcrossed to the indigenous chickens to obtain a body weight of 1.6-2.1 Kg at 20 weeks of age in 3 generation of crossbreeding using artificial insemination. These chickens are currently 37.5 to 62.5% indigenous in their bloodline (Adebambo, 2015).

Many reports in Animal Science research especially in poultry have used spline functions to model growth and egg production performance (Aggrey, 2002; Meyer, 2005; Vitezica *et al.,* 2010 and Monkprom *et al.,* 2017). In particular, Aggrey (2002) comparatively evaluated three non-linear growth models (Richards, Gompertz, and Logistic) and the spline linear regression model for a population of unselected, random-bred, chicken population raised from day-old till 170 days. This author fixed three knots at 6, 18 and 113 days of age to generate a four-line segment for both male and female chickens. This author concluded that the non-linear models fitted the data better than the spline regression model using the coefficient of determination and residual standard deviation (RSD) as the goodness-of-fit criteria. Vitezica *et al.* (2010) compared four nonlinear models (Gompertz, Logistic, Richard's, and Weibull) and a spline linear regression model for a population of mule ducks using Akaike Information criterion (AIC) as the goodness-of-fit criterion. The spline regression model was found to fit the data better than Gompertz, Logistic and Richards' models. Monkprom *et al.* (2017) evaluated egg production curve in Thai native chickens by random regression models and linear spline models. These investigators analyzed nine random regression models using the Koops and Grossman function (KG), Wilmink function (WM), and Legendre polynomials functions with second, third, and fourth orders and spline linear functions with 4, 5, 6, and 8 knots were comparatively evaluated. To compare their models, mean square error (MSE), the coefficient of determination (R^2)and the correlation between observed and predicted values were used as the goodness-of-fits. These authors found out that the spline functions with 5, 6 and 8 knots fitted the data more appropriately than all the random regression models fitted and their covariance functions proved appropriate for the genetic evaluation of egg production curves for Thai native chickens. These authors concluded that spline functions could be applied to breeding programmes for the improvement of both egg number and persistence of egg production. Modelling the growth of these chickens with spline functions will generate regression coefficients, which can be used as the basis for comparison with other breeds of chickens. The objective of the study, therefore, was to fit four spline linear regression models to describe the growth of FUNAAB-Alpha Chickens (FAC).

Materials 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 224m above sea level.

Experimental birds

Three hundred (300), one day-old chicks 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 45 to 45°C was provided during brooding using electric bulbs and gas burner as the source of heat. They were there after transferred to the deep litter pen at the end of the fourth week.

Housing

The deep litter pen, containing thirty cells each of 1.5m × 1.5m dimension, were 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.

Nutrition

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 of metabolizable energy from day old till the fifth week while they were thereafter fed with grower ration containing 18% CP and 2900 Kcal/Kg 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 chicks to the feed while water was provided in a specialized 2.5 litre plastic drinker, placed upside down for proper water dispensation and to avoid water spillage.

Health management

Proper hygiene was ensured all the time. Bio-security was guaranteed by barring visitors and strangers from entering the pen while a foot dip was provided at the entrance which was 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 chicks were vaccinated against Newcastle disease on the 10th day and other medications were administered as at when due, following the standard practice in poultry management.

Data collection

Each bird was 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 body weight records were taken early in the morning before feeding following FAO (2012).

Data analysis

The raw data was first plotted to determine the appropriate locations of the knots as described by 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 along the trajectory) of these models are presented in Table 1. PROC REG of SAS® was used to fit the linear spline models.

Table 1: Equations for spline and modified spline functions

Spline model	Number of knots	Location of knots(age)	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 (bodyweight 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 which is assumed to be normally and independently distributed with mean = 0 and constant variance.

Results and discussion

Growth performance of FUNAAB-Alpha chickens from day-old to 20 weeks

The least square means and standard error of body weight of FUNAAB-Alpha chickens (FAC) raised under a deep litter system from hatch till the birds were 20 weeks old are shown in Table 2. The body weight of the male and female chickens were similar at hatch (P>0.05). However, the males were heavier than the female chickens thereafter 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. Weight at hatch obtained in this study are higher than 29.00±1.0g and 23±1.6g and 24±0.8g and 25.6±0.7g 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 FAC 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±6.17g, 844.30±21.84, 1158.15±25.71, and 1587.93±40.00, respectively, reported by Oleforuh-Okoleh *et al.* (2017) for FUNAAB-Alpha.

