# Principal Components Regression of Body Measurements in Five Strains of Locally Adapted Chickens in Nigeria

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**Abstract**

This study aimed at unfolding the interdependence among the linear body measurements in chickens and to predict body weight from their orthogonal body measurements using principal component regression. Body weight and seven biometric traits that are; body length (BL), breast girth (BG), wing length (WL), wing span (WS), thigh length (TL), shank length (SL), keel length (KL) were measured on eight week old chickens chickens comprising 53 each of Marshal (M), Marshal x naked-neck (MNk), Marshal x normal-feathered (MNm), Naked-neck (Nk) and Normal-feathered (Nm). General linear model, factor and partial least squares procedures of statistical analysis system (S.A.S 9.1) were used to compute the variations among the five genotypes. Pearson correlations between body weight and biometric traits were positive and highly related (r = 0.614-0.937, 0.518-0.929 and 0.496-0.943, 0.411-0.959 and 0.760-0.961 in M, MNk, MNm, Nk and Nm genotypes respectively). In all the five genotypes studied, only the first principal component (PC) exhibited eigenvalues greater than 1. Using Bartlet test, observed communalities ranges from 0.787 to 0.946 in M, 0.784 to 0.957 in MNk, 0.685 to 0.928 in MNm, 0.818 to 0.959 in Nk and 0.930 to 0.998 in Nm. This offered credibility to the relevance of the principal component regression. In principal component regression models, TL alone accounted for 76.21%, 62.72%, and 75.52% of the variation in BW for M, MNm and Nk respectively. The best prediction equation ($R^2$=85.61%, $R^2$=85.52%) for BW was obtained when BG was included in the model for M and Nk respectively. BG alone accounted for 91.66% and 69.05% of the variation in BW for Nm and MNk respectively. Also, In MNm chickens, the best prediction equation ($R^2$=70.88%) for BW was obtained when KL was included in the model. It can be concluded that the use of principal components' scores from chickens' morphometric traits was more appropriate than the use of original traits in body weight prediction as multicollinearity problems were eliminated.

***Keywords:*** body weight, biometric traits, orthogonal and eigenvalues

## Introduction

Nigeria is endowed with a number of locally adapted chickens that are important in meat and egg production. The Nigerian indigenous chickens represent a large group of unexploited genetic resource. Despite increase in the growth of the poultry industry in Nigeria utilizing exotic chicken in production, the indigenous chicken genotypes still remain the largest source of poultry meat and eggs. Although they are less productive when compared to the exotic counterpart, indigenous chickens play a vital role in the socio-economic life of those keeping them (Alabi et al., 2012). Indigenous chickens represent a highly conserved genetic reservoir, with high level of heterozygosity, which may provide the biological material for the development of genetic stocks with improved adaptability and productivity (Ajayi et al., 2012). Also, they have potential to serve as broiler meat if they are improved on. Meanwhile, Marshal genotype is among the strains of broiler chickens reared by farmers in Southern Nigeria. They cope fairly well with the hot season of January to March in Nigeria and reach market weight at about 8 weeks of age (Udeh and Ogbu, 2011). Poultry consumers buy live chicken especially during festive period using visual appraisal to choose heavy chicken. This visual appraisal is an inaccurate judgment. However, understanding the interrelationships between body weight and body measurements in these chickens and their crossbreds will help the poultry consumers and farmers to predict their body weight at various ages especially in the rural areas when scales are not available.

The accuracy of models used to predict body weights from linear body measurements has a colossal financial input to livestock production enterprises. Ability of livestock producers and buyers to relate linear body measurements to body weight will result in an optimum production and value-based trading system as a result of accurate predictions. This will ensure that livestock farmers are adequately rewarded rather than the middlemen and/or livestock product processors who tend to gain more profit in livestock production enterprises, especially in the rural areas of developing countries (Afolayan et al., 2006) such as Nigeria. Also, accuracy of models developed to predict body weights from linear body measurements could improve efficiency of selection for growth by enabling the breeder to recognise early maturing and late maturing animals of different sizes. Linear body measurements have been used to predict body weights by several authors in many chicken breeds (Mendes, 2009; Yakubu et al., 2009; Udeh and Ogbu, 2011; Ajayi et al., 2012).

