



Relationship Between Body Weight and Linear Body Measurements at Various Stages of Permanent Tooth Eruption in Indigenous Matebele Female Goats of Zimbabwe

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Abstract | This study aimed to evaluate the influence of dental age on predicting body weight (BWT) using Linear body measurements (LBM) in 168 indigenous Matebele goat females of Zimbabwe. LBM and BWT were recorded at various stages of permanent incisor eruption (PE): second pair (I2), third pair (I3), fourth pair (I4), full mouth (FM), and broken mouth (BM). The LBMs were measured using a ruler and centimeter-calibrated tailor's tape, while BWT was measured using an electronic weighing scale in kilograms. The correlation between BWT and LBMs was assessed using Pearson's correlation and regression were used for data analysis. The highest correlation was observed between body length (BL) and rump height (RH) ($r = 0.70$), while BWT and heart girth (HG) showed a significant correlation ($r = 0.68$) ($p < 0.05$) at I2 stage. Simple regression models demonstrated good predictive power on BWT at the FM stage for HG ($R^2 = 74\%$), BL ($R^2 = 65\%$), and WT ($R^2 = 53\%$) ($p < 0.05$). The predictive power of multiple regression models for I3 was slightly reduced when non-significant components were removed. The findings suggest that HG is the best predictor of BWT during the I3 to FM tooth eruption phases, supporting genetic improvement and selection of replacement females based on LBM. The study concludes that dentition-based age determination influences the correlation between BWT and LBMs in female indigenous goats, with the strongest correlation observed between I2 and I4 eruption periods. Combining HG and RH can optimize body weight prediction for I3 females by reducing variables in the model. The results highlight the importance of dentition-based age estimation and morphometric feature-based body weight prediction in small ruminants, particularly in small-scale animal agriculture where scales and record-keeping are often lacking.

Keywords | Body weight, Dentition, Linear body measurements, Indigenous matebele goat, Zimbabwe

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The Matebele goat, a medium to large breed, is primarily found in Matabeleland North, Matabeleland South, and some parts of Midlands province (Devendra and Burns, 1983). It is a medium to large breed with a height of around 65cm at withers and mature weights ranging from 35kg to 55kg (Matopos Research Station, 2003). The typical birth weight for kids is 2.5kg, with weaning weights ranging from 12kg to 16kg. Both male and female Matebele goats have powerful legs for bi-pedal browsing and a short and moderate neck proportional to body length (Sikosana and Senda, 2007). The indigenous Matabele goat is often cross-bred with other breeds, like the Kalahari buck, to produce desirable offspring (Assan and Makuza, 2005). Efforts are being made to conserve and promote the use of indigenous goat breeds in Zimbabwe, with breed standards established to guide farmers and promote conservation (Assan, 2007). The indigenous Matabele goat is a crucial component of Zimbabwe's smallholder farming sector, with a significant population presence in this area.

Body weight is another critical factor in animal husbandry, as it serves as a reference point for carrying out a range of procedures, including breeding and selection, marketing, and managing the animal's health, including supplementation and medicine dosage, particularly during dry spells. An accurate estimation of body weight is crucial to maximize profitability (Skapetas *et al.*, 2006). Linear body measurements can be used to estimate live weight easily and inexpensively (Aduku *et al.*, 1991). Evaluating the live weight of goats can be accomplished easily and affordably by using linear body measurements, as demonstrated by research conducted by Tadesse *et al.* (2012) and Chitra *et al.* (2012). Establishing a reliable live weight method for field application is essential, as emphasized by Muhammad *et al.* (2021). The lack of weighing scales has made it difficult for farmers to manage dosage regimens, choose suitable breeding animals, and determine acceptable supplementing proportions (Ravimurugan, *et al.*, 2013).

Age estimation and body weight prediction are essential practices in small-scale animal agriculture, particularly in goats (McGregor, 2011). Dentition is used for goats, but teeth eruption can be the most accurate method in resource-limited areas (Wilson and Durkin, 1984). Age affects edible body parts, meat offal, and carcass yield, making it crucial to know an animal's age before processing it (Mahilet, 2012). However, small-scale animal agriculture faces problems such as a shortage of scales for weighing animals and poor record keeping for determining animal age (Yakubu *et al.*, 2011). These factors make it difficult for farmers to manage dosage regimens, choose suitable breeding animals, and determine acceptable supplementing proportions (Ravimurugan *et al.*, 2013). In the informal market, farmers

who rely on the informal market have lost revenue from the sale of their animals due to the lack of records that could be used to determine the age of the animals. The pricing of goats of unknown age is particularly challenging in the informal market (Van Rooyen *et al.*, 2007).

