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Fixing Collinearity Instability in Body Weight Estimation Based on Morpho-Biometric Traits of Mixed Breeds of Pigs in Nigeria

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Abstract

Morpho-biometric studies were conducted on 500 mixed breed of pigs' comprising Yorkshire, Duroc, Large White, and Hampshire breeds to identify the estimation of body weight collinearity issue. The body weight and biometric traits taken were analyzed using Statistical Package for the Social Sciences (SPSS) version 16. Body weight and zoometrical factors had positive and highly significant bivariate relationships in most parameters. The body weight and body length showed the best relationship (0.935 $p<0.01$), whilst the chest girth and ear length showed the lowest correlation (0.007; $p<0.05$). Since none of the body measurements were greater than 10.00, the variance inflation factors (VIFs) displayed non-collinearity issues in all of the measurements. Tolerance (T) values greater than 0.10 in all of the same measurements served as confirmation of this. No collinearity was also evident in the eigenvalues of the correlation matrix, condition indices, or variance proportions. Body length was kept as the most crucial attribute for prediction among the variables. This study showed that there is no collinearity among selected morphometric traits. Stepwise multi-regression models showed that the best predictor of body weight was based on a combination of body length, head length, height at wither and hind leg length (R2= 0.881 and adjusted R2 =0.880). This research has the practical application that morphological indices can be utilized in the field to estimate body weight for selection and to estimate market values for different breeds of pigs.

Keywords: Body Weight; Pigs; Collinearity; Morpho-Biometric

Abbreviations: VIF: Variance Inflation Factor; T: Tolerance; CI: Condition Indices; BWT: Body Weight; BL: Body Length; CG: Chest Girth; HW: Height at Wither; EL: Ear Length; HDL: Head Length; FL: Foreleg Length; HL: Hind Leg Length; CV: Coefficient of Variation.

Introduction

Collinearity, a phenomenon prevalent in regression analysis, signifies the high correlation among predictor variables within a model. This correlation often results in numerical instability and challenges the interpretability of estimated coefficients [1]. When observed in predictive models, collinearity distorts the accuracy of coefficients, leading to inflated standard errors and potential misinterpretation of variable importance [2]. Its impact reverberates across various disciplines, prominently affecting animal science studies, particularly in estimating body weight from morpho-biometrical traits in pigs.

Morphometric parameters and their indices are central to characterization, selection and genetic improvement of farm animals. The estimation of body weight in livestock, including pigs, plays an important role in animal husbandry, nutritional management, and overall farm productivity [3]. Various statistical techniques involving prediction models such as principal component analysis, canonical correlation, factor score analysis, regression tree analysis, linear, quadratic, cubic and multiple regression models, etc. have been employed by researchers to investigate relationships between body measurements and body weight and also to predict the expected improvement of this polygenic trait [4-6]. Body weight is an important economic trait in farm animals and high premium is attached to it by livestock farmers [6]. In pig farming, accurate body weight estimation is essential for feed optimization, health monitoring, and breeding decisions. Morpho-biometrical traits, encompassing a range of physical measurements and characteristics, have been widely employed as valuable indicators for predicting pig body weight [7].

These morpho-biometrical traits, such as body length, chest girth, and height at withers, offer a non-invasive and practical means to estimate pig weight without resorting to direct weighing, this can be stressful to the animals and impractical on a large scale. However, the accuracy of such estimates hinges on the establishment of robust statistical models, which introduces the concept of collinearity instability. Collinearity occurs when predictor variables within a model are highly correlated, leading to challenges in estimating their individual effects on the response variable [8]. In the specific context of pig weight estimation, collinearity among morpho-biometrical traits can introduce biases, reduce prediction accuracy, and hinder the effectiveness of livestock management strategies [9]. Mixed breed populations in pig farming are characterized by genetic diversity and variability, presenting a unique set of challenges in body weight estimation. As a result, addressing collinearity becomes an even more pressing concern in such populations.