The authors used different models (canonical discriminant, multiple regressions and principal components) to predict body weight in different breeds, sexes and environmental conditions. Both canonical discriminant and multiple regressions models are highly affected by high correlations (multicollinearity problem) between predictor variables. It is well known that in the presence of multicollinearity problem, the standard errors of the parameter estimates could be quite high, resulting in unstable estimates of the regression model.

Hence, the multicollinearity between predictor variables can lead to incorrect identification of the most important predictors (Sharma 1996; Thompson et al., 2001 and Hoe and Kim, 2004). Sousa et al. (2007) and Mendes (2009) reported that one of the approaches to avoid multicollinearity problem is the principal component analysis. However, principal component analysis (PCA) might not be able to account for variation due to differences in breeds. Hence, categorization of data according to breed is necessary (if its effect is significant) to improve prediction power of the principal component analysis. Also, multivariate analyses involving the use of PCA has been reported for extensively-managed Nigerian indigenous chickens in the Northern part of Nigeria (Yakuku et al., 2009) while Ajayi et al. (2012) reportedfor intensively-managed Nigerian indigenous chickensand Anak Titan (an exotic chicken). However, Yakubu et al. (2009) did not account for spatially dependent correlation as a result of sampling of data in different locations and PCA carried out with spatially-dependent samples will most often result in identifying spatial correlations (Clemens et al., 2008).

Strong spatial correlations may completely mask linear body measurement correlations within the sample variables which PCA needed to account for. Also, Ajayi et al. (2012) used small sample size (30 naked-neck and 27 Anak Titan chickens). This might make the results to be biased. Guadagnoli and Velicer (1988) reviewed several studies that reached the conclusion that the minimum sample size should be 50. Gorsuch (1983) and Hatcher (1994) also supported ratio of the minimum value of sample size to variables as being of greater importance in PCA and recommended at least 5:1. Therefore, this study sought to increase sample size of all variables to minimum of 50 and use Principal components regression (PCR) to correct for multicollinearity among linear body measurements when fitting multiple regression models. The PCR approach involves constructing principal component (PC) and then using these components as the predictors in a linear regression model that is fit using least squares. The prime idea of PCR is to use scores rather than the original data for the regression step.

This has two advantages: scores are orthogonal, so there are no problems with correlated variables, and secondly, the number of PCs taken into account usually is much lower than the number of original variables. This reduces the number of coefficients that must be estimated considerably, which in turn leads to more degrees of freedom for the estimation of errors.

## Materials and Methods

### Study Location

The research was conducted at the Poultry Breeding Unit of the Federal University of Agriculture, Abeokuta, (FUNAAB) located on latitude 7˚10 N in Odeda Local Government Area, Ogun State, in South-Western Nigeria. The ambient temperature during the period ranged from 26.9˚C in June to 27.1˚C in December with average relative humidity of 80%, while the vegetative site represents an inter-phase between the tropical rainforest and the derived savannah (AGROMET, FUNAAB, 2014).

### Experimental Animals and Their Management

A total of 265 chicks comprising 53 each of Normal-feathered, Marshal, Naked-neck Marshal x naked-neck and Marshal x normal-feathered crosses generated from Hatchery in Abeokuta were used for the study. The chicks were raised in deep litter pen for eight weeks. The birds were fed *ad libitum* on broiler starter diet from day-old to 4 weeks of age and a broiler finisher diet from 4 to 8 weeks of age. Clean drinking water was also made available to the birds all the time. All the necessary vaccines for broiler chicks were administered at the appropriate ages. The body weights of the birds were recorded on weekly basis to 8 weeks of age. The body measurements namely shank length, thigh length, drumstick length, body length, body width, breast width and wing length were measured at 8 weeks of age.

### Traits Measured

Body weight (BW) (grammes) and seven linear body measurements were measured on each chicken. The body measurements (centimetres) were taken using a measuring tape except for body weight that was taken using a measuring scale in grammes. The parts measured were body length (BL), measured as the distance between the tip of the beak and the longest toe without the nail; wing length (WL), taken as the distance between the tip of the phalanges and the coracoids-humerus joint; wing span (WS), measured as the distance between the left wing tip to the right wing tip across the back of the chicken; shank length (SL), taken as the distance from the hock joint to the tarsometatarsus; thigh length (TL) measured as the distance between the hock joint and the pelvic joint; breast girth (BG), measured as the circumference of the breast around the deepest region of the breast and keel length (KL), taken as the distance between the anterior and posterior ends of the keel.

