Turkish Journal of Agriculture - Food Science and Technology

Predicting Body Weight of Ethiopian Indigenous Chicken Populations from Morphometric Measurements

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A R T I C L E I N F O	A B S T R A C T
	The purpose of this study was to estimate the relationship between body weight (BW) and morphometric measurements of Ethiopian indigenous chicken populations and to develop prediction equations used to estimate BW from body measurements. A total of 621 chickens comprising 134 males and 487 females reared under smallholder management conditions were used for the study. Body weight and morphometric measurements including body length (BL), chest circumference (CC), shank length (SL), and shank circumference (SC) were taken using a hanging scale and a textile measuring tape, respectively. The relationship between BW and morphometric measurements was determined using Pearson's correlation coefficients (*r*) and stepwise multiple regression analyses. Descriptive statistics indicated that male birds were heavier than female birds. Correlation results revealed that body weight was significantly and strongly correlated with SL (*r* = 0.76) in both sexes, and moderately correlated with SC (*r* = 0.69), BL (*r* = 0.67), and CC (*r* = 0.52) in male birds, BL (*r*=0.68) and SC (*r* = 0.59) in female birds. Compared to other measurements, SL best predicted BW in both male and female birds, with coefficients of determination (R^2) = 0.58. Combining SL with other body measurements (BL, CC, and SC) generally improved the predictive power of the equation. Thus, multiple regression equations that included a combination of the four linear body measurements are more suitable for predicting BW of Ethiopian indigenous chicken populations.

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Introduction

Body weight (BW) is one of the most important attributes of farm animals. A better understanding of BW and its changes is important in evaluating growth performance, feed efficiency, responses of animals to various environmental conditions and production systems, determination of feed requirements, and making economic decisions (Momoh and Kershima, 2008; Assan, 2013; Lukuyu et al., 2016; Deribe et al., 2018). The most common and direct way to estimate an animal's BW is to weigh it using a calibrated electronic or mechanical weighing scale. However, this method poses a challenge for smallholder farmers in rural areas because the weighing scale may not be readily available (Lukuyu et al., 2016). Lack of technical skills may also be a constraint to accurately weighing and assessing animals (Adeyinka and Mohammed, 2006). An alternative and the simplest method is to measure body parts and relate the measurements to BW (Latshaw and Bishop, 2001; Assan, 2013). Although it is not more accurate compared to direct measurement of live weight (Sowande and Sobola, 2008),

body measurements have been used to estimate BW in poultry and livestock species.

Elsewhere, a strong relationship between BW and chest circumference (Semakula et al., 2011), shank length (Alabi et al., 2012; Ukwu et al., 2014), shank circumference (Alabi et al., 2012), and body length (Egena et al., 2014) have been reported for indigenous chicken populations. These studies indicated that these body measurements are useful and reliable predictors of BW in chickens. However, the predictive equation developed for a particular breed may not apply to chickens found under different production and management conditions. There is a general agreement that the estimation of BW from the animal's body measurements can be influenced by several factors, including breed, sex, environment, and production system. Body measurements of the same breed in different environments and production systems may not be similar (Assan, 2013). Therefore, specific models are needed for different breeds of chickens (Latshaw and Bishop, 2001) and similar breeds of chickens under different management systems.

To my best knowledge, only one study (Tadele, 2019) has developed prediction equations to estimate the BW of Ethiopian indigenous chicken populations from body measurements. The author reported a positive and significant (P<0.01) correlation between BW and body measurements, including body, wing, back, keel bone and shank lengths as well as chest and shank circumferences for indigenous chickens in the southwestern region of the country. A higher correlation was reported between BW and back length ($r = 0.44$), relative to other measurements. However, the results do not necessarily represent indigenous chicken populations in other rural areas of the country. Understanding the relationship between BW and linear body measurements is of interest not only to develop the prediction equation, but also to use the relationship as a selection criterion in genetic improvement programs aimed at improving indigenous chickens. Thus, the purpose of this study was to analyse the association between BW and four morphometric measurements (body length, chest circumference, shank length, and shank circumference) of indigenous chicken populations under smallholder management conditions in central Ethiopia and to establish prediction equations for estimating BW from linear body measurements.

