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Short Communication: Prediction of body weight using morphometric measurements in Creole goats from Peru

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Abstract. *Paredes-Chocce M, Sessarego E, Tafur L, Temoche V, Salinas J, Acosta I, Ruiz J, Cruz J, Trillo F. 2025. Short Communication: Prediction of body weight using morphometric measurements in Creole Goats from Peru. Biodiversitas 26: 3193-3198.* Goats are an important component of smallholder family farms along the coast and highlands of Peru. The weight of an animal is an important indicator of the production and economy of farmers in rural areas. Therefore, this study aimed to develop predictive models for Body Weight (BW) using Morphometric Measurements (MM) of Creole goats (*Capra hircus*) in Perú. BW and five MM were collected from 356 goats from the coast and highlands of Peru. Variables were analyzed using correlation and stepwise regression analysis to select the best model based on the coefficient of determination (r^2), adjusted r^2, Residual Standard Error (RSE), and Akaike Information Criterion (AIC) using the RStudio statistical software. The highest correlation was found between BW and TG (0.76), followed by RW (0.67), and RH (0.65). The combinations of MM selected as predictors of BW by stepwise regression were TG, RH, and RW, with r^2: 0.640. The selected candidate model met all established tests and, upon validation, reached an r^2 of 0.66 ($p<0.001$), indicating that the model can adequately predict the BW of Peruvian Creole goats and serve as a practical tool to support selection programs, feeding strategies, and market decision-making in smallholder systems.

Keywords: Goat farming, goats, morphometric traits, regression model, stepwise

INTRODUCTION

Goats are one of the most abundant and economical sources of animal protein in developing countries. Livestock can contribute to food security and income generation for poor rural households (Hyera et al. 2020). Goat farming represents an important and efficient agricultural enterprise for farmers with limited land and other resources because they require little capital and constitute insignificant competition for arable land in rural areas (Hyera et al. 2020; Cooke et al. 2024). Government initiatives to enhance goat farming is crucial because, although it is considered a secondary livestock activity in the country when compared to other agricultural and livestock activities, it has a very significant economic and social influence on the population in rural areas (Arroyo 1998; Paredes et al. 2024).

In Peru, the Integrated System of Agricultural Statistics (Sistema Integrado de Estadística Agraria 2022), reported a population of 1,774 523 goats, which are mainly raised under an extensive grazing system. Three geographical areas of the country are described, mainly in which these extensive systems exist: north coast; west of the Andes and valleys of the central coast. In north coast are raised mainly for the sale of meat, they are bought by intermediaries who process the animals in slaughterhouses in the cities (Sarria et al. 2014). In the western Andes, goats feed on native vegetation (grasses, herbaceous plants, and shrubs) that grow on the slopes of hills and mountains. While, in the valleys of the central coast, goats graze crop corn (*Zea mays*) and vegetables in summer; cotton (*Gossypium hirsutum*), cassava (*Manihot esculenta*), asparagus (*Asparagus officinalis*) and vegetables in winter) (Sarria et al. 2014).

Body weight is a characteristic of economic importance directly related to the farmer's income, as well as evaluation of the general condition of the animal, evaluation of feed efficiency, calculation of the amount of medicine to be supplied, estimation of carcass yield, and selection criteria for the genetic improvement of Creole goat herds raised in extensive systems (Kunene et al. 2009; Abd-Allah et al. 2019). Morphometric measurements complement productive records to describe an individual or herd, using nonconventional methods to estimate body weight (Mathapo et al. 2022; Okoro et al. 2023).

The problem for goat farmers in rural areas is the lack of knowledge of their body weight at the time of sale. Therefore, a need arises to be able to estimate the body weight of goats in a practical and precise manner. One procedure is that of linear regression models generated from morphometric characteristics that are easy to measure in the field. Weighing animals with a high precision scale would be the most accurate way to estimate them; however, rural goat producers do not have a scale to routinely weigh them. Similarly, high-cost logistics are required, so morphometric measurements and body conditions are reliable alternatives to estimate live body weight (Rocha-Silva et al. 2024).

Various methods have been developed to estimate the live weight of goats (Marco et al. 2022; Mathapo et al. 2022; Rashijane et al. 2023; Tırınk et al. 2023). Stepwise multiple regression allows for better predictions considering morphometric measurements; however, the standard error of the predicted values and the confidence interval are too large. Many authors have reported the use of morphometric measurements to predict body weight in goats and sheep; however, few studies have been conducted in Peru to determine the body weight of Creole goats using morphometric measurements (Palomino et al. 2024, Temoche et al. 2024). Therefore, the objective of the present study was to estimate the live body weight of Creole goats in Peru, based on morphometric measurements.

