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A Noninvasive Approach to Predict Body and Carcass Weights in Goats and Sheep using *in vivo* Body Measurements

Research Article

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ABSTRACT

This study aimed to develop and validate predictive models for estimating body weight (BW) and hot carcass weight (HCW) in small ruminants using *in vivo* morphometric measurements. A total of 400 animals (250 sheep and 150 goats) were used for BW prediction, and among them, 200 sheep and 64 goats were slaughtered to develop HCW models. The *in vivo* measurements included chest circumference (CC), body length (BL), and withers height (WH). Model performance was evaluated through K-fold cross-validation, considering the coefficient of determination (R^2), root mean square error of cross-validation (RMSECV), and prediction bias (BIAS). For BW, the combined-species simple model achieved R^2= 0.90 and RMSECV= 3.34 kg, while the multiple model yielded R^2= 0.91 and RMSECV= 4.44 kg. Sheep-specific models showed R^2= 0.82 and RMSECV= 3.47 kg for the simple model, and R^2= 0.85 and RMSECV= 4.33 kg for the multiple model. Goat models reached R^2= 0.89 and RMSECV= 2.95 kg (simple), and R^2= 0.90 and RMSECV= 4.29 kg (multiple). For HCW, the combined simple model (R^2=0.79; RMSECV=1.89 kg) and the sheep-specific simple model (R^2=0.75; RMSECV=1.90 kg) showed good predictive ability. The simple model for goats presented moderate predictive power (R^2=0.73; RMSECV=1.75 kg), whereas the multiple model was not significant. In conclusion, BW and HCW can be accurately estimated using simple linear regression models, which may be applied either separately or jointly across species.

KEY WORDS chest circumference, morphometry, prediction models, ruminants.

INTRODUCTION

Small ruminant production has grown in Brazil, with current populations of approximately 21.7 million sheep and 12.8 million goats, particularly concentrated in the Northeast region (IBGE, 2023). Sheep and goats are an important source of meat and milk for human consumption and play a crucial socio-economic role by providing income and food security to rural communities. In production systems, live body weight (BW) is a key parameter for decision-making, including animal selection for breeding, nutritional management, drug dosage, and marketing (Karna *et al.* 2024).

Although weighing scales remain the most accurate method for assessing BW, their high cost, limited availability in remote farming areas, and lack of infrastructure restrict their use by smallholder farmers (Chay-Canul *et al.* 2019; Macedo-Barragán *et al.* 2021; Rocha-Silva *et al.* 2024). Consequently, regular animal weighing is infrequent in Brazilian semiarid regions, where production systems are typically extensive and technologically limited.

To overcome these constraints, low-cost, practical, and noninvasive alternatives have been developed to predict BW through mathematical models based on *in vivo* morphometric measurements. These approaches have been successfully applied in different animal species, including buffalo (Rashad *et al.* 2019), cattle (Rocha-Silva *et al.* 2024), goats (Abd-Allah *et al.* 2019; Karna *et al.* 2022; Atoui *et al.* 2023), and sheep (Bautista-Díaz *et al.* 2020; Canul-Solis *et al.* 2020). Morphometric-based estimations are particularly advantageous in rural areas where access to conventional weighing equipment is limited, as they enable reliable field measurements with minimal infrastructure. However, such predictive models should not be generalized, as they are often population- or breed-specific, reflecting genetic and environmental influences (Rocha-Silva *et al.* 2024).

Native and locally adapted breeds play an important role in semiarid environments due to their resilience to harsh conditions and their economic and cultural value for low-income farmers (Souza *et al.* 2019; Selvan *et al.* 2023). In Brazil, several studies have developed morphometric models to predict BW in sheep breeds such as Morada Nova, Santa Inês, Texel, and Suffolk (Ramos *et al.* 2019; Costa *et al.* 2020; Gurgel *et al.* 2021). Nevertheless, to the best of our knowledge, no studies have addressed goats. Moreover, while BW is often used as an indirect predictor of carcass traits (Bautista-Díaz *et al.* 2020), few studies have evaluated the potential of external *in vivo* morphometric traits to directly predict hot carcass weight (HCW) in small ruminants raised under semiarid conditions. There is a critical lack of studies focusing on non-defined breed (NDB) small ruminants that dominate herds in the Brazilian semiarid region (Martins *et al.* 2014). NDB goats and sheep are the most representative genetic resources in Northeast Brazil, largely due to their resilience to heat stress, feed scarcity, and other harsh environmental conditions. Despite their numerical and economic importance, no predictive models are available to estimate either BW or HCW for these animals. Therefore, the objective of this study was to develop mathematical models to predict BW and HCW based on noninvasive body measurements in small ruminants.