Materials and Methods

Study areas

Oromia is one of the National Regional States located within Ethiopia. Regional states are further divided into zones and districts (i.e., subdivisions within the zone). Data were generated from indigenous chicken populations reared by smallholder farmers of East Shoa zone (Adama, Bora, and Lume districts) and West Arsi zone (Dodola, Shashemene, and Siriaro districts) of Oromia Regional State, central Ethiopia (Figure 1).

Body Measurements

Measurements were obtained from a total of 621 matured (i.e., above 8 months) indigenous chickens comprising 134 males and 487 females. The age of the birds was determined using the farmer's "recollecting method". Body weight (g) and linear body measurements (cm) were taken using a hanging spring balance and textile measuring tape, respectively. Body length (BL) was taken as the distance between the tip of the rostrum maxillae (beak) and that of the cauda (tail, without feather). Chest circumference (CC) was measured as the circumference of the body around the deepest region of the breast. Shank length (SL) was the length of the tarsometatarsus measured from the top of the flexed hock joint to the spur of either leg. Shank circumference (SC) was taken as the circumference of the shank around its midway.

Data Preparation

The whole dataset was randomly partitioned into two samples, namely fitting sample and validation sample. The former, which consisted of 75 percent (114 and 356 records in male and female, respectively) of the whole samples, was used to fit the regression model. The latter, which consisted of 25 percent (20 and 129 observations in male and female, respectively), was used to validate the effectiveness of the model.

Statistical Analysis

Data were analyzed using SPSS Statistics 20 (IBM SPSS, 2011). Descriptive statistics (mean, SD, minimum, maximum, and coefficient of variation) were used to present the estimates of BW and linear body measurements (BL, CC, SL, and SC) for both male and female birds. Pearson's correlation coefficients (r) were also used to determine the linear relationship between BW and body measurements. Both descriptive statistics and correlation coefficients were generated using the whole sample. Stepwise multiple linear regression was used to predict BW from body measurements using the fitting sample. The analyses were conducted separately for male and female birds. Prior to the analysis, the data set was assessed to ensure that the assumptions of normality, linearity, multicollinearity, and homoscedasticity are not violated. The model used were:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + e$$

where, $Y = BW$, $b_0 =$ the intercept, $b_i =$ regression coefficient of BW on body measurements, $X_i =$ body measurements (SL, BL, CC, and SC), and $e =$ residual.

Finally, the developed model was applied to the validation sample to evaluate the predictive ability of the multiple regression model. The predictive efficiency of the model was assessed using R^2 and standard error of the estimate (root mean square error; RMSE).
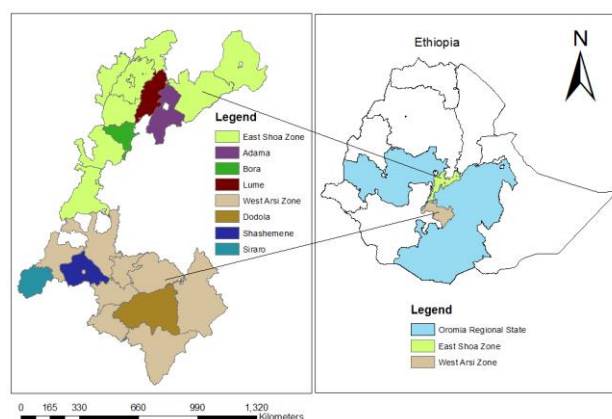

