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Prediction of growth curves in Nigerian sheep using non-linear mathematical models

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Target audience: *Animal scientists, Breeders and farmers of sheep*

Abstract

Information on growth pattern is required for selection and management plans in sheep production. In this study, weights of 156 sheep comprising 36 Balami, 37 Uda, 41 Yankasa and 42 WAD were measured monthly from birth to the 12th month and used to model the relationship between weigh and age data by fitting the Logistic, Gompertz, Von Bertalanffy, Verhulst and Brody mathematical growth models. The goodness of fits of the models were assessed using the coefficient of determination, R2, the mean square error, MSE and Akaike's information criterion, AIC. Over all, the growth model parameter A ranged from 31.9 (Verhulst) to 115 (Brody, which was consistently higher than in other growth models). Parameter B was highest in Verhulst (7.60) and lowest in Logistics (-0.277). Parameter K was consistently lowest (-0.005) in the Logistics model and generally highest in the Verhulst model. All the models had high R2 ranging from 0.81 to 0.99, while MSE ranged from 0.20 to 14.5. As in other measures of fitness, similar order of ranking of models was exhibited by the AIC which values ranged from 42.1582 to 16.8644. All the models presented similar predictions of body weight with generally low residuals between them and the observed weights at the same stages of growth. This indicated that all the mathematical models compared and fitted the body weight data well and could be used to predict sheep weights, but Brody and von Bertalanffy were best.

Keywords: sheep; live weight prediction; growth models; goodness of fit; model parameters.

Description of Problem

Growth, known as the relationship between lifetime weight and age, is a biological phenomenon that can be described mathematically by functions (models) that have parameters with biological meaning (1). It is a time(age) dependent change manifested in the weight or size of organ, composition of tissue/organ, size of cell and number as well as in live weight (2). Growth curve is the graph of weight as a function of age on time. The curve elucidates gradual changes taking place in animal's body with the passage of time and is often sigmoid in shape. Sigmoid curve has 3 three phases: preparing, increasing and quietness. In first phase, growing starts at a specific point and increases gradually. In second phase, curve adopts somewhat linear shape up to distortion point. In the last phase, the curve reaches asymptote. Growth curve parameters provide information on growth characteristics. The most commonly used functions to estimate animal's growth have three to four parameters (A, b, k and in some cases y). Interpretation of growth varies according to breed and model (3). Growth curves are of many uses in farm animals. These curves have been used to estimate mature body weight and increase in liveweight in goat and sheep (4). Growth curve could be useful in selection of animal as it provides prediction of future growth at any age and breeding strategies (5, 6). Growth curve is used for evaluation of response to specific treatment over time, interaction between subpopulations and/or treatments and time and identifying heavier animals at younger age within population (7). Further, information on the growth pattern helps determine feeding and management plans and planning breeding strategies to improve the efficacy of whole growth process (8). Fitting growth functions to data is an interesting method of assessing management factors and for breeding purpose (9). The growth curve covers all or part of the animal lifespan (9,10). However, several mathematical functions have been used to represent growth curves in sheep. In this specie, the models that best represent growth are non-linear Brody, von Bertalanffy, Verhulst, Logistic and Gomperz (9, 11, 12, 13). Parameters from growth curve functions are highly heritable and have been used in many selection studies (14). In Nigeria, sheep contribute 11% of the meat supplied from slaughter houses and this is even greater if rural unregistered slaughters are considered (15). They play significant role in the nutrition, social and economic life of the people. The indigenous breeds of sheep of Nigeria in the order of importance are Yankasa (60%), West African dwarf (WAD) (20%), Uda (10%) and Balami (10%) (16).

Study on growth curves of Nigerian sheep breeds as described by growth models can enable better management and early selection for breeding to improve growth traits. Therefore, the objective of this study was to compare the goodness of fit of five non-linear mathematical growth functions (Brody, Gompertz, von Bertalanfy, Verhulst and Logistics) for the prediction of body weights of four Nigerian sheep breeds (Balami, Uda, West African Dwarf and Yankasa) from birth to twelve months of age.

Materials and methods 4
Location and Climate

The research was carried out on the Jos Plateau which has been described by (17) as a pear-shaped upland located in the middle of Nigeria between latitude 8oand 100north and longitudes 70 and 110 east, at an average attitude of 1,200m above sea level. Jos Plateau has near temperate climate with average monthly temperatures ranging between 180 and 250C. It experiences an average humidity of 60% and rainfall of 1400mm. The vegetation is aptly described as montane (18).

