Path analysis and prediction of carcass traits based on the body weight of Boschveld chickens

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Abstract

The objectives of this investigation were to establish the correlation among variables, quantify the magnitudes of the direct and indirect effects of independent variables on the response variable, and model the relationships and predict carcass variables using a regression model. Day-old, healthy Boschveld chicks were reared intensively for 91 days. The birds were offered commercial broiler starter and grower diets ad libitum. Fifteen randomly selected chickens were slaughtered by cervical dislocation. The weights of the live chickens and carcass variables were recorded. Descriptive statistics, Pearson correlation coefficients, direct and indirect path coefficients, and simple linear regression functions were computed. A regression line was added to determine the best fit for the observed data and the relationship between the predicted and independent variables. The regression line intersected the data and showed that body weight had a positive influence on the weight of the observed variables. A very strong positive correlation was noted between body and carcass weights (r = 0.98). The direct and indirect coefficient effects ranged from -0.01 to 0.79 and -0.04 to 0.70, respectively. The coefficient for determination the prediction equations ranged from 0.52 to 0.96. Body weight is a good predictor of carcass weight in Boschveld chickens.

Keywords: correlation coefficients, indigenous chickens, regression model
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Introduction

Native chickens are a valuable asset for farmers who cannot afford to maintain exotic breeds (Nweke-Okorocha *et al*., 2020). They are resilient, require less intensive care, scavenge for food, and can survive under harsh climatic conditions (Okumu *et al*., 2017), making them an affordable choice for farmers with limited resources. Their meat and eggs are also an affordable source of protein for human consumption (Raphulu *et al*., 2015; Sarma *et al*., 2020). Chicken meat is classified as white meat and is preferred over red meat due to its low fat and cholesterol content (Jaturasitha *et al*., 2008). Low-fat meat is favoured due to the potential health risks associated with high-fat consumption for meat consumers (Mutibvu *et al*., 2020). Their genetic resource base may serve as a foundation for genetic diversification and improvement to create breeds that are adapted to local conditions (Yakubu *et al*., 2008). However, their production performance is low due of biological variations, such as poor feed conversion efficiency and genetic makeup.

Several studies have investigated the relationship between linear body measurements and body weight or carcass weight in indigenous chickens (Tyasi *et al*., 2017; Tyasi *et al*., 2018; Petrus *et al*., 2019; Tadele, 2019). However, the results have been inconsistent. Body measurements are commonly used to estimate live body weight or carcass weight in chickens, but there is limited information on using live body weight to predict carcass weight in indigenous chickens like Boschveld chickens. Carcass traits, such as dressing percentage and weights of different carcass parts (breast, thigh, wing, and drumstick), play a significant role in the economic value of poultry production. However, these traits are typically measured post-slaughter, making it challenging to select chickens for breeding based on carcass traits (Huang *et al*., 2018).

The development of models that predict carcass yields without slaughtering chickens is crucial for biological studies, breeding, and marketing purposes. The objectives of this investigation were to establish relationships between live body weight and carcass variables, quantify the direct and indirect effects of independent variables on the dependent variable, and model the relationships to predict carcass variables from the live body weight of Boschveld chickens using a simple regression model. The Boschveld chicken is a result of crossbreeding among Venda, Matabele, and Ovambo chickens (Bosch, 2018).

Materials and Methods

The data for this study were sourced from a previous study conducted by Maoba *et al*. (2021). Only the data from chickens that were fed a control diet were utilized, with nutrient composition shown in Table 1. The chickens were raised intensively in a conventional poultry house and were given commercial broiler starter feed from 1 to 49 days and grower feed from 50 to 91 days. They had access to feed and fresh drinking water *ad libitum* during the entire rearing period.

Table 1 Nutrient chemical composition of starter and grower feeds

Nutrients (% kg $^{-1}$)	Starter feed	Grower feed
Crude protein	20.0	18.0
Lysine	1.3	1.1
Methionine	4.7	4.4
Moisture	12.0	12.0
Crude fat	2.5	2.5
Crude fibre	5.0	6.0
Calcium	1.1	1.0
Phosphorus	0.6	0.5

Adapted from Maoba *et al*. (2021)

On day 91, 15 chickens were randomly selected and euthanized by cervical dislocation. The body weight of each chicken was measured before slaughtering using an electronic Adam weighing scale with a capacity of 30 kg and readability of 0.5 g. After slaughter, the following weights were measured: carcass weight (CW), breast weight (BW), thigh weight (TW), wing weight (WW), and drumstick weight (DW) as described by Maoba *et al*. (2021).