MATERIALS AND METHODS

The research was conducted between May and September 2023 in eight regions of Peru, where the Caprine project "PROCAP" (Unique Identification Code: 2506684) of the National Institute of Agrarian Innovation developed research and technology transfer activities with farmers who breed Creole goats. Stratified sampling was conducted based on the goat populations reported by Sistema Integrado de Estadística Agraria (2022) in each of the eight PROCAP intervention regions (983 390 goats) using a 95% confidence level and a 5% margin of error. The sample size in each region was stratified based on the districts with the largest number of goats, which are considered the most important and representative of their regions. This sample was collected for monitoring farmers. A total of 1215 goats of milk teeth and full mouth ages were registered. From this group, 356 goats between four and eight years of age were selected for the present study. The animals were distributed across the following regions: Amazonas (10; 0.06%), Ayacucho (53; 0.04%), Ica (50; 0.06%), Lima (56; 0.03%), Piura (74; 0.02%), La Libertad (32; 0.04%), Lambayeque (47; 0.04%), and Tumbes (34; 0.04%). A random sample of animals from each herd was selected for evaluation, ensuring that only those in good health were included in the study. Animals at an advanced stage of pregnancy were excluded from the study. The sampling procedure adhered to Peruvian Law N° 30407-the the Animal Protection and Welfare Law and the guidelines established by the FAO (2012) for proper animal handling.

Six morphometric measurements were selected based on previous studies (FAO 2012; Oyolo 2020). The selected variables were Chest Width (CW), Thoracic Girth (TG), Withers Height (WH), Rump Height (RH), Rump Width (RW), and Rump Length (RL). Data were collected according to the FAO (2012) guidelines. The animals were evaluated by trained personnel using a measuring tape (sensitivity, 0.1 cm), zoometric stick (sensitivity, 0.1 cm), and electronic hook scale (Henkel Games, 200 kg; sensitivity, 0.01 kg). Personnel were trained prior to field sampling. All staff members used measuring instruments of the same brand and model acquired through the PROCAP project. Interobserver measurements were not performed because each trained staff member evaluated only the animals in their work area. Data were analyzed to determine correlations between variables and multiple linear regression using the statistical software R Studio 4.3.2. The correlations between the variables were analyzed using Pearson's correlation, and the regression between BW and body measurements was analyzed using simple and multiple regression. Weight was the dependent variable, and morphometric measurements were independent variables in the regression equations. The collected data were randomly segmented into two parts, with 70% used for model calibration and 30% for validation.

The Shapiro-Wilk test was used to assess the normality of the body weight data and morphometric measurements. The best regression model was selected based on the coefficient of determination (r^2), adjusted r^2, Residual Sum of Squares (RSE), Akaike Information Criterion (AIC), and stepwise regression analysis in the forward direction (Dakhlan et al. 2021). The model with the highest r^2 and adjusted r^2, as well as the lowest RSE and AIC values, was selected as the best regression model to predict the BW of the goats. To ensure the robustness of the model, the normality of residuals, multicollinearity (assessed using the variance inflation factor, VIF) (Akinwande et al. 2015), and heteroskedasticity in multiple linear regression were evaluated as the best model. Cross-validation we also performed to assess the model´s efficiency. The adequacy of the models was evaluated using several criteria, including: the coefficient of determination (r^2), the F-test for the identity of the regression parameters between the predicted and observed data, the Coefficient of Correlation and Concordance (CCC), and the square Root of the Mean Square prediction Error (RMSE) (Tedeschi 2006).

RESULTS AND DISCUSSION

Body weight and morphometric measurements

Averages, standard deviations, ranges, and coefficients of variation of the body weight and morphometric measurements are shown in Table 1. The average body weights of the goats were 47.88 with a standard deviation of 10.66 kg. Based on the Shapiro-Wilk test, it was observed that body weight ($p>0.05$) and morphometric measurements (CW, TG, WH, RH, RW) from goats followed a normal distribution ($p>0.05$). The RL variable did not meet the assumption of normality ($p<0.05$) and was therefore removed from the analysis. With these assumptions, a correlation analysis was performed, and the prediction equations between live weight and morphometric measurements were determined.