MATERIALS AND METHODS

All experimental procedures were conducted in accordance with ethical standards for animal research and were approved by the Ethics Committee on Animal Experimentation of the Universidade Federal do Vale do São Francisco (UNIVASF), Petrolina, PE, Brazil, under protocol number 0004/260321.

Experimental site and animals

The study was carried out on smallholder farms and in a commercial slaughterhouse located in the Northeast region of Brazil. According to the Köppen climate classification, the region has a tropical semi-arid climate (BSw'h), characterized by low and irregular rainfall, with precipitation concentrated in the summer months and high evapotranspiration caused by elevated temperatures. A total of 400 NDB small ruminants were used in the experiment, including 250 sheep and 150 goats, to develop prediction models for BW. Of these, 200 sheep and 64 goats were randomly selected and slaughtered to develop HCW prediction models.

In vivo morphometric measurements

In vivo morphometric measurements were obtained using a measuring tape, with animals gently restrained in a standing position by holding the flanks with minimal pressure to ensure animal welfare. The measurements collected included the following traits: withers height (WH), measured as the distance from the top of the withers to the ground; chest circumference (CC), taken around the chest just behind the front legs and withers; and body length (BL), measured as the distance from the point of the shoulder at the outer tuberosity of the left humerus to the left tuber ischii. These procedures followed the methodologies described by Atoui *et al.* (2023) and Rocha-Silva *et al.* (2024) (Figure 1). BW was recorded using a calibrated digital scale, with animals securely restrained inside a weighing cage to ensure accurate and consistent readings.

Animal slaughter

Animals were slaughtered in a commercial abattoir following established humane handling protocols. Mechanical stunning was performed by cerebral concussion using a pneumatic captive bolt device, in accordance with welfare regulations. Immediately after stunning, animals were exsanguinated by severing the carotid arteries and jugular veins. Subsequent procedures included skinning, evisceration, and removal of the head, hide, viscera, and distal limbs, as stipulated by the Regulation of Industrial and Sanitary Inspection of Products of Animal Origin (Brasil, 2017). Following slaughter, HCW was recorded using a calibrated digital scale. Hot carcass yield (HCY) was calculated as HCY= (HCW/BW) × 100.

Statistical analysis

Statistical analyses were performed using SAS software (SAS, 2023) in a completely randomized design, with each animal considered an experimental unit. Descriptive statistics (mean, standard deviation, standard error of the mean, minimum, and maximum values) were calculated using the PROC MEANS procedure.

Pearson correlation coefficients between morphometric variables and BW and HCW were estimated using the PROC CORR procedure. Correlations were classified as low (0.00–0.29), moderate (0.30–0.59), or high (0.60–0.99) (Callegari-Jacques, 2003). Simple linear regression models were fitted individually for each morphometric variable (CC, BL, and WH) in relation to BW and HCW using the PROC REG procedure. Multiple linear regression analysis was then performed, with variable selection using the stepwise method (PROC REG). Cross-validation was carried out with the PROC GLMSELECT procedure, splitting the dataset randomly into training (70%) and validation (30%) subsets. Additionally, a 10-fold cross-validation was implemented using the PROC IML module to assess the predictive robustness of the fitted models. For each fold, the following performance metrics were calculated: coefficient of determination (R^2), root mean square error of cross-validation (RMSECV), regression slope between observed and predicted values, mean bias, and significance of the bias (two-tailed t-test, P-value). The average of these metrics was used to summarize the overall predictive performance of the models.