The study calculated means, standard deviations, and coefficients of variation for body weight and carcass variables. Pearson's correlation coefficient (r) was employed to assess the relationships between the variables (Table 2).

Table 2 Description of degree of association between variables

Correlation coefficients range	Explanation
0.00	No linear relationship
0.01 to 0.29 or -0.01 to -0.29	Very weak positive or negative relationship
0.30 to 0.49 or -0.30 to -0.49	Weak positive or negative relationship
0.50 to 0.69 or -0.50 to -0.69	Moderate positive or negative relationship
0.70 to 0.89 or - 0.70 to - 0.89	Strong positive or negative relationship
0.90 to 1.00 or - 0.90 to -1.00	Very strong positive or negative relationship

To determine the direct effects of the independent variables on the dependent variable, the standardized partial regression coefficients, or direct path coefficients (beta weights), were calculated using Microsoft excel statistical analysis (Akintunde, 2012). The path coefficient from an explanatory variable (X) to a response variable (Y) was measured, following the methodology outlined by Mendes *et al*. (2005).

$$\mathrm{Py}\,.\,x_i = \frac{b_i S x_i}{S_y}$$

where:
$\mathrm{Py}\,.\,x_i$ = path coefficient from X_i to Y (i = carcass variables)
b_i = partial regression coefficient
Sx_i = standard deviation of X_i
S_y = standard deviation of Y

The following multiple linear regression model was adopted:

$$\mathrm{Y} = \mathrm{a} + \mathrm{b}_1\mathrm{X}_1 + \mathrm{b}_2\mathrm{X}_2 + \mathrm{b}_3\mathrm{X}_3 + \mathrm{b}_4\mathrm{X}_4 + \mathrm{b}_5\mathrm{X}_5 + \ldots\ldots\ldots \mathrm{b}_{13}\mathrm{X}_{13} + \mathrm{e}$$

where:
Y = endogenous variable (body weight),
a = intercept,
$b's$ = regression coefficients,
$X's$ = independent or exogenous variables (carcass variables),
e = error term.

The significance of each path coefficient in the multiple linear regression model was tested by t-test. The indirect effects of X_i on Y through X_j were calculated as follows:

$$IE_{YXi} = r_{XiXj}P_{Y.Xi}$$

where:
IE_{YXi} = direct effect of X_i via X_j on Y
r_{XiXj} = correlation coefficient between i^{th} and j^{th} independent variables
$P_{Y.Xi}$ = path coefficient that indicates the direct effect of j^{th} independent variable on the dependent variable.

Simple linear regression function was used for estimating of carcass variables from live body weight:

$$y = a + bx$$

where:
y = estimated carcass variables, a = intercept, b = slope of the line, x = live body weight.

Results

Descriptive data for body weight and carcass traits are summarized in Table 3. The mean body weight of 91-day old Boschveld chickens was 1313.8 g bird^{-1}, with a carcass weight of 963.3 g bird^{-1}. Carcass parts varied from 119.2 g bird^{-1} (drumstick weight) to 196.4 g bird^{-1} (breast weight). The coefficient of variation ranged from 0.8% to 7.1%, with the highest variation observed in wing weight, followed by breast weight. However, body weight had the lowest variation.

Table 3 A descriptive analysis of body weight and carcass traits of Boschveld chickens

Variables (g bird $^{-1}$)	Mean	Standard deviation	coefficient of variation
Body weight	1313.8	8.2	0.8
Carcass weight	963.3	34.3	4.3
Breast weight	196.4	10.5	6.2
Thigh weight	138.6	2.7	2.5
Wing weight	123.5	5.7	7.1
Drumstick weight	119.2	1.9	2.3

The Pearson correlation coefficients (r) in Table 4 range from 0.59 to 0.98. All variables showed significant positive correlations (P <0.01). The strongest correlation was between body and carcass weight, followed by carcass and breast weight. The moderate positive relationship (P <0.01) was between drumstick and carcass weights, wing and breast weights, wing and thigh weights, drumstick and thigh weights, and wing and drumstick weights.

