BIODIVERSITAS
Volume 26, Number 6, June 2025
Pages: 2696-2705

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260614

Prediction of live body weight from linear body measurements in sheep breeds of Botswana

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Department of Animal Sciences, Faculty of Animal and Veterinary Sciences, Botswana University of Agriculture and Natural Resources. Sebele Content Farm, Private Bag 0027, Gaborone, Botswana. Tel./fax.: +267-3650100, ♥email: mabolowe@yahoo.com

Manuscript received: 11 March 2025. Revision accepted: 21 May 2025.

Abstract. *Pelotshweu K, Bolowe MA, Mosweu NP, Thutwa K, Kgwatalala PM. 2025. Prediction of live body weight from linear body measurements in sheep breeds of Botswana. Biodiversitas 26: 2696-2705.* Phenotypic correlation data serve as a baseline to predict the outcomes of selection, which can in turn be used to inform appropriate conservation and breed improvement programs and strategies. Therefore, the study aimed to determine phenotypic correlations between body weight and morphometric traits and develop body weight prediction equations using morphometric traits for different sheep (*Ovis aries*) breeds in Botswana. Phenotypic correlation coefficients were determined from 595 sheep (Damara: 79, Dorper: 177, Karakul: 135, Meat-master: 156; Tswana: 48). Prediction equations were estimated from 94 sheep (Damara: 20, Dorper: 30, Karakul: 16, Meat-master: 28) using Stepwise regression procedures of Statistical Analysis System (SAS) 9.4. The highest positive significant ($p<0.05$) correlation coefficients were found between body weight and heart girth in both sexes across different sheep breeds. Males had higher correlation coefficients than females, except for Karakul males. Body length was more positively correlated (r: 0.81, 0.79, and 0.97) with body weight than height at withers (r: 0.78, 0.44, and 0.08) in Dorper, Meat-master, and Tswana male sheep, respectively. Morphometric traits like heart girth, body length, height at withers, neck length, cannon bone length, cannon bone circumference, and scrotal circumference in males were used for the prediction of body weight in Dorper, Damara, Meat-master, and Karakul sheep. Heart girth accounted for more variability in the prediction model for both sexes of all breeds, except for Damara males, where it was coupled with body length to predict their body weight. This indicates that body weight can be indirectly selected through selection for heart girth, height at withers, and body length. The study shows that heart girth, height at withers, and body length are the main traits that can be used in prediction equations of different sheep breeds to estimate body weight in the absence of weighing scales.

Keywords: Botswana sheep**,** morphometric traits, prediction equations, ranch management, relationships

INTRODUCTION

Live body weight of animals plays a pivotal role as the most economically important trait that is used by farmers for routine farm management activities such as drug administration dosage, assessment of the amount of feed consumed, and response thereof to that feed (Haq et al. 2020; Rotimi et al. 2020; Hlokoe et al. 2022). Moreover, knowledge of an animal's weight and weight changes is also key in determining responses to selection (Faraz et al. 2021). Furthermore, the condition of the animal can be easily assessed using live body weight, especially during marketing and determination of livestock sale prices in rural areas (Temoso et al. 2017). Although live body weight is a main indicator of growth in sheep (*Ovis aries*), it does not describe the morphological composition of the animal (Becker 2021). As such, other morphometric traits such as heart girth, body length, and height at withers can also be used as growth indicators (Hlokoe et al. 2022; Selala and Tyasi 2022). For example, heart girth has been found to have the highest correlation coefficient with body weight in both goats (*Capra hircus*) and sheep (Temoso et al. 2017; Bolowe et al. 2021). This indicates that heart girth can be used as an indirect selection criterion for body weight in sheep. Even though body weight is a major trait of economic importance, farmers in rural areas do not directly select for body weight to maximize response to selection due to the lack of weighing scales. Consequently, this resulted in farmers using visual observations to determine the body weight of animals, which may be prone to individual errors and inaccuracies (Haq et al. 2020; Hlokoe et al. 2022). Animal breeders have recently focused more on unraveling the relationships between linear morphometric traits and body weight with the aim of improving meat production (Faraz et al. 2021). This is because the association between body weight and most linear body measurements could be helpful, easier to use, and a more practical phenomenon in predicting animal live body weight, particularly in communal areas where weighing scales are not readily available and accessible (Fatih et al. 2021; Atta et al. 2023; Madikadike and Tyasi 2024). The farmer only ought to know the prediction equation, take a few measurements relevant to the formulated equation using a measuring tape or ruler, and fit the measurements into the equation to come up with a precise animal's live body weight.

Studies on phenotypic correlations and the use of linear body measurements to predict live body weight have been done in indigenous Tswana sheep of Botswana (Temoso et al. 2017; Bolowe et al. 2021), Meat-master sheep (Becker

2021), and Dorper sheep breeds (Mohammed et al. 2018; Selala and Tyasi 2022) of Ethiopia and South Africa. However, not all sheep breeds found in Botswana were covered. This suggests that very little research has been done on sheep breeds found in Botswana. Again, the studies by Temoso et al. (2017) and Bolowe et al. (2021) on Tswana sheep only focused on extensively managed sheep populations in the Southern District of Botswana, while studies on other breeds like the Dorper and Meat-master were done outside Botswana. It is, therefore, essential to carry out these studies in our local Botswana environmental conditions to come up with correlations and prediction equations relevant for use in sheep breeds kept in Botswana. It is worth noting that animal genetic resources evolve to suit a particular agroecological region better. This implies that similar sheep breeds outside or within Botswana, raised under different production environments, are likely to have different prediction equations. There is, therefore, a fervent need to develop prediction equations relevant to Botswana sheep. From the review of the literature, studies on correlation coefficients between live body weight and linear body measurements and regression equations using linear body measurements to predict body weight have not been carried out in Karakul and Damara sheep breeds. Again, it has been reported by Temoso et al. (2017) that weighing scales are usually not available to small-scale farmers in Botswana because they are highly costly, and difficult to operate and maintain. Therefore, the use of phenotypic correlation coefficients is an alternative user-friendly tool that small-scale farmers in Botswana can use to estimate body weight in sheep. The objectives of this study were, therefore, to estimate phenotypic correlations between live body weight and various linear body measurements and develop prediction regression equations using linear body measurements for Tswana, Dorper, Karakul, Meat-master, and Damara sheep breeds under ranch management conditions in Botswana.

