ESTIMATION OF BODY WEIGHT FROM MORPHOMETRIC TRAITS IN THREE CHICKEN STRAINS USING LINEAR AND QUADRATIC MODELS.

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ABSTRACT
The experiment was conducted to compare the growth rate of three chicken strains using linear and quadratic models at different ages. A total of 300 day-old chicks, 100 chicks each of three strains – Arbor Acre broilers, Noiler hybrid and Yoruba ecotype cockerels were used for the study which lasted for 16 weeks. Linear measurements of body length, keel length, shank length, wing length, breast width, body depth and drumstick were regressed against body weight using linear and quadratic models at 2-8 and 10-16 weeks of age, respectively. Accuracy of body weight prediction based on the coefficient of determination (R^2 %) for the cockerel ranged from very low to moderate at 2-8 weeks. The range of values was 0.10 - 46.90 % (linear) and 24.40 - 48.20 % (quadratic). R^2 (%) values were generally low at age 10-16 weeks for both functions. Regression of linear traits against body weight of Arbor Acre strains also had low to moderate estimates at 2-8 weeks – 3.50 - 32.70 % (linear) and 10.10 - 34.80 % (quadratic). However, the R^2 (%) values for week 10-16 estimates were very high and ranged from 71.10 % - 92.60 % (linear) and 71.20 - 93.70 % (quadratic). For the Noiler hybrid strain, moderate R^2 (%) values were observed at weeks 2-8 having a range of 21.80 - 37.40 % (linear) and 26.80 - 39.10 % (quadratic). Estimates were generally low at weeks 10-16 for this strain. The result of this study showed that the best accuracy of prediction was obtained with quadratic function with body depth, breast width, body length, shank length and drumstick as best regressors.

Keywords: Morphometric trait, chicken strains, linear, quadratic, model

INTRODUCTION
Designing an appropriate improvement programme for poultry and livestock involves proper recording of their characteristics and performance, including measurement and monitoring of their body weight. Apart from the usefulness of body weight in estimating growth, health and feed efficiency, it is used in evaluating type, function and potential values of animals intended for use as breeding stock, meat, egg and milk production as well as draught power (Lesosky *et al*., 2013). Pinto *et al.* (2006) reported that body weight at various ages and performance characteristics are significant variables that indicate the usefulness of the chicken for commercial purposes.

Accurate and proper assessment of body weight is difficult under field conditions (Atansuyi *et al*., 2017), as it is mostly estimated by visual appreciation, a method which is widely inaccurate (Chitra *et al*., 2012), especially when it is done by different evaluators. Thus, reliable and easy-to-apply methods have been developed to estimate body weight on-farm where weighing scales are not usually available. Several authors have found strong association between body weight and linear body parts and have developed body weight prediction models (both linear and non-linear) using the linear body components (Grossma *et al*., 1985; Yakubu *et al*., 2009; Lukuyu *et al*., 2016). However, the effectiveness of the models depends on the linear body measurements under consideration (Assan, 2015). It has also been noted that accurate estimation of body weight could be influenced by other factors such as breed, sex and age (Lesosky *et al*., 2013). In corroboration, some authors reported that correlations and equations of prediction are very specific to strain, age of bird and stage at which carcasses were processed for analysis (Musa *et al*., 2006; Ojedapo *et al*., 2008). Hence, these factors have been used in body weight prediction by various authors (Tsegaye *et al*., 2013; Rashid *et al*., 2016).

Regression models have majorly been established for estimating body weight from body traits. Some authors have reported that these models allow a fact evaluation of body weight and are useful in selection criteria (Amao *et al*., 2012; Ojedapo *et al*., 2010). For instance, prediction of marketable weight of broilers at an early age using breast girth as a prediction can assist in early selection of broilers. Allometric, quadratic, cubic and linear models are commonly used to predict body weight at different ages. The allometric model produced a better goodness of fit followed by the quadratic and linear models in goats (Yakubu *et al*., 2011). Semakula *et al*. (2011) revealed that prediction from quadratic regression was most reliable when compared to simple linear regression and polynomial. Yakubu *et al*. (2009) and Ojedapo *et al*. (2012) also reported that cubic function predicted body weight and other body traits accurately compared to quadratic and linear functions. In another study, Adebayo *et al.* (2012) noted multiple regressions as the best predictor of body weight from linear body components in relation to quadratic and exponential functions.