Correlation and regression between morphometric measurements and bodyweight of creole goats

The correlation between BW and morphometric measurements (CW, TG, WH, RH, and RW) of Creole goats is shown in Figure 1. High correlations were observed between BW and TG, RH, and RW; therefore, they were considered more suitable for incorporation into the model. The highest correlation was found between BW and TG (0.778, $p<0.001$), followed by RW (0.674, $p<0.001$) and RH (0.650, $p<0.001$). The variable with the lowest correlation with BW was CW (0.532, $p<0.001$). The highest correlation between morphometric measurements was observed between RH and WH (0.845, $p<0.001$). The lowest correlation between morphometric variables was observed between WH and CW (0.520, $p<0.001$). The correlation between BW and morphometric measurements and the regression equation, along with selection parameters for the estimation of BW of Creole goats based on body measurements, are presented in Table 2. Additional models with each variable were tested; however, they were discarded because they showed lower r^2 values. The best two equations found according to stepwise regression are shown.

The highest correlation (0.645) between BW and a combination of morphometric measurements was obtained with the model that incorporated the variables CW, TG, WH, RH, and RW (five predictors); however, the model with the lowest AIC selected by the stepwise algorithm (928.29) incorporated the morphometric measurements TG, RH, and RW (three predictors), which had a correlation of 0.644, similar to the previous one. Because the r^2 values were very close, the best model was selected based on the number of predictors and AIC values. Therefore, it was selected as the most appropriate model for estimating body weight from the morphometric measurements of female Creole goats. The homogeneity of variance tests (heteroskedasticity) and normality of residuals ($p>0.05$) were met with the selected model with nonsignificant values ($p>0.05$); therefore, the model met these conditions.

Table 1. Descriptive statistics of body weight and morphometric measurements in Peruvian Creole goats

Variable	n	Mean±SD	Range	CV (%)
Body weight (kg)	356	48.06±10.51	23.2-75	21.88
Chest width (cm)		18.98±2.75	12.0-27.0	14.50
Thoracic girth (cm)		84.97±7.32	65.0-103.0	8.61
Withers height (cm)		70.49±6.79	49.0-88.0	9.63
Rump height (cm)		72.61±6.57	51.0-89.2	9.05
Rump width (cm)		17.17±2.82	8.70-27.0	16.44

Table 2. Regression equation for estimating the body weight of Peruvian Creole goat based on body measurements along with parameters

Regression equation	r^2	Adj. r^2	RSE	AIC
Y = -46.73 + 0.01CW+ 0.71TG + 0.09WH + 0.14RH + 0.96RW	0.645***	0.638	6.321	931.58
Y = -45.642 + 0.71TG + 0.21RH + 0.99RW	0.644***	0.640	6.305	928.29

Note: Chest Width (CW), Thoracic Girth (TG), Withers Height (WH), Rump Height (RH), Rump Width (RW). ***$p<0.001$