MATERIALS AND METHODS

Study site

The study was carried out from March 2023 to August 2023 at Lobu field station, which is located southwest of Botswana in the Kgalagadi South District (26°35'13'S 21°49'02'E) (Figure 1). The Kgalagadi area is characterized by low summer rainfalls with an average rainfall of 300 mm per annum, which contributes to extreme temperatures ranging from 29-35ºC during summer and from 1-12ºC during winter (Seifu et al. 2019). The research area is an arid savannah woodland and grassland with sparsely distributed vegetation and various grass species (Kgaudi 2014).

Study animals

A total of 595 sheep (Damara: 79, Dorper: 177, Karakul: 135, Meat-master: 156, and Tswana: 48) were used for linear body measurements and to estimate phenotypic correlations between body weight and linear body measurements for five sheep breeds. The sample size was determined by the sheep population found at the study site. Ninety-four (94) sheep (Damara: 20, Dorper: 30, Karakul: 16, and Meat-master: 28) were used to develop regression equations used to predict the body weight of the four sheep breeds. Only adult sheep (non-pregnant) aged two and three years participated in the construction of regression equations, while those animals that were 1 year and above 3 years old were excluded from this study (2 years old ≤ animal ≤ 3 years old). This is because the sheep population in the study areas had majority of the animals falling between the 2-3 years age range, while only a few were in the extreme age categories (≤1 and above 3 years). The age of the sheep was estimated using the dentition procedure described by Wilson and Durkin (1984).

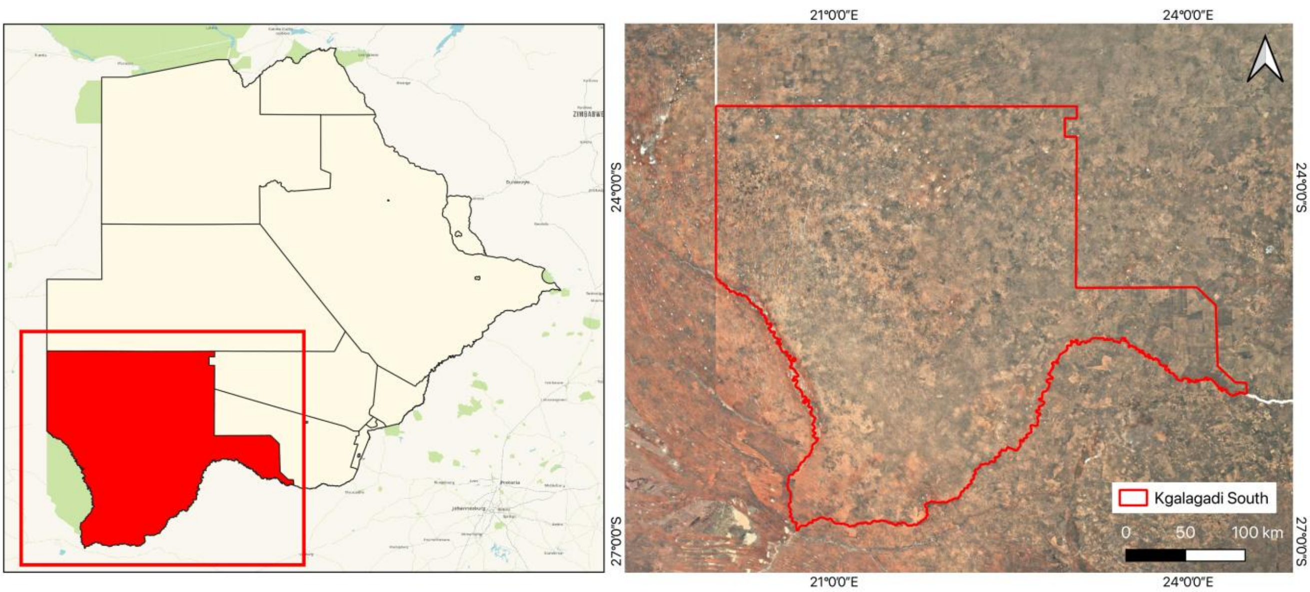

Figure 1. Study area in Kgalagadi South District, southwest of Botswana

Data collection

Quantitative traits were measured using a flexible measuring tape, following the breed morphological characteristics descriptor list for phenotypic characterization of sheep by FAO (2012). Quantitative traits which were measured included Body Length (BL), Heart Girth (HG), Height at Withers (HW), Shoulder Width (SW), Rump Height (RH), Rump Width (RW), Neck Length (NL), Tail Length (TL), Tail Circumference (TC), Cannon Bone Circumference (CBC), Cannon Bone Length (CBL) and Scrotal Circumference (SC) for rams. A weighing band was used to estimate the Body Weight (BW) of the sampled sheep populations used for the estimation of phenotypic correlations. Morphometric traits that were measured for the development of regression equations included Body Length (BL), Height at Withers (HW), Heart Girth (HG), Cannon Bone Length (CBL), Cannon Bone Circumference (CBC), and Scrotal Circumference (SC) in males. A weighing scale crate with a capacity of 300 kg and a precision of 100 g was used to measure the actual Body Weight (BW) of sheep used for the construction of regression prediction equations of both males and females of Damara, Dorper, Karakul, and Meat master sheep breeds of Botswana.