### Statistical Analysis

Means and standard errors values of body weight and body measurements of each genotype were obtained using the descriptive statistic of S.A.S (Version 9.1). Two-way analysis of variance was used to test the effects and sex of genotypes on the parameters. Pearson correlation coefficients among the body measurements were calculated for each genotypes and the correlation matrix which was the primary data required for PCA generated.

PCR is an appropriate multivariate technique to reduce the dimension of a data set consisting of a large number of interrelated variables, while retaining as much as possible the variation present in the data set (Sharma, 1996; Özkan and Mendes, 2004). This is achieved by transforming a set of original variables to a new set of variables, the principal components which are ordered so that the first few retain most of the variation present in all of the original variables (Joliffe, 2002).

Principal component analysis is a method for transforming the variables in a multivariate data set $x_1$, $x_2$, ---, xp, into new variables, $y_1$, $y_2$,---, yp which are uncorrelated with each other and account for decreasing proportions of the total variance of the original variables defined as:

$$y_1 = a_{11}\, x_1 + a_{12}\, x_2 + \text{--------------} + a_{1p}x_p$$

$$y_2 = a_2\, x_1 + a_{22}\, x_2 + \text{---------------} + a_{2p}x_p$$

$$y_p = a_{p1}\, x_1 + a_{p2}\, x_2 + \text{--------------} + a_{pp}x_p$$

The aim of the Varimax rotation is to maximize the sum of variances of $a_{ij}^2$ quadratic weight.

The stepwise variable selection multiple regression procedure was used to obtain models for predicting body weight from body measurements (a) and from established principal components (b).

$$BW = a + B_i x_i + \text{-------} B_k x_k \text{---------} (a)$$

$$BW= a + B_i PC_i + \text{------} B_k PC_k \text{--------} (b)$$

where; BW is the body weight, a is the regression intercept, $B_1$ is the ith partial regression coefficient of the i-th linear body measurement, Xi or the ith principal component. Anti-image correlations and Barlett's Test of Sphericity were computed to test the validity of the factor analysis of the data sets. The appropriateness of the factor analysis was further tested using communalities and ratio of cases to variables. Components were extracted until some stopping criteria is encountered or until p components were formed. The weights used to create the principal components are the eigenvectors of the characteristics equation:

$$(R- \lambda_1 I)\, a = 0$$

Where R is the correlation matrix, the $\lambda_1$ are the eigenvalues (the variances of the components). The eigenvalues were obtained by solving $(R- \lambda_1 I)a = 0$ for $\lambda_1$. Cumulative proportion variance was employed in determining the number of principal components to extract. The overall reliability of the factor solution was tested using Chronbach's Alpha. The means, correlation, factor, PLS and regression procedures of S.A.S 9.1 statistical package were used for the principal component regression analysis.

## Results and Discussion

Table 1 shows the means, standard errors and coefficients of variation of body weight and body measurements of three genotypes and their two crossbred of chickens at 8 weeks of age. Genotype had significant effect ($P<0.001$) on all the biometric traits with Marshal chickens having significantly highest means compared to the four other genotypes (Table 1). Marshal, Marshal x normal-feathered and Marshal x naked-neck attained average body weight of 790.06, 626.34 and 611.03g respectively which were superior to normal-feathered (Nm) (472.24g) and naked-neck (494.62g) at 8 weeks of age. This observation attested to previous reports that Nigerian indigenous chickens were light breeds (Peters, 2000 and Adeleke et al., 2011), but suggests the suitability of Marshal chickens for crossbreeding programmes which when mated with indigenous genotypes will eventually improve the growth and carcass trait potentials of Nigerian indigenous chickens. The observable differences between body weight of naked-neck and normal-feathered chickens were similar to the findings of Patra et al. (2002) who reported that naked-neck chickens had heavier body weight compared to their Normal-feathered counterparts. However, the higher average body weight observed in naked-neck chickens compared to normal-feathered chickens was contrasted to that observed by Gunn (2008) and Ajayi et al. (2012) who reported better performance of normal-feathered chickens in comparison to naked-neck chickens.

Also, male birds had higher values for all linear body measurements compared to their female counterparts (Table 2). This result is in agreement with the findings of earlier researchers (Peters et al., 2006; and Ajayi et al., 2012). This observed dimorphism might be attributed to the differential sex hormonal effects on growth. As a result of differential sex hormonal effects, Male chickens tend to be aggressive and eat more feed with overall effect on growth. Also based on coefficient of variation, body weight and morphometric traits were variable with exception of males thigh length (9.50) and females thigh and wing length (9.26 and 9.98) respectively. This might be attributed to some degree of environmental effects and the condition of each animal (Yakubu and Ayoade, 2007).