The study aims to provide an in-depth knowledge of the use of morpho-biometrical traits for pig weight estimation, highlighting their accuracy and limitations, while also examining the implications of collinearity in statistical modelling. It also sets to review approaches and methodologies used in pig weight estimation, emphasizing the studies that have already attempted to mitigate collinearity-related issues [10]. Furthermore, the review will showcase the innovative solutions and methods proposed by researchers to tackle the problem of collinearity instability in pig weight estimation, including advances in statistical modeling and data analysis techniques [11].

The main objectives of the study are to evaluate:

1. The Phenotypic Correlation of Body Weight and Biometric Traits of Mixed Breed of Growing Pigs
2. The Coefficient of Determination (R^2), Variance Inflation Factors (VIFs) and Tolerance (T) Values for Body Measurements of Mixed Breed of Growing Pigs
3. The Eigenvalues, Condition Indices (CI) and Variance Proportions of Body Measurements for Predicting Body Weight in Mixed Breed of Growing Pigs
4. The Regression Models for Estimating Body Weight from Morphometric Characters of Mixed Breed of Growing Pigs.

Material and Methods

Study Area and Experimental Animals

The study was conducted in five local government areas within Kaduna State, namely Kaura, Chikun, Jaba, Zango-Kataf, and Jema'a local government areas. A total of 500 pigs, representing different breeds including Yorkshire, Duroc, Large White, and Hampshire, were measured for various parameters, with a sample size of 100 pigs selected from each of the mentioned local government areas. The pigs were reared semi-intensive and extensively.

Parameters Measured

The parameters measured were body weight (BWT), body length (BL), chest girth (CG), and height at wither (HW), ear length (EL), head length (HDL), foreleg length (FL), and hind leg length (HL) were measured. Body Weight estimation was carried out using a hanging scale to determine the weight of each animal. Body length (BL) was measured as the distance between the occipital protuberance and the tail drop, ensuring precise alignment during measurement. Chest girth (CG) was determined as the circumference of the chest just behind the forelimbs, meticulously recorded using a measuring tape. Height at wither (HW) was measured as the distance between the most dorsal point of the withers and the ground, ensuring a consistent angle of measurement to maintain accuracy. Amongst other parameters measure were; Ear length (EL), Head length (HDL), Foreleg length (FL), and Hind leg length (HL) were measured using specific tools: EL and HDL were assessed using a measuring tape, while FL and HL were measured using a calibrated wooden calliper. To minimize variations in measurements, all assessments were consistently carried out by the same person, ensuring accuracy and reducing potential discrepancies arising from inter-personnel variations.

Statistical Analysis

Data collected were analysed for descriptive statistics (Mean±SE) and coefficient of variation (CV). As a first indication of severity of collinearity, correlation coefficients among all the five independent body measurements were estimated. Due to the inadequacy of correlation as a method of detecting collinearity, the method of variance inflation factor Rook AJ, et al. [12] was employed as follows:

$$VIF = \frac{1}{1 - R^2}$$

Where, R^2 = Coefficient of Determination.

A further step for testing collinearity was to calculate the tolerance (T) value. To obtain measures of tolerance, each independent variable was treated as a dependent variable and regressed on the other independent variables. The R^2 so obtained was used to calculate T.

$$T = 1 - R^2$$

Where, R^2 = coefficient of determination.

Eigen values of the correlation matrix (X'X), condition indexes and variance proportions were also computed to confirm the existence or otherwise of collinearity following the procedures adopted by Malau-Aduli AEO, et al. [13] and Pimentel ECG, et al. [14]. In order to delete redundant variables arising from multicollinearity, the following model as described by Weisberg S, et al. [15] was employed:

$$RV = \frac{|Bj|}{a}$$

Where, RV = redundant variable.
Bj = regression coefficient of Xj variable.
a = square root of residual mean square of the full regression model.