RESULTS AND DISCUSSION

Descriptive statistics for *in vivo* morphometric measurements, BW, and HCW of sheep and goats are summarized in Table 1. On average, sheep exhibited larger body size and higher weights than goats across all variables measured. The mean BW of sheep was 39.72 ± 0.53 kg (SD=8.35 kg), ranging from 16.84 to 60.40 kg (n=250). In contrast, goats had a lower average BW of 27.06 ± 0.75 kg (SD=9.24 kg; range=6.56–49.28 kg; n=150). HCW followed a similar pattern, with sheep averaging 18.55 ± 0.27 kg (SD=3.83 kg) and goats 14.22 ± 0.42 kg (SD=3.35 kg), based on 200 and 64 animals, respectively. Although absolute values differed, HCY was relatively similar between species, with means of 45.15 ± 0.25% for sheep and 43.60 ± 0.52% for goats. These results indicate a consistent proportional relationship between live and carcass weights across species, despite differences in body size. Morphometric traits such as CC, BL, and WH also showed clear interspecies variation. Sheep had greater CC (82.66±0.46 cm), BL (80.03±0.43 cm), and WH (67.78±0.38 cm) compared to goats (70.34±0.75 cm, 69.66±0.80 cm, and 63.67±0.60 cm, respectively). Pearson correlation coefficients between morphometric traits, BW, and HCW for all animals (sheep and goats combined) are presented in Table 2. BW was strongly and positively correlated with HCW (r=0.93, P≤0.001), indicating a close linear relationship between live weight and carcass mass. Among morphometric measurements, CC showed the strongest correlation with BW (r=0.95, P≤0.001), followed by BL (r=0.89, P≤0.001) and WH (r=0.70, P≤0.001).

Similar trends were observed for correlations between morphometric traits and HCW:CC again showed the highest association (r=0.89, P≤0.001), followed by BL (r=0.75, P≤0.001) and WH (r=0.52, P≤0.001). HCY (%), on the other hand, showed only weak or non-significant correlations with morphometric traits, suggesting that yield is less influenced by overall body dimensions and may be more affected by factors such as body composition or fat distribution. Specifically, HCY had a weak correlation with CC (r=0.15, P≤0.05) and was not significantly correlated with BL or WH. When analyzed separately, sheep showed strong and significant positive correlations between morphometric traits and both BW and HCW (Table 3). BW was highly correlated with HCW (r=0.92, P≤0.001). Among the morphometric traits, CC had the strongest correlation with BW (r=0.91, P≤0.001), followed by BL (r=0.81, P≤0.001) and WH (r=0.57, P≤0.001). Similarly, CC also showed the highest correlation with HCW (r=0.87, P≤0.001). HCY in sheep showed a weak but statistically significant correlation with CC (r=0.15, P≤0.05), while correlations with BL and WH were not significant. In goats, strong and statistically significant correlations were observed between morphometric traits and both BW and HCW, while no meaningful associations were found with HCY (Table 4). BW showed a strong correlation with HCW (r=0.90, P≤0.001). Among the morphometric traits, CC showed the strongest correlation with BW (r=0.94, P≤0.001), followed by BL (r=0.89, P≤0.001) and WH (r=0.81, P≤0.001). These traits were also significantly correlated with HCW, with CC again showing the highest correlation (r=0.85, P≤0.001). Predictive models based on morphometric traits were developed to estimate BW and HCW across all animals (sheep and goats), and their performance was assessed through cross-validation (Table 5). For BW, the multiple linear regression model incorporating CC and BL showed the highest predictive power (R^2=0.91; RMSECV=4.44 kg), with a regression slope of 0.91 and minimal bias (–0.07). Among the simple models, the equation using only CC was nearly as effective (R^2=0.90; RMSECV=3.34 kg). In comparison, models using BL (R^2=0.79) or WH (R^2=0.48) alone had lower performance. Similarly, for HCW, the multiple regression model including CC and BL provided the best prediction (R^2=0.80; RMSECV=4.67 kg), outperforming all simple models. The simple regression model based solely on CC also showed strong predictive capacity (R^2=0.79; RMSECV=1.89 kg). In contrast, BL (R^2=0.56) and WH (R^2=0.27) alone were less effective for predicting HCW. All models were statistically significant (P<0.0001), with low bias and slopes close to unity in the most accurate models, indicating strong agreement between predicted and observed values.