Table 3 shows the coefficient of correlations of body weight and body measurements of the chicken genotypes. The correlation coefficients ranged from 0.614 to 0.937, 0.518 to 0.929 and 0.496 to 0.943, 0.411 to 0.959 and 0.760 to 0.961 in Marshal (M), Marshal x naked-neck (MNk), Marshal x normal-feathered (MNm), naked-neck (Nk) and normal-feathered (Nm) genotypes respectively.

**Table 1** Means, standard errors (SE) and coefficients of variation (CV) for body weight (kg) and body measurements (cm) of five Nigerian genotype chickens according to genotype.

| | Marshal | | Marshal x naked | | Marshal Normal | | Naked-neck | | Normal | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean ± SE | CV | Mean ± SE | CV | Mean ± SE | CV | Mean ± SE | CV | Mean ± SE | CV |
| Body weight | 790.06±22.67[a] | 19.59 | 611.03±20.09[b] | 22.44 | 626.34±18.96[b] | 23.84 | 494.62±18.42[c] | 22.82 | 472.24±21.78[c] | 32.49 |
| Body length | 14.53±0.17[a] | 8.29 | 12.77±0.18[c] | 9.79 | 13.47±0.13[b] | 7.63 | 12.46±0.21[cd] | 10.55 | 12.17±0.24[d] | 13.47 |
| Breast girth | 19.02±0.22[a] | 8.06 | 16.83±0.26[b] | 10.83 | 17.16±0.18[b] | 8.08 | 15.07±0.20[c] | 8.38 | 15.07±0.30[c] | 13.86 |
| Width length | 17.81±0.22[a] | 8.58 | 16.20±0.26[b] | 11.19 | 16.68±0.15[b] | 6.98 | 15.53±0.21[c] | 8.43 | 15.26±0.26[c] | 11.55 |
| Wing span | 38.82±0.45[a] | 8.04 | 34.11±0.58[c] | 11.66 | 36.49±0.32[b] | 7.01 | 33.09±0.45[cd] | 8.41 | 32.63±0.74[d] | 15.47 |
| Thigh length | 15.09±0.16[a] | 7.59 | 13.88±0.18[b] | 8.91 | 13.86±0.13[b] | 7.85 | 13.41±0.19[bc] | 8.67 | 13.17±0.21[c] | 10.84 |
| Shank length | 11.83±0.17[a] | 9.96 | 10.61±0.16[b] | 10.53 | 10.99±0.12[b] | 8.88 | 10.08±0.19[c] | 11.96 | 9.84±0.19[c] | 13.59 |
| Keel length | 7.99±0.11[a] | 9.35 | 6.90±0.09[b] | 9.05 | 7.27±0.07[c] | 8.19 | 6.44±0.10[d] | 10.02 | 6.19±0.13[d] | 15.37 |

**Table 2** Means, standard errors (SE) and coefficients of variation (CV) for body weight (kg) and body measurements (cm) of five Nigerian genotype chickens according to sex.

| Traits | Male | | Female | |
|---|---|---|---|---|
| | Mean ± SE | CV % | Mean ± SE | CV % |
| Body weight | 643.82±16.85[a] | 30.37 | 553.90±15.03[b] | 27.47 |
| Body length | 13.39±0.13[a] | 12.32 | 12.76±0.14[b] | 10.34 |
| Breast girth | 17.09±0.19[a] | 13.13 | 16.17±0.19[b] | 12.15 |
| Wing length | 16.60±0.15[a] | 11.07 | 15.99±0.15[b] | 9.98 |
| Wing span | 35.96±0.34[a] | 13.06 | 34.10±0.40[b] | 10.20 |
| Thigh length | 14.29±0.12[a] | 9.50 | 13.47±0.11[b] | 9.26 |
| Shank length | 11.01±0.11[a] | 12.74 | 10.34±0.12[b] | 11.44 |
| Keel length | 7.15±0.08[a] | 14.12 | 6.76±0.09[b] | 12.29 |

Relationships between body weight and all the body measurements were positive and significant ($p<0.001$) in the five chicken genotypes. Highest positive correlations were recorded between wing span and wing length in M, MNm and Nk while shank length and thigh length had highest positive correlations in MNk and Nm genotypes. Shank length and body length had lowest positive relationship in M. Meanwhile, lowest positive correlations were recorded between body length and wing length (0.518) in MNk, body length and shank length (0.496) in MNm, shank length and thigh length (0.411) in Nk and wing span and body weight (0.760) in Nm. The lowest positive correlations recorded between body weight and other linear body measurements were observed between body weight and body length (0.567) in MNm. In all the five chicken genotypes, body weight had highly positive correlations with all the linear body measurements.