Statistical analysis

Pearson's correlation coefficients of Tswana, Dorper, Damara, Meat-master, and Karakul sheep breeds were estimated between body weight and other Linear Body Measurements (LBMs) within each sex using the procedure correlation (PROC CORR) of Statistical Analysis System (SAS, release 9.4, 2013). Linear body measurements, which were significantly correlated to body weight, were then subjected to regression analysis to develop prediction equations for body weight. Stepwise multiple regression procedures (PROC REG) of SAS 9.4 were used for regression analysis. This included using Variance Inflation Factor (VIF) to check for multicollinearity within the data. The formula below was used to calculate VIF of the different parameters added to the prediction model.

$$VIF = 1/(1-R^2)$$

Where,
R^2: Coefficient of determination

Independent variables were first individually regressed, and then stepwise addition of more independent variables was done to determine the best predictor variables to estimate body weight in each sex. The regression models were selected based on the coefficient of determination (R^2) and the adjusted R^2, together with the VIF value. The regression models with R^2 that produce VIF less than 5 were regarded as the best predictor models (Akinwande et al. 2015), as they indicated moderate correlation between parameters, hence minimal autocorrelation. The complete regression model for the linear body measurements was defined as follows:

For female:

$$Yj = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + ej$$

Where:

Yj	: Dependent variable (body weight)
β_0	: The intercept
$X_1, X_2 \ldots X_6$	: Independent variables BL, HG, HW, CBC, and CBL, respectively
$\beta_1, \beta_2 \ldots \beta_6$	: Regression coefficients of the variables $X_1, X_2 \ldots X_6$
ej	: Random error

For males:

$$Yj = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + ej$$

Where:

Yj	: Dependent variable (body weight)
β_0	: The intercept
$X_1, X_2 \ldots X_7$	: Independent variables BL, HG, HW, CBC, CBL, NL, and SC, respectively
$\beta_1, \beta_2 \ldots \beta_7$	: Regression coefficients of the variables $X_1, X_2 \ldots X_7$
ej	: Random error

RESULTS AND DISCUSSION

Phenotypic correlations between live body weight and linear body measurements in males

The data used in this study are quantitative in nature, and follow the bell shape of a histogram, where few animals were on the extremes (below and above the mean), and most of the animals centered around the mean, signifying normal distribution of the data. Pearson's correlation coefficients for predicting the associations between body weight and linear body measurements revealed that body weight had strong, positive, and significant ($p<0.05$) correlations with BL, HG, and SW in Damara, Dorper, Meat-master, and Tswana sheep males (Table 1). Non-significant correlations ($p>0.05$) between BW and all other morphometric traits were observed in Karakul sheep. Most of the correlations were negative and weak, namely, HW, SW, RH, TL, CBC, and CBL. However, positive, non-significant ($p>0.05$), and moderate associations were found between BW and BL, HG and RW. Non-significant ($p>0.05$) and weak associations between BW and NL were observed in Damara and Karakul males. There were also weak, non-significant ($p>0.05$) associations between BW and CBL in Damara, Karakul, and Meat-master males. Strong and significant ($p<0.05$) positive correlations were found between BW and NL and between BW and CBL in Dorper and Tswana males. Karakul and Meat-master males had weak correlation coefficients between BW and TL, with Karakul males having a negative correlation, while Meat-master males had a positive one. BW also had strong, positive, and significant ($p<0.05$) correlations with TC in Damara and Meat-master males, and the relationship between BW and SC for the breeds above was also positive and moderate.

Table 1. Phenotypic correlations at a 5% significant level between live body weight and other morphometric traits in males of different sheep breeds