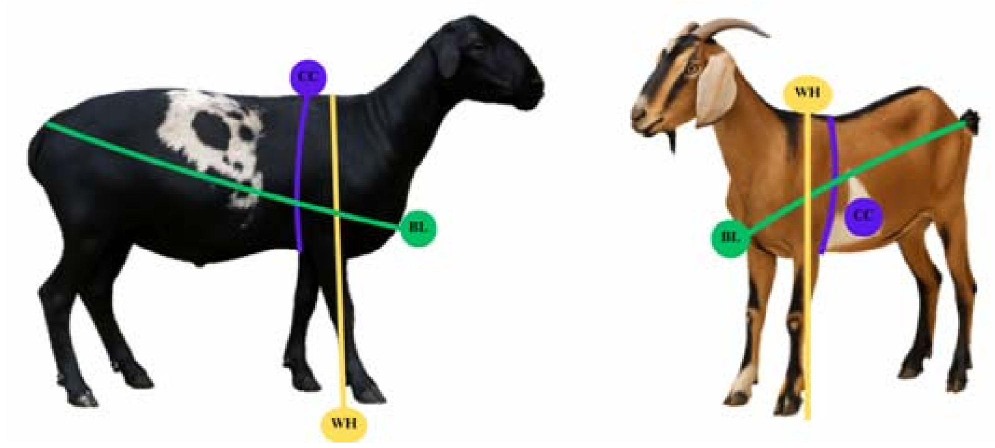

Figure 1 *In vivo* morphometric measurements of goats and sheep
CC: Chest circumference; BL: body length and WH: withers height

Table 1 Descriptive statistics (mean±standard error (SE), standard deviation (SD), minimum, and maximum) for morphometric measurements, body weight, and hot carcass weight of sheep and goats

Item	Sheep					Goat				
	Mean±SE	SD	Minimum	Maximum	N	Mean±SE	SD	Minimum	Maximum	N
Body weight, kg	39.7±0.53	8.35	16.9	60.4	250	27.1±0.75	9.24	6.56	49.3	150
Hot carcass weight, kg	18.5±0.27	3.83	9.54	29.9	200	14.2±0.42	3.35	7.42	24.0	64
Hot carcass yield, %	45.1±0.25	3.60	36.8	57.2	200	43.6±0.52	4.13	33.9	50.9	64
Chest circumference, cm	82.7±0.46	7.34	60.9	102.9	250	70.3±0.75	9.24	42.0	89.1	150
Body length, cm	80.0±0.43	6.73	59.0	101	250	69.7±0.80	9.75	42.0	92.5	150
Withers height, cm	67.8±0.38	6.08	54.0	93.5	250	63.7±0.60	7.30	41.0	85.0	150

N: number of observations.

Table 2 Pearson correlation coefficients between morphometric measurements and body weight and hot carcass weight for all animals (sheep and goats combined)

Item	Body weight, kg	Hot carcass weight, kg	Hot carcass yield, %	Chest circumference, cm	Body length, cm	Withers height, cm
Body weight, kg	1	0.93^{***}	0.05^{ns}	0.95^{***}	0.89^{***}	0.70^{***}
Hot carcass weight, kg		1	0.40^{***}	0.89^{***}	0.75^{***}	0.52^{***}
Hot carcass yield, %			1	0.15^{*}	0.00^{ns}	0.04^{ns}
Chest circumference, cm				1	0.88^{***}	0.73^{***}
Body length, cm					1	0.72^{***}
Withers height, cm						1

* (P≤0.05) and *** (P≤0.001).
NS: non significant.

Table 3 Pearson correlation coefficients between morphometric measurements and body weight and hot carcass weight in sheep

Item	Body weight, kg	Hot carcass weight, kg	Hot carcass yield, %	Chest circumference, cm	Body length, cm	Withers height, cm
Body weight, kg	1	0.92^{***}	0.06^{ns}	0.91^{***}	0.81^{***}	0.57^{***}
Hot carcass weight, kg		1	0.43^{***}	0.87^{***}	0.72^{***}	0.47^{***}
Hot carcass yield, %			1	0.15^{*}	0.00^{ns}	0.06^{ns}
Chest circumference, cm				1	0.77^{***}	0.59^{***}
Body length, cm					1	0.53^{***}
Withers height, cm						1

* (P≤0.05) and *** (P≤0.001).
NS: non significant.