The full regression model (all the five morphometric indices inclusive) was defined as:

$$Y = Bo + [BiXi]$$

The eventual regression models were fitted using stepwise multiple regression analysis. Each model was assessed using R^2, Adjusted R^2 and RMSE (Root mean squares error). SPSS Statistical package was employed in the analysis [16].

Results and Discussion

The descriptive statistics pertaining to body weight and various body dimensions of growing pigs from mixed breeds are presented in Table 1. Each trait is presented with its mean values, standard errors, standard deviations, coefficients of variation. In the case of body weight (BWT), the average weight stands at approximately 37,800 grams (±1,457.681), showcasing a relatively low coefficient of variation at 8.63%. This suggests a moderate level of variability among the observed pigs regarding their weight, spanning from 16,600 grams to 2,000 grams. Moving to body dimensions such as body length (BL), chest girth (CG), height at wither (HW), ear length (EL), head length (HDL), foreleg length (FL), and hind leg length (HL), they exhibit varying levels of standard deviations and coefficients of variation. Body length (BL) averages around 76.37 cm (±1.023), displaying a higher coefficient of variation at 29.96%. This indicates a broader range of lengths within this pig population, from 150 cm to 40 cm. Notably, certain dimensions like ear length (EL) and head length (HDL) display higher coefficients of variation, suggesting more considerable variability among the pigs for these traits compared to others, such as body weight (BWT) and height at wither (HW). The data highlights diverse ranges and variability's in these measured dimensions among the mixed breeds of growing pigs. These variations may be influenced by genetic diversity, environmental factors, or a combination thereof, emphasizing potential opportunities for genetic manipulation and improvement to optimize desired traits in pig breeding programs.

Traits	Mean ± SE	SD	CV (%)
BWT(g)	37800 ± 1457.681	3262.732	8.63
BL(cm)	76.37 ± 1.023	22.888	29.96
CG(cm)	81.67 ± 9.491	21.24	26.01
HW(cm)	58.18 ± 0.753	16.854	28.97
EL(cm)	20.03 ± 0.303	6.787	33.88
HDL(cm)	27.91 ± 0.304	6.8	24.36
FL(cm)	39.32 ± 4.344	9.72	24.72
HL (cm)	41.76 ± 0.471	10.543	25.25

Table 1: Descriptive Statistics of Body Weight (g) and Body Dimensions (cm) of Mixed Breeds of Growing Pigs. SE: Standard Error CV: Coefficient of Variation SD: Standard Deviation BWT: Body Weight BL: Body Length CG: Chest Girth HW: Height at Wither EL: Ear Length HDL: Head Length FL: Foreleg Length HL: Hind leg Length

Table 2 presents the phenotypic correlations between body weight (BWT) and various biometric traits within a mixed breed of growing pigs. Starting with body weight (BWT), it exhibits strong positive correlations with certain biometric traits. The result shows a high correlation with withers height (HW) at r=0.813** and a notably strong correlation with hind leg length (HL) at r=0.839**. These correlations are statistically significant, denoted by ** indicating a high level of significance at p<0.01. Body length (BL) also demonstrates considerable positive correlations with various traits. It exhibits a strong correlation with withers height (HW) at r=0.899** and hind leg length (HL) at r=0.896**, both highly significant. Chest girth (CG), however, displays weaker correlations with other traits, mostly showing non-significant (NS) relationships. It demonstrates negligible correlations with the other measured traits, suggesting a lack of substantial association with body weight or other dimensions in this context. The correlations among other measured traits like ear length (EL), head length (HDL), foreleg length (FL), and hind leg length (HL) vary in strength. These traits exhibit moderate to strong positive correlations with certain other traits, indicating associations between these morphometric measurements. The observed correlations between body weight and various biometric traits suggest relationships that can inform insights into the pig's physical development. Traits such as withers height (HW) and hind leg length (HL) appear particularly influential in relation to body weight, potentially serving as reliable indicators or predictors of overall body weight in these growing pigs. The positive correlation between body weight and linear body measurements are similar to the report of Akanno EC, et al. [17] who observed the highest correlation between body weight and shoulder-to-tail length. Similarly, Yakubu A, et al. [18] observed that body weight to withers height correlation was (0.95; p<0.01) in West African Dwarf goat. According to Mallam I, et al. [19] obtained highest correlation between body weight and head-to-shoulder in New Zealand white rabbits and highest correlation between body weight and body length in chinchilla rabbits.

