ESTIMATION AND MODELING OF PIG BODY WEIGHT USING LINEAR BODY MEASUREMENTS

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ABSTRACT
Body weight is an essential index used by producers to determine market-ready pigs, and its accurate estimation before the finishing stage helps reduce losses in pig production. However, since most pig farms have limited or no access to weighing scales, this study aimed at modeling linear body measurements to estimate pig body weight. The study involved 83 weaners from a commercial farm at three different ages (4, 5 and 7 weeks) from four breeds comprising Camborough, Large White, and crosses of Camborough with Large White and Landrace. Body weight was measured using digital weighing scale sensitive to 0.00 g, while the eight linear body measurements were taken using a flexible graduated tape, for the points of reference. Nine parameters including body weight (BW), total body length (BL), thoracic circumference (TC), palette length (PL), shank length (SKL), shank circumference (SC), hip circumference (HC), heart girth (HG) and standard body length (SL) were measured, with mean values of 23.12±1.04 kg, 65.24±3.95 cm, 39.66±3.93 cm, 21.49±0.29 cm, 16.16±1.00 cm, 12.96±0.81 cm, 47.12±2.95 cm, 44.77±2.79 cm and 46.78±2.78 cm, respectively. Breed and age exerted significant (p<0.05) influence on each of the nine variables measured, while multiple correlation of variables was mostly highly significant except for palette length and other variables which was mostly not significant (p>0.05). Four of the variables, BW, TC, HG and HC had highest loadings in the eigenvalues obtained from the two principal components, which accounted for 99.1 percent of the total variation. The general model describing body weight in the study was Body Weight = -18.69 - 1.19 TC + 1.46 HG + 0.50 HC which explained 88.26 percent of the total variation in body weight. The study confirmed the reliability of body weight estimation using linear body measurements in pigs, and thus it is recommended that a quick appraisal of the thoracic circumference, heart girth and or hip circumference can give a fair estimate of the pig body weight.

Keywords: *Pig weaners, body weight, linear body measures, statistical modeling, estimation*

INTRODUCTION
Pig farming worldwide is undergoing intense genetic improvement, producing pigs with high growth potential, feed efficiency and good carcass composition (Lima *et al*., 2018). Pork accounts for 33% of worldwide meat output and ranks second in terms of volume behind poultry (FAO, 2018). Pigs are farmed for food (pork, bacon, gammon) and their skin. Aside from poultry, it is the other livestock specie common-

ly reared in the socio-economically disadvantaged areas of the society (Chauvin *et al*., 2012; Adetunji and Adeyemo, 2012).

Pig as compared to other livestock species has great potentials to contribute to faster economic return to the farmers, due to inherent traits like high fecundity, better feed conversion efficiency, early maturity and relatively shorter generation intervals compared to sheep or cattle (Pluhar, 2010). It also requires smaller investment on buildings and equipment and has immense potentials to ensure nutritional and economic security for the weaker section of society (Kambashi *et al*., 2014; Madzimure *et al*., 2012; Obayelu *et al*., 2017). However, cultural and religious restrictions have militated against pigs' popularity in some areas globally (Amills *et al*., 2012; Nwachukwu and Udegbunam, 2020).

Knowledge of pig weight at any given time is important for a number of reasons which include determination of feed requirement, animal health status, determination of growth rates, determination of when animals are sent to market, space allowances and determination of drug dosage (Gunawan and Jakaria, 2011). Body weight is essentially used by producers to determine market-ready pigs and its accurate estimation before the finishing stage helps reduce losses associated with the sorting process (Que *et al*., 2016).

Basically, there are two main approaches to estimate weight of pigs which are the direct and indirect approaches (Zaragoza, 2009). The direct method involves physically moving the pigs to a weighing location and placing them on a weighing scale. This method comes with its attendant consequences of requiring additional labour (Marinello *et al*., 2015), changes in the feeding behavior of pigs which might lead to weight loss, stress which at times can lead to death and injury occurring to the people handling the pigs (Machebe and Ezekwe, 2010). However, an indirect method entails the visual estimation based on condition score and the use of linear measurements (Zaragoza, 2009), where the latter is the most common tool that is used to predict body weight in farm animals, especially at smallholder farms (Holanda *et al*., 2020; Alenyorege *et al*., 2013).