The aim of this study was to determine if the accuracy of body weight prediction models from some linear body measurements of three chicken strains can be improved using different equations. This could aid in the selection and breeding strategies for improvement of the strains in the study area.

MATERIALS AND METHODS

Study area

The study was conducted at the Poultry unit of the Teaching and Research Farm of Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. Umudike is geographically located on 05° 29′ and longitude 07° 33′. It has an annual rainfall of about 2177 mm, relative humidity of 57 – 90 % depending on the season and temperature range of 27- 38°C during the dry season (December – March) and 18 - 26°C during the rainy season (April – November). Umudike is approximately 122 m above sea level, day light and night ratio is 12:12 hours.

Experimental birds and their management

Three strains of chicken – Noiler (local x exotic hybrid), Arbor Acre broiler and Yoruba ecotype cockerels were used for the study. A total of 300 day-old chicks, 100 each of the three strains were purchased from a reputable hatchery (Amo Nigeria Ltd) in Ibadan, Oyo State. Brooding was done in an environmentally controlled brooder house for 14 days, after which they were transferred to deep litter rearing pens. The floor of the pens was covered with wood shavings and routine management operations were carried out regularly. Routine vaccinations were strictly adhered to together with other medications when necessary. Each strain was replicated 5 times with 20 birds per replicate. Feed and water were given *ad libitum*. The birds were fed diets containing 20.64% CP, 2784.65 Kcal/kgME (starter phase), 19.15% CP, 2693.39 kcal/kgME (finisher phase) and 21.24% CP, 3062.90 Kcal/kgME (grower phase).

Measurements were taken firstly on the 14^{th} day, thereafter forth nightly till the 16^{th} week. Birds were measured before being fed in the morning. The following parameters were taken on the birds:

Body weight was measured using a top loading weighing scale in grams.

Body length (cm) was measured as the distance between the base of the neck and pygostyle.

Keel length (cm) was taken as length of the cartilaginous keel bone, from the V-joint to the end of the sternum.

Shank length (cm) was taken as the beginning of the hock joint to the last ring before the tarsal or meta-tarsal digit.

Wing length (cm) was taken as distance from the shoulder joint to the extremity of the terminal phalange.

Breast width (cm) was measured as the region of the largest breast expansion when positioned ventrally

Drumstick length (cm) was measured as length of femur bone.

Measuring of the linear body parameters was done with the aid of tailor's tape.

Statistical Analysis

Regression of body weight on each morphometric trait was done to determine the growth pattern within each strain. The analysis was done using SAS (2011) analytical package. The regression models used were as indicated below:

$Y_1 = a + bX + e$ . . . (1) Linear

$Y_2 = a + bX + cX^2 + e$ . . . (2) Quadratic

Where,

Y_1, Y_2 = dependent variable (body weight)

a = intercept/regression constant

b, c = regression coefficients/required growth rate

X = independent variables (body length, shank length, keel length, breast width and drumstick length).