The study highlights the importance of the relationship between body weight and linear body at different stages of permanent tooth eruption as part of characterization of indigenous Matabele goat females, aiding conservation efforts and preserving genetic diversity in this breed. Linear body measurements such as body length, height-at-withers, and heart girth can be used to accurately predict body weight in goats, which is essential for management decisions (Mokoena *et al.*, 2022). Selection for breeding due to the strong correlation between body weight and linear measurements suggests that selection for breeding can be based on these easily measurable traits (Dige *et al.*, 2022). The relationship can be used for monitoring growth and development in goats, enabling farmers to identify any growth-related issues (Yakubu *et al.*, 2011). Understanding the relationship between body weight and linear measurements can inform nutrition and feeding strategies to optimize growth and productivity. The relationship between body weight and linear measurements can be used to estimate the age of goats, particularly in the absence of birth records (Idamokoro *et al.*, 2018). The study's findings can be used in genetic improvement programs to develop breeds with desirable body weight and linear measurement traits.

Tsegaye *et al.* (2013) suggest that predicting live weight from body measurements is efficient, quicker, and less costly in rural areas lacking the necessary facilities for breeders. Linear body measurements were used to calculate and predict goats' weight without weighing, using a stepwise multiple balance and a prediction equation (Atta and El Khidir, 2004; Adeyinka and Mohammed, 2006a; Fajemilehin and Salako, 2008; Olatunji-akiyo and Adeyemo, 2009; Agamy *et al.*, 2015; Sam *et al.*, 2016; Yakubu *et al.*, 2015). This method can explain live body weight for males and females at maximum variation in the dependent variable (Lawrence and Fowler, 1997). The relationship between live weight and heart girth in animals growing over a wide weight range is curvilinear, and morpho-biometrical traits with high correlations with body weight can be used for selection purposes in meat production and to predict live weight in the field when scales are unavailable, especially in villages or smallholder farms (Thiruvengadan, 2005; Ojedapo *et al.*, 2007). A linear regression model with a 0.934 coefficient of determination can predict the body weight of Red Sokoto goats in the field and for selection purposes, considering indices like body length, chest girth, shoulder width, cannon circumference, and neck circumference (de Villiers *et al.*, 2009). The study found a strong correlation between body weight and linear body measurements, with heart girth

being the most suitable linear measurement for predicting body weight (Sam *et al.*, 2016).

A few studies have explored the relationship between body weight, linear body measurements, and tooth eruption in female goats, with most being cross-sectional (Bello and Adam, 2012). Tooth eruption stages are not well-defined, making it difficult to standardize the relationship (Matika *et al.*, 1992). The relationship may vary across breeds, but breed-specific studies are scarce (Tsegaye *et al.*, 2013). Nutrition's impact on this relationship is poorly understood, and environmental factors like climate, management practices, and health status may influence it (Tsegaye *et al.*, 2013). Standardized measurement protocols make comparisons challenging (Abd-Allah *et al.*, 2019). Most studies focus on kids and yearlings, with limited information on adult females (Idamokoro *et al.*, 2018). Some studies may not use appropriate statistical models to account for the complex relationships between these variables (Yakubu *et al.*, 2011; Eyeduran *et al.*, 2017). Addressing these knowledge gaps through well-designed studies can provide valuable insights.

The potential research questions to investigate the relationship between body weight and linear body measurements at different tooth eruption stages in female goats: Is there a significant correlation between body weight and linear body measurements (height, length, chest circumference) at different tooth eruption stages in female goats? It is hypothesized that body weight increases linearly with each stage of tooth eruption, with specific dentition stages having a greater impact on one sex. Body weight is positively correlated with the number of permanent teeth erupted and significantly increases once a certain stage is reached. The study aims to develop models that predict body weight and age in female indigenous Matebele goats based on linear body measurements at different stages of tooth eruption, and to determine if there are sex-specific differences in this relationship.

MATERIALS AND METHODS

ETHICAL APPROVAL

The study was approved by the Zimbabwe Open University Animal Research Ethics Committee (Projects 2023).