The most accurate way to measure body weight is using weighing scale (Marinello *et al*., 2015). However, since most of the farmers in the developing countries are smallholders, they do not have access to a weighing scale, which calls for other methods to assess the live weight of animals without incurring additional production cost.

The linear body measurement is the distance between any two given points of the body, which can be used to quantify the size of an animal and to estimate its weight. Linear body measurements have been shown to be a useful predictor of body weight using any of the following parameters: Heart Girth, Thoracic Circumference, Hip Circumference, Shank Length, Shank Circumference, Palette Length, Body Standard Length and Body Total Length (Holanda *et al*., 2020).

In Nigeria, since pigs are mostly sold in markets that do not have weighing scale, body dimensions can be used to estimate body weight. Thus, the objectives of this study were to evaluate relationship between body weight of pigs and their Linear Body Measurements (LBM), and model body weight based on the LBMs with a view to build a general mathematical function to estimate body weight using the computed regression from LBM and recommend same for practical application in real market situation.

MATERIALS AND METHODS

Study Area

Data for this study was obtained from a private piggery farm located at Ilara in Epe-Lagos State located on latitude 6.53° N, longitude 4.06° E and altitude of 48.99 m above sea level.

Study Animals (Breed and animal population)

A total number of 83 weaners consisting of 43 male and 40 female piglets from three different age groups (4, 5 and 7 weeks old), comprising piglets of Camborough (CB), Large White (LW) and crosses of LW x CB and Landrace (LR x CB) breeds were evaluated.

The piglets were individually tagged and appropriately labelled with unique identifier depicting their breed, sex, age and ID.

Management practices

The piglets were suckled by their dams from birth to four weeks before weaning, and all piglets were weaned at four weeks of age. The sows were fed supplemental concentrate throughout the period of rearing the piglets prior to weaning. Weaners were separated from their dams from four weeks and placed on compounded ration with proximate composition including, Crude protein (16.8%), Crude Fat (2.5%), Crude Fibre (7.4%) and Metabolizable Energy (3400 kcal/kg). Piglets were managed intensively and penned in groups according to their age, and were ear notched for identification purposes at the commencement of the study. Weaners were fed ad libitum diets suitable for the growing and fattening period.

Data collection

Information about the piglets' breed, sex, dam and sire identification number, date of birth along with their respective body weights were taken once at the post weaning period (4, 5, and 7 weeks). Each animal was individually weighed and all linear measures recorded against their identification records. Body weight was taken using a digital hanging balance sensitive to 0.00 g while the linear body measurements were taken using a graduated flex tape for each of the measured parameter. Details of the weighing and linear measures were immediately recorded against the ID of the piglet.

Piglets were restrained to one side of the pen and each piglet was taken and placed in a bucket to weigh, after the scale has been tarred to zero with the bucket. The weight was immediately recorded for each piglet and such piglets were released back to the main pen area. While restrained, linear body measurements were taken as described by Holanda *et al.* (2020), with appropriate modifications as presented in figure 1. All measurements were recorded against individual animal's ID.

Linear body measures studied included; Heart Girth (HG), Thoracic Circumference (TC), Hip Circumference (HC), Shank Length (SKL), Shank Circumference (SC), Palette Length (PL), Standard Body Length (SL) and Total Body Length (BL) which were as described by earlier researchers (Machebe and Ezekwe, 2010; Groesbeck *et al.*, 2010; Holanda *et al*., 2020).

Statistical analyses

Preliminary exploratory analysis was conducted to test data integrity using box plots and normality test for outliers. All statistical analysis was conducted using Minitab® (2010) Statistical Software.

Descriptive statistics for all measurements (body weight, total body length, thoracic circumference, hearth girth, shank length, shank circumference, hip circumference, standard body length and palette length) was generated within and across breeds, sex and age groups. Multiple correlation amongst all the measured variables was computed to assess the degree of linear relationship between pairs of variables in order to avert multicollinearity in the statistical model.