e = random error

RESULTS AND DISCUSSION

Regression equations of Yoruba ecotype chicken strain in weeks 2-8 and 10-16

The linear and quadratic prediction models of body weight from body components of Yoruba ecotype strain, including coefficients of determination (R^2) for the fitted functions in weeks 2-8 and 10-16 are presented in Table 1. In weeks 2-8, the regression equations were all highly significant (P<0.01; P<0.001) except the linear function fitted for body weight and keel length which showed no significance. The coefficient of determination (R^2%) ranged from 0.10 % (BL) – 46.90 % (BWD) for linear regression and 24.40 % (DS) to 48.20 % (BWD) for the quadratic function. In weeks 10-16, the relationship between body weight and body length and keel length was highly significant (P<0.001) for both models and body depth for quadratic function, while significant (P<0.05) relationships were noted for body weight and drumstick (linear and quadratic) and wing length (linear). The R^2 (%) values in weeks 10-16 were very low compared to the values in weeks 2-8 which were mostly moderate. This lends credence to the report that factors like strain, sex and age influences accurate prediction of body weight from linear body traits (Lesosky *et al.*, 2013). Nwaogwugwu *et al.* (2018) noted low R^2 % (0.15 and 0.17) for Panda White and Cinnamon Brown Japanese quails, respectively in week 5 compared to weeks 3 and 4. This also confirms the findings that prediction of body weight using linear body

Table 1: Linear and quadratic regression models of body weight on linear body traits of Yoruba ecotype chicken strain in weeks 2-8 and 10-16

Traits	Model type	Equation	R^2(%)	SE	Sig.
Weeks 2-8					
BL	Linear	BW = -30.407+12.646BL	42.00	63.11	***
	Quadratic	$BW = 228.663-24.700BL+1.241BL^2$	48.20	59.95	***
KL	Linear	BW = 156.597+0.279KL	0.10	82.83	NS
	Quadratic	$BW = -114.133+70.671KL-3.878KL^2$	28.90	70.28	***
SL	Linear	BW = -26.628+33.074SL	32.60	67.98	**
	Quadratic	$BW = 32.971+10.838SL+1.946SL^2$	32.90	68.26	***
WL	Linear	BW = 9.804+11.310WL	40.90	63.68	***
	Quadratic	$BW = 218.565-25.938WL+1.446WL^2$	45.90	61.31	***
BWD	Linear	BW = -43.570+20.885BWD	46.90	60.38	***
	Quadratic	$BW = 63.546-1.719BWD+1.107BWD^2$	47.70	60.24	***
BD	Linear	BW = 36.378+8.865BD	39.90	64.21	***
	Quadratic	$BW = 149.837-12.346BD+0.799BD^2$	45.90	61.31	***
DS	Linear	BW = 91.361+7.446DS	7.50	80.09	***
	Quadratic	$BW = -175.584+72.032DS-3.485DS^2$	24.40	72.85	***
Weeks 10-16					
BL	Linear	BW = 581.15.043BL	2.80	239.24	**
	Quadratic	$BW = -1046.820+163.257BL+3.321BL^2$	5.00	237.13	**
KL	Linear	BW = 538.547+39.120KL	3.50	238.47	**
	Quadratic	$BW = -432.338+241.816KL-10.430KL^2$	4.10	238.32	**
SL	Linear	BW = 774.573+16.007SL	0.70	241.82	NS
	Quadratic	$BW = -155.032+217.168SL-10.680SL^2$	1.60	241.40	NS
WL	Linear	BW = 587.920+15.510WL	2.10	240.10	*
	Quadratic	$BW = -311.044+101.186WL-2.017WL^2$	2.40	240.44	NS
BWD	Linear	BW = 710.646+14.611BWD	1.30	241.10	NS
	Quadratic	$BW = 93.810+100.512BWD-2.940BWD^2$	1.60	241.38	NS
BD	Linear	BW = 765.911+6.872BD	0.50	242.04	NS
	Quadratic	$BW = 1790.279+234.569BD-5.004BD^2$	4.40	237.97	**
DS	Linear	BW = 703.082+15.961DS	2.00	240.27	*
	Quadratic	$BW = -220.459+152.616DS-4.935DS^2$	3.30	239.24	*

BL = body length, KL = keel length, WL = wing length, BWD = breast width, BD = body depth, DS = drumstick, SE = standard error, Sig = significance; $^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$, NS = not significant

components is better done within the younger age groups of animals (Oni *et al*., 2011). Adebayo *et al*. (2012) also obtained low to moderate R^2 % values for West African Dwarf (WAD) goats.