STUDY PERIOD AND AREA

The study was conducted in April 2023. The research was undertaken 30km Southwest of Bulawayo, at Matopos Research Station (20° 0' 23" S, 31° 0' 30" E), Zimbabwe. The area experiences high temperatures ranging in the hottest months to 21.6 °C and 11.4 °C and low rainfall (<450mm) (Hagreveas *et al.*, 2004; Homann *et al.*, 2007). The research area is a rangeland with sweet veld vegetation with good

nutritional value to sustain ruminants (Ward *et al.*, 1979; Ncube, 2005; Van Rooyen *et al.*, 2007).

STUDY DESIGN AND MEASUREMENTS

The study used a cross-sectional design where the animals were observed once per animal. The BW and linear body measurement (LBMs) properties of 168 indigenous Matebele females at different stages of permanent tooth eruption were obtained from a randomly selected experimental flock kept at Matopos Research Station. The ages of the study's indigenous Matebele females were approximated using dentition. The study analyzed indigenous Matebele females aged 2-5 years based on their dentition, using categories I2 (second pair permanent incisors emerged), I3 (third pair permanent incisors emerged), and I4 (fourth pair of permanent incisors emerged full mouth) and BM (broken mouth lost or broken).

The study examined Linear body measurements (LBMs), namely heart girth (HG), body length (BL), wither height (WTH) and rump height (RH) following FAO (2011) recommendations. Measurements were recorded in centimeters and evaluated using a flexible tape and wood ruler, while BW was described in kilograms using a weighing scale that does not cause pain to animals. Data were extracted following Animal Ethics Committee protocols. The study measured animals in the morning before grazing on pastures. All animals experienced a fast period before weighing, with minimal variation due to gut-fill. To maintain consistency, measurements were taken by the same person and performed early in the morning before the flock left for grazing.

Figure 1, Below shows the LBMs in indigenous matabele female goats.

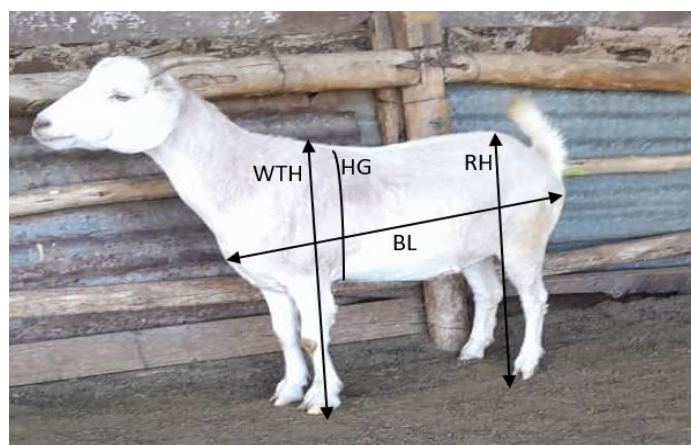


Figure 1: Linear body features measured in female Matebele goat.

The four linear body measurements were taken into consideration in this study.

HEART GIRTH (HG): Chest circumference, behind the posterior edge of the shoulders at the point of least perimeter.

WITHERS HEIGHT (WTH): Distance from the top of the withers to the ground.

BODY LENGTH (BL): Body length from the anterior edge of the shoulder to the posterior edge of the ischium.

Table 1: Descriptive statistics for body weight (kg) and linear body measurements (cm) at different permanent tooth eruption stages.

PTE	Trait	Mean	SE	SD	CV(%)
Incisor (I2) (N=28)	BWT (Kg)	23.30	0.52	2.34	22.22
	HG	69.30	1.20	5.38	22.30
	WH	48.30	0.42	1.86	22.58
	BL	46.40	0.77	3.42	22.51
	RH	58.70	0.58	2.57	22.56
Incisor (I3) (N=35)	BWT (Kg)	31.28	0.71	3.86	18.39
	HG	77.55	0.72	3.88	18.56
	WH	51.08	0.68	3.70	18.37
	BL	52.07	0.69	3.69	18.69
	RH	60.86	0.86	4.62	18.61
Incisor (I4) (N=45)	BWT (Kg)	27.90	0.66	4.19	15.75
	HG	74.20	0.53	3.33	15.91
	WH	48.55	0.53	3.33	15.91
	BL	47.53	0.61	3.84	15.88
	RH	57.50	0.88	5.58	15.77
FM(N=33)	BWT (Kg)	31.13	1.60	4.51	35.47
	HG	77.75	1.33	3.77	35.27
	WH	50.75	0.94	2.66	35.33
	BL	53.38	1.52	4.31	35.27
	RH	60.38	1.59	4.50	35.33
BM (N=25)	BWT (Kg)	33.86	0.65	3.87	16.79
	HG	77.91	0.68	4.04	16.83
	WH	50.69	0.47	2.75	17.09
	BL	52.14	1.13	6.70	16.86
	RH	62.69	0.56	3.32	16.86