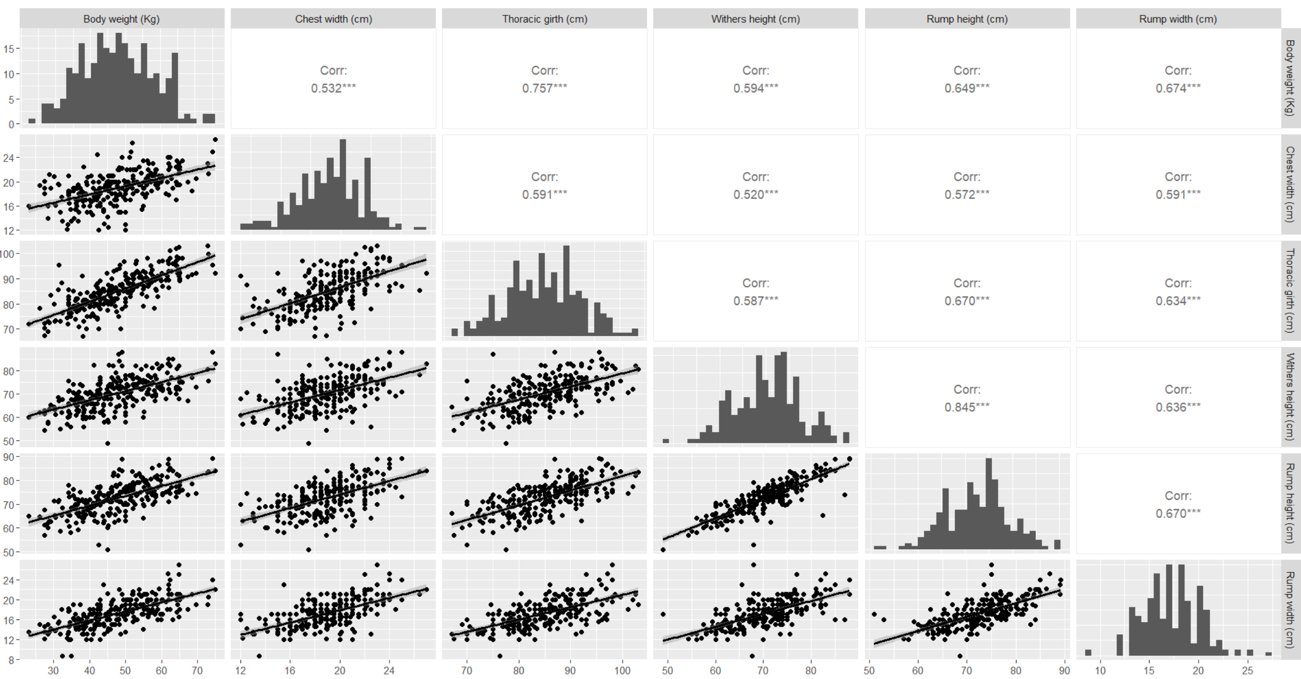

Figure 1. Correlation graph between morphometric variables and body weight for creole goats in Peru

According to the variance inflation factor analysis, the predictor equation values were less than two; therefore, it was concluded that multicollinearity was very low. No evidence of autocorrelation was observed in the Durbin-Watson test, despite an intermediate correlation between the morphometric variables used as predictors. The generated candidate model was tested with a new dataset, and the results of the respective analyses showed an MSE value of 41.54, RMSE of 6.445, MAE of 4.876, and CCC of 0.776. The coefficients for the morphometric measurements in the equation were similar to those obtained during model generation. Furthermore, the predicted values were plotted against the actual values, resulting in an r of 0.79 and r^2 of 0.66, showing that the model explains 66% of the total variability of the data, which is considered acceptable for this study (Figure 2).

Discussion

Body weight and morphometric measurements

The average BW of Creole goats (Table 1) was higher than that reported by Palomino et al. (2024) for the Ayacucho region, whereas the CV was lower, which was due to the higher number of heavy animals and the origin of the herds in this study, which included animals from the Ayacucho region and other regions. Figure 1 and Table 1 show a wide range of variability in BW (23.2-75 kg), which can be associated with factors such as food availability, orientation of the production system, and physiological state of the animal (early pregnancy, production, etc.). Forage availability was associated with the sampling period in each region, with some regions experiencing periods of low forage availability during field sampling, while in others, it was the opposite, affecting the weight of the animals. This variation in feed availability is governed by the geographic area in which the farming takes place (dry forest; west of the Andes and valleys of the central coast), determining the productive objective (milk, meat, and dual purpose), and the selection of animals (e.g., the north coast focuses on the sale of animals as meat as opposed to the central coast, which focuses mainly on milk production) (Arroyo 1998; Sarria et al. 2014; Palomino et al. 2024; Paredes et al. 2024; Temoche et al. 2024). The reproductive status of livestock contributes to the variability of BW because, in goat farming systems, males and females are normally kept in a single pen with little chance to track or control when pregnancy starts (Arroyo 1998). Consequently, it was not possible to distinguish between pregnant and non-pregnant animals during the field sampling.

For morphometric measurements, CW, WH, RH, RW, and TG were higher than that found by Palomino et al. (2024). Body weight values and morphometric measurements were lower than those reported by Oyolo (2020), who evaluated Creole females from the central coast of Peru in the Lima region, finding body weight values of 62.18±10.64 kg and morphometric measurements of TG, WH, RH, RW with values of 92.35±5.46, 79.83±3.75, 81.66±3.40, 20.18±1.97, respectively; only in CW the value was lower (16.75±2.22). The RW values in this study were lower than those found by De la Barra et al. (2019), who found a value of 19.8; however, for WH, the values found in the present study were higher than those reported by the same author (68.0 cm) for Creole goats from the semi-arid region of Chile. Similar morphometric measurements were obtained for Chilean Creole goats, which showed a Creole biotype different from the other specialized breeds used in that study, such as Anglonubian, Saanen, and hybrid. A wide range of values was observed for morphometric measurements of TG, WH, RH, and RW. This may be due to the structure and body type of the animals evaluated, a consequence of their adaptation to the geographical areas of the country, and the type of farming systems in each region.