These values revealed the pattern of correlations among the traits and high positive correlations among most of the linear body measurements with body weight in all the genotypes may be useful as selection criterion in the absence of multicollinearity. Positive correlations of traits suggest that the traits are under the same gene action (pleiotropy) (Yakubu et al., 2009) and selection for a trait may lead to a correlated response in the other trait.

Although only the first principal component (PC) exhibited eigenvalues greater than 1, observed communalities, which represent the proportion of the variance in the original variables that is accounted for by the factor solution ranged from 0.787 to 0.946 in M, 0.784 to 0.957 in MNk, 0.685 to 0.928 in MNm, 0.818 to 0.959 in Nk and 0.930 to 0.998 in Nm (Table 4). This offered credibility to the relevance of the principal component regression. PC1 accounted for the largest variance (81.74%,

**Table 3** Pearson correlations among body weight and linear body measurements of five Nigerian genotype chickens weight and linear body traits of Marshal (first upper diagonal), Marshal x naked-neck (first-middle upper diagonal) Marshal x normal (second-middle upper diagonal), naked-neck (first lower diagonal) and normal-feathered chickens (second lower diagonal).

| | BW | BL | BG | WL | WS | TL | SL | KL |
|---|---|---|---|---|---|---|---|---|
| BW | 1 | 0.774*** | 0.869*** | 0.754*** | 0.795*** | 0.873*** | 0.769*** | 0.696*** |
| BL | 0.721*** | 1 | 0.787*** | 0.659*** | 0.686*** | 0.713*** | 0.614*** | 0.726*** |
| BG | 0.831*** | 0.706*** | 1 | 0.748*** | 0.786*** | 0.774*** | 0.757*** | 0.729*** |
| WL | 0.635*** | 0.518*** | 0.565*** | 1 | 0.937*** | 0.828*** | 0.925*** | 0.831*** |
| WS | 0.707*** | 0.679*** | 0.734*** | 0.645*** | 1 | 0.854*** | 0.942*** | 0.819*** |
| TL | 0.799*** | 0.837*** | 0.837*** | 0.582*** | 0.802*** | 1 | 0.856*** | 0.704*** |
| SL | 0.766*** | 0.829*** | 0.768*** | 0.562*** | 0.755*** | 0.929*** | 1 | 0.804*** |
| KL | 0.794*** | 0.745*** | 0.805*** | 0.623*** | 0.763*** | 0.854*** | 0.818*** | 1 |
| BW | 1 | 0.567*** | 0.718*** | 0.778*** | 0.771*** | 0.792*** | 0.724*** | 0.770*** |
| BL | 0.856*** | 1 | 0.547*** | 0.643*** | 0.615*** | 0.639*** | 0.496*** | 0.511*** |
| BG | 0.869*** | 0.741*** | 1 | 0.688*** | 0.708*** | 0.695*** | 0.537*** | 0.690*** |
| WL | 0.868*** | 0.825*** | 0.822*** | 1 | 0.943*** | 0.872*** | 0.848*** | 0.752*** |
| WS | 0.837*** | 0.775*** | 0.799*** | 0.959*** | 1 | 0.885*** | 0.851*** | 0.779*** |
| TL | 0.787*** | 0.716*** | 0.781*** | 0.813*** | 0.772*** | 1 | 0.828*** | 0.723*** |
| SL | 0.760*** | 0.767*** | 0.614*** | 0.733*** | 0.699*** | 0.411*** | 1 | 0.721*** |
| KL | 0.821*** | 0.781*** | 0.778*** | 0.796*** | 0.766*** | 0.681*** | 0.751*** | 1 |
| BW | 1 | 0.941*** | 0.957*** | 0.909*** | 0.760*** | 0.909*** | 0.946*** | 0.935*** |
| BL | | 1 | 0.923*** | 0.919*** | 0.779*** | 0.917*** | 0.928*** | 0.932*** |
| BG | | | 1 | 0.923*** | 0.763*** | 0.920*** | 0.950*** | 0.929*** |
| WL | | | | 1 | 0.816*** | 0.954*** | 0.949*** | 0.903*** |
| WS | | | | | 1 | 0.788*** | 0.767*** | 0.767*** |
| TL | | | | | | 1 | 0.961*** | 0.915*** |
| SL | | | | | | | 1 | 0.942*** |
| KL | | | | | | | | 1 |