A one-way analysis of variance (ANOVA) using breed, age or sex as factors was conducted on all the nine parameters studied. The statistical model describing the one-way ANOVA was given as $Y_{ij} = \mu + \alpha_i + e_{ij}$ where Y_{ij} is the record of the j^{th} piglet of the i^{th} breed (LW, CB, LW x CB and LR x CB), age (4, 5 and 7) or sex (male and female), μ is the general mean, α_i is the effect of the i^{th} breed, age or sex and e_{ij} is the uncontrolled environmental and genetic deviations attributable to the individual piglet. The error term is assumed to be random, normal, and independent with expectations equal to zero. After a significant ANOVA, further mean comparison procedure was conducted using the Tukey's honestly significant difference to separate the means at 5% level of significance.

Due to the large numbers of variables investigated, a functional data reduction method using PCA (principal component analysis) procedure was conducted for all the parameters. Due to the differences in the unit of measurement among variables, and the variability within some measurements, there is need for transformation of the raw data using the log base 10 transformation. Principal component analysis (PCA) is a multivariate technique that analyzes a data table in which observations are described by several inter-correlated quantitative dependent variables (Mishra *et al.,* 2017). To interpret data in a more meaningful form, it is necessary to reduce the number of variables to a few, interpretable linear combinations of the data, with each linear combination corresponding to a principal component. PCA is used successfully when characteristics are correlated, and it explains a percentage of total variance accumulated by each principal component. The principal components are eigenvectors of the data's covariance matrix. PCA is mostly used as a tool in explanatory data analysis, and for making predictive models. The essence of the PCA was to evaluate those predictor variables that accounted for the largest variation in the dependent/response variable (Body Weight).

Regression analyses was conducted to build the model of best fit for the estimation of pig body weight based on its linear body measurements. The statistical model describing the regression is given as $Y_i = \beta_o + \beta_1 X_i + \varepsilon_i$ where Y_i is dependent variable (body weight), β_0 is the intercept, β_1 is the slope, X_i is the independent variable (linear measure) and ε_i is the random error term.

RESULTS

Descriptive of Measured Variables

Body weight of pigs in the study ranged from 11.40 kg to 47.90 kg with a mean of 23.12 kg. Mean body length in the study was between 27.00 cm to 123.00 cm with a mean value of 65.24 cm, while thoracic circumference ranged from 5.00 cm to 90.00 cm, with a mean value of 36.66 cm. Palette length had values ranging between 15.00 cm to 27.00 cm with a mean of 21.49 cm, whereas Shank length was between 7.00 cm to 34.00 cm with a mean of 16.16 cm. The values for shank circumference varied between 5.00 cm and 27.00 cm, with a mean of 12.96 cm, while hip circumference had values from 18.00 cm to 93.00 cm with a mean of 47.12 cm. Heart girth was between 18.00 cm and 84.00 cm with an overall mean of 44.77 cm while the standard body length varied between

Table 1: Analysis of Variance of effect of sex on body weight and linear body measures

Source	df	Weight	BL	TC	PL	SKL	SC	HC	HG	SL
Sex	1	154.22^{ns}	1918.0^{ns}	2098.0^{ns}	0.074^{ns}	105.40^{ns}	91.08^{ns}	1238.1^{ns}	1207.0^{ns}	862.3^{ns}
Error	81	88.95	1287.0	1272.0	7.021	83.06	53.82	715.3	639.8	636.7
R-sq (%)		2.10	1.81	1.99	0.01	1.54	2.05	2.09	2.28	1.64

BW = Body Weight; BL = Body Length; TC = Thoracic Circumference; PL = Palette Length; SKL = Shank Length; SC = Shank Circumference; HC = Hip Circumference; HG = Hearth Girth and SL= Standard Body Length
df=degree of freedom, ^{ns}= p>0.05

Table 2: Analysis of Variance of Effect of breed on body weight and linear body measures

Source	df	Weight	BL	TC	PL	SKL	SC	HC	HG	SL
Breed	3	1488.69***	34062.6***	34307.5***	18.09*	2109.51***	1373.87***	18543.9***	17026.9***	16454.5***
Error	79	36.92	50.6	28.4	6.51	6.39	4.17	44.8	24.7	38.9
R-sq (%)		60.69	96.23	97.87	9.54	92.62	92.60	94.01	96.32	94.14

BW = Body Weight; BL = Body Length; TC = Thoracic Circumference; PL = Palette Length; SKL = Shank Length; SC = Shank Circumference; HC = Hip Circumference; HG = Hearth Girth and SL= Standard Body Length
****= p0.001; **= p<0.01; *=p<0.05*

20.00 cm and 90.00 cm with an overall mean of 46.78 cm.