Experimental sheep and their management

The research commenced with a stock of 64 yearling sheep which comprised 12 each of Uda and Balami and 20 each of West African Dwarf (WAD) and Yankasa in a sex ratio 1: 1 per breed. The Uda and Balami were bought from Railway market in Bauchi, North Eastern Nigeria while the Yankasa and WAD were sourced from local farmers and markets within the Jos Plateau. The animals were quarantined and acclimatized for 2 months. One hundred and fifty six (156) offspring of the starting stock produced from controlled mating (only within breed mating) were used.

At the research station, sheep were housed in pens constructed with concrete blocks, floored and roofed with corrugated iron sheets. The females and a breeding ram of the same breed were kept together and all other males were collectively housed. Few days to lambing pregnant ewes were isolated and housed in a well littered lambing pen. After lambing, all necessary cleaning and identification processes were observed. New born lambs were kept with their ewes under close observation for 24 hours to ensure that they were suckled with colostrums. Ewes were allowed to graze without their lambs after 3 weeks of lambing. Throughout the period of the experimental study (4 years). Animals were grazed separately by sex on locally available pasture from 9:00am to 5:00pm. Crop residues such as legumes and corn stalks, leafy shrubs and herbs were made available. In the evening they were returned to the pen and provided with salt lick and supplementary maize offals, groundnut haulm, cowpea and corn husks. Drinking water was supplied ad libitum. Routine veterinary care especially deworming, prophylaxis and ectoparasites control were given

Measurement of growth rate and mathematical models

Body weights were measured in kilogramme using the Salter scale. The weights measured included at birth (within the first day), monthly up to the 12th and at weaning, 90th day.The 5

Logistic and Gompertz (19), Von Bertalanffy (11), Verhulst (9) and Brody (7) functions were fitted to the growth data using Levenberg-Marquardts' method (20) to model the relationship between weight and age. These models are as follows:

Brody $y = a*(1-b*exp(-k*t))$
Von Bertalanffy $y = a*(1-b*exp(-k*t))**3$
Verhulst $y = a/(1 + b*exp(-k*t))$
Logistic $y = a*(1+ exp(-k*t))**(-m)$
Gompertz $y = a*exp(-b*exp(-k*t))$

Where:
y= weight in kg at age t expressed in months
t= age in days
a= asymptotic limit of the weight when t approaches infinity (mature weight)
b= the proportion of asymptotic mature weight to be gained after birth
k= function of the ratio of maximum growth rate to mature weight (maturing rate)

The goodness of fits of the models were assessed using the coefficient of determination, R2, the mean square error, MSE and Akaike's information criterion, AIC (21, 10, 13, 21). The expressions used for their computation were

i. $R2 = 1\text{-}RSS/TSS$

Where:
R2 = Coefficient of determination
RSS= Residual sum of squares
TSS = Total corrected sum of squares

ii. MSE = Sum of squares error/degree of freedom

iii. $AIC = n\log(SSE/n)+2p$

Where:

n = number of observations
SSE = sum of squares error
p = number of parameters + 1

Results and discussion

Mathematical growth model parameters 6

Growth model parameters estimated by sheep breed are shown in Table 1. Respectively, in the overall, Balami, Uda, WAD and Yankasa, the growth model parameter A (average weight of a mature sheep) ranged from 31.9 (Verhulst) to 115 (Brody), 16.0 (logistics) to 83.4 (Brody), 17.5 (logistics) to 62.7 (Brody), 10.8 (Von Bertalanffy) to 47.5 (Brody). Parameter A was consistently higher in Brody function than in other growth models. Generally, the estimates of parameter B were highest in Verhulst and lowest in logistics. They ranged respectively from -0.136 (logistics) to 7.60 (Verhulst), -0.277 (logistics) to 6.26 (Verhulst), -0.252 (Logistics) to 5.77 (Verhulst), -0.120 (logistics) to 7.76 (Verhulst) and -0.224 (logistics) to 7.18 (Verhulst) in the overall, Balami, Uda, WAD and Yankasa. Similarly, the growth rate, parameter K, was consistently lowest (-0.005) across breeds in the Logistics model and generally highest in the Verhulst model. The values in the Verhulst model ranged from 0.012 (in overall, Balami and Uda) to 0.016 in WAD.