Table 4 Pearson correlation coefficients (r) between body weight and carcass traits of Boschveld chickens

	BW	CW	BrW	TW	WW	DW
Body weight (BW)	-					
Carcass weight (CW)	0.98**	-				
Breast weight (BrW)	0.89**	0.88**	-			
Thigh weight (TW)	0.83**	0.85**	0.71**	-		
Wing weight (WW)	0.78**	0.70**	0.64**	0.60**	-	
Drumstick weight (DW)	0.71**	0.67**	0.70**	0.65**	0.59**	-

**P <0.01

The direct and indirect effects of carcass traits on body weight of Boschveld chickens are shown in Table 5. The correlation between carcass weight and body weight was significant, with a strong direct effect on body weight (P <0.01).

The indirect effect of carcass weight on body weight was primarily influenced by breast and thigh weights. Although the direct effect of breast weight on body weight was not significant, the total indirect effect through carcass, thigh, wing, and drumstick weights was low. Thigh weight had a negative direct effect on body weight (*P* >0.05), with corresponding negative total indirect effects. The direct effect of drumstick and wing weights on body weight were not significant and the total indirect effects were higher than the direct effects.

Table 5 Direct and indirect effects of carcass variables on body weight of Boschveld chickens

Variables	Correlation coefficient with BW	Direct effect	Indirect effect					Total
			CW	BrW	TW	WW	DD	
CW	0.98**	0.79**		0.70	0.67	0.55	0.53	2.45
BrW	0.89**	0.04	0.04		0.03	0.03	0.03	0.13
TW	0.83**	-0.01	-0.01	-0.01		-0.01	-0.01	-0.04
WW	0.78**	0.16	0.11	0.10	0.10		0.09	0.40
DW	0.71**	0.07	0.05	0.05	0.05	0.04		0.19

**P* <0.01, BW – body weight, CW – carcass weight, BrW – breast weight, TW – thigh weight, WW – wing weight, DW – drumsticks weight

The relationship between body weight and observed carcass variables was depicted in Figures 1-5. A regression line was added to establish the best fit for the data and to demonstrate the connection between the predicted and independent variables. The regression line intersected the data, indicating that body weight positively influenced the weights of the observed variables.

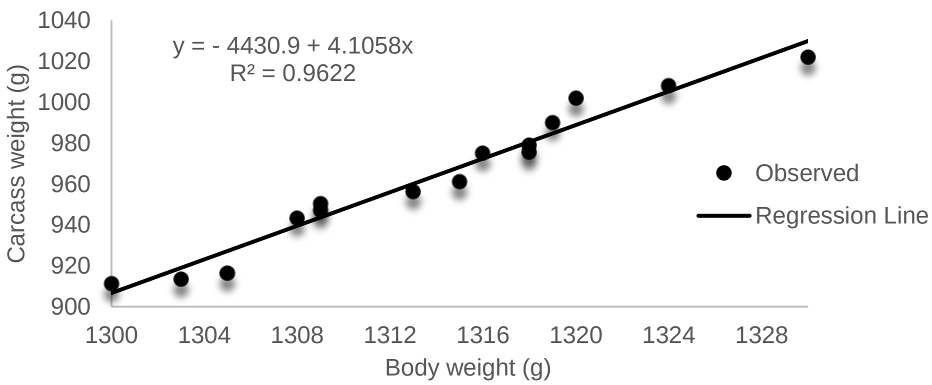

Figure 1 The relationship between the Boschveld chicken’s body and carcass weights