BW body weight, BL body length, BG breast girth, WL wing length, WS wing span, TL thigh length, SL shank length, KL keel length ***P<0.001

77.44%, 76.02%, 78.95%, and 90.57%) for M, MNk, MNm, Nk and Nm respectively. This had been the usual trend in studies that involved PCA as stated by earlier researchers (Mendes, 2009; Yakubu et al., 2009; Udeh and Ogbu, 2011 and Ajayi et al., 2012).

The best loading of each trait is indicated by a bolded number for each PCs in each genotypes. PC1 had high positive loadings on all biometric traits ranged from 0.811 to 0.954 in M, 0.734 to 0.983 in MNk, 0.724 to 0.966 in MNm, 0.797 to 0.959 in Nk and 0.848 to 0.977 in Nm. This implies an increase in any of the traits will results to correlated increase in the other traits.

Based on PCA criteria, seven linear body measurements were reduced to three components. Combined PC1, PC2 and PC3 accounted for 93.82%, 90.43%, 91.33%, 92.13% and 96.90% of the total variance for M, MNk, MNm, Nk and Nm respectively. Higher combined PC1, PC2 and PC3 values were recorded for M and Nm in this study compared to report Udeh and Ogbu, (2011) who reported 74.76% in M at 8 weeks old and Ajayi et al. (2012) who reported 89.78% in Nm. However, Ajayi et al. (2012) reported higher value (94.83%) for combined PC1, PC2 and PC3 in Nk compared to this study. The three principal components (PC1, PC2 and PC3) obtained for each genotype could be useful in assessing animals for breeding and selection purposes especially in the crossbred genotypes.

Table 5 illustrates the percent variation accounted for by PCs and cross validation for the number of extracted factors of the linear body measurements of chickens. Only one PC is retained according to the PRESS in MNk, MNm and Nk. The seven traits were collapsed into a single measure and the percent of the variance explained in the model was 77.44%, 76.02% and 78.95% in MNk, MNm and Nk respectively. Needless to say, this is adequate. If all seven PCs are treated as independent variables (no variable reduction is used),

**Table 4** Eigenvalues and share of total variance along with factor loadings after rotation and communalities of the linear body measurements of chickens.