For breeds of sheep in the present study, estimates of parameters by the different models were within the range reported by earlier workers (9, 21,,22). In the present study, parameter A was highest (83.360kg in Balami) for Brody model. (22) had 62kg (highest) in the von Bertalanfy model for WAD sheep. (7) reported an estimate of 70.02 for Brody model in Mehraban Iranian fat tailed sheep. Comparable to (22) parameter A in the present study was lowest in the logistic models in all breeds. Parameter B estimates in the present study were generally highest in Verhulst and lowest in Logistics. This is at variance with the report of (22). The authors observed the highest estimate in Gompertz and the lowest in von Bertalanffy. The parameter K in the present study are within the range reported in literature (9, 11, 21). The smallest values of K were consistently found in logistics model while the greatest values were observed in Verhulst across all the four breeds. (22) observed the highest K value (0.0166) in the logistic function and the lowest (0.0024) in the Brody model in WAD sheep. (23) found that K varied between 0.0132 to 0.0171 for Gompertz model and 0.010 to 0.12 for von Bertalanffy but the value of 0.005 to 0.008 had been reported by (21). Similar to the present study, (9, 24, 25 and 26) obtained varying A, B, and K values using different models for the same weight – age data suggesting that the parameter estimates depend on model of choice.

Goodness of fit measures

The coefficient of determination (R2), mean square error (MSE) and Akaike's information criterion (AIC) of all mathematical models are shown in Table 1. All the models had high R2 7 ranging from 0.815 (logistics model from WAD) to 0.998 (in Brody and Von Bertalanffy models for overall and Balami). According to the R2 values, the models ranked in the following order: Brody and Von Bertalanffy > Gompertz > Verhulst > Logistics in the overall, Balami, Uda and WAD respectively. However, in Yankasa the ranking was in the order Verhulst > Gompertz > Brody and Von Bertalanffy > Logistics. The MSE ranged from 0.196 in Brody and Von Bertalanffy to 14.489 in the logistics model for Balami. The ranking of models based on MSE is similar to that of the R2. The Brody and Von Bertalanffy ranked best while the logistics was worst in all breeds except Yankasa in which the Verhulst model was the best. Furthermore, similar order of ranking was exhibited by the AIC which values ranged from 42.2 in Brody and Von Bertalanffy (best) to 16,864 in logistics (worst) for all breeds except Yankasa. Verhulst model was best while the Logistics model was still worst for Yankasa.

The R2, MSE and AIC values found for the different models in this study were high and within or close to the ranges reported in literature. The values depended on models, data structure and species of animal. (22) reported an R2 value range of 0.82 to 0.84 in WAD for Brody, von Bertalanffy, Logistic and Gompertz models. Similar R2 values (0.98 to 0.99) were reported for Morkaraman and Awassi Sheep (11) and 0.938 to 0.994 in Scottish Blackface and Texel lambs (8). (11) reported an MSE range of 2.1 to 3.2 while (23) 0.0662 to 0.4557. 8 found an AIC range of 45.95 to 83.61 in Scottish Blackface and Texel lambs.

Similar to the present study, (22) found that the Brody model had the lowest MSE and AIC and therefore of the best fit. However, in the present study, Brody and von Bertalanffy ranked equal. In previous studies, a wide range of models have been selected based on accuracy of data fit. The Logistics model was selected as against Brody and Richards in Bergamasca Sheep in Brazil (27). (8) selected Richards and Gompertz leaving out Logistics and exponential models. The Gompertz and von Bertalanffy were of best fit in Morkaraman and Awassi breeds (11), while Gompertz model was selected for Suffolk (28). In the present finding, Brody and von Bertalanffy were the best fits for Balami, Uda and WAD while Verhulst was best for Yankasa.