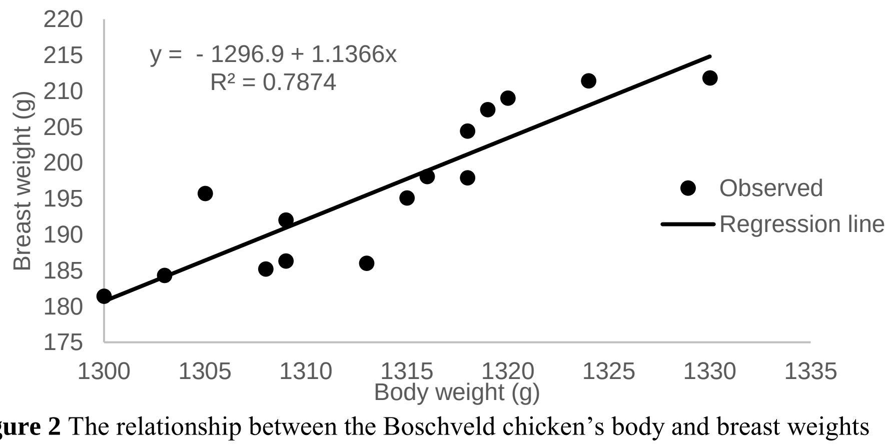

Figure 2 The relationship between the Boschveld chicken’s body and breast weights