Permanent tooth eruption stages (PTE): (I2) = 2nd pair permanent incisors emerged; Incisor (I3) = 3rd pair permanent incisors emerged; SD= Standard deviation; Incisor (I4) = 4th pair permanent incisors emerged; FM= Full mouth; BM= Broken mouth (Lost or broken); HG= heart girth; BWT = body weight; WH = withers height; BL = body length; RH= rump height; N =number per each category; SE = standard error, CV=coefficient of variation.

RUMP HEIGHT (RH): The distance from the surface of a platform to the rump using a measuring stick as described for height at withers.

STATISTICAL ANALYSIS

The study analyzed data from indigenous Matabele female goats of Zimbabwe, focusing on body weight, heart girth, wither height, body length, and rump height. Means, standard deviations, and coefficients of variation were obtained, and bivariate correlations were found. Descriptive statistics were used to present phenotypic measurements at different stages of permanent tooth eruption, and Pearson's correlation coefficient was used to estimate associations. Simple and multiple regression was used to establish a formula to predict the BWT using linear body measurements (SPSS 2010). All the findings were tested at 0.05 significant value. The simple linear regression of body weight on linear body parameters below was performed:

$$Model: Y = \alpha + \beta X$$

Where;

Y = dependent variable (BWT), X = independent variable (HG, WTH, BL, RH), α = the intercept, β = regression coefficient.

The below multiple linear regression was adopted:

$$Model: Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$$

Where;

Y = dependent variable (BWT), a = intercept, $b_1 - b_4$ = coefficient of regression, and $X_1 - X_4$ = independent variables (HG, WTH, BL, RH).

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS FOR LINEAR BODY MEASUREMENTS AND BODY WEIGHT AT DIFFERENT PERMANENT TOOTH ERUPTION STAGES

The evaluation of live weight in goats can be carried out easily and affordably by linear body measurements, as demonstrated by Tadesse *et al.* (2012) and Chitra *et al.* (2012). It is essential, therefore, to establish a live weight determination procedure that can be employed in the field (Muhammad *et al.*, 2021). Many studies across various animal species have investigated the relationship between live weight and biometric measurements. These studies include Abdelhadi and Babiker (2009); Gunawan and Ja (2011); Agung *et al.* (2018) (on cattle); Cam *et al.* (2010a); Musa *et al.* (2012) (on sheep); Machebe and Ezekwe (2010); Sun-girai *et al.* (2014); Birteeb *et al.* (2015) (on pigs); Mendes *et al.* (2005) (on poultry); Variedades (2010) (on turkey); Ojo *et al.* (2013) (on Guinea fowl); Yakubu *et al.* (2015) (on ducks); Sadick *et al.* (2020) (on broiler chicken); Tyasi *et al.*

(2020) (on layers chicken); and Vilakazi *et al.* (2020) (on indigenous chicken). However, the calculations that result from this research can be intricate or complex to interpret, as the coefficients for each body measurement gathered comprise unique decimal numbers. The study's objective is to assess the age of animals using the rate of permanent incisor eruption and to relate this to assessing BWT using LBM in Matebele goat females. Age estimation based on dentition and body weight prediction based on morphometric features are essential practices in small ruminant management. These practices can help address the primary challenges facing small-scale animal agriculture, such as the scarcity of scales for weighing animals and poor record-keeping for determining the age of animals. Accurate estimation of age and body weight is crucial for maximizing profitability and ensuring the health and well-being of the animals. The study's findings may be influenced by factors such as goat breed, season, age, sex, and management approach, as well as the specific season and data collected.