Breed	Trait	BL	HG	HW	SW	RH	RW	NL	TL	TC	CBC	CBL	SC
DA	BW	0.744*	0.937*	0.748*	0.859*	0.837*	0.730*	0.223	0.638*	0.835*	0.659*	0.021	0.624*
DO		0.809*	0.946*	0.781*	0.953*	0.755*	0.785*	0.842*	NR	NR	0.449*	0.674*	0.348*
KR		0.634	0.649	-0.298	-0.008	-0.499	0.547	0.174	-0.337	0.03	-0.014	-0.162	0.174
MM		0.792*	0.904*	0.444*	0.650*	0.593*	0.635*	0.455*	0.389*	0.743*	0.726*	0.067	0.736*
TS		0.966*	0.972*	0.078	0.990*	0.937	0.931	0.952*	NR	NR	-0.702	0.979*	0.69
DA	BL		0.657*	0.811*	0.732*	0.712*	0.646*	0.197	0.615*	0.674*	0.594*	-0.101	0.485*
DO			0.764*	0.647*	0.808*	0.652*	0.687*	0.730*	NR	NR	0.335*	0.573*	0.26
KR			0.716	-0.122	0.025	-0.497	0.842*	0.736	0.183	0.562	-0.438	0.155	-0.235
MM			0.798*	0.436*	0.556*	0.635*	0.639*	0.453*	0.335*	0.639*	0.677*	-0.008	0.632*
TS			0.886	0.319	0.991*	0.982*	0.819	0.984*	NR	NR	-0.856	0.912	0.822
DA	HG			0.626*	0.872*	0.760*	0.772*	0.091	0.558*	0.758*	0.691*	0.188	0.680*
DO				0.793*	0.842*	0.828*	0.850*	0.649*	NR	NR	0.615*	0.694*	0.520*
KR				-0.068	-0.376	-0.551	0.418	0.462	0.057	0.27	-0.458	-0.497	0.204
MM				0.497*	0.681*	0.578*	0.665*	0.340*	0.400*	0.643*	0.720*	-0.008	0.707*
TS				-0.155	0.939	0.827	0.991*	0.853	NR	NR	-0.52	0.960*	0.499
DA	HW				0.714*	0.841*	0.427*	0.478*	0.646*	0.748*	0.456*	-0.176	0.464*
DO					0.693*	0.922*	0.695*	0.600*	NR	NR	0.449*	0.553*	0.296*
KR					-0.686	0.8	-0.572	0.544	-0.069	-0.485	-0.181	0	-0.683
MM					0.535*	0.795*	-0.091	0.174	0.239	0.046	0.184	0.278*	0.135
TS					0.193	0.413	-0.283	0.365	NR	NR	-0.763	0	0.748
DA	SW					0.787*	0.684*	0.235	0.642*	0.710*	0.648*	0.212	0.632*
DO						0.664*	0.734*	0.886*	NR	NR	0.307*	0.633*	0.259
KR						-0.513	0.45	-0.315	-0.241	0.622	-0.108	0.243	0.018
MM						0.5268	0.432*	0.292*	0.488*	0.552*	0.459*	0.340*	0.454*
TS						0.960*	0.887	0.969*	NR	NR	-0.782	0.945	0.748
DA	RH						0.454*	0.440*	0.563*	0.740*	0.479*	-0.008	0.574*
DO							0.795*	0.468*	NR	NR	0.521*	0.615*	0.474*
KR							-0.676	0.101	0.075	-0.727	0.374	0.344	-0.474
MM							0.024	0.235	0.194	0.206	0.322*	0.061	0.266
TS							0.744	0.999*	NR	NR	-0.895	0.906	0.899
DA	RW							-0.392	0.326	0.458*	0.856*	0.212	0.568*
DO								0.435*	NR	NR	0.648*	0.640*	0.542*
KR								0.345	0.272	0.701	-0.166	0.371	0.027
MM								0.211	0.371*	0.785*	0.624*	0.03	0.641*
TS								0.775	NR	NR	-0.405	0.923	0.378
DA	NL								0.528*	0.458*	-0.311	-0.275	0.068
DO									NR	NR	0.093	0.497*	-0.044
KR									0.165	0.295	-0.581	0.186	-0.724
MM									0.266	0.346	0.331*	-0.123	0.318*
TS									NR	NR	-0.87	0.927	0.878
DA	TL									0.666*	0.25	-0.189	0.292
DO										NR	NR	NR	NR
KR										0.163	0.257	0.471	0.189
MM										0.547*	0.197	0.211	0.123
TS										NR	NR	NR	NR
DA	TC										0.355*	-0.267	0.485*
DO											NR	NR	NR
KR											-0.646	0.036	-0.085
MM											0.583*	0.054	0.703*
TS											NR	NR	NR
DA	CBC											0.452*	0.692*
DO												0.299*	0.692*
KR												0.447	0.427
MM												0.056	0.777*
TS												-0.623	-0.968
DA	CBL												0.524*
DO													0.113
KR													-0.368
MM													-0.064
TS													0.659

*: p≤0.05; NR: Not Recorded; 1: Perfect positive correlation; DA: Damara; DO: Dorper; KR: Karakul; MM: Meat-Master; TS: Tswana; BW: Body Weight; BL: Body Length; HG: Heart Girth; HW: Height at Withers; SW: Shoulder Width; RH: Rump Height; RW: Rump Width; NL: Neck Length; TL: Tail Length; TC: Tail Circumference; CBC: Cannon Bone Circumference; CBL: Cannon Bone Length; SC: Scrotal Circumference

Phenotypic correlations between live body weight and linear body measurements in females

Positive and significant ($p<0.05$) correlations were observed between body weight and all other linear body measurements in all the female sheep breeds except for the association between BW and CBC in Meat-master females (Table 2). The highest, strong, positive, and significant ($p<0.05$) associations occurred between BW and HG. In comparison, the lowest non-significant ($p>0.05$) and weakest associations were observed between BW and CBC in Damara, Dorper, Karakul, Meat-master, and Tswana females. Weak positive associations between BW and BL and between BW and SW were found in Dorper, Karakul, and Tswana females. Weak, positive correlation coefficients were also observed between BW and NL in all the sheep breeds. There was a moderate, positive, and significant ($p<0.05$) correlation between BL and linear body measurements like HG, HW, SW, and RH in Damara and Meat-master females. BL had a weak, positive correlation coefficient with traits such as NL and TL in Damara and Meat-master females. Weak, negative, and significant ($p<0.05$) associations between BL and RW and between BL and CBC were found in Karakul females. At the same time, CBL had negatively weak non-significant ($p>0.05$) correlations with BL in Tswana females. The highest, positive, and significant ($p<0.05$) correlation coefficient was observed between HG and HW, followed by HG and RH, HG and RW, and HG and SW in Damara females. Significantly ($p<0.05$) strong and positive correlations were observed between HW and RH in Karakul and between SW and NL in Dorper females. Strong, significant ($p<0.05$), and negative correlations occurred between NL and CBC in Damara, Dorper, and Meat-master females, respectively.

Prediction of live body weight using morphometric traits for different female sheep breeds

Heart girth alone produced fairly good body weight estimates, ranging from the coefficient of determination (R^2): 0.46- 0.77 for all the female sheep breeds. However, as more traits were added, there was an increase in the coefficient of determination (Table 3). The addition of morphometric traits like HW and CBL in the prediction models increased the R^2 of almost all the breeds, except for Meat-master, where HW was not among the added traits. However, CBL also contributed to an increased R^2 in Meat-master ewes. This resulted in the model accounting for higher variability percentages in body weight of Dorper, Karakul, Meat-master, and Damara sheep breeds. Table 3 shows italicized prediction models which are the models with the highest accuracy of prediction. However, after checking for multicollinearity using VIF it was found that variables constituting the model have a high risk of autocorrelation. Therefore, the bolded best predictor models with the highest R^2 and minimal autocorrelation risk were selected. Thus, the best prediction equations that can be used to estimate the live body weight of Dorper, Karakul, Meat-master, and Damara ewes are $y=30.03+1.08HG-2.02HW+0.65BL$, $y=-107.08+0.58HG+0.69HW+5.58CBL$, $y = -34.25+0.99HG$, and $y=-54.90 +0.47HG+0.32HW +4.88CBC$, respectively. From the afore mentioned prediction equations, y is the body weight, and HG, HW, BL, CBL, and CBC are heart girth, height at withers, body length, cannon bone length, and cannon bone circumference, respectively.