	BWT(g)	BL(cm)	CG(cm)	HW(cm)	EL(cm)	HDL(cm)	FL(cm)	HL (cm)
BWT(g)	1	0.935**	0.063NS	0.813**	0.589**	0.724**	0.050NS	0.839**
BL(cm)		1	0.052NS	0.899**	0.669**	0.814**	0.031NS	0.896**
CG(cm)			1	0.049NS	0.007NS	-0.030NS	-0.001NS	0.054NS
HW(cm)				1	0.682**	0.841**	0.040NS	0.829**
EL(cm)					1	0.786**	0.025NS	0.742**
HL(cm)						1	0.042NS	0.847**
FL(cm)							1	0.047NS
HL (cm)								1

Table 2: Phenotypic Correlation of Body Weight and Biometric Traits of Mixed Breed of Growing Pigs.

Table 3 presents the R^2 values, VIFs, and Tolerance values for various body measurements within a mixed breed of growing pigs. These values serve as indicators of multicollinearity among the measured traits. Body length (BL) exhibits an R^2 value of 0.874, indicating a strong association with other body measurements, accompanied by a VIF of 8.502 and a Tolerance value of 0.118. Despite a higher VIF, the Tolerance value suggests non-collinearity, implying that while BL correlates strongly with other traits; it doesn't significantly contribute to multicollinearity concerns. Similar observations of non-collinearity are noted across other measured traits such as chest girth (CG), height at wither (HW), ear length (EL), head length (HDL), foreleg length (FL), and hind leg length (HL). Each of these traits displays high R^2 values ranging from 0.878 to 0.888, coupled with VIFs below 10 and Tolerance values above 0.1, reinforcing the absence of significant multicollinearity concerns among these measured body dimensions. The coefficients of determination (R^2) illustrate the proportion of variance shared between body measurements, suggesting strong relationships between these traits. Despite some higher VIF values, the corresponding Tolerance values affirm the absence of substantial multicollinearity issues, implying that these measurements can be considered independently without significant redundancy or overlap. Collinearity problems may not be resolved by applying a pairwise correlation matrix to the explanatory variables, as there may be near-linear dependencies among more complicated combinations of regression [14]. This means that the VIF need to be used. The VIF is the amount of variation that happens because the predictors are so close together. This study showed that the predictors were not collinear in all the traits with the highest VIF of 6.065 in the hind leg. Although, there is no one-size-fits-all approach to measuring the size of a VIF, here is a rough guide, according to Gill JL, et al. [20], if the VIF is more than 10.00, it is to be considered collinear. According to Rook AJ, et al. [12] also reported similar results in their study. The tolerance (T) values confirmed the non-collinearity problem as T values were all greater than 0.10. There is no specific critical value that defines small tolerance. However, when the tolerance value for any X variable is less than 0.10, collinearity can have more than a marginal effect on the parameter estimates [20]. Multicollinearity refers to a situation in which more than two explanatory variables in a multiple regression model are highly linearly related. The implication of non-collinearity means no linear relationship exists between the independent variables.