Momoh and kershima (2008) earlier reported moderate and low linear relationship between body weight and body length (R^2% = 0.47 and 0.13) for male and female Nigerian local chickens, respectively. With cockerels, Oluwatosin (2007) reported higher magnitude of coefficient of determination between body weight and some selected growth traits compared to the result obtained in this study. The difference could be attributed to differences in strain and possibly type of functions fitted. Positive and negative regression intercepts were observed for some equations in the two study periods. However, the relationship between body weights and the linear body parameters were best described by the quadratic function in both phases.

Regression equations of Arbor Acre chicken strain in weeks 2-8 and 10-16

The regression equation, estimate of parameter and coefficient of determination (R^2 %) for the fitted linear and quadratic function between body weight and linear body measurements of Arbor Acre broiler strain in weeks 2-8 and 10-16 are presented in Table 2. The regression analysis in weeks 2-8 were either significant (P<0.05) or highly significant (P<0.01; P<0.001). The coefficient of determination varied from 3.50 - 32.70 % (linear) and 10.10 - 34.80 % (quadratic). Body depth was the best estimator of body weight compared to other traits for both functions. In weeks 10-16, the analysis showed a very strong inter-relationship (P<0.001) between body weight and linear body traits. The R^2 (%) values varied from 71.10 - 92.60 % (linear) and 71.20 - 93.70 % (quadratic). This corroborated the result of Ojedapo *et al*. (2012) who reported R^2 (%) values which varied from 85 - 99 % for chest girth and keel length of layer strains as well as that of Amao *et al*. (2011) who recorded a range of 82 - 92 % for linear traits in broiler chickens. At 10 weeks of age, Sanda *et al*. (2014) regressed body weight of different broilers on breast girth, shank length, thigh length and wing span and obtained R^2 (%) which ranged from 55-79 % (Arbor Acre), 49-76 % (Marshall) and 58-67 % (Ross) which also conforms with this result.

In this phase, best accuracy of prediction was obtained with body depth though body weight of the Arbor Acre broilers can be easily estimated with all the linear body components studied with the high R^2 % values. Contrary to the results observed with the Yoruba ecotype cockerels, body weight of Arbor Acre broiler chickens can be best predicted at the later age rather than early age of life. Regression intercepts were mostly negative in weeks 10-16 compared to weeks 2-8. The relationship between body weights and the linear body measurements were best described by the quadratic model in both phases.

Regression equations for Noiler hybrid strain in weeks 2-8 and 10-16.

Table 3 shows the estimate of parameters in linear and quadratic functions fitted for body weight and the linear body traits with the corresponding coefficient of determination (R^2%) values at 2-8 and 10-16 weeks, respectively. The regression equations were all significant (P<0.01; P<0.001)

Table 2: Linear and quadratic regression models of body weight on linear body traits of Arbor Acre chicken strain in weeks 2-8 and 10-16