Prediction of live body weight using morphometric traits for different male sheep breeds

The inclusion of Independent linear body measurements like HG, NL, and CBL helped to increase the coefficient of determination of Dorper and Meat-master males (Table 4). Scrotal circumference caused an increment in R^2 (0.93) when added to HG and BL in Karakul males. Body length and heart girth accounted for 87% variability of the model used to predict the body weight of Damara males, than when the traits were fitted individually. Table 4 shows that the bolded and italicized models for almost all the breeds except for Damara had higher accuracy of prediction with minimal risk of autocorrelation after checking for multicollinearity of variables using VIF. As for Damara, after checking for multicollinearity using VIF it was found that variables constituting the italicized model have a high risk of autocorrelation. The boldened best predictor model with the highest R^2 and minimal autocorrelation risk were selected. The live body weight of Dorper, Karakul, Meat-master, and Damara males can be best estimated using the prediction equations $y=-20.13+0.71HG+1.09HW-2.05NL$, $y = -137.20 + 1.60HG + 0.41BL + 0.61SC$, $y=16.45+0.42HG+0.79HW+0.34SC-2.05NL$, and $y=-777.56+6.27HG+3.75BL$, respectively. From the above equations, y is the body weight, while HG, HW, NL, BL, and SC are heart girth, height at withers, neck length, body length, and scrotal circumference, respectively.

Discussion

Phenotypic correlations between live body weight and linear body measurements in males

The use of the body weight estimation approach using linear body measurements is a broadly used phenomenon that determines the relationship between linear body morphometric traits in animals (Rashijane et al. 2023). The first part of this study examined the associations between body weight and linear body measurements of different sheep breeds found in Botswana under ranch management systems. The associations revealed strong, positive, and significant correlations of body weight with BL, HG, and SW in Damara, Dorper, Meat-master, and Tswana male sheep. The results are consistent with the findings of Becker (2021), Bolowe et al. (2021), and Selala and Tyasi (2022), who reported strong, significantly positive associations between body weight and morphometric traits like body length and heart girth for meat master, Tswana, and Dorper sheep males, respectively. Strong significant correlations suggest that body weight in Meat-master, Tswana, and Dorper rams can be indirectly selected by selecting and improving HG, BL, and SW.

Table 2. Phenotypic correlations at a 5% significant level between live body weight and other morphometric traits in females of different sheep breeds

Breed	Trait	BL	HG	HW	SW	RH	RW	NL	TL	TC	CBC	CBL
DA	BW	0.576*	0.903*	0.652*	0.519*	0.512*	0.418*	0.301*	0.196	0.488*	0.003	0.193
DO		0.389*	0.764*	0.411*	0.329*	0.446*	0.579*	0.248*	NR	NR	0.11	0.306*
KR		0.320*	0.800*	0.215*	0.339*	0.287*	0.248*	0.222	NR	NR	0.106	0.186*
MM		0.535*	0.717*	0.529*	0.501*	0.460*	0.210*	0.344*	0.297*	0.516*	-0.023	0.403*
TS		0.128	0.828*	0.473*	0.319	0.155	0.423*	0.12	NR	NR	0.072	0.182
DA	BL		0.619*	0.564*	0.528*	0.402*	0.434*	0.276	0.225	0.147	0.007	0.25
DO			0.417*	0.371*	0.319*	0.386*	0.364*	0.229*	NR	NR	-0.007	0.266
KR			0.188*	0.473*	0.407*	0.384*	-0.177	0.539*	NR	NR	-0.249	0.335*
MM			0.494*	0.524*	0.312*	0.519*	0.241*	0.219*	0.352*	0.432*	0.122	0.259*
TS			0.207	0.488*	-0.11	0.372*	0.294	0.068	NR	NR	0.21	-0.192
DA	HG			0.718*	0.532*	0.610*	0.567*	0.235	0.104	0.351*	0.103	0.187
DO				0.283*	0.071	0.390*	0.481*	-0.016	NR	NR	0.324*	0.124
KR				0.154	0.200*	0.240*	0.307*	-0.007	NR	NR	0.242*	-0.025
MM				0.302*	0.213*	0.347*	0.492*	-0.019	0.175	0.371*	0.303*	0.155
TS				0.411*	0.324	0.302	0.335	0.176	NR	NR	0.165	0.026
DA	HW				0.567*	0.746*	0.487*	0.117	0.338*	0.253	0.117	0.262
DO					0.447*	0.626*	0.397*	0.516*	NR	NR	-0.273	0.441*
KR					0.387*	0.833*	-0.27	0.522*	NR	NR	-0.263	0.465*
MM					0.472*	0.749*	-0.036	0.489*	0.311*	0.433*	-0.22	0.483*
TS					-0.085	0.488*	0.584*	0.304	NR	NR	0.443*	-0.007
DA	SW					0.612*	0.198	0.205	0.346*	0.092	-0.045	0.246
DO						0.462*	0.410*	0.810*	NR	NR	-0.57	0.611*
KR						0.304*	-0.214	0.712*	NR	NR	-0.286	0.275*
MM						0.280*	-0.263	0.682*	0.337*	0.562*	-0.552	0.572*
TS						0.032	0.147	0.057	NR	NR	-0.114	0.460*
DA	RH						0.351*	0.094	0.256	0.316*	0.083	0.053
DO							0.415*	0.464*	NR	NR	-0.159	0.348*
KR							-0.228	0.365*	NR	NR	-0.199	0.375*
MM							0.033	0.237*	0.273*	0.458*	0.009	0.351*
TS							0.409*	-0.154	NR	NR	0.634*	-0.172
DA	RW							-0.337	-0.155	-0.033	0.588*	0.133
DO								0.278*	NR	NR	0.01	0.337*
KR								-0.463	NR	NR	0.571*	-0.201
MM								-0.568	-0.161	-0.042	0.700*	-0.327
TS								0.339	NR	NR	0.274	-0.007
DA	NL								0.407*	0.303*	-0.757	0.113
DO									NR	NR	-0.738	0.672*
KR									NR	NR	-0.492	0.488*
MM									0.459*	0.406*	-0.728	0.639*
TS									NR	NR	0.103	-0.038
DA	TL									0.251	-0.428	0.453*
DO										NR	NR	NR
KR										NR	NR	NR
MM										0.265*	-0.284	0.374*
TS										NR	NR	NR
DA	TC										-0.248	-0.31
DO											NR	NR
KR											NR	NR
MM											-0.145	0.362*
TS											NR	NR
DA	CBC											0.016
DO												-0.533
KR												-0.161
MM												-0.442
TS												-0.232