Sex Effect
Sex distribution in the study was fairly uniform, with male piglets accounting for 51.81% and female accounting for 48.19%. The sex ratio in the study did not significantly (*p>0.05*) deviate from the expected symmetrical sex ratio of 1:1 for male and female piglets. The sex of piglet was not a significant (*p>0.05*) source of variation on all the nine variables studied (Table 1).

Breed Effect
Breed of pig was a significant (p<0.05) source of variation on all the nine variables studied, albeit at varying levels (Table 2). The largest influence was recorded in Thoracic Circumference (97.87%), while the least influence of breed was on Palette Length (9.54%) as depicted in Figure 2.

The Camborough breed had the highest values in all measured variables (Table 3), closely followed by the Large White breed. The CB x LR cross consistently had the least values across all variables studied.

Age Effect
Age of piglet exerted significant (p<0.05) influence although at varying levels on all nine variables investigated (Table 4). The highest influence was on body weight (50.82%), while the least was on palette length (14.41%). The five weeks old piglets had intermediate values between the lowest in the four weeks old and the highest in the seven weeks old in all variables except in palette length where the difference between it and the four week old was marginal (Table 5).

Relationship amongst variables studied
The correlation matrix of body weight and linear body measurements were mostly highly significant (Table 6), except for palette length that did not have significant (*p>0.05*) relationship with all other variables excluding shank circumference.

All correlation coefficients were direct (positive) except for the pair of palette length and thoracic circumference that was inverse (negative). The highest correlation coefficient was recorded between the pair of thoracic circumference and heart girth, while the least was between heart girth and palette length.

Table 3: Mean ± S.E. of Body weight and linear body measurements by Breed of Pigs

Breeds	N	BW (kg)	BL (cm)	TC (cm)	PL (cm)	SKL (cm)	SC (cm)	HC (cm)	HG (cm)	SL (cm)
		Mean ± S.E.	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.
Camborough	6	36.27±2.88^{a}	110.33±3.67^{a}	81.00±2.34^{a}	23.50±1.59^{a}	28.50±1.15^{a}	23.50±0.89^{a}	77.83±4.01^{a}	75.17±2.36^{a}	78.00±3.04^{a}
CB x LR	43	16.51±0.57^{c}	31.56±0.44^{c}	5.77±0.09^{c}	21.77±0.30^{ab}	7.81±0.12^{c}	6.23±0.14^{c}	22.35±0.37^{c}	20.93±0.27^{c}	23.42±0.37^{c}
Large White	23	31.24±1.67^{a}	102.26±2.01^{a}	77.09±1.63^{a}	21.17±0.56^{ab}	25.26±0.75^{b}	19.78±0.64^{b}	76.30±1.85^{a}	71.26±1.44^{a}	73.17±1.68^{a}
CB x LW	11	24.84±2.45^{b}	94.91±3.31^{b}	71.36±2.57^{b}	20.00±1.02^{b}	23.00±1.20^{b}	19.27±0.74^{b}	66.18±3.13^{b}	66.00±2.36^{b}	65.91±3.19^{b}
Overall	83	23.12±1.04	65.24±3.95	39.66±3.93	21.49±0.29	16.16±1.00	12.96±0.81	47.12±2.95	44.77±2.79	46.78±2.78

Means with different superscripts within the same column are significantly (p<0.05) different
N = Sample size: CB = Camborough; CB x LR = Camborough x Landrace; LW=Large White;
CB x LW = Cambrough x Large White, BW = Body Weight; BL = Body Length; TC = Thoracic Circumference;
PL = Palette Length; SKL = Shank Length; SC = Shank Circumference; HC = Hip Circumference;
HG = Hearth Girth and SL= Standard Body Length.