Table 1: Estimates of parameters of growth models by sheep breeds

Model parameters /statistical analysis		Genetic Group				
Model	**Parameters**	**Overall**	**Balami**	**Uda**	**WAD**	**Yankasa**
A	Brody	115	83.9	62.6	32.5	47.5
	Logistics	26.5	16.0	17.5	25.3	16.1
	Von Bertalanffy	38.4	28.0.	21.0	10.8	15.8
	Verhulst 3	1.9	34.5	32.0	21.1	25.8
	Gompertz	37.1	39.6	36.0	22.8	28.6
B	Brody	0.981	0.963	0.951	0.984	0.963
	Logistics	-0.136	-0.277	-0.252	-0.120	-0.224
	Von Bertalanffy	0.983	0.963	0.63	0.982	0.962
	Verhulst	7.60	6.26	5.77	7.76	7.18
	Gompertz	2.52	2.27	2.18	2.56	2.39
K	Brody	0.001	0.001	0.002	0.003	0.002
	Logistics	-0.006	-0.005	-0.005	-0.005	-0.005
	Von Bertalanffy	0.001	0.001	0.002	0.003	0.002
	Verhulst	0.012	0.012	0.012	0.016	0.014
	Gompertz	0.007	0.007	0.007	0.010	0.008
Selection Criteria						
R2	Brody	0.99	0.99	0.99	0.99	0.98
	Logistics	0.88	0.88	0.87	0.82	0.83
	Von Bertalanffy	0.99	0.99	0.99	0.99	0.98
	Verhulst	0.98	0.99	0.98	0.98	0.99
	Gompertz	0.99	0.99	0.99	0.99	0.99
MSE	Brody	0.213	0.196	0.312	0.427	0.992
	Logistics	12.1	14.5	13.7	11.5	13.2
	Von Bertalanffy	0.213	0.196	0.312	0.427	0.992
	Verhulst	1.23	0.747	1.22	1.22	0.411
	Gompertz	0.525	0.309	0.622	0.595	0.467
AIC	Brody	3767	42.2	1866	3090	6384
	Logistics	16167	16864	16649	15917	16508
	Von Bertalanffy	3767	42.2	1866	3090	6384
	Verhulst	7224	5275	7175	7196	2942
	Gompertz	3865	1822	4562	4580	3437

A = Asymptotic weight when age approaches infinity indicating average weight of mature sheep; B= point of inflection/rate of bodyweight gained after birth to maturity; K= rate of growth/maturity rate; R2= coefficient of determination; MSE = mean square error; AIC = Akaike's information criterion.

Tables 2 and 3 indicated observed, predicted and residual weights of sheep from birth (Day 0) to 360 days of age for different growth models for Balami, Uda, WAD and Yankasa respectively.

Predicted weights

Table 2: Observed, predicted and residual weights for different growth models for Balami

	Age (days)	Observed weight (kg)	Gompertz predicted	Residual	Logistics predicted	Residual	Verhulst predicted	Residual	Von Bertalanffy predicted	Residual	Brody predicted
Overall	0	2.37	2.01	0.36	2.01	0.36	3.7	-1.33	7.24	-4.87	2.99
	30	4.21	4.64	-0.43	4.64	-0.43	5.07	-0.86	7.92	-3.71	4.69
	60	6.72	7.2	-0.48	7.2	-0.48	6.82	-0.1	8.72	-2	6.8
	90	10.30	9.71	0.59	9.71	0.59	8.97	1.33	9.67	0.63	9.21
	120	12.31	12.15	0.16	12.15	0.16	11.48	0.83	10.81	1.5	11.83
	150	14.09	14.54	-0.45	14.54	-0.45	14.27	-0.18	12.16	1.93	14.52
	180	17.24	16.88	0.36	16.88	0.36	17.16	0.08	13.75	3.49	17.18
	270	23.41	23.56	-0.15	23.56	-0.15	24.74	-1.33	20.58	2.83	24.24
	360	39.82	29.79	0.03	29.79	0.03	29.05	0.77	32.01	-2.19	29.33
Balami	0	3.21	4.08	-0.87	8.9	-5.69	4.75	-1.54	3.19	0.02	3.19
	30	6.22	6.14	0.08	9.67	-3.45	6.41	-0.19	6.17	0.05	6.17
	60	9.42	8.58	0.84	10.58	-1.16	8.49	0.93	9.04	0.38	9.04
	90	11.48	11.3	0.18	11.65	-0.17	10.98	0.5	11.8	-0.32	11.8
	120	14.21	14.16	0.05	12.9	1.31	13.81	0.4	14.47	-0.26	14.47
	150	16.48	17.04	-0.56	14.37	2.11	16.85	-0.37	17.03	-0.55	17.03
	180	19.93	19.83	0.1	16.1	3.83	19.91	0.02	19.5	0.43	19.5
	270	26.91	27.04	-0.13	23.3	3.61	27.59	-0.68	26.38	0.53	26.38
	360	32.23	32.1	0.13	34.95	-2.72	31.78	0.45	32.52	-0.29	32.52
Uda	0	3.12	4.06	-0.94	8.78	-5.66	4.72	-1.6	3.16	-0.04	3.16
	30	6.10	6.12	-0.02	9.53	-3.43	6.38	-0.28	6.14	-0.04	6.14
	60	9.40	8.55	0.85	10.39	-0.99	8.45	0.95	8.98	0.42	8.98
	90	11.44	11.2	0.24	11.41	0.03	10.9	0.54	11.67	-0.23	11.67
	120	13.92	13.96	-0.04	12.6	1.32	13.65	0.27	14.22	-0.3	14.22
	150	16.10	16.69	-0.59	13.98	2.12	16.54	-0.44	16.65	-0.55	16.65
	180	20.0	19.29	0.71	15.61	4.39	19.4	0.6	18.96	1.04	18.96
	270	24.82	25.79	-0.97	22.31	2.51	26.27	-1.45	25.21	-0.39	25.21
	360	30.65	30.13	0.52	33.03	-2.38	29.8	0.85	30.56	0.09	30.56