*: P≤0.05; NR: Not Recorded; 1: Perfect positive correlation; DA: Damara; DO: Dorper; KR: Karakul; MM: Meat-Master; TS: Tswana; BW: Body Weight; BL: Body Length; HG: Heart Girth; HW: Height at Withers; SW: Shoulder Width; RH: Rump Height; RW: Rump Width; NL: Neck Length; TL: Tail Length; TC: Tail Circumference; CBC: Cannon Bone Circumference; CBL: Cannon Bone Length

Table 3. Multiple regression analysis of live body weight with other linear body measurements for females of different sheep breeds

Breed	Model	Parameters								
		Inter	β 1	β 2	β 3	β 4	β 5	β 6	R^2	Adj R^2
Dorper	HG	-13.80	0.76	-	-	-	-	-	0.53	0.47
	HG+HW	70.61	1.11	-1.96	-	-	-	-	0.75	0.68
	HG+HW+BL	30.03	1.08	-2.02	0.65	-	-	-	0.85	0.77
	HG+HW+BL+NL	-33.88	0.58	-1.54	0.64	3.33	-	-	0.91	0.84
	HG+HW+BL+NL+CBL	-102.29	0.26	-0.77	0.34	4.71	3.61	-	0.95	0.89
	HG+HW+BL+NL+CBL+CBC	-60.46	0.49	-1.20	0.55	5.10	1.48	-4.21	0.96	0.89
Karakul	HG	-36.27	0.98	-	-	-			0.60	0.55
	HG+HW	-68.26	0.92	0.59	-	-			0.68	0.59
	HG+HW+CBL	-107.08	0.58	0.69	5.58	-			0.84	0.76
	HG+HW+CBL+CBC	-110.19	0.50	0.60	5.13	2.75			0.85	0.72
Meat-master	HG	-34.25	0.99	-	-	-			0.46	0.39
	HG+BL	-129.62	1.18	1.10	-	-			0.86	0.82
	HG+BL+CBL	-101.45	1.13	1.00	-1.14	-			0.92	0.88
	HG+BL+CBL+NL	-102.11	1.02	1.00	-1.71	0.75			0.95	0.91
Damara	HG	-25.20	0.80	-	-	-	-	-	0.77	0.73
	HG+HW	-34.62	0.78	0.17	-	-	-	-	0.78	0.69
	HG+HW+CBC	-54.90	0.47	0.32	4.88	-	-	-	0.81	0.67
	HG+HW+BL+NL+CBL+CBC	77.80	-0.48	-3.12	-8.38	-6.06	66.26	66.26	1.00	0.99

Note: Inter: intercept; β_1, β_2…β_6: Regression coefficients of the variables; HG: Heart Girth; HW: Height at Withers; BL: Body Length; NL: Neck Length; CBL: Cannon Bone Length; CBC: Cannon Bone Circumference

Table 4. Multiple regression analysis of live body weight with other linear body measurements for males of different sheep breeds

Breed	Model	Parameters							
		Inter	β 1	β 2	β 3	β 4	β 5	R^2	Adj R^2
Dorper	HG	-15.56	0.87	-	-	-		0.54	0.52
	HG+HW	-44.75	0.62	0.86	-	-		0.64	0.60
	HG+HW+NL	-20.13	0.71	1.09	-2.05	-		0.68	0.63
	HG+HW+NL+CBL	-6.02	0.68	1.15	-2.05	-1.20		0.70	0.62
Karakul	HG	-105.50	1.73	-	-			0.75	0.68
	HG+BL	-125.06	1.46	0.64	-			0.85	0.75
	HG+BL+SC	-137.20	1.60	0.41	0.61			0.93	0.81
Meat-Master	HG	9.56	0.64	-	-	-	-	0.41	0.37
	HG+HW	-20.29	0.54	0.56	-	-	-	0.49	0.42
	HG+HW+SC	-25.55	0.46	0.50	0.57	-	-	0.56	0.46
	HG+HW+SC+NL	16.45	0.42	0.79	0.34	-2.05	-	0.67	0.57
	HG+HW+SC+NL+CBL	5.59	0.39	0.83	0.33	-2.17	0.93	0.70	0.57
Damara	HG+BL	-777.56	6.27	3.75	-	-		0.87	0.84
	HG+HW+BL	-1063.34	8.02	0.86	4.64	-		0.99	0.98
	HG+HW+BL+NL	-1350.82	10.68	2.03	5.35	-3.60		1.00	1.00
	HG+HW+BL+CBC	-724.97	4.45	1.34	1.89	18.00		1.00	1.00
	HG+HW+BL+SC	-1054.84	7.93	0.73	4.57	0.50		1.00	1.00