Table 4 Pearson correlation coefficients between morphometric measurements and body weight and hot carcass weight in goats

Item	Body weight, kg	Hot carcass weight, kg	Hot carcass yield, %	Chest circumference, cm	Body length, cm	Withers height, cm
Body weight, kg	1	0.90***	-0.25ns	0.94***	0.89***	0.81***
Hot carcass weight, kg		1	0.17ns	0.85***	0.67***	0.62***
Hot carcass yield, %			1	-0.12ns	-0.27ns	-0.12ns
Chest circumference, cm				1	0.90***	0.87***
Body length, cm					1	0.86***
Withers height, cm						1

* (P≤0.05) and *** (P≤0.001).
NS: non significant.

In sheep, the best predictive model for BW was a multiple linear regression including CC and BL, which explained 85% of the variability (R^2=0.85) and showed good predictive accuracy (RMSECV=4.33 kg), with a slope of 0.88 and negligible bias (–0.00) (Table 6). The simple regression model using only CC also provided high predictive accuracy (R^2=0.82; RMSECV=3.47 kg). In contrast, BL alone yielded a lower R^2 of 0.66, and WH performed poorly (R^2=0.32).

Regarding HCW, the multiple regression model combining CC and BL achieved an R^2 of 0.77 and RMSECV of 4.51 kg, with minimal bias and a slope of 0.79, indicating reliable performance. The simple model based on CC alone explained 75% of the variation in HCW (RMSECV=1.90 kg), while models using BL (R^2=0.51) or WH (R^2=0.22) were less accurate.

In goats, the most accurate predictive model for BW was a multiple linear regression including CC, BL, and WH. This model explained 90% of the variation in BW (R^2=0.90), with an RMSECV of 4.29 kg, a slope of 0.97, and minimal bias (–0.02) (Table 7). Among the simple regression models, CC alone provided the best predictive performance (R^2=0.89; RMSECV=2.95 kg; slope=1.00), outperforming both BL (R^2=0.78; RMSECV=4.22 kg; slope=0.90) and WH (R^2=0.65; RMSECV=5.51 kg; slope=1.01), which showed higher prediction errors and lower explanatory power.

For HCW, the multiple regression model was not statistically significant. The simple model based solely on CC demonstrated the highest accuracy, with an R^2 of 0.73 and an RMSECV of 1.75 kg. In contrast, simple regressions using BL (R^2=0.44; RMSECV=2.48 kg) or WH (R^2=0.39; RMSECV=2.60 kg) showed substantially lower predictive capacity.

This pioneering study on NDB small ruminants highlights the importance of using morphometric measurements to categorize body conformation, compare growth trajectories (Varkoohi *et al*. 2018; Bousbia *et al*. 2021), and provide insights into the morphological structure and developmental potential of these animals (Atoui *et al*. 2023).

The results showed that although sheep had greater BW and HCW than goats, body measurements consistently increased with BW (Table 1), supporting the strong correlations observed and the feasibility of developing combined predictive models for both species.

Correlation analysis revealed that morphometric traits were positively associated with both BW and HCW, which was expected since animals were evaluated across a wide range of ages, covering different points of the growth curve. Accordingly, BL, WH, and CC increased proportionally with BW and HCW. Among these, CC was the most informative predictor, showing the strongest correlations across sheep, goats, and the combined dataset (Tables 2, 3, and 4). In sheep, BW was highly correlated with CC (r=0.91), with a similar pattern observed in goats (r=0.94). This agrees with the typical onset of puberty in crossbred lambs at approximately six months of age (Osório *et al*. 2012; Pereira *et al*. 2023). After this stage, CC remains the principal morphometric variable that continues to change, reflecting increases or decreases in BW and HCW. Our findings corroborate previous studies reporting strong associations between CC and BW in Woyto-Guji goats (r=0.85) and Central Highland goats (r=0.82) (Zergaw *et al*. 2017), as well as in Dorper × Santa Inês sheep (r=0.88; Santos *et al*. 2020) and hair sheep populations (Ramos *et al*. 2019; Costa *et al*. 2020; Gurgel *et al*. 2021). Thus, linear morphometric measurements can serve as reliable indicators of growth throughout an animal's life (Atoui *et al*. 2023).

Our hypothesis that morphometric traits could effectively predict BW and HCW was supported by predictive modeling with cross-validation. The results confirmed the effectiveness of using *in vivo* morphometrics to predict BW and HCW in small ruminants (Tables 5, 6, and 7). While predictive equations can be derived from a single trait, combining multiple variables often increases predictive power, as also shown by Rocha-Silva *et al*. (2024). Nevertheless, several studies have demonstrated that CC alone can reliably predict BW under field conditions (Nahari *et al*. 2018; Abd-Allah *et al*. 2019; Habib *et al*. 2019; Nascimento *et al*. 2019; Dakhlan *et al*. 2020; Silva *et al*. 2024).