Traits	R^2	VIF	T	Remarks
BL(cm)	0.874	8.502	0.118	Non-collinearity
CG(cm)	0.878	1.032	0.969	Non-collinearity
HW(cm)	0.888	6.461	0.155	Non-collinearity
EL(cm)	0.881	2.799	0.357	Non-collinearity
HDL(cm)	0.88	5.598	0.179	Non-collinearity
FL(cm)	0.882	1.004	0.996	Non-collinearity
HL (cm)	0.88	6.918	0.145	Non-collinearity

R^2: Coefficient of Determination VIF: Variance Inflation Factors T: Tolerance values BWT: Body Weight BL: Body Length CG: Chest Girth HW: Height at Wither EL: Ear Length HDL: Head Length FL: Foreleg Length HL: Hind leg Length

Table 3: Coefficient of Determination (R^2), Variance Inflation Factors (VIFs) and Tolerance (T) Values for Body Measurements of Mixed Breed of Growing Pigs.

The presence of collinearity within the dataset was investigated through eigenvalues, condition indices (CI), and variance proportions presented in Table 4. This analysis aimed to understand the potential multicollinearity among body measurements for predicting body weight in a mixed breed of growing pigs. Table 4, made it apparent that the eigenvalues varied across different dimensions. Components 1 and 2 exhibited relatively high eigenvalues of 6.192 and 0.868 respectively, suggesting substantial contributions to the overall variance among the measured body traits in predicting body weight. Condition indices (CI) revealed varying degrees of multicollinearity among these dimensions. Notably, components 4, 5, 6, and 7 displayed higher condition indices, indicating a higher tendency toward collinearity, specifically with values above 10, ranging from 10.5 to 26.153. These components with elevated condition indices may signify potential collinear relationships among specific body measurements.

The variance proportions associated with each eigenvalue indicate the relative contribution of these components to the overall variance of the regression coefficients. Components 4 and 5, despite having relatively small eigenvalues, exhibited variance proportions that are not negligible. These components with smaller eigenvalues yet considerable variance proportions may suggest potential collinearity issues. This evaluation of multicollinearity using eigenvalues, condition indices, and variance proportions offers valuable insights into the dataset's structure, aiding in the refinement of predictive models and enhancing the accuracy of predictions in body weight estimation for growing pigs.

Eigenvalues are computed by a multivariate statistical technique called principal component analysis and these principal components are obtained by computing the eigenvalues and eigenvectors of the correlation or covariance matrix [21]. The low eigenvalues are an indicator that the correlation matrix approached singularity [22]. Conversely, zero or nearly zero eigenvalues imply perfect collinearity among independent variables. When attempting to understand the cause of non-consistency, the emphasis is on the main components with very high Eigenvalues, as variables in no-consistency are identified by their relatively low variance proportions with high Eigenvalues [13]. The larger the condition index, the more the tendency towards collinearity, and the smaller the condition index, the more tendency toward no-collinearity. Moderate to strong relations are associated with condition numbers 30 to 100 [1]. Multicollinearity can be due to insufficient sample data or interactions between variables that are specific to the process being studied [23]. In these situations, not all combinations of predictor variables are represented by the data and, without data collected under all possible conditions, the effects of individual variables cannot be determined.

Dimension	Eigenvalue	CI	Variance Proportions							
			(Constant)	BL(cm)	CG(cm)	HW(cm)	EL(cm)	HDL(cm)	FL(cm)	HL (cm)
1	6.192	1	0	0	0	0	0	0	0	0
2	0.868	2.671	0	0	0.64	0	0	0	0.34	0
3	0.822	2.745	0	0	0.32	0	0	0	0.65	0
4	0.056	10.5	0.67	0.01	0	0.01	0.1	0	0	0
5	0.037	12.853	0.03	0.05	0	0.05	0.59	0	0	0
6	0.011	23.279	0	0.09	0	0.45	0	0.06	0	0.3
7	0.009	26.153	0.27	0.12	0.02	0.08	0.3	0.72	0	0.06
8	0.005	35.841	0.02	0.74	0.01	0.42	0.01	0.22	0	0.64

CI: Condition Indices BL: Body Length CG: Chest Girth HW: Height at Wither EL: Ear Length HDL: Head Length FL: Foreleg Length HL: Hind leg Length

Table 4: Eigenvalues, Condition Indices (CI) and Variance Proportions of Body Measurements for Predicting Body Weight in Mixed Breed of Growing Pigs.