Principal Components Analysis

From the loadings of the eigenvalues of the co-variance matrix in the study, it was observed that the first two principal components cumulatively accounted for 99.1 percent of the total variation, with principal components 1 and 2 respectively contributing 97.3 and 1.8 percent (Table 7) to the variation in the transformed data. Variables that loaded heavily on both principal components are the thoracic circumference, heart girth, hip circumference and body weight.

The thoracic circumference had the highest loading on PC1, while the hip circumference and the heart girth had relatively lower values compared to thoracic circumference on PC1. Body weight had the highest absolute value in the loading on PC2 followed by the thoracic circumference (Table 7).

Regression Analyses

The regression analysis result is presented in Table 8. The three linear measures; thoracic circumference (TC), heart girth (HG) and hip circumference (HC) were all highly significant (*$p<0.001$*) on the body weight. This regression model accounted for 88.26 percent of the total variation in body weight of pigs. The regression equation in this study is given as Body Weight = -18.69 – 1.19 TC + 1.46 HG + 0.50 HC, with an R^2 of 88.26 percent. However, due to the difference in ages of the piglets, including age as a

Table 4: Analysis of Variance of effect of age on body weight and linear body measures

Source	df	Weight	BL	TC	PL	SKL	SC	HC	HG	SL
Age	2	1870.02^{***}	22563.0^{***}	20052.4^{***}	40.99^{**}	1306.06^{***}	1056.7^{***}	11382.7^{***}	10859.4^{***}	10877.5^{***}
Error	80	45.24	763.3	813.2	6.09	52.76	29.22	455.1	391.4	383.5
R-sq (%)		50.82	42.50	38.14	14.41	38..23	47.48	38.47	40.95	41.49

*df = degrees of freedom; BW = Body Weight; BL = Body Length; TC = Thoracic Circumference; PL = Palette Length; SKL = Shank Length; SC = Shank Circumference; HC = Hip Circumference; HG = Hearth Girth and SL= Standard B ody Length ***= p<0.001, **=p<0.01, *=p<0.05.*

Table 5: Least Square Means ± S.E. of Body Weight and Linear body Measurements by Age of Pigs

Age (Weeks)	N	BW (kg) Mean ± S.E.	BL (cm) Mean ± S.E.	TC (cm) Mean ± S.E.	PL (cm) Mean ± S.E.	SKL (cm) Mean ± S.E.
4	17	$14.13±0.62^{c}$	$29.71±0.46^{c}$	$5.65±0.15^{c}$	$20.24±0.30^{b}$	$7.82±0.21^{c}$
5	55	$22.97±1.02^{b}$	$66.98±4.51^{b}$	$41.60±4.67^{b}$	$21.44±0.35^{b}$	$16.45±1.18^{b}$
7	11	$37.78±2.03^{a}$	$111.45±2.15^{a}$	$82.55±1.75^{a}$	$23.73±0.94^{a}$	$27.55±0.88^{a}$
Combined	83	23.12±1.04	65.24±3.95	39.66±3.93	21.49±0.29	16.16±1.00

SC (cm) Mean ± S.E.	HC (cm) Mean ± S.E.	HG (cm) Mean ± S.E.	SL (cm) Mean ± S.E.
$5.77±0.18^{c}$	$21.12±0.44^{c}$	$19.77±0.34^{c}$	$22.00±0.37^{c}$
$13.07±0.87^{b}$	$48.80±3.46^{b}$	$46.18±3.23^{b}$	$48.05±3.19^{b}$
$23.55±0.80^{a}$	$78.91±2.54^{a}$	$76.36±1.64^{a}$	$78.73±2.05^{a}$
12.96±0.81	47.12±2.95	44.77±2.79	46.78±2.78

Means with different superscripts within the same column are significantly (p<0.05) different
N = Sample size: CB = Camborough; CB x LR = Camborough x Landrace; LW=Large White; CB x LW = Cambrough x Large White, BW = Body Weight; BL = Body Length; TC = Thoracic Circumference; PL = Palette Length; SKL = Shank Length; SC = Shank Circumference; HC = Hip Circumference; HG = Hearth Girth and SL= Standard Body Length.