Table 5 Predictive models, accuracy, and precision estimates based on cross-validation for body weight and hot carcass weight using morphometric measurements in sheep and goats combined

Response variable[1]	Model type	Mathematical model (±SE)	R^2	RMSECV	Slope	Bias	P-value
Body weight, kg	Multiple	–44.9 ± 1.55 + (0.80±0.03×chest circumference, cm) + (0.27±0.03×body length, cm)	0.91	4.44	0.91	–0.07	<0.0001
	Simple	–43.3 ± 1.31 + (1±0.01×chest circumference, cm)	0.90	3.34	0.95	0.04	<0.0001
	Simple	–41.3 ± 1.98 + (1±0.02×body length, cm)	0.79	4.92	0.84	0.03	<0.0001
	Simple	–36.7 ± 3.71 + (1.08±0.05×withers height, cm)	0.48	7.93	0.73	–0.03	<0.0001
Hot carcass weight, kg	Multiple	–25.0 ± 1.62 + (0.42±0.03×chest circumference, cm) + (0.09±0.03×body length, cm)	0.80	4.67	0.84	–0.07	<0.0001
	Simple	–23.4 ± 1.26 + (0.49±0.01×chest circumference, cm)	0.79	1.89	0.90	0.01	<0.0001
	Simple	–15.9 ± 1.83 + (0.42±0.02×body length, cm)	0.56	2.79	0.79	0.01	<0.0001
	Simple	–7.20 ± 2.50 + (0.36±0.03×withers height, cm)	0.27	3.65	0.73	0.00	<0.0001

R^2: coefficient of determination; RMSECV: root mean square error of cross-validation; SE: standard error; Slope: regression coefficient between predicted and observed values and Bias: mean prediction error.

Table 6 Predictive models, accuracy, and precision estimates based on cross-validation for body weight and hot carcass weight using morphometric measurements in sheep

Response variable	Model type	Mathematical model (±SE)	R^2	RMSECV	Slope	Bias	P-value
Body weight, kg	Multiple	–53.9 ± 2.67 + (0.77±0.04×chest circumference, cm) + (0.34±0.04×body length, cm)	0.85	4.33	0.88	–0.00	<0.0001
	Simple	–45.6 ± 2.51 + (1.03±0.03×chest circumference, cm)	0.82	3.47	0.93	–0.01	<0.0001
	Simple	–41 ± 3.68 + (1.00±0.04×body length, cm)	0.66	4.90	0.88	–0.04	<0.0001
	Simple	–13.5 ± 4.87 + (0.78±0.07×withers height, cm)	0.32	7.03	0.87	–0.03	<0.0001
Hot carcass weight, kg	Multiple	–25.2 ± 1.86 + (0.42±0.02×chest circumference, cm) + (0.10±0.02×body length, cm)	0.77	4.51	0.79	0.00	<0.0001
	Simple	–23.0 ± 1.68 + (0.49±0.01×chest circumference, cm)	0.75	1.90	0.86	0.01	<0.0001
	Simple	–15.1 ± 2.32 + (0.41±0.02×body length, cm)	0.51	2.69	0.79	0.00	<0.0001
	Simple	– (0.29±0.03×withers height, cm)	0.22	3.41	0.82	0.02	<0.0001

R^2: coefficient of determination; RMSECV: root mean square error of cross-validation; SE: standard error; Slope: regression coefficient between predicted and observed values and Bias: mean prediction error.