Figure 1. Map of the study location

Results and Discussion

Table 1 shows the mean, standard deviation (SD), minimum, and maximum values and coefficient of variation (CV) estimates of BW and linear body measurements (BL, CC, SL, and SC) for both male and female birds. Compared to females, males had significantly higher mean values in all the measurements. On average, a male bird weighed 1267.16g, while the female weighed 998.76g. Male birds were 21.18 percent heavier than females. This difference suggests the existence of sexual dimorphism, which also accounted for 18.27, 16.17, 8.94, and 6.82 percent of the difference in SL, SC, BL, and CC, respectively. According to Semakula et al. (2011), the observed sexual dimorphism is explained by superior muscle development in males than in females, which is associated with the differences in the level of sex hormone. Sexual size dimorphism (i.e. the difference in sizes of

males and females) is the result of different selective pressures (Owens and Hartley, 1998). It is also an essential evolutionary attribute that is related to behavior, ecology and life histories of organisms (Remeš and Székely, 2010). Moreover, sexual size dimorphism is usually attributed either to some degree of intra-sexual competition or differences in parental care (Owens and Hartley, 1998). The inter-sexual variation in sizes have also been reported for indigenous chickens (Guèye et al., 1998; Momoh and Kershima, 2008; Semakula et al., 2011; Alabi et al., 2012; Egena et al., 2014), specialized commercial chickens (Latshaw and Bishop, 2001; Abdel-Lattif, 2019), and Muscovy duck (Raji et al., 2009) reared under different management conditions.

The average BW observed in the present study was generally lower than those reported for indigenous chickens of Nigeria (Egena et al., 2014), Uganda (Semakula et al., 2011), South Africa (Alabi et al., 2012) and Senegal (Guèye et al., 1998). The results were also lower than that of Tadele (2019), who reported 1.36kg of BW in indigenous chickens (female) of southwestern Ethiopia. However, the average BW in the present study was slightly comparable with that of Tareke et al. (2018), who observed 1.4 and 1.0 kg of BW, respectively, for male and female chickens of Bale zone, southeastern Ethiopia. This suggests that indigenous chicken populations in the current study area were smaller in size. Smaller body size is believed to play an essential role in reducing the maintenance nutrient requirements and increase feed efficiency (Semakula et al., 2011). According to the same authors, this significantly contributes to the survival of indigenous chickens under the scavenging system, where feed shortage is often a big challenge. For both male and female birds, high variability (CV) was found in BW than linear body measurements, which could reflect environmental and nutritional variations among sampling locations. Compared with morphometric measurements, higher CV was reported in BW for French broiler guinea fowl in the humid tropics of Nigeria (Dzungwe et al., 2018). Generally, the differences within and among the populations could be explained by the variation in genetics, the purpose of chicken rearing in different regions, and environmental factors under which the chickens reared. This variation suggests that indigenous chickens could be used as genetic material in the genetic improvement program aimed to produce breeds adapted to smallholder conditions. The variation in BW of chickens among studies could also be associated with the difference in the age of the birds when measurements were taken.

The relationship between BW and body measurements (BL, CC, SL, and SC) for both male and female birds was investigated using Pearson's correlation coefficients (Table 2). Correlations between BW and morphometric measurements were generally positive and significant ($p <$ 0.01) in both sexes, suggesting that BW could be estimated from one or a combination of these body measurements. In both males and females, the significant ($p < 0.01$) and a strong correlation was found between BW and SL ($r =$ 0.76). Body weight was also significantly ($p < 0.01$) and moderately correlated with BL ($r = 0.68$) in females, and SC ($r = 0.69$) and BL ($r = 0.67$) in males. Thus, SL, SC, and BL could be considered as selection criteria in a breeding program aimed to improve BW in Ethiopian indigenous chickens. Since positive correlations of traits suggest that a single gene influences the traits (i.e., pleiotropy), the relationship between BW and different morphometric measurements could be useful as a selection criterion (Yakubu, 2009; Malomane et al., 2014). According to Sowande and Sobola (2008), thus, an improvement in any one of the body measurements would result in a corresponding improvement in BW.