Table 6: Correlation matrix of body weight and linear body measurements

	BW	BL	TC	PL	SKL	SC	HC	HG
BL	0.845^{***}							
TC	0.814^{***}	0.992^{***}						
PL	0.405^{***}	0.034^{ns}	-0.026^{ns}					
SKL	0.847^{***}	0.979^{***}	0.974^{***}	0.073^{ns}				
SC	0.829^{***}	0.973^{***}	0.968^{***}	0.081^{*}	0.952^{***}			
HC	0.861^{***}	0.983^{***}	0.988^{***}	0.043^{ns}	0.973^{***}	0.952^{***}		
HG	0.847^{***}	0.993^{***}	0.996^{***}	0.019^{ns}	0.976^{***}	0.970^{***}	0.990^{***}	
SL	0.861^{***}	0.995^{***}	0.985^{***}	0.072^{ns}	0.981^{***}	0.965^{***}	0.982^{***}	0.987^{***}

BW = Body Weight; BL = Body Length; TC = Thoracic Circumference; PL = Palette Length; SKL = Shank Length; SC = Shank Circumference; HC = Hip Circumference; HG = Hearth Girth and SL= Standard Body Length. $^{***} = p<0.001$; $^{**} = p<0.01$; $^{*} = p<0.05$; $^{ns}=p>0.05$*(not significant)*

Table 7: Eigenanalysis of the Covariance Matrix and Loadings of the PCA

Eigenvalue	0.739	0.014	0.003	0.002	0.001	0.001	0.000	0.000	0.000
Proportion	0.973	0.018	0.003	0.002	0.001	0.001	0.001	0.000	0.000
Cumulative	0.973	0.991	0.994	0.996	0.998	0.999	1.000	1.000	1.000
Variables	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**	**PC9**
BW	0.165	0.812	0.154	0.221	-0.172	-0.249	-0.329	-0.188	-0.071
BL	0.299	0.052	0.088	0.053	0.560	0.019	0.116	0.160	-0.738
TC	0.654	-0.398	0.071	0.083	-0.216	0.234	-0.427	-0.339	-0.046
PL	-0.002	0.379	-0.214	-0.405	-0.023	0.801	-0.052	0.044	-0.024
SKL	0.299	0.030	0.138	-0.820	-0.191	-0.400	0.075	0.126	-0.035
SC	0.303	0.079	-0.905	0.074	0.011	-0.227	0.152	-0.040	0.043
HC	0.307	0.102	0.212	0.238	-0.420	0.167	0.767	-0.005	-0.022
HG	0.311	0.035	0.055	0.196	0.010	0.049	-0.196	0.850	0.312
SL	0.288	0.128	0.179	-0.067	0.629	0.018	0.194	-0.287	0.590

PC = Principal Component; BW = Body Weight; BL = Body Length; TC = Thoracic Circumference; PL = Palette Length; SKL = Shank Length; SC = Shank Circumference; HC = Hip Circumference; HG = Hearth Girth and SL= Standard Body Length.

Table 8a: ANOVA of regression analysis

Source	df	MS
Regression	3	2165.16^{***}
TC	1	1034.20^{***}
HG	1	658.30^{***}
HC	1	301.25^{***}
Error	79	10.93
R-sq (%)		88.26

***= P<0.001; **= P<0.01; *=P<0.05

Table 8b: ANOVA of regression analysis (with age)

Source	df	MS
Regression	5	1345.16^{***}
TC	1	750.94^{***}
HG	1	372.83^{***}
HC	1	364.18^{***}
Age	2	115.17^{***}
Error	77	10.93
R-sq (%)		91.39

***= P<0.001; **= P<0.01; *=P<0.05

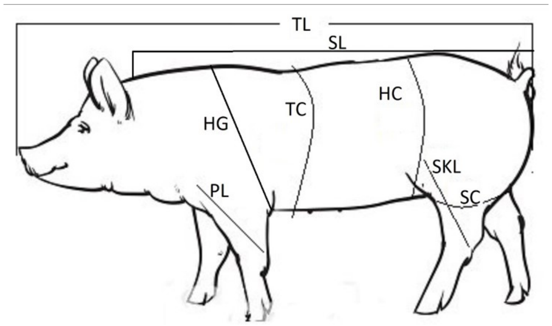

Figure 1: Pig linear body measures as amended from Holanda et al. (2020).