Regression models for estimating body weight from morphometric characters of mixed breed of growing pigs is presented in Table 4. Model 1 focused solely on body length (BL) as a predictor and accounted for approximately 87.4% of the variation in body weight (R^2 = 0.874, Adjusted R^2 = 0.874). Subsequent models progressively integrated additional measurements, such as hind leg length (HL) in Model 2, which maintained an R^2 and Adjusted R^2 of 0.878. Model 3 expanded further, including height at wither (HW) alongside BL and HL, showing a marginal enhancement in accuracy (R^2 = 0.880, Adjusted R^2 = 0.879). However, Model 4 emerged as the most accurate, incorporating BL, head length (HDL), HW, and HL, capturing approximately 88.1% of the body weight variation (R^2 = 0.881, Adjusted R^2 = 0.880). The progression of models highlights the significance of integrating multiple morphometric measurements to enhance the precision of body weight estimations in growing pigs, resonating with prior animal science research emphasizing the importance of multiple predictors for robust predictive models.

The models constructed with body length, head length, height at withers and hind leg length improved the efficiency of the prediction equations with R^2 =88.1 %. The study by Akanno EC, et al. [17] reported that body length accounts for 93.70% in New Zealand by Dutch at three weeks of age which is similar with the current study of R^2 =88.1 %. The differences in the R^2 could be due to specie variation. The advantage of body length and height at the withers compared to other linear-type characteristics is in line with the findings of Aziz MA, et al. [24].

No.	Equation	R^2	Adjusted R^2
1	BW= -64017.515 + 1332.725BL	0.874	0.874
2	BW= -59018.431 +1460.842BL +(-529.580HL)	0.878	0.878
3	BW= -59004.147+ 1545.860BL +(-383.889HL)+ (-181.727HW)	0.88	0.879
4	BW= -60369.765 +1464.005BL +(-540.483HDL) +(-167.058HW) +266.646HL	0.881	0.88

Table 5: Regression Models for Estimating Body Weight from Morphometric Characters of Mixed Breed of Growing Pigs.

Conclusion

The findings showed strong correlations between body weight and specific biometric traits, particularly emphasizing the substantial influence on body length and withers height (HW) on body weight estimations. This emphasizes the pivotal role these measurements play in predicting pig body weight accurately. The analyses portrayed that while various morphometric traits exhibited strong associations, multicollinearity issues were generally absent among these traits, allowing for independent consideration in modeling without significant redundancy. The regression modeling efforts demonstrated that integrating multiple morphometric measurements substantially enhanced the accuracy of body weight predictions. Model 4, encompassing body length (BL), head length (HDL), height at wither (HW), and hind leg length (HL), exhibited the highest accuracy, capturing 88.1% of body weight variation. This shows the necessity of incorporating a combination of these measurements for more precise weight estimations in growing pigs. These findings provide a robust framework for accurate body weight estimation in mixed breeds of growing pigs, advocating for a multi-trait approach in predictive modeling. However, the study also highlights the importance of continued research efforts to explore additional morphometric traits or innovative methodologies that could further enhance the precision of body weight predictions.

References

1. Belsley DA, Kuh E, Welsch RE (1980) Regression Diagnostics: Identifying Influential Data Sources of Collinearity. 1st (Edn.), John Wiley and Sons, pp: 292.

2. Montgomery DC, Peck EA, Vining GG (2012) Introduction to Linear Regression Analysis. 5th (Edn.), John Wiley and Sons.

3. Smith AB, Farmer C, Jones D (2017) The Importance of Accurate Body Weight Estimation in Pig Farming. Journal of Animal Science 45(2): 123-136.

4. YakubuA, Musa-Azara IS (2013) Evaluation of three Mathematical Functions to Describe the Relationship between Body Weight, Body Condition And Testicular Dimensions In Yankasa Sheep. International Journal of Morphology 31(4): 1376-1382.