PHENOTYPIC CORRELATION OF LINEAR BODY MEASUREMENTS AND BODY WEIGHT

Table 2. displays the correlation coefficients between BWT and LBMs in indigenous Matebele goat does in Zimbabwe. PE phases influence the phenotypic correlation of biometric body measurements with BWT. When a female goat reaches the mature stage, her phenotypic connection with BWT is highest at incisor (I4) = 4th pair permanent incisors emergencies. At this time, the phenotypic correlation of LBM characteristics with BWT was in a downward sequence: HG ($r = 0.80$), BL ($r = 0.70$), WH ($r = 0.69$), and RH ($r = 0.57$). The stronger correlation between BWT and HG in this dental group was likely because HG contributed more to body weight due to its morphology, which includes muscles, viscera, and bones (Thiruvankadan, 2005). The present study's findings contradict those of Hassan and Ciroma (1990), who found a connection between heart girth and body weight.

The lowest phenotypic correlation of LBM characteristics with BWT emerged at the PE second set of permanent incisors (I2), with the following values: BL ($r = 0.45$), HG ($r = 0.37$), WH ($r = 0.23$), and RH ($r = 0.21$). A weak and negative correlation was observed between HG and WH, BL and RH at this stage of tooth eruption. This suggests that while HG grows, WH, BL, and RH may decrease, albeit at a moderate rate, or may grow slowly. Indigenous Matebele goat female HG exhibited a high positive correlation with BW in most tooth eruption classes, except for I2, with the following values: (I3) ($r = 0.68$), (I4) ($r = 0.80$), FM ($r = 0.72$), and BM ($r = 0.71$). The findings correspond with Atta and El Khidir, 2004; Thiruvankadan, 2005; Afolayan *et al.*, 2006; Alade *et al.*, 2008; and Cam *et al.*, 2010b, who revealed a strong phenotypic relationship between HG and BWT.

Table 2: Bivariate Pearson correlation coefficients between linear body measurements and body weight.

PTE	TRAIT	BWT	HG	WH	BL	RH
(I2)						
	BWT	1				
	HG	0.37	1			
	WH	0.23	-0.43	1		
	BL	0.45	-0.40	0.85	1	
	RH	0.21	-0.45	0.87	0.81	
(I3)						
	BWT	1				
	HG	0.68	1			
	WH	0.12	0.47	1		
	BL	0.36	0.38	0.20	1	
	RH	0.61	0.51	0.37	0.70	1
(I4)						
	BWT	1				
	HG	0.80	1			
	WH	0.69	0.66	1		
	BL	0.70	0.74	0.84	1	
	RH	0.57	0.46	0.76	0.65	
FM						
	BWT	1				
	HG	0.72	1			
	WH	0.64	0.54	1		
	BL	0.45	0.51	0.68	1	
	RH	0.44	0.58	0.74	0.37	1
BM						
	BWT	1				
	HG	0.71	1			
	WH	0.09	0.15	1		
	BL	0.18	0.16	-0.03	1	
	RH	0.36	0.25	0.23	0.01	1

Permanent tooth eruption stages (PTE): (I2) = 2nd pair permanent incisors emerged; Incisor (I3) = 3rd pair permanent incisors emerged; Incisor (I4) = 4th pair permanent incisors emerged; RH = rump height; FM= Full mouth; r = non-significant at ($r > 0.50$); BM = Broken mouth (Lost or broken); BWT = body weight; HG = heart girth; BL = body length; Phenotypic correlation (r): r = significant at ($r < 0.50$); WH = withers height.

This implies a substantial relationship between HG and BWT as a potential predictor of body weight. The favourable relationship that exists between BWT and HG at this stage of tooth eruption showed that this biometric feature may be utilized to assess the BWT of indigenous Matebele goat females accurately.

According to a study by Khargharia *et al.* (2015), there

is a positive statistical correlation between body weight (BWT) and body length (BL) ($r = 0.86$) and heart girth (HG) ($r = 0.79$) in Indian Assam Hill goats. These findings are consistent with those obtained from the eruption of the 4th pair of permanent incisors (I4). The high correlation between BWT and HG, BL, and wither height (WH) suggests that these linear body measurement traits could be used to estimate BWT without a weighing scale in the fields.

Okpeku *et al.* (2011) reported a positive relationship between BWT and wither height ($r = 0.66$) and heart girth ($r = 0.54$) in Nigerian WAD goats. These findings agree with the current study's findings for the 4th pair of permanent incisors (I4). The association between BWT and linear body measurements (LBMs) was found to be positive, ranging from $r = 0.09$ to $r = 0.80$, indicating that there was no multicollinearity because they were all under 0.90 (Dakhlan, 2019).