| Traits | PC1 | PC2 | PC3 | Communality |
|---|---|---|---|---|
| Marshal | | | | |
| BL | 0.811 | **0.535** | 0.042 | 0.946 |
| BG | 0.880 | 0.280 | -0.152 | 0.853 |
| WL | 0.942 | -0.231 | 0.062 | 0.939 |
| WS | **0.954** | -0.190 | -0.013 | 0.950 |
| TL | 0.907 | -0.040 | -0.315 | 0.824 |
| SL | 0.938 | -0.283 | -0.038 | 0.958 |
| KL | 0.887 | 0.020 | **0.424** | 0.787 |
| Eigen values | 5.722 | 0.536 | 0.309 | |
| Total variance (%) | 81.74 | 7.66 | 4.42 | |
| Marshal x naked-neck | | | | |
| BL | 0.892 | -0.225 | **0.349** | 0.809 |
| BG | 0.907 | -0.064 | -0.312 | 0.786 |
| WL | 0.734 | **0.637** | 0.166 | 0.957 |
| WS | 0.897 | 0.138 | -0.182 | 0.784 |
| TL | **0.983** | -0.155 | 0.008 | 0.941 |
| SL | 0.952 | -0.179 | 0.123 | 0.893 |
| KL | 0.940 | -0.012 | -0.116 | 0.837 |
| Eigen values | 5.421 | 0.589 | 0.319 | |
| Total variance (%) | 77.44 | 8.42 | 4.57 | |
| Marshal x normal-feathered | | | | |
| BL | 0.724 | **0.620** | -0.233 | 0.898 |
| BG | 0.801 | 0.235 | **0.415** | 0.685 |
| WL | 0.959 | -0.083 | -0.088 | 0.909 |
| WS | **0.966** | -0.117 | -0.042 | 0.928 |
| TL | 0.941 | -0.048 | -0.079 | 0.871 |
| SL | 0.882 | -0.335 | -0.172 | 0.880 |
| KL | 0.859 | -0.120 | 0.218 | 0.739 |
| Eigen values | 5.322 | 0.588 | 0.438 | |
| Total variance (%) | 76.02 | 8.41 | 6.9 | |
| Naked-neck | | | | |
| BL | 0.900 | 0.128 | 0.046 | 0.831 |
| BG | 0.891 | -0.173 | 0.262 | 0.828 |
| WL | **0.959** | -0.062 | -0.279 | 0.925 |
| WS | 0.931 | -0.073 | **-0.361** | 0.874 |
| TL | 0.835 | -0.466 | 0.042 | 0.934 |
| SL | 0.797 | **0.544** | -0.069 | 0.959 |
| KL | 0.891 | 0.136 | 0.391 | 0.818 |
| Eigen values | 5.526 | 0.643 | 0.277 | |
| Total variance (%) | 78.95 | 9.19 | 3.99 | |
| Normal-feathered | | | | |
| BL | 0.962 | -0.095 | 0.217 | 0.930 |
| BG | 0.964 | -0.163 | 0.079 | 0.942 |
| WL | 0.972 | 0.003 | -0.258 | 0.944 |
| WS | 0.848 | **0.743** | 0.049 | 0.998 |
| TL | 0.972 | -0.083 | -0.255 | 0.946 |
| SL | **0.977** | -0.170 | -0.102 | 0.970 |
| KL | 0.962 | -0.144 | **0.282** | 0.933 |
| Eigen values | 6.339 | 0.324 | 0.119 | |
| Total variance (%) | 90.57 | 4.63 | 1.70 | |

the percent of variance explained becomes 100%, but the model might be over-fitted. Meanwhile, three components should be retained according to the PRESS in M and Nm. PCR suggested number of the proper number of PCs based on the PRESS statistics and variance explained in the model effects. Principal component factor score coefficients for M, MNk, MNm, Nk and Nm chickens were generated and used instead of the original interdependent linear body measurements in predicting the BW of each genotypes.

The interdependent original linear body measurements and their independent principal component factor scores were used for the prediction of BW (Table 6). TL alone accounted for 76.21%, 62.72%, and 75.52% of the variation in BW for M, MNm and Nk respectively. However, the best prediction equation ($R^2$=85.61%) for BW was obtained when BG was included in the model for M. In Nk chickens, the best prediction equation ($R^2$=85.52%) for BW was obtained when BG was included in the model. Also, In MNm chickens, the best prediction equation ($R^2$=70.88%) for BW was obtained when KL was included in the model. BG alone accounted for 91.66% and 69.05% of the variation in BW for Nm and MNk respectively. The high association between BW and BG in Nm might be attributed to large deposits of cartilage and muscles in breast region of the birds (Ajayi et al., 2012). The proportion of the explained variance increased to 93.85% when body length was included in the model. In MNk genotype, the proportion of the explained variance was further increased to 70.88% when KL was included in the model. Meanwhile, PC1 explained 76.17%, 73.09%, 70.92%, 87.04% and 91.41% of the total variability in BW in M, MNk, MNm, Nk and Nm respectively. However, a combination of PC1, PC2 and PC3 led to a significant improvement in the proportion of variance explained ($R^2$=85.03%) in M genotype while PC1, PC2 and PC3 led to substantial improvement in the percentage of variance explained ($R^2$=93.57%) in Nm genotype. The use of principal component scores (orthogonal traits) gave an improved and more reliable assessment of body weight since it was able to remove multicollinearity, a problem associated with the use of interdependent original body measurements (Yakubu et al., 2009).