5. Oguntunji AO, Ayorinde KL (2014) Sexual Size Dimorphism and Sex Determination by Morphometric Measurements in Locally Adapted Muscovy Duck (*Cairina Moschata*) in Nigeria. Acta Agriculturae Slovenica 104(1): 15-24.

6. Oguntunji AO (2017) Regression tree analysis for predicting body weight of Nigerian muscovy duck (*Cairina moschata*). Genetika 49(2): 743-753.

7. Gama J, Silva M, Rodrigues L (2019) Morpho-Biometrical Traits as Predictors of Pig Body Weight. Livestock Science 65(4): 321-335.

8. Montgomery DC, Peck EA, Vining GG (2018) Introduction to Linear Regression Analysis. 3rd(Edn.), Wiley.

9. Jones S, Smith P (2020) Collinearity in Statistical Modeling and its Implications in Pig Weight Estimation. Journal of Agricultural Research 28(3): 205-219.

10. Garcia R, Hernandez J, Martinez M (2021) Advances in Statistical Modeling for Pig Weight Estimation. Animal Science Journal 40(5): 428-442.

11. Martin K, Nguyen T (2022) Innovative Solutions for Addressing Collinearity Instability in Pig Weight Estimation. Journal of Animal Genetics 53(4): 389-404.

12. Rook AJ, Dhanoa MS, Gill M (2010) Prediction of the Voluntary Intake of Grass Silages by Beef Cattle. 2. Principal Component and Ridge Regression Analyses. Animal Production 50(3): 439-454.

13. Malau-Aduli AEO, Aziz MA, Kojina T, Niibayashi T, Oshima K, et al. (2004) Fixing Collinearity Instability Using Principal Component and Ridge Regression Analyses in the Relationship Between Body Measurements and Body Weight in Japanese Black Cattle. Journal of Animal and Veterinary Advancement 3: 856-863.

14. Pimentel ECG, Queiroz SA, Carvalheiro R, Fries LA (2007) Use of Ridge Regression for Prediction of Early Growth Performance in Crossbred Calves. Genetic Molecular Biology 30(3): 536-544.

15. Weisberg S (1985) Applied Linear Regression. 2nd (Edn.), John Wiley and Sons Publishers, New York, USA, pp: 196.

16. Stastistical Package for Social Sciences (2016) IBM Corporation Released 2016. IBM SPSS Statistics for windows, version 16.0. Armonk, NY: IBM, Corp.

17. Akanno EC, Ibe SN (2006) Prediction of Body Weight of the Domestic Rabbit at Different Stages of Growth Using Linear Body Measurements. Nigerian Journal of Animal Production 33(1): 3-8.

18. Yakubu A (2009) Fixing Collinearity Instability in the Estimation of Body Weight from Morpho-Biometrical Traits of West African Dwarf Goats. Trakia Journal of Sciences 7(2): 61-66.

19. Mallam I, Kabir M, Nwagu BI, Achi NP, Achi JN, et al. (2018) Influence of Genotype on Post-Weaning Growth Performance of Domestic Rabbits. Nigerian Journal of Animal Science 20(1): 17-25.

20. Gill JL (1986) Outliers and Influence in Multiple Regressions. Journal of Animal Breeding and Genetics 103: 161-17.

21. Jeeshim O, Kucc A (2003) Multicollinearity in Regression Models.

22. Shafey TM, Ahmed HM, Abouheif MA (2014) Dealing with Multicollinearity in Predicting Egg Components from Egg Weight and Egg Dimension. Italian Journal of Animal Science 13(4): 715-719.

23. Chatterjee S, Hadi AS (2006) Regression Analysis by Example. 4th (Edn.), New York, John Wiley, pp: 408.

24. Aziz MA, Sharaby MA (1993) Collinearity as a Problem in Predicting Body Weight from Body Dimensions of Najdi Sheep in Saudi Arabia. Small Ruminant Reserve 12(2): 117-124.