SIMPLE AND MULTIPLE REGRESSION EQUATIONS FOR PREDICTING BODY WEIGHT

Simple regression equations with their coefficients of determination (R^2) obtained from body weight and linear body measurements of indigenous Matebele goat ewes at different permanent tooth eruption stages are presented in Table 3. In I2, the single contribution to the variation in BWT was low and not significant, ranging from R^2 (0.03 to 0.15). In I3, the contribution to the variation in BWT was less than 50%, and in descending order, HG (47%), RH (38%), WH (24%), and BL (13%). In I4 however, HG was the highest contributor to BWT, followed by BL, WH, and RH (64, 50, 47, and 32%, respectively).

For HG (74%), BL (65%), and WH (53%), simple regression models exhibited strong predictive power with respect to BWT at the FM stage. Conversely, RH exhibited a poor coefficient of determination (6%), even at the same stage of PEs. For the BM stage, only HG had an R^2 greater than 50% ($R^2 = 53\%$), whereas the others had low R^2 (RH = 16%, BL = 5%, and WH = 3%). Except for RH in FM and BM and BL in the BM tooth eruption group, simple regression models for LBM on BWT in (I2) were statistically non-significant at first but turned statistically significant as PE progressed. Sam *et al.* (2016) discovered that heart girth may be utilized to predict body weight at different ages based on permanent incisor eruption using simple linear regression analysis.

Multiple regression, on the other hand, demonstrated great accuracy when additional factors were included in the female goat estimation model ($R^2 = 0.694$). The present research also confirmed this, as shown by our findings in Tables 3 and 4. Their predictive value of $R^2 = 0.694$ is close to the $R^2 = 0.697$ obtained in the current investigation for

the fourth pair of permanent incisors in the female group.

Table 3: Simple regression between body weight and body measurements of indigenous Matebele goat ewes at different permanent teeth eruption stage.

PTE	Regression Equation	R^2 (%)	SE	P-Value
(I2)	BWT= 13.954 + 0.135 HG	0.09	2.28	0.1840 ^{NS}
	BWT= 11.06+0.251WH	0.04	2.35	0.3995 ^{NS}
	BWT= 10.888 +0.268BL	0.15	2.21	0.00881 ^{NS}
	BWT= 13.625+0.165RH	0.03	1.89	0.4445 ^{NS}
(I3)	BWT= -21.494 +0.680HG	0.47	2.87	0.0000 ^{**}
	BWT= 14.725+0.468WH	0.24	3.29	0.0070 ^{**}
	BWT= 11.307+ 0.384 BL	0.13	3.66	0.0500 [*]
	BWT= -0.009 + 0.514RH	0.38	3.10	0.0000 ^{**}
(I4)	BWT= -46.712+ 1.005HG	0.64	2.56	0.0000 ^{**}
	BWT= -14.082 + 0.865WH	0.47	3.08	0.0000 ^{**}
	BWT= -8.871 + 0.774BL	0.50	2.99	0.0000 ^{**}
	BWT= 3.358 + 0.427RH	0.32	3.49	0.0000 ^{**}
FM	BWT= -48.773 +1.028HG	0.74	2.51	0.0064 ^{**}
	BWT= -31.671 + 1.237WH	0.53	3.34	0.0400 [*]
	BWT= -13.928 + 0.844BL	0.65	2.90	0.0160 ^{**}
	BWT= 16.390 + 0.244RH	0.06	4.73	0.5620 ^{NS}
BM	BWT= -20.859 +0.702HG	0.53	2.67	0.0000 ^{**}
	BWT= 22.554+0.222WH	0.03	3.87	0.3624 ^{NS}
	BWT= 27.410+0.124BL	0.05	3.83	0.2164 ^{NS}
	BWT= 4.408+0.469RH	0.16	3.59	0.0929 ^{NS}

Permanent tooth eruption stages (PTE): (I2) = 2nd pair permanent incisors emerged; Incisor (I3) = 3rd pair permanent incisors emerged; WH = withers height; BL = body length; Incisor (I4) = 4th pair permanent incisors emerged; FM = Full mouth; RH = rump height; BM = Broken mouth (Lost or broken); BWT = body weight; ^{**}significant at ($p < 0.01$); R^2 = coefficient of determination; SE = standard error, ^{*}significant at ($p < 0.05$); HG = heart girth; NS = non-significant.