**Table 5** Percent variation accounted for by Principal components and Cross validation for the number of extracted factors of the linear body measurements of chickens

| Number of extracted factors | Model effects | | Dependent variables | | Prob>PRESS |
|---|---|---|---|---|---|
| | Current | Total | Current | Total | |
| Marshal | | | | | |
| 1 | 81.739 | 81.739 | 76.171 | 76.171 | 0.0001 |
| 2 | 7.660 | 89.400 | 3.191 | 79.361 | 0.006 |
| 3 | 4.415 | 93.815 | 5.672 | 85.033 | 0.031 |
| Marshal x naked-neck | | | | | |
| 1 | 77.442 | 77.442 | 73.095 | 73.095 | 0.004 |
| Marshal x normal-feathered | | | | | |
| 1 | 76.023 | 76.023 | 70.916 | 70.916 | 0.0001 |
| Naked-neck | | | | | |
| 1 | 78.950 | 78.950 | 87.041 | 87.041 | 0.0001 |
| Normal-feathered | | | | | |
| 1 | 90.569 | 90.569 | 91.413 | 91.413 | .0001 |
| 2 | 4.632 | 95.201 | 1.128 | 92.542 | 0.01 |
| 3 | 1.701 | 96.902 | 1.024 | 93.566 | 0.05 |

**Table 6** Stepwise multiple regression of body weight on original body measurements and on their principal component (PC) factor scores in chickens.

| Variables | Model | SE | $R^2$ |
|---|---|---|---|
| Marshal chickens | | | |
| Original body measurements as explanatory variables | | | |
| Thigh length | BW= -981.656+117.564TL | 9.180 | 76.21 |
| breast girth and thigh length | BW= -981.656+48.676BG+117.564TL | 12.304 | 85.61 |
| Orthogonal traits as independent variables | | | |
| | BW=785.130+56.116PC1 | 3.838 | 76.17 |
| | BW=785.130+56.116PC1-65.886PC3 | 16.514 | 81.84 |
| | BW=785.130+56.116PC1+37.516PC2-65.886PC3 | 12.538 | 85.03 |
| Marshal x naked-neck chickens | | | |
| Original body measurements as explanatory variables | | | |
| breast girth | BW= -447.878+63.141BG | 6.233 | 69.05 |
| breast girth and thigh length | BW= -626.199+41.4716BG+78.505TL | 28.733 | 73.45 |
| Orthogonal traits as independent variables | | | |
| | BW=620.395+51.130PC1 | 4.573 | 73.09 |
| Marshal x normal-feathered chickens | | | |
| Original body measurements as explanatory variables | | | |
| thigh length | BW= -886.690+109.185TL | 10.777 | 62.72 |
| breast girth and keel length | BW= -1072.933+67.933TL+104.214KL | 25.411 | 70.88 |
| Orthogonal traits as independent variables | | | |
| | BW=631.333+54.945PC1 | 4.505 | 70.92 |
| Naked-neck chickens | | | |
| Original body measurements as explanatory variables | | | |
| breast girth | BW= -671.302+77.303TL | 7.439 | 75.52 |
| breast girth and thigh length | BW= -704.931+40.285BL+46.221BG | 8.311 | 85.52 |
| Orthogonal traits as independent variables | | | |
| | BW=490.972+44.469PC1 | 2.900 | 87.04 |
| Normal-feathered chickens | | | |
| Original body measurements as explanatory variables | | | |
| breast girth | BW= -565.974+68.558BG | 3.116 | 91.66 |
| breast girth and thigh length | BW= -609.395+34.963BL+43.185BG | 8.938 | 93.85 |
| Orthogonal traits as independent variables | | | |
| | BW=454.652+56.102PC1 | 2.592 | 91.41 |
| | BW=454.652+56.102PC1-27.560PC2 | 10.805 | 92.54 |
| | BW=454.652+56.102PC1-27.560PC2+43.339PC3 | 16.759 | 93.57 |

Based on this study, orthogonal variables derived from PCs gave a better and more dependable estimation of body weight than the use of the original independent variables. Hence, Principal component regression should be used to classify chicken morph-structural variables thereby eliminating redundant information for the purpose of reducing costs of chickens' genetic programmes.

## Conclusions

Principal components regression analysis has been presented to be useful in the prediction of body weight using orthogonal variable traits. In Stepwise multiple regression analysis, BG, KL and TL were the only traits involved in prediction of body weight for original traits, while only PC1 in MNk, MNm and Nk but PC1, PC2 as well as PC3 in M and Nm for orthogonal traits. The use of orthogonal body shape characteristics derived from principal components' scores was more appropriate than the use of original traits in body weight prediction as multicollinearity problems were eliminated. Also, the best result was obtained in Nm (using number of PCs that stepwise multiple regressions selected and $R^2$ value) followed by M while the least prediction was obtained in MNk.

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