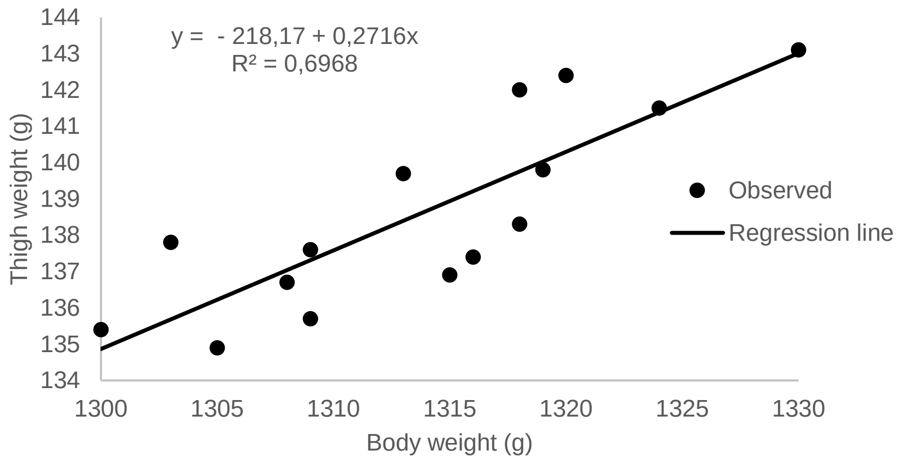

Figure 3 The relationship between the Boschveld chicken's body and thigh weights

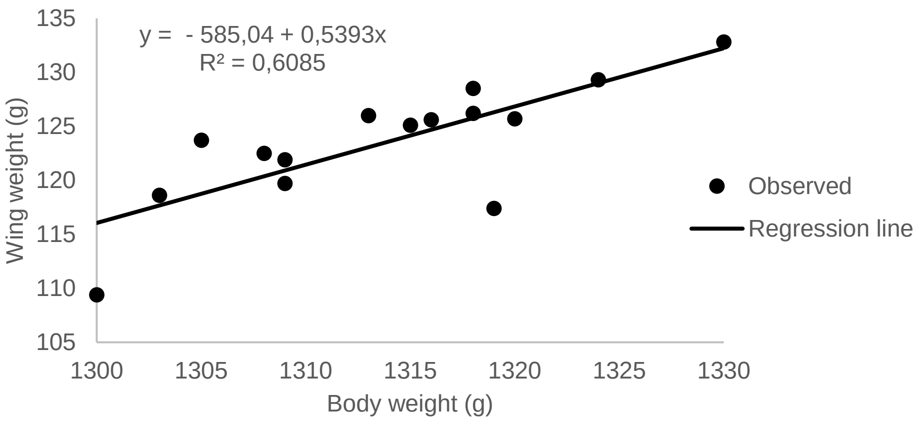

Figure 4 The relationship between the Boschveld chicken's body and wing weights

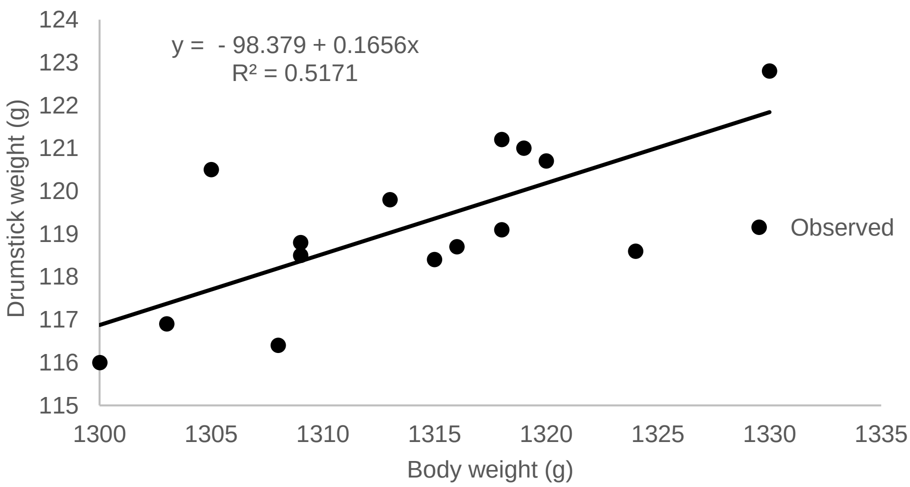

Figure 5 The relationship between the Boschveld chicken's body and drumstick weights

Table 6 presents predictive equations for carcass variables. The coefficients of determination (R^2) for the prediction equations varied from 0.52 to 0.96. Carcass weight prediction model had the highest R^2 value, followed by breast weight. Drumstick weight prediction model had the lowest R^2 value.

Table 6 Prediction equations for carcass variables of Boschveld chickens

Variables	Formula	R^2
Carcass weight (g)	Y = - 4430.9 + 4.1058BW	0.9622
Breast weight (g)	Y = - 1296.9 + 1.1366BW	0.7874
Thigh weight (g)	Y = - 218.17 + 0.2716BW	0.6968
Wing weight (g)	Y = - 585.04 + 0.5393BW	0.6085
Drumsticks weight (g)	Y = 98.379 + 0.1656BW	0.5171

r^2 – coefficients of determination, BW – body weight

Discussion

Carcass weight is a crucial trait in breeding programs and is closely linked to live body weight (Adenaike *et al*., 2022). Growth rate is influenced by both genetic and non-genetic factors (Atansuyi *et al*., 2018). In Boschveld chickens, carcass weight makes up 73.3% of body weight, providing a useful estimate for carcass weight when body weight is known. This information can help producers compare prices of live and dressed chickens based on weight. The observed dressing percentage of Boschveld chicken was higher than the percentages reported for Ovambo (67.6%), Potchefstroom Koekoek (65.3%), and Venda (62%) indigenous chickens (Motsepe *et al*., 2016; Mabelebele *et al*., 2017). However, it was lower than the percentages reported for indigenous chickens in Goba (76.8%) and Agarfa (80.9%) in south eastern Ethiopia (Mekonnen *et al*., 2023). This indicates that while Boschveld chickens may have a higher dressing percentage compared to some indigenous breeds, they are still not superior to other indigenous breeds in Ethiopia. The weights of breast, thigh, wing, and drumstick make up 20.4%, 14.4%, 12.8%, and 12.4% of the carcass weight of Boschveld chicken, respectively. Variability in these weights ranged from 0.8% to 7.1%, with the highest variability observed in wing weight. Despite this, the coefficient of variation was relatively low, making these values reliable reference points for Boschveld chickens. The breast weight of Boschveld chicken as a percentage of carcass weight was 1.8% and 0.8% lower compared to Ovambo and Potchefstroom Koekoek breeds, respectively. The thigh weight was 2.2% and 2.7% lower than the reported values for these breeds (Motsepe *et al*., 2016). Additionally, the drumstick weight was 3.3% and 2.8% lower compared to indigenous chickens in Goba and Agarfa in South eastern Ethiopia. On the other hand, the wing weight of Boschveld chickens was 4.4% and 4.2% higher than the reported values for indigenous chickens in Goba and Agarfa (Mekonnen *et al*., 2023). These variations can be attributed to the genotype, environmental factors, production management practices, and slaughter age.