Traits	Model type	Equation	R^2(%)	SE	Sig.
Weeks 2-8					
BL	Linear	BW = -57.66+22.982BL	28.40	172.66	***
	Quadratic	BW = 380.549-34.807BL+1.743BL^2	30.90	170.57	***
KL	Linear	BW = 189.163+22.484KL	3.50	200.47	*
	Quadratic	BW = -549.410+248.157KL-16.212KL^2	11.30	193.20	**
SL	Linear	BW = 174.274+30.432SL	3.60	200.35	*
	Quadratic	BW = -739.342+378.787SL-1.409SL^2	10.10	194.51	**
WL	Linear	BW = 23.824+22.549WL	18.30	184.47	***
	Quadratic	BW = 153.232-0.442WL+0.907WL^2	18.50	185.22	***
BWD	Linear	BW = 106.952+20.915BWD	28.70	172.28	***
	Quadratic	BW = 108.001+20.684BWD+0.010BWD^2	28.70	173.20	***
BD	Linear	BW = -96.291+21.517BD	32.70	167.43	***
	Quadratic	BW = 301.561-21.496BD+1.077BD^2	34.80	165.74	***
DS	Linear	BW = 54.395+33.872DS	15.60	187.45	***
	Quadratic	BW = 88.550+25.376DS+0.495DS^2	15.70	188.43	***
Weeks 10-16					
BL	Linear	BW = -4316.901+264.988BL	89.70	327.70	***
	Quadratic	BW = -8845.426+605.986BL-6.312BL^2	90.10	329.82	***
KL	Linear	BW = -3076.295+481.636KL	85.90	383.19	***
	Quadratic	BW = -7080.482+1141.376KL-26.560KL^2	86.60	384.47	***
SL	Linear	BW = -1756.666+448.621SL	71.10	548.00	***
	Quadratic	BW = -3562.695+801.178SL-16.696SL^2	71.20	562.84	***
WL	Linear	BW = -4248.428+322.960WL	83.10	419.41	***
	Quadratic	BW = 2251.934-2299.934WL+62.834WL^2	87.40	371.84	***
BWD	Linear	BW = -1716.965+248.322BWD	92.60	277.74	***
	Quadratic	BW = 1903.302-189.026BWD+12.509BWD^2	93.70	263.32	***
BD	Linear	BW = -1126.769+121.652BD	93.30	264.59	***
	Quadratic	BW = -1935.324+174.291BD-0.808BD^2	93.40	269.07	***
DS	Linear	BW = -2592.306+370.136DS	87.40	361.92	***
	Quadratic	BW = 2430.866-382.509DS+27.111DS^2	89.20	344.08	***

BL = body length, KL = keel length, WL = wing length, BWD = breast width, BD = body depth, DS = drumstick, SE = standard error, Sig = significance; *P<0.05, **P<0.01, ***P<0.001

in the two phases and R^2 (%) estimates ranged from moderate (weeks 2-8) to low (weeks 10-16). The result obtained for estimation of body weight from the linear body traits studied in Noiler hybrid followed the same trend with those of the Yoruba ecotype cockerels ie body weight could be better predicted with linear traits at early age (2-8 weeks) than later age of life (10-16 weeks). In weeks 2-8, the moderate R^2 (%) values varied between 21.80 and 37.40 % for the linear model and 26.80 % and 39.10 % for the quadratic function. The intercepts of all the regression line were all positive. The relationship between body weight and the linear body measurements were best described by the quadratic model with drumstick having the best accuracy of prediction. This corresponds to the findings of Nwaogwugwu *et al*. (2018) who reported all positive regression intercepts when body weight was regressed on body length, thigh length, wing length and shank length of Panda White and Cinnamon Brown Japanese quail strains. In week 10-16, the R^2 % were low varying from 2.60 - 18.50 % (linear function) and 2.80 - 18.60 % (quadratic function). The relationship between body weight and the linear body measurements were also best described by the quadratic function having shank length as the best estimator of body weight in this phase. Ukwu *et al*. (2014) reported shank length as the best predictor of body weight of Nigerian local chickens.

The result of this study showed that significant (P<0.05, P<0.001, P<0.001) variations exist in the functions fitted at the two different periods, coefficient of determination and linear body measurements of each chicken strain. The result is in line with the conclusion that prediction equations are very specific to strain and age of bird (Musa *et al*., 2006; Ojedapo *et al*., 2008). It has also been opined that these relationships are important in the genetic improvement of growth through selection. Coefficient of determination (R^2 %) according to Mason *et al.* (1983) is the percentage of variations in the value of the dependent variable that can be explained by variations in the value of the independent variable(s). Therefore, the magnitude of the coefficients of determination obtained in this study in the prediction equations indicates the relative contribution of each linear body trait to the body weight of the birds belonging to each strain.

Table 3: Linear and quadratic regression models of body weight on linear body traits of Noiler hybrid strain in weeks 2-8 and 10-16.