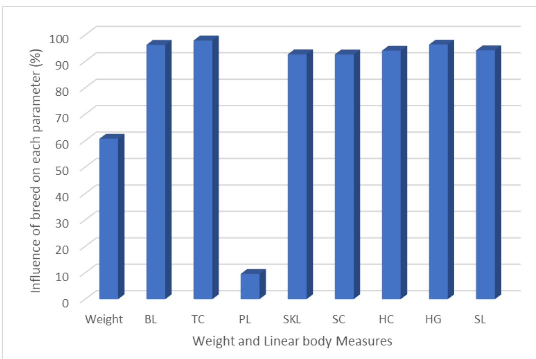

Figure 2: Percentage contribution of breed effect on the nine variables studied

continuous variable in the regression analyses give Body Weight = -15.01 - 1.06 TC + 1.19 HG + 0.55 HC for four week old, Body Weight = - 14.63 - 1.06 TC + 1.19 HG + 0.55 HC for five week old, and Body Weight = -8.79 - 1.06 TC + 1.19 HG + 0.55 HC for seven week old with R^2 of 91.39 percent.

DISCUSSION

Descriptive Statistics of Measured Variables

The difference of 36.50 kg between the lower and upper values in body weight could be ascribed to the difference in the ages at weaning of the piglets. Weaning of piglets in the farm was done between the ages of four and six depending on the management system adopted on the farm, physiological state of the sow and offspring and more importantly the body weight of the piglets just before weaning. Early weaning is usually done with piglets from small litter sizes at birth, due to the fact that they tend to grow faster compared to piglets from large litters (Zindove *et al*., 2021; Beaulieu *et al*., 2010).

Body length of the piglets varied with a range of 96 cm which is indicative of the differences in body length as a consequence of age or breed of the pig. A direct relationship has been established between body length and body weight of pigs. Thus, this study is in line with earlier reports that body weight increases with body length in pigs (Banik *et al*., 2012; Zhang *et al*., 2021).

Variability in palette length, shank length, shank circumference, hip circumference, heart girth and standard body length in this study all followed the same trend as previously discussed (Holanda *et al*., 2020; Alenyorege *et al.,* 2013). This is due to the fact that each of the variables investigated is a component part of what constitute the body weight of the animal, an observation which was in consonance with submission of earlier researchers (Holanda *et al.,* 2020; Khanji *et al.,* 2018; Birteeb *et al.,* 2015) who variously worked on body weight estimation in different breeds of pigs.

Sex Effect

Since sex of pigs at farrowing is purely a chance event in natural situations, it is therefore not surprising that the sex ratio in this study is very close and did not deviate from the symmetrical 1:1 ratio for male or female which is equally likely. This observation was in consonance with report from earlier studies (Ajayi and Akinokun, 2013). Sex of piglet did not exert significant ($p>0.05$) on any of the nine variables studied, thus could not be classified as a source of variation for any of the measured variable.

Sexual difference in pigs was not a significant ($p>0.05$) source of variation on the nine measures studied (Table 1), which implied that factors except sex may be responsible for the differences observed.

Breed Effect

Differences in breed of the pigs greatly impacted all the parameters studied, with the greatest influence of breed recorded in thoracic circumference which incidentally is highly positively correlated to other variables except palette length that was negatively correlated to it. Breed differences in performance traits could be explained by the fact that phenotypes expressed by animals is a function of both its genetic makeup and the prevailing environment under which it was reared. Thus, differences in breed or strain are expected to result in varying effect on productivity traits even when the environmental condition under which the animals are raised does not differ. This observation corroborates the earlier reports of Holanda *et al.* (2020) and Onyimonyi *et al.* (2010), who all reported significant influence of breed on productivity traits of pigs.