Table 7 Predictive models, accuracy, and precision estimates based on cross-validation for body weight and hot carcass weight using morphometric measurements in goats

Response variable	Model type	Mathematical model (± SE)	R^2	RMSECV	Slope	Bias	P-value
Body weight, kg	Multiple	–37 ± 2.06 + (0.85±0.06×chest circumference, cm) + (0.25±0.05×body length, cm) – (0.21±0.07×withers height, cm)	0.90	4.29	0.97	-0.02	<0.0001
	Simple	–39.4 ± 1.90 + (0.94±0.02×chest circumference, cm)	0.89	2.95	1.00	0.05	<0.0001
	Simple	–31.5 ± 2.52 + (0.84±0.03×body length, cm)	0.78	4.22	0.90	0.03	<0.0001
	Simple	–38.3 ± 3.89 + (1.00±0.06×withers height, cm)	0.65	5.51	1.01	0.02	<0.0001
Hot carcass weight, kg	Multiple	–20.5 ± 2.67 + (0.45±0.03×chest circumference, cm)	0.73	1.75	1.06	0.02	<0.0001
	Simple	–20.5 ± 2.67 + (0.45±0.03×chest circumference, cm)	0.73	1.75	1.06	0.02	<0.0001
	Simple	–7.83 ± 3.12 + (0.29±0.04×body length, cm)	0.44	2.48	1.28	0.00	<0.0001
	Simple	–12.2 ± 4.20 + (0.39±0.06×withers height, cm)	0.39	2.60	1.36	-0.04	<0.0001

R^2: coefficient of determination; RMSECV: root mean square error of cross-validation; SE: standard error; Slope: regression coefficient between predicted and observed values and Bias: mean prediction error.

Consistent with these findings, our results indicated that simple CC-based models produced slightly lower R^2 values than multivariate models but achieved lower RMSECV, suggesting greater precision. For the combined dataset, R^2 decreased from 0.91 (multivariate) to 0.90 (simple), while RMSECV decreased from 4.44 to 3.34. Similar trends were observed in sheep (R^2=0.85 *vs.* 0.82; RMSECV=4.33 *vs.* 3.47) and goats (R^2=0.90 *vs.* 0.89; RMSECV=4.29 *vs.* 2.95). The same pattern was observed for HCW. For pooled data, the multiple model (R^2=0.80; RMSECV=4.67) performed similarly to the simple model (R^2=0.79; RMSECV=1.89). For sheep, the multiple model (R^2=0.77; RMSECV=4.51) and the simple model (R^2=0.75; RMSECV=1.90) produced comparable results, while the multiple model for goats was not significant.

Model performance was evaluated using cross-validation metrics, including R^2, RMSECV, and bias, following recommendations by Chai and Draxler (2014), Bennett *et al.* (2013), and Rauschenberger *et al.* (2021). High R^2 values and low RMSECV indicated strong predictive capacity, while bias values near zero and slopes close to 1 reflected accuracy. As suggested by Tedeschi (2006), model robustness was assumed when R^2 exceeded 0.80, whereas values below 0.50 indicated poor predictive ability. By these criteria, both BW and HCW in goats and sheep can be effectively predicted, either through species-specific or combined models.

The ability to predict HCW in addition to BW represents an important contribution of this study. Carcass weight is a key determinant of profitability in meat production systems (Alves *et al.* 2019; De Carvalho *et al.* 2025). However, HCW is traditionally assessed post-mortem, limiting its application for management and selection decisions. Our results demonstrate that morphometric models can provide reliable *in vivo* estimates of carcass traits, enabling more efficient selection of superior animals before slaughter. This has direct implications for management, marketing strategies, and breeding programs aimed at improving carcass traits.

Furthermore, this study provides pioneering evidence for the use of *in vivo* morphometric measurements to predict HCW in commercial hair sheep and goats raised under semi-arid conditions in Brazil. The predictive equations developed here validate the feasibility of applying either unified models across species or species-specific models. All models tested were significant and robust, underscoring their suitability for both commercial and research applications in which rapid, non-invasive, and low-cost estimation of BW and HCW is advantageous (Moro *et al.* 2019; Gomes *et al.* 2021).

This study demonstrates that BW and HCW of NDB small ruminants can be predicted with accuracy and precision using morphometric models. These models can be applied separately for sheep and goats or jointly for both species, facilitating practical decision-making in herd management, such as animal grouping, medication dosage, evaluation of growth performance, and carcass estimation. However, future research is needed to assess how variation in HCW influences meat quality parameters and to extend model applicability to other small ruminant populations, including dairy goats and wool sheep, which may present distinct growth patterns and body conformations. Purebred populations should also be investigated, as their genetic uniformity may alter growth dynamics and model performance.

CONCLUSION

The BW and HCW of sheep and goats can be accurately and precisely estimated using *in vivo* morphometric measurements through mathematical models.

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