Traits	Model type	Equation	R^2(%)	SE	Sig.
Weeks 2-8					
BL	Linear	BW = 52.425+7.505BL	27.60	54.64	***
	Quadratic	BW = 124.794-3.197BL+0.360BL^2	28.90	54.45	***
KL	Linear	BW = 36.352+20.388KL	36.00	51.36	***
	Quadratic	BW = 115.820-6.204KL+2.038KL^2	37.40	51.09	***
SL	Linear	BW = 47.696+21.945SL	26.40	55.07	***
	Quadratic	BW = 106.431-1.606SL+1.154SL^2	26.80	55.25	***
WL	Linear	BW = 60.196+7.470WL	30.80	53.40	***
	Quadratic	BW = 167.627-10.545WL+0.684WL^2	25.10	53.35	***
BWD	Linear	BW = 68.702+ 4.3775BWD	37.40	50.78	***
	Quadratic	BW = 101.509+2.580BWD+0.449BWD^2	38.10	55.86	***
BD	Linear	BW = 7.020+9.859BD	37.40	50.82	***
	Quadratic	BW = 220.963-17.920BD+0.852BD^2	38.10	50.79	***
DS	Linear	BW = 66.529+12.26DS	35.10	51.72	***
	Quadratic	BW = 35.071+20.676DS-0.504DS^2	39.10	50.37	***
Weeks 10-16					
BL	Linear	BW = -72.198+54.899BL	10.10	399.91	***
	Quadratic	BW = -4276.979+369.231BL-5.823BL^2	11.30	398.20	***
KL	Linear	BW = 10.424+120.197KL	9.30	401.65	***
	Quadratic	BW = 1071.218-64.152KL+7.937KL^2	9.50	402.26	***
SL	Linear	BW = -470.094+178.419SL	18.50	380.93	***
	Quadratic	BW = -1740.675SL+426.898SL-12.032SL^2	18.60	381.35	***
WL	Linear	BW = 394.864+41.791WL	4.10	413.04	**
	Quadratic	BW = 3173.540-192.996WL+4.921WL^2	4.60	412.90	**
BWD	Linear	BW = 247.431+65.442BWD	4.80	411.55	***
	Quadratic	BW = -152.779+112.058BWD-1.348BWD^2	4.80	412.42	**
BD	Linear	BW =481.652+33.046BD	2.60	416.25	**
	Quadratic	BW =-4608.260+410.066BD-6.941BD^2	2.80	415.06	**
DS	Linear	BW = -137.480+96.653DS	13.30	392.83	***
	Quadratic	BW = 2947.584-301.231DS+12.698DS^2	14.30	391.34	***

BL = body length, KL = keel length, WL = wing length, BWD = breast width, BD = body depth, DS = drumstick, SE = standard error of estimate, Sig = significance

Based on the magnitudes of R^2 (%), the relationship between the body weights and the other body components were best predicted by the quadratic function compared to the linear model fitted for each strain across the two age groups. For the Yoruba ecotype cockerels, body length was a more reliable index for estimating body weight with R^2 of 48.20 % and 5.00 % in weeks 2-8 and 10-16, respectively. In the estimations for Arbor Acre broiler strain, body depth having 34.80 (%) in weeks 2-8 and 93.70 (%) in weeks 10-16 were the most reliable single index estimators of body weight while the Noiler hybrid strain had drumstick (39.10 %) and shank length (18.60 %) as best predictors of body weight in weeks 2-8 and 10-16, respectively. This result is in agreement with the reports of earlier authors who gave breast girth, shank length and body length as good body weight predictors for Japanese quails and chickens (Obike and Iwuji, 2015; Fayeye *et al*., 2014; Momoh and Kershima, 2008).

CONCLUSION

The result of this study showed mostly significant variability in the estimates of the relationship between body weight and the linear body measurements. The magnitude of the coefficient of determination (R^2 %) ranged between low and moderate in the estimates for the Yoruba ecotype cockerels and the Noiler hybrid strains whereas those of Arbor Acre broiler strain were low, moderate and very high estimates. Predictions of body weight from the linear measurements were best described by the quadratic function with body depth, breast width, body length, shank length and drumstick as best estimators. It is therefore recommended that quadratic function could be used in estimating body weight of chicken strains.

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