Age Effect

The varying levels of influence of pig age on its weight and linear body measurements is indicative of the continuous growth of the animal with increasing age till the point of senescence when the animal could not grow further. Consequently, all parameters associated with growth would be expected to be influenced by increases in age, which explains why the younger piglets tend to have the lowest values for all the parameters studied. The very little influence of age on palette length is explained by the fact that the parameter had non-significant relationship with other parameters except body weight and shank circumference. Influence of age on body weight of different breeds of pigs had previously been reported by Mutua *et al.* (2011) and Alenyorege *et al.* (2013).

Relationship amongst variables studied

Body weight is a combination of the individual weight of the various parts of the animal and as such some kind of relationship or association is expected between body weight and its component parts. Thus, the aggregation of the individual weight of the various body parts cumulatively makes the body weight. The proportional growth of these body parts explains why the relationship between the variables were mostly high and significant except those involving palette length and other variables which was either low, negative or not significant. This further confirms earlier works on linear body measurements and body weight in pigs (Zhang *et al.,* 2021; Holanda *et al.,* 2020; Walugembe *et al.,* 2014; Vincek *et al.,* 2012; Banik *et al.,* 2012; Mutua *et al.,* 2011).

Principal Components Analysis

This analysis revealed the latent relationship amongst the variables studied. It also provides an insight into the probable multicollinearity in the variables which may confound the results from further analyses if it is not taken care of. The choice of thoracic circumference, heart girth and hip circumference in the loadings of the eigenvalues indicated that the three parameters exert the greatest influence on body weight and as such provide veritable platform for the choice of predictors in the final regression analysis.

Use of principal component analysis has been extensively reported in literature on estimation of body weight using linear measurements by several researchers (Panda *et al.,* 2020; Nascimento *et al.,* 2014) and their results are similar to what was obtained in this study.

Of all the variables investigated, only body weight, thoracic circumference, heart girth and hip circumference had greatest loading on principal components one and two, which both explained 99.1 percent of variation in the analysis. The essence of this principal component analysis is to reduce the variables in the study by investigating those that loaded more in the study. Thus, rather than modeling with all the variables investigated, the PCA was able to identify the few variables that correlated (99.1% of the eigenanalysis) well with body weight of the piglets and therefore the mathematical model for estimating body weight using linear body measurements was limited to the variables (thoracic circumference, hip circumference and heart girth) that contributed the largest source of variation in body weight.

Regression Analyses

Different regression models have been previously proposed using different linear measurement parameters for body weight estimation, however this study adopted the covariance matrix of the log transformed values to identify the variables that most impacted weight and limited itself to such parameters, and also included age as a categorical predictor due to the differences in the piglet's age.

Using the parameters so identified in the PCA, the regression model was given as Body Weight = -18.69 – 1.19 TC + 1.46 HG + 0.50 HC, with an R^2 of 88.26 percent. Further inclusion of age as a categorical factor in the regression analysis improved the R^2 to 91.39 percent with a Durbin-Watson statistic of 1.74.

Consequently, a better regression equation model was obtained considering the Durbin-Watson statistic of 1.74 obtained in the final regression analysis. The values obtained in this study were specific to the population under reference but not too far from previous researches (Zhang *et al*., 2021; Panda *et al.,* 2020; Khanji *et al.,* 2018; Birteeb *et al.,* 2015; Alenyorege *et al.,* 2013; Vincek *et al*., 2012; Mutua *et al.,* 2011; Onyimonyi *et al.,* 2010) who worked on estimation of pig body weight based on linear measurements in different pig breeds.

CONCLUSION

Sex ratio observed in the study did not statistically deviate from the expected 1:1 ratio in normal pig parturitions, and sex of pig was not a significant source of variation on all parameters studied, whereas breed and age of pigs exerted significant influence on all measured variables. The Camborough breed consistently had higher values in all measured parameters than the other three breeds, while the Camborough x Landrace breed had the least.

It was also observed from the study that body weight and linear body measurements obtained from pigs correlated significantly with one another. However, palette length had no significant relationship with most variables studied except body weight and shank circumference.

The study revealed very strong relationship between pig body weight and its linear body measurements and also confirmed that pig body weight to a very large extent can be modeled or estimated using some of the linear body measurements.

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