Note: Inter: intercept; β_1, β_2…β_6: Regression coefficients of the variables; HG: Heart Girth; HW: Height at Withers; BL: Body Length; NL: Neck Length; CBL: Cannon Bone Length; CBC: Cannon Bone Circumference; SC: Scrotal Circumference

In other words, HG, BL, and SW may be utilized as selection criteria during mating in an endeavor to increase body weight in Meat-master, Tswana, and Dorper rams. However, the findings differ with those reported by Saputro et al. (2025), who found higher correlation coefficients of body weight with body length (0.838) and height at withers (0.836) as compared to heart girth (0.794) in Sakub male sheep. The strong, significant, and positive correlation coefficients found between BW and NL and between BW and CBL in Dorper and Tswana males, respectively, agree with Bolowe et al. (2021), who reported moderate and positive correlations between body weight and neck length and cannon bone length in Tswana sheep males.

The weak association between body weight and tail length in Karakul and Meat-master males found in the current study is consistent with Becker (2021), who reported weak correlations between body weight and tail length in Meat-master rams. The difference between the negative and positive correlations between body weight and tail length in the above breeds suggests that karakul males, which are heavier in weight, tend to have shorter tails, while Meat-master males with higher body weight have longer tails. However, the strong, significant, and positive correlations observed between body weight and tail circumference and scrotal circumference in Damara and Meat-master males indicate that selecting for heavier Damara and Meat-master males will also result in animals with bigger tails and larger scrotal circumferences. These findings are contrary to the findings of Becker (2021), who reported weak positive correlations between body weight and scrotal circumference in Meat-master rams in South Africa. On the other hand, the weak and negative correlations between body weight and HG, SW, RH, TL, CBC, and CBL in Karakul suggest that directly selecting for body weight in Karakul males will indirectly reduce HG, SW, RH, TL, CBC, and CBL.

Phenotypic correlations between live body weight and linear body measurements in females

In ewes, positive and significant correlations between body weight and all other linear body measurements in ewes of the different sheep breeds were observed, except for the association of body weight and cannon bone circumference in Meat-master ewes. The observed strong and positive correlations occurred between body weight and heart girth plus the weakest association of cannon bone circumference with body weight in Damara, Dorper, Karakul, Meat-master, and Tswana females, respectively is consistent with Mohammed et al. (2018), Becker (2021), Bolowe et al. (2021) and Castillo et al. (2023) who reported high positive correlations in females between body weight and heart girth in Dorper and local breeds of Ethiopia, Meat-master in South Africa, Tswana in Botswana, and Socorro Island Merino in Mexico, respectively. Sabbioni et al. (2020) also found the highest correlation between body weight and heart girth in Cornigliese sheep. On the contrary, Rotimi et al. (2020) and Selala and Tyasi (2022) reported much higher correlations between body weight and body length compared to body weight and heart girth in female Sahelian goats of Nigeria and Dorper lambs of South Africa, respectively. This suggests that selecting for heart girth and body length in Damara, Dorper, Karakul, Meat-master, and Tswana ewes might lead to simultaneous positive improvements in body weight. HG and BL can thus be used to select body weight in sheep indirectly. In the current study, however, weak positive associations were found between body weight and body length and between body weight and shoulder width in Dorper, Karakul, and Tswana females, respectively. Weak, positive correlation coefficients were also observed between body weight and neck length in all the sheep breeds.

Prediction of live body weight using morphometric traits for different female sheep breeds

Live body weight is a very crucial trait in animal husbandry as it determines animal management practices like feeding and drug dosage (Rotimi et al. 2020). One of the ways to estimate the live body weight of sheep is the use of independent linear body measurements to develop prediction models. Hlokoe et al. (2022) emphasized that morphometric traits play an important role in predicting body weight, and the precision therein can be up to 90% of the actual body weight. The results of the current study indicated the highest correlation between body weight and heart girth in all the female sheep breeds. Furthermore, when fitted into the prediction model, heart girth alone produced the coefficient of determination (R^2) ranging from 0.46-0.77. This indicates that heart girth explained a fairly good variability percentage in the body weight of Dorper, Karakul, Meat-master, and Damara ewes. This coincides with the findings of Selala and Tyasi (2022), who reported a positive correlation between body weight and heart girth, with heart girth explaining about 66% of the variation in body weight of female Dorper sheep.

Heart girth accounted for a high (77%) proportion of changes in the live body weight of Damara females. The results are consistent with Atta et al. (2023) and Mathapo et al. (2025), who reported that heart girth alone explained more variation in the body weight of sheep and goats of Qatar and Nguni goats of Limpopo in South Africa, respectively. This indicates that heart girth can be used as a sole predictor of body weight for Damara females. Ibrahim et al. (2021) and Ozenturk et al. (2025) indicated that the high association between body weight and heart girth may be attributed to the fact that heart girth is made up of muscles, bones, and viscera, which contribute mainly to the body weight of an animal. The findings of the current study are contrary to Selala and Tyasi (2022), who reported that body length can be used as a sole predictor of body weight since body length explains most of the variability in body weight of Dorper lambs in South Africa.

A major increment was found when body length was coupled with heart girth in a prediction model for Meat-master ewes. The findings are consistent with those of Ibrahim et al. (2021), who found that the combination of chest girth and body length provided the best model for the prediction of body weight in female Batur sheep of Indonesia. This means that heart girth and body length can be used as the only parameters to estimate the body weight of Meat-master females. The current findings indicate that heart girth can be used as the only predictor of Meat-master ewes with minimal autocorrelation. Several authors, Michael et al. (2016) and Bolowe et al. (2021), reported the preference for using fewer parameters in estimating body weight, particularly under field conditions, for simplicity, as animal handling may be difficult. Thus, the chances of errors when measuring more variables are high. On the contrary, Taye et al. (2016) and Kumar et al. (2017) argued that including more independent variables in a regression equation enhances its precision and accuracy when estimating the body weight of sheep.