The strong correlation between BW and SL has also been observed for indigenous chickens of Nigeria (Ukwu et al., 2014), French broiler guinea fowl in Nigeria (Dzungwe et al., 2018), and naked neck chickens of South Africa (Alabi et al., 2012). On the contrary, BW was strongly correlated with BL ($r = 0.87$) and CC ($r = 0.85$) in Muscovy duck (Raji et al., 2009), SC in Venda and Potchefstroom koekoek chickens of South Africa (Alabi et al., 2012), and BL in Nigerian indigenous chickens (Egena et al., 2014). Semakula et al. (2011) also observed that CC was the best single predictor ($r = 0.88$) of BW, closely followed by BL ($r = 0.81$), and femur length ($r = 0.80$) for indigenous chickens in Uganda. Slightly higher correlation coefficients were observed in males than females. According to Alabi et al. (2012), this implies that more improvement will be expected for the traits in male birds than female birds. These results were also supported by R^2 values (Table 5), where slightly higher variations for the traits were observed in males than females.

Table 1. Descriptive statistical summary of body weight and linear body measurements of indigenous chickens using the whole sample.

Variables	Sex	Mean	SD	Minimum	Maximum	CV (%)
BW (g)	Male	1267.16[a]	402.21	600.00	2500.00	31.74
	Female	998.76[b]	342.93	500.00	2400.00	34.34
BL (cm)	Male	37.69[a]	2.79	31.00	44.00	7.40
	Female	34.32[b]	2.32	28.00	42.00	6.76
CC (cm)	Male	27.70[a]	2.63	21.00	36.00	9.51
	Female	25.81[b]	2.08	19.00	33.00	8.05
SL (cm)	Male	9.36[a]	1.31	7.00	12.00	13.95
	Female	7.65[b]	1.01	5.00	11.00	13.23
SC (cm)	Male	4.33[a]	0.72	3.00	8.00	16.63
	Female	3.63[b]	0.57	3.00	6.00	15.68

Means with different superscript differ significantly between sexes; SD = Standard deviation, CV = Coefficient of variation, BW = Body weight, BL = Body length, CC = Chest circumference, SL = Shank length, and SC = Shank circumference.

Table 2. Pearson's correlations between BW and body measurements of male birds (above diagonal) and female birds (below diagonal) using the whole samples.

	BW	BL	CC	SL	SC
BW	1.00	0.67**	0.52**	0.76**	0.69**
BL	0.68**	1.00	0.53**	0.60**	0.52**
CC	0.29**	0.33**	1.00	0.29**	0.36**
SL	0.76**	0.66**	0.05^{NS}	1.00	0.67**
SC	0.59**	0.48**	0.03^{NS}	0.65**	1.00

**Correlation is significant at 0.01 (2-tailed); NS = Not significant, BW = Body weight, BL = Body length, CC = Chest circumference, SL = Shank length, and SC = Shank circumference.

Table 3. Stepwise regression analysis summary for each of the independent variables (or predictors) included in the model for male birds.

Model	Predictors	B	SE	Beta	P-value	Tolerance	VIF
1	Constant	-911.588	175.673		0.000		
	SL	232.223	18.679	0.764	0.000	1.000	1.000
2	Constant	-1966.014	256.850		0.000		
	SL	212.168	17.275	0.698	0.000	0.949	1.054
	CC	45.022	8.745	0.293	0.000	0.949	1.054
3	Constant	-265.891	242.263		0.000		
	SL	147.419	21.345	0.485	0.000	0.527	1.899
	CC	42.633	8.066	0.277	0.000	0.945	1.058
	SC	204.455	44.967	0.318	0.001	0.533	1.877
4	Constant	-2585.933	285.932		0.000		
	SL	122.043	22.968	0.402	0.000	0.432	2.316
	CC	31.690	8.913	0.206	0.001	0.735	1.361
	SC	191.062	44.112	0.297	0.000	0.525	1.903
	BL	27.061	10.397	0.187	0.011	0.480	2.084

B = Unstandardized coefficients, Beta = Standardized coefficients, SE = Standard error of coefficients, *p*-value = Significant level, VIF = Variance inflation factor, BL = Body length, CC = Chest circumference, SL = Shank length, and SC = Shank circumference.