Modelling the growth of FUNAAB-Alpha chickens (FAC) using spline functions

The estimated hatch weights and regression coefficients for FUNAAB-Alpha chicks using spline functions of 3 (SP3), 4 (SP4), 5 (SP5) and 6 (SP6) knots are presented in Table 3. 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 chicks, while it ranged from -39.40 to 40.47 for female chicks. Highest magnitudes of these coefficients were estimated at early ages. The hatch weight predicted by SP3 for the male (74.71g) was higher than 32.80g 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 differences in the location of knots utilized. The value of 33.60g obtained by Aggrey (2002) for

Table 2: 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 ($P<0.05$)

female chickens was however, similar to 34.40g 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 locations of knots utilized in these studies are different, and may be data- and genotype-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 was 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 it was from hatch to day 6 for the male chickens. 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 and validate this point.

Table 3: Estimated coefficients for spline regression model parameters in FAC 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

Selection of the best-fit model

Table 4 showed the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) for the spline models fitted. 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, SP4 had the lowest AIC and BIC values and was selected as the best-fit model followed by SP3, SP6 and SP5 in that order. 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 theoretical background to assume that the relationship being studied changes rapidly.

Table 4: 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

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

Growth curves of FAC predicted by spline models of 3, 4, 5 and 6 knots

Figures 1 and 2 show graphical representations of growth rate of male and female FAC respectively as predicted by spline functions of 6 (SP6), 5 (SP5), 4 (SP4) and 3 (SP3) knots. Generally, body weight increased with age but at different rates as predicted by different spline functions. There exists an overlap in the growth rate predicted by these functions from hatch till about 4th to 6th week for most cases. For the male FAC, there was an overlap 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 was found to be lowest. For the female, the growth rate predicted by the SP5 and SP6 functions were similar and highest while the growth rate predicted by SP3 was observed to be the lowest.

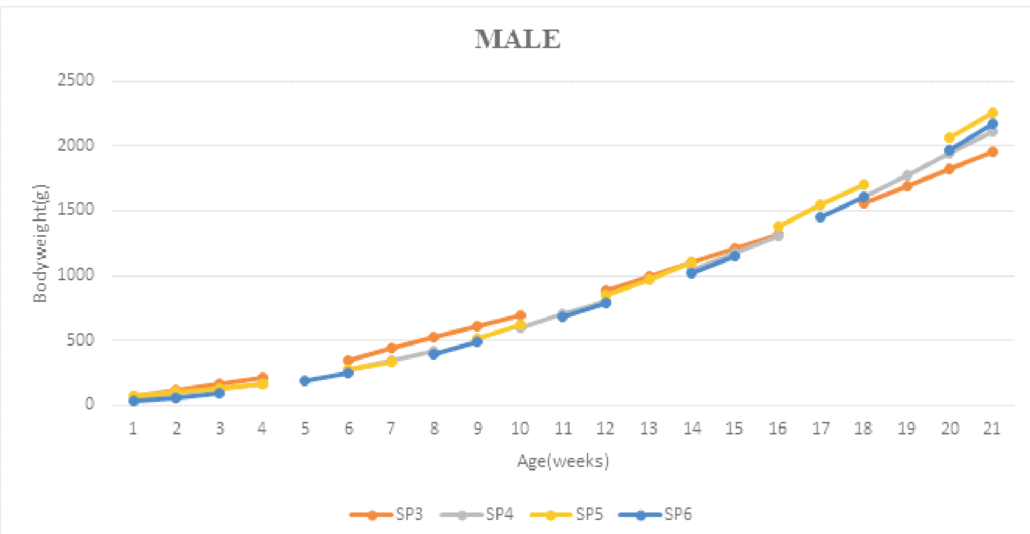

Fig 1: Growth curve of FAC as predicted by spline models (Male)