The contribution of RH was not significant in I2, while HG and BL were significant in the current study (BWT = $-10.126 + 0.316HG^{**} - 0.434WH + 0.801BL^{**} - 0.076RH$). HG and BL were highlighted as the best predictors of live weight in Nigerian Red Sokoto goats (Adeyinka and Mohammed, 2006b). This finding is partly consistent with the current results. Dakhlan *et al.* (2020), studying female Ettawa Grade goats, found that the combination of HG and BL in the body weight estimate regression model is consistent with the current research.

Table 4, displays a range of multiple regression equations and their corresponding R^2 values, which were derived from the BWT and other variables. The best fit was found in FM, although individual variables were not statistically

Table 4: Preliminary multiple regression equation for predicting body weight of indigenous Matebele goat ewes at different permanent teeth eruption stage.

PTE	Regression Equation	R ² (%)	R ² (adj)	SE
(I2)	BWT= -10.126+0.316HG [*] -0.434WH+0.801BL [*] -0.076RH	0.599	0.492	1.669
(I3)	BWT= -20.286+0.607HG [*] -0.307WH-0.054BL+0.377RH [*]	0.624	0.561	2.558
(I4)	BWT= -45.917+0.765HG ^{**} +0.149WH+0.054BL+0.126RH	0.697	0.663	2.435
FM	BWT= -53.043+0.886HG+0.862WH-0.021BL+/-0.340RH	0.845	0.689	2.714
BM	BWT= -28.931+0.640HG ^{**} -0.087WH+0.038BL+0.245RH	0.580	0.524	2.668

Permanent tooth eruption stages (PTE): (I2) = 2nd pair permanent incisors emerged; Incisor (I3) =3rd pair permanent incisors emerged; HG = heart girth; Incisor (I4) = 4th pair permanent incisors emerged; R² = coefficient of determination; FM = Full mouth; BM = Broken mouth (Lost or broken); BWT = body weight; WH = withers height; RH = rump height; ^{*}significant at (p<0.01); BL = body length; SE = standard error; ^{*}significant at (p<0.05); all LBMs in a model without a superscript are non-significant.

Table 5: Optimal regression equation for predicting body weight of indigenous Matebele goat ewes at different permanent teeth eruption stage.

PTE	Regression Equation	R ² (%)	R ² (adj)	SE
(I2)	BWT= -10.126+0.316HG ^{**} -0.434WH+0.801BL ^{**} -0.076RH	0.599	0.482	1.669
	BWT=-23.45+0.266HG+0.486RH	0.286	0.202	2.092
(I3)	BWT= -20.286+0.607HG ^{**} -0.307WH-0.054BL+0.377RH [*]	0.624	0.561	2.558
	BWT=-25.033+0.495HG+0.294RH	0.556	0.522	2.671
(I4)	BWT= -45.917+0.765HG ^{**} +0.149WH+0.054BL+0.126RH	0.697	0.663	2.435
	BWT= -46.712+ 1.005HG	0.638	0.628	2.557
FM	BWT= -53.043+0.886HG+0.862WH-0.021BL+/-0.340RH	0.845	0.689	2.714
	BWT= -48.773 +1.028HG	0.735	0.691	2.900
BM	BWT= -28.931+0.640HG ^{**} -0.087WH+0.038BL+0.245RH	0.580	0.524	2.668
	BWT= -20.859 +0.702HG	0.538	0.524	2.667

Permanent tooth eruption stages (PTE): (I2) = 2nd pair permanent incisors emerged; Incisor (I3) =3rd pair permanent incisors emerged; ^{*}significant at (p<0.01); RH= rump height; Incisor (I4) =4th pair permanent incisors emerged; HG= heart girth; FM= Full mouth; BM= Broken mouth (Lost or broken); R²= coefficient of determination; BWT = body weight; WH = withers height; BL = body length; ^{*}significant at (p<0.05); SE= standard error; all LBMs in a model without a superscript are non-significant.

significant. The next best fit was found in I4, followed by I3 and I2, with BM having the lowest R² value. The simple regression of heart girth on BWT was consistent with previous studies, and the R² for basic modeling of HG and other LBM was relatively high. However, the study found that estimating live weight using two or more body measures did not yield higher accuracy than using heart circumference alone. The findings of Iqbal *et al.* (2013) were similar, where multiple regression provided the greatest predictors for BW in female Beetal goats with an R² of 0.69.