Table 4. Stepwise regression analysis summary for each of the independent variables (or predictors) included in the model for female birds.

Model	Predictors	B	SE	Beta	P-value	Tolerance	VIF
1	Constant	-1052.148	91.567		0.000		
	SL	269.142	11.854	0.770	0.000	1.000	1.000
2	Constant	-2163.142	162.300		0.000		
	SL	192.574	14.509	0.551	0.000	0.566	1.766
	BL	49.331	6.157	0.333	0.000	0.566	1.766
3	Constant	-2514.733	174.856		0.000		
	SL	208.036	14.486	0.596	0.000	0.536	1.864
	BL	36.650	6.574	0.247	0.000	0.469	2.132
	CC	26.005	5.582	0.156	0.000	0.824	1.214
4	Constant	-2569.225	173.630		0.000		
	SL	183.434	16.357	0.525	0.000	0.411	2.435
	BL	35.050	6.515	0.236	0.000	0.466	2.145
	CC	27.118	5.527	0.163	0.000	0.820	1.219
	SC	73.880	23.788	0.121	0.002	0.591	1.691

B = Unstandardized coefficients, Beta = Standardized coefficients, SE = Standard error of coefficients, *p*-value = Significant level, VIF = Variance inflation factor, BL = Body length, CC = Chest circumference, SL = Shank length, and SC = Shank circumference.

Table 5. Linear regression equations for estimation of BW from linear body measurements using fitting sample

Model	Prediction equation	P-value	R^2	RMSE
	Male			
1	BW = -911.59 + 232.22(SL)	<0.001	0.58	254.94
2	BW = -1966.01 + 212.17(SL) + 45.02(CC)	<0.001	0.67	229.70
3	BW = -2165.89 + 147.42(SL) + 42.63(CC) + 204.46(SC)	<0.001	0.72	211.41
4	BW = -2585.93 + 122.04(SL) + 31.69(CC) + 191.06(SC) + 27.06(BL)	<0.001	0.74	205.98
	Female			
1	BW = -1052.15 + 269.14(SL)	<0.001	0.59	224.10
2	BW = -2163.14 + 192.57(SL) + 49.33(BL)	<0.001	0.66	206.38
3	BW = -2514.73 + 208.04(SL) + 36.65(BL) + 26.01(CC)	<0.001	0.68	200.57
4	BW = -2569.23 + 183.43(SL) + 35.05(BL) + 27.12(CC) + 73.88(SC)	<0.001	0.69	198.15

R^2 = Coefficient of determination, *p*-value = Significant level, RMSE = Root mean square error, BW = Body weight, BL = Body length, CC = Chest circumference, SL = Shank length, and SC = Shank circumference.

Table 6. Evaluating the performance of multiple regression analysis using fitting and validation samples.

	Fitting sample	Validation sample
Male		
Number of records	114	20
RMSE	205.978	239.440
R^2	0.736	0.775
Adjusted R^2	0.726	0.716
Correlation coefficient	0.858**	0.880**
Female		
Number of records	356	129
RMSE	198.146	182.049
R^2	0.685	0.685
Adjusted R^2	0.681	0.674
Correlation coefficient	0.828**	0.828**

** Pearson's correlation is significant at 0.01; RMSE = Root mean square error, R^2 = Coefficient of determination.

The stepwise regression summary for each of the predictors (BL, CC, SL, and SC) is indicated for both males (Table 3) and females (Table 4). The collinearity problem on each variable was diagnosed using tolerance and its reciprocal, called the variance inflation factor (VIF). If tolerance, a value which indicates how much of the variability of a specific predictor is not explained by the other predictors in the model, is below 0.10, it indicates that the variable has high correlations with other variables (Pallant, 2011). This suggests the possibility of multicollinearity (i.e., high inter-associations among independent variables). In the present study, the tolerance value was found in the range of 0.43 and 1.00 in males and 0.41 and 1.00 in females, which is above the cutoff point. This was also supported by the VIF values, ranging from 1.00 to 2.32 in males and from 1.00 to 2.44 in females, which are well below the recommended value. VIF value above 10 is regarded as indicating multicollinearity.