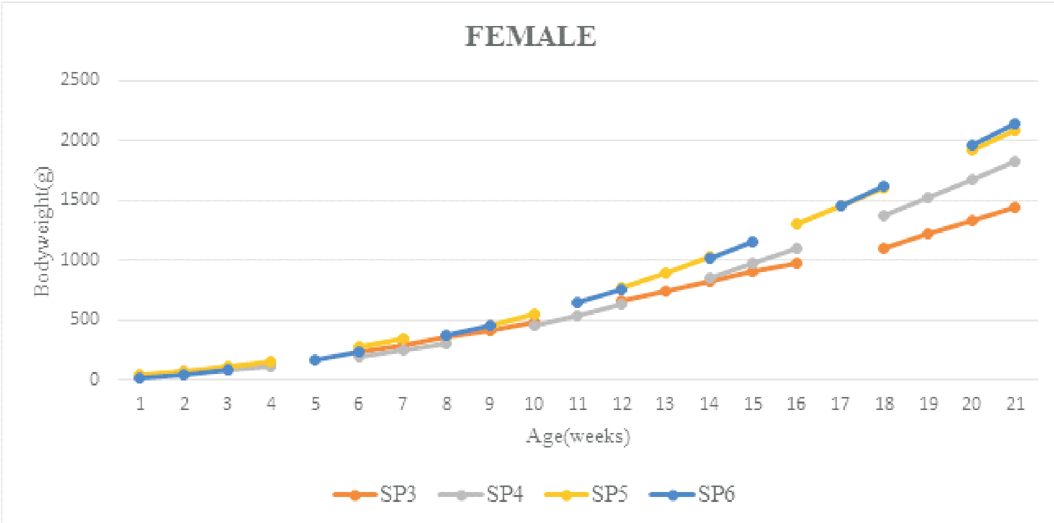

Figure 2: Growth curve of FAC as predicted by spline models (Female)

Conclusion

This study generated regression coefficients (relative growth rate) to describe growth performance of FUNAAB-Alpha chickens using 3, 4, 5 and 6 knots. These coefficients can serve as breed descriptors for FUNAAB-Alpha chickens during selection and performance testing. The highest values of regression coefficients were estimated for the period of 3-10 weeks after hatching implying that growth rates at early stage of life may be indicator traits for growth performance later in life. Spline models of 3 and 4 knots were found to be the best fit for describing the growth performance of male and female FUNAAB-Alpha chickens, respectively.

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References

Adebambo, O. A. 2015. From PEARL project to ACGG in Nigeria. Paper presented at the First ACGG Nigeria Innovation Platform meeting Ibadan, Nigeria, 20 – 22 July. Retrieved June 5th, 2018, from https://cgspace.cgiar.org/bitstream/handle/10568/72670/acggpearlnigeriajul2015.pdf?sequence=1

Adebambo O. A., Ikeobi, C. O. N., Ozoje, M. O., Adebambo, A. O., Peters, S. O., Adeleke, M. A., Wheto, M. Y., Ojoawo, H. T., Osinbowale, D. A., Ogunpayimo, O., Bamidele, O., Sonaiya, E. B. and Dessie, T. 2018. Indigenous Chicken Breeding in Nigeria. In: *Proc. 43rd Annual Conference of the Nigerian Society for Animal Production, March 18th – 22nd 2018, Federal University of Technology, Owerri, Nigeria.*

Adedokun, S. A. and Sonaiya, E. B. 2001. Comparison of the performance of Nigerian Indigenous chickens from the three agro-ecological zones. *Livest. Res. Rural Dev.,* 13: 1-6.

Aggrey, S. E. 2002. Comparison of Three Nonlinear and Spline Regression

Models for Describing Chicken Growth Curves. *Poultry Science* 81:1782–1788

Budiantara, N. and Purnomo, J. D. T. 2011. Infants' Weight Growth Model in Surabaya (Indonesia) By Using Weighted Spline Regression. *International Journal of Basic & Applied Sciences* 11(02)119 -124

FAO. 2012. Phenotypic characterization of animal genetic resources. FAO Animal Production and Health Guidelines No. 11. Rome.

Kaya, E. 2014. Spline Interpolation Techniques. *Journal of Technical Science and Technologies,* 2(1):47-52.

Monkprom, S., Boonkum, W., Kunhareang, S., Siripanya, S. and Duangjinda, M. 2017. Genetic evaluation of egg production curve in Thai native chickens by random regression and spline models. *Poultry Science,* 8(1): 274-281.

Meyer, K. 2005. Random regression analyses using B-splines to model growth of Australian Angus cattle. *Genet. Sel. Evol.* 37: 473–500.

Oleforuh-Okoleh, V. U., Kurutsi, R.F. and Ideozu, H. M. 2017. Phenotypic Evaluation of Growth Traits in Two Nigerian Local Chicken Genotypes. *Animal Research International*, 14(1): 2611 – 2618.

SAS. 2002. Statistical Analysis System, Computer software, Version 9.0: SAS Institute Inc., Cary, NC. 27513, USA.

Stone, C. J. 1986. Generalized Additive Models: Comments. *Statistical Science, 1(3)*, 312-314.

Vitezica, Z.G., Marie-Etancelin, C., Bernadet, M. D., Fernandez, X., and Robert-Granie, C. 2010. Comparison of nonlinear and spline regression models for describing mule duck growth curves. *Poultry Science*, 89 :1778–1784.

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