Table 5. provides an optimal regression model for estimating the body weight of native Matebele goat ewes at different permanent tooth eruption stages. The multiple regression model in I2 lost 31% of its R² value when non-significant components (WH and RH) were removed, falling from 60% to 29%. Similarly, removing non-significant components from I3 reduced the predictive power by

6%, and removing them from I4 had a negligible effect. The variables removed were WH, BL, and RH. Although none of the factors used in the multiple regression equation were significant for FM, this model provided the best fit (R² = 0.845). It was noted that the full model with all LBMs included gave the best result for (I2) (R² = 0.599); however, under field conditions, using all LBMs is impossible since the main aim of predicting BW from LBMs is to easily predict BW from LBMs.

In this case, farmers might opt for a simple model, such as BWT = -23.45 + 0.266 HG + 0.486 RH, with a compromised low predictive power (R² = 0.286). Fitting HG alone produced an identical best coefficient of determination of R² = 0.735 with a loss of value of 11% in the optimal model. The removal of non-significant variables from the BM multiple regression model had no effect on the coefficient of determination. Yakubu and Salako (2009)

proposed a method of eliminating non-significant variables to generate optimal equations. The following optimal regression models for predicting the body weight of indigenous Matebele goat ewes at different stages of permanent tooth eruption were established for the current study: In Model (I2): $BWT = -23.45 + 0.266 HG + 0.486 RH$ ($R^2 = 0.286$). NB: This model indicates that at an early stage of tooth eruption, most morphological traits will not be well developed to warrant any measurement for use in predicting body weight. For (I3): Optimal Model: $BWT = -25.033 + 0.495HG + 0.294RH$ ($R^2 = 0.556$), Model (I4): $BWT = -46.712 + 1.005HG$ ($R^2 = 0.638$), Model FM: $BWT = -48.773 + 1.028HG$ ($R^2 = 0.735$), and Model BM: $BWT = -20.859 + 0.702HG$ ($R^2 = 0.538$). This study's findings are consistent with those published by *Dea et al. (2019)*, *Seid et al. (2016)*, *Selolo et al. (2015)*, and *Khargharia et al. (2015)*. Based on dentition-based age determination, HG is the most reliable indicator of body weight in female goats. The precision of determination improves when comparing I3 with FM. This stage corresponds to adulthood, at which point all body measurements are fully taken. The low prediction value in BM (broken mouth) can be attributed to muscle loss induced by animals in this group who fail to use feed adequately owing to tooth loss. BM animals cannot always eat enough to keep their bodies in excellent shape.

CONCLUSION

The study investigates the correlation between body weight and linear body measurements in indigenous Matebele female goats during permanent tooth eruption, concluding that dentition-based age determination influences this correlation. Dentition and LBMs can be combined to determine BWT accurately. The indigenous Matebele female goats showed a strong correlation between LBM and BWT during permanent tooth eruptions, while HG was found to be the most accurate predictor of BWT between I3 and FM teeth eruption phases. Combining HG and RH can optimize BWT prediction for I3 females. The study provides new insights into the relationship between these measurements' protocols and their morphological development, which could benefit female goat replacement management and future breeding programs.

IMPLICATIONS

However, the study's findings should be interpreted with caution due to potential limitations in sample size and other methodological factors. The study's limitations may limit its generalizability. Despite its limitations, the study offers important insights into the link between body weight and linear body measures during permanent tooth eruption in female goats that are scarce in the literature. Future research on teeth eruption should use larger sample sizes and longitudinal designs to improve accuracy and

consider individual variability. It should evaluate multiple phases, manage dietary aspects, and use machine learning algorithms for data analysis. Collaborating with other researchers is crucial for merging data and knowledge, as regional and environmental factors may be considered in data collection from multiple locations.

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NOVELTY STATEMENT

The estimation of body weight at different ages of indigenous goats is limited. This study identified linear body measurements that might be used by goat farmers at different ages of goats.

AUTHOR'S CONTRIBUTIONS

Never Assan designed and drafted the manuscript. Nicholas Mwayera, Micheal Musasera and Maphios Mpofu collected and analysed the data. Louis Tyasi and Kwena Mokoena revised the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors have stated that they have no competing interests.

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