Correlation and regression between morphometric measurements and bodyweight of creole goats

Pearson's correlation coefficients of 0.84 and 0.63 between BW and TG, and between BW and CW were found in Oyolo (2020), which were higher than those of the present study (0.76 and 0.53, respectively). These differences were attributed to the variability associated with the adaptations of goat populations to climatic differences and management conditions in the eight regions, as well as to their selection due to their productive orientation (meat, milk, and dual purpose). Waheed et al. (2020) found that the BW of Beetal goats had a Pearson correlation value of 0.921 with the variable chest girth in the first place, followed by body length with 0.875, WH with 0.864 and CW with 0.777. The differences found are associated with the sample size and characteristics of the Beetal breed, which could be more homogeneous because it is a specialized livestock breed. Dakhlan et al. (2021) found correlations with similar values, with chest girth having the highest r^2 of 0.956, followed by shoulder height and body length, with values of 0.862 and 0.858, respectively, which were higher than those found in this study.

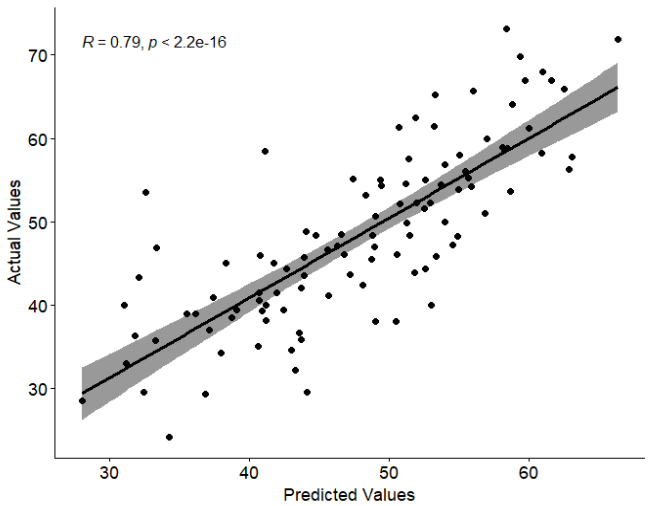

Figure 2. Correlation graph between predicted and actual body weight values estimated by the best multiple linear regression model for Creole goats in Peru

Oliveira et al. (2024) found similar correlations with thoracic perimeters of 0.95 and 0.98 and body length of 0.94 in Brazilian alpine goats. These high correlations indicate that a variable such as TG is strongly correlated with BW and can be a good predictor in a simple linear regression model. Similar to what different authors mention, one of the best predictors of BW is thoracic circumference or girth, depending on the sex and age of the animal (Mahmud et al. 2014; Berhe 2017; Ouchene-Khelifi and Ouchene 2021). This predictor can be used indirectly to select heavier animals; however, it is an imprecise estimate that can be improved with a larger number of predictors.

These models allow for the development of tools, such as zoometric tapes, equations, and mobile applications, to estimate the BW of animals more practically. Farmers can easily perform morphometric measurements, and the tool generates the estimated BW value according to certain criteria previously established during the development of the tools, such as the breed, age, or origin of the animals. However, it is also recommended that a greater number of predictors improve the fit of the model for weight estimation (Sebolai et al. 2012; Dakhlan et al. 2021). The results in Table 2 show that the generated equations have three to six predictors correlated with BW, and the selected candidate model has three. The number of predictors used was higher than Dakhlan et al. (2021) who used two predictors (body length and chest girth) with saburai goats in Indonesia (adjusted r^2 of 0.94); similar to Perez et al. (2016) who found a model with three predictors (Heart girth, body length and rump height) for mixed-breed goats in the Philippines (adjusted r^2 of 0.83) and superior to Sebolai et al. (2012), with Tsawana goats over 37 months of age (adjusted r^2 of 0.57) with a 4-predictor equation (heart girth, body length, shoulder width, height at withers). These results had a higher r^2 and a lower number of predictors owing to the greater homogeneity in the morphometric measurements evaluated in purebred animals. This is different in Creole animals in Peru because of factors such as age, physiological state, and origin of the herds