Table 3: Observed, predicted and residual weights for different growth models for West African Dwarf (WAD) and Yankasa sheep.

	Age (days)	Observed weight (kg)	Gompertz predicted	Residual	Logistics predicted	Residual	Verhulst predicted	Residual	Von Bertalanffy predicted	Residual	Brody predicted	Residual
WAD	0	3.21	1.76	-0.37	6.06	-4.67	2.41	-1.02	0.8	0.59	0.8	0.59
	30	6.22	3.35	-0.56	6.59	-3.8	3.64	-0.85	3.51	-0.72	3.51	-0.72
	60	9.42	5.42	0.4	7.2	-1.38	5.34	0.48	5.99	-0.17	5.99	-0.17
	90	11.48	7.77	0.04	7.93	-0.12	7.48	0.33	8.25	-0.44	8.25	-0.44
	120	14.21	10.18	0.53	8.78	1.93	9.94	0.77	10.32	0.39	10.32	0.39
	150	16.48	12.46	0.01	9.78	2.69	12.46	0.01	12.22	0.25	12.22	0.25
	180	19.93	14.5	0.14	10.96	3.68	14.77	-0.13	13.95	0.69	13.95	0.69
	270	26.91	18.83	-1.37	15.86	1.6	19.15	-1.69	18.31	-0.85	18.31	-0.85
	360	32.23	21.02	0.88	23.78	-1.88	20.58	1.32	21.65	0.25	21.65	0.25
Yankasa	0	3.21	2.61	-0.29	7.23	-4.91	3.15	-0.83	1.95	0.37	1.95	0.37
	30	6.22	4.39	0.85	7.85	-2.61	4.55	0.69	4.66	0.58	4.66	0.58
	60	9.42	6.59	0.4	8.57	-1.58	6.4	0.59	7.2	-0.21	7.2	-0.21
	90	11.48	9.07	-1.07	9.42	-1.42	8.7	-0.7	9.6	-1.6	9.6	-1.6
	120	14.21	11.63	-0.36	10.41	0.86	11.33	-0.06	11.86	-0.59	11.86	-0.59
	150	16.48	14.14	-0.05	11.58	2.51	14.11	-0.02	13.98	0.11	13.98	0.11
	180	19.93	16.48	0.73	12.94	4.27	16.77	0.44	15.97	1.24	15.97	1.24
	270	26.91	21.95	0.06	18.6	3.41	22.48	-0.47	21.27	0.74	21.27	0.74
	360	32.23	25.2	-0.17	27.7	-2.67	24.79	0.24	25.68	-0.65	25.68	-0.65

Conclusions and Application

1. All mathematical functions (Brody, Logistics, Gompertz, von Bertalanffy and Verhulst) fitted well into the weight-age data of all sheep breeds
2., Brody and von Bertalanffy were however, of best fit for Balami, Uda and WAD while Verhulst model was best for Yankasa.
3. Body weights of sheep predicted from non-linear models could be used for early selection to improve growth traits of Nigerian sheep.

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