The coefficient of determination increased to 0.68 in Karakul ewes when heart girth and height at withers were included in the model, and this is consistent with Mohd-Hafiz et al. (2016) who found an increment in the R^2 when heart girth and height at withers were used to develop regression equations for Bali cattle (*Bos taurus*). The inclusion of cannon bone length contributed to a major increase in the prediction model, and this resulted in the model accounting for 84% of the variability in body weight of Karakul females. On the contrary, Mahmud et al. (2014) reported a negative correlation between body weight and cannon bone length in Nigerian breeds of sheep aged one year and below. This resulted in cannon bone length being excluded from the body weight prediction equation of Nigerian breeds of sheep.

When more independent traits were added to all the models, the R^2 kept on increasing, meaning that the equation became even more precise. This finding is consistent with Michael et al. (2016) and Kumar et al. (2017), who highlighted that R^2 increases when new independent variables are added to the prediction model. Furthermore, it should be noted that when adding new variables to the model, only those independent traits that increase the R^2 should be retained. At the same time, those causing a decrement should be removed from the model as they make the equation less precise (Kumar et al. 2017). However, the current findings indicate that even though adding more traits to the prediction increases its accuracy, it also increases the risk of autocorrelation. In this regard, the best bodyweight prediction model for all the female sheep breeds was selected based on the R^2 and Adj R^2 and the risk of autocorrelation. This means that only prediction models with Varience Inflation Factor (VIF) less than 5 were selected.

Prediction of live body weight using morphometric traits for different male sheep breeds

Heart girth alone explained 75% of the variability in body weight of Karakul males, and this is consistent with Mohd-Hafiz et al. (2016), who found the coefficient of determination of heart girth to be 0.77 for Brakmas cattle. This indicates that heart girth can be used as the sole predictor of body weight in Karakul males. This is in line with the findings of Bolowe et al. (2021), who found that heart girth alone may not only be sufficient but also preferred, in comparison with other linear body measurements in predicting body weight in Tswana sheep, due to the simplicity of the prediction equation. Bolowe et al. (2021) further stated that this could be very useful, especially under field conditions where animal restraint might be difficult during measuring. Several authors, Mohammed et al. (2018) and Atta et al. (2023) have also used heart girth as a sole predictor of body weight in crossbred Ethiopian rams and sheep and goats of Qatar, respectively. This is because of the high correlation between heart girth and body weight. However, heart girth alone explained 54% of the variability in body weight of Dorper males, which is lower compared to the findings of Mohammed et al. (2018) and Selala and Tyasi (2022), who reported that heart girth accounted for 86% and 79% of the variability in body weight of Dorper rams, respectively.

In the case where heart girth was used with body length to regress body weight, the prediction model explained 85% and 87% of the total variability in body weight of Karakul and Damara males. This indicates that body length and heart girth can be used to predict the body weight of Damara males precisely. The findings are consistent with Ibrahim et al. (2021), who reported that body length and heart girth are the best fit for the prediction equation for body weight in female Batur sheep. The high R^2 may be attributed to the fact that body length measures the skeletal frame of the animal while heart girth contains both the bones and muscles, meaning a combination of these two traits will contribute more to the changes in body weight (Dakhlan et al. 2020; Ibrahim et al. 2021). Rotimi et al. (2020) found that paunch girth and body length had the highest contribution to body weight of Sahelian goats when compared to other traits. This means that body length and heart girth can be used during breeding to select for body weight. Scrotal circumference caused an increment in R^2 (0.93) when added to heart girth and body length in Dorper males. Ramirez-Bautista et al. (2023) reported that scrotal circumference can be used to precisely estimate the body weight of Zulu rams who are under 22 months of age.

The use of heart girth and height at withers increased the precision of the prediction models as the R^2 increased from 0.54 to 0.64 and 0.41 to 0.49 for Dorper and Meat-master males, respectively. The findings are consistent with Mohd-Hafiz et al. (2016) who found that including heart girth and height at withers in the model to predict body weight in Bali cattle increased R^2 by 0.41%. Parameters like heart girth, height at withers, scrotal circumference, neck length, and cannon bone length were found fit to predict the body weight of Meat-master males. This is because they formulated a prediction equation that explained 70% of the total variability in the body weight of Meat-master males. However, the model including all the aforementioned, except for cannon bone length was selected because it could best predict the body weight of Meat-master males with minimal autocorrelation.

In conclusion, there were strong, significant, and positive correlations between body weight and heart girth, body length, and shoulder width in all the males across the different sheep breeds, except for Karakul males, which had a non-significant moderate correlation between body weight and heart girth. The highest positive correlation was found between body weight and heart girth in all the female sheep breeds. From the independent traits that were used to develop prediction equations of different breeds, heart girth accounted for most of the variability in body weight of almost all the sheep breeds, irrespective of sex. Independent traits like height at withers and body length also caused an increase in the coefficient of determination across various sheep breeds. Body weight can be indirectly selected through selection for heart girth, height at withers, and body length.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Ministry of Agriculture, Botswana, for granting permission to utilize the Lobu field station for data collection. We extend our deep appreciation to the Botswana University of Agriculture and Natural Resources (BUAN), Botswana, for providing the necessary data collection equipment and funding the study. We also appreciate Lindile Chiwaya, BUAN colleagues, and Lobu staff for their invaluable assistance during the data collection process. The Botswana University of Agriculture and Natural Resources funded this study.

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