A model was developed to predict BW from morphometric measurements (BL, CC, SL, and SC) for both male and female birds using the coefficients of the predictors (Table 5). Since BW is highly dependent on growth (Alabi et al., 2012), the predictive equations developed in the present study showed that BW could be estimated from most morphometric measurements. Among the four body measurements, SL best predicted BW in both sexes, with coefficients of determination (R^2) equals 0.58 in males and 0.59 in females. This indicates that nearly 60 percent of the variance in BW was explained by SL thus this body measurement could be used as a single most important predictor of BW. Similar observations were reported in Nigerian indigenous chickens (Ukwu et al., 2014), and Japanese quail (Gambo et al., 2014). A combination of SL with one or more of other measurements (BL, CC, and SC) generally improved the predictive power of the equations. When SL was combined with CC, R^2 increased to 0.67 in male birds. In female birds, however, the combination SL and BL best predicted BW, with R^2 = 0.66. If possible combinations of additional measurements were considered, the combinations that included SL, CC, and SC best predicted BW in male (R^2 = 0.72) and combinations that included SL, BL, and CC in female (R^2 = 0.68) birds. If all the measurements of BL, CC, SL, and SC were included, R^2 increased to 0.74 and 0.69, respectively, in male and female birds. Thus, a model that combines all four measurements could be best in

accurately predicting BW in the studied chicken populations. This agrees with the conclusion of Latshaw and Bishop (2001), who implied that the predictive power of the equations was improved when more measurements are included. Likewise, Adeyinka and Mohammed (2006) concluded that multiple regression equations could accurately predict BW in goat than prediction equations with a single measurement.

The standardized coefficient (Beta) indicates which of the variables included in the model contributed to the prediction of the dependent variable (Pallant, 2011). Each of the independent variables included in the model significantly contributed to the prediction of the dependent variable with p-value ranging from <0.0001 to 0.015 (Tables 3 and 4). In models that included more than two measurements, SL makes the strongest unique contribution in predicting BW for both male and female birds. For instance, in model 4, the largest beta coefficients were 0.40 and 0.53 for SL in males and females, respectively. On the contrary, the Beta values for BL, CC, and SC were much lower than SL, indicates that they made less of a contribution in predicting BW. The standardized beta coefficient values obtained can also be used for more practical interpretations than the theoretical model testing from a genetic improvement point of view. According to Pallant (2011), these values indicate the number of standard deviations in the dependent variable would change if there was a one standard deviation unit change in the predictor. In model 1, for instance, if SL could increase by one standard deviation, BW would likely be raised by 0.76 and 0.77 standard deviation units in male and female birds, respectively.

Table 6 summarizes accuracy of the fitted models to predict BW from linear body measurements. Although slightly higher RMSE value was recorded in validation sample (239.44) compared to fitting sample (205.98), the prediction accuracy was increased from 74 percent in fitting sample to 78 percent in validation sample in male birds. In female, both fitting and validation samples showed similar prediction efficiency with R^2 = 0.69. However, slightly lower RMSE value was recorded for validation sample (182.05) than for fitting sample (198.15). The results generally suggest that fitting the multiple regression model to the validation sample can effectively predict BW in indigenous chickens in Ethiopia from their linear body measurements.

Conclusion

The positive and significant correlation between BW and morphometric measurements suggests that these measurements can be used as a selection criterion in the genetic improvement of Ethiopia indigenous chicken populations. The stepwise regression results also indicate that BW of these chickens can be predicted from morphometric measurements, especially SL. Although SL is the best single predictor of BW than other morphometric measurements, combining it with one or more body measurements improved the accuracy of the prediction equation. Thus, the choice of the optimal equation may depend on the body measurements that are easy to take and practical under the on-farm condition. Under smallholder management conditions, where the weighing balance may not be readily available, a simple measuring tape can be used to estimate BW of Ethiopia indigenous chickens using the developed prediction equations.

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