The correlation between variables ranged from moderate to very strong. A positive relationship was observed between body weight and carcass traits, indicating that an increase in body weight leads to an increase in the weight of these traits. The strongest positive correlation was found between body weight and carcass weight (0.98), which was expected as carcass weight accounted for 73% of the body weight of Boschveld chickens. There were also strong positive correlations between body weight and the weights of the breast (0.89), thigh (0.83), wing (0.78), and drumstick (0.71). These significant correlations suggest that the weights of these traits can be predicted based on body weight, which is important for selecting Boschveld chickens for breeding to maximize meat production. Similar strong positive correlations between body weight and carcass weight have been reported in Nigerian (0.99) and Ethiopian (0.94 - 0.98) indigenous chickens in previous studies (Adenaike *et al*., 2022; Mekonnen *et al*., 2023). Additionally, Ethiopian indigenous chickens have shown strong positive relationships between body weight and drumstick (0.81 – 0.89), thigh (0.77 – 0.88), and breast (0.77 – 0.79) weights (Mekonnen *et al*., 2023).

The correlation coefficients did not provide detailed information on how the independent variables affected the response variable. To determine the magnitude of the influence of carcass variables on the body weight of Boschveld chickens, path coefficient analysis was used. Path analysis, as described by Norris *et al*. (2015), is an extension of the multiple regression model that helps identify the explanatory variables that have the most significant impact on the response variable.

Path coefficient analysis revealed that carcass weight had the most significant direct influence (0.79) on the body weight of Boschveld chickens. This meant that a 1 g increase in body weight would result in a 0.79 g gain in carcass weight in Boschveld chickens. Additionally, body weight had four indirect effects on carcass weight, namely breast (0.70), thigh (0.67), wing (0.55) and drumsticks (0.53) weights. The total indirect effect of these variables was 2.45, indicating a substantial influence on the body weight of Boschveld chickens.

This implied that a unit change in breast, thigh, wing, and drumstick weights led to 0.70, 0.67, 0.55, and 0.53 unit changes in body weight through carcass weight, respectively. The total indirect effects on body weight via carcass weight were primarily through the breast and thigh weights of Boschveld chickens. This shows that breast and thigh weights are important variables in determining the overall weight of the Boschveld chickens. The direct effect of carcass weight (0.79) on body weight was lower than the total indirect effect (2.45). This indicates that while carcass weight does influence body weight, but it is dependent on breast, thigh, wing, and drumstick weights which indirectly affect body weight. Thigh weight had a negative direct effect on body weight, with corresponding negative total indirect effects. That means the variables had an inverse effect on the body weight of Boschveld chickens. Carcass weight remained the only variable with the highest direct and indirect effects on body weight compared to the other variables, and breast and thigh weights had a high indirect effect on body weight. This affirmed that carcass weight has the most significant impact on overall body weight, both directly and indirectly. Although breast and thigh weights also play a substantial role in determining body weight through their indirect influence. Adenaike *et al*. (2022) also found a significant direct effect of body weight on the carcass weight of Nigerian indigenous chickens.

The ability to predict chicken carcass weight is a significant endeavour that can aid in making informed production and breeding management decisions (Adenaike *et al*., 2022). The high R^2 value for the carcass model confirmed a strong relationship between carcass and body weight. Therefore, body weight appears to be a good predictor of carcass weight in Boschveld chickens. The predictive model showed that body weight was responsible for 91% of the carcass weight. However, body weight was a poor predictor of breast, thigh, wing, and drumstick weights because it accounted for only 77%, 50%, 61%, and 46%, respectively. This indicates that while body weight is a strong indicator of overall carcass weight, it does not equally influence the distribution of weight across specific cuts of meat. Other factors may play a more significant role in determining the weights of individual chicken parts. That means the likelihood of prediction values being close to the actual values is very low for prediction models with low R^2. Hence, it is imperative to use prediction models with a high R^2 to obtain estimates close to the true value.

Conclusions

There is a high and significant correlation between body weight and carcass weight of Boschveld chickens. Body weight has a direct effect on carcass weight, while the total indirect effect is mainly determined by breast weight. The regression line intersected the data and showed that body weight had a positive influence on the weights of the observed variables. The carcass weight prediction equation had the highest R^2 value, indicating that body weight is a good predictor of carcass weight in Boschveld chickens.

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Authors' contributions

S. Maoba conceived and designed the study, analysed, interpreted the data, and wrote the manuscript.

Conflict of interest declaration

The author wishes to declare that there were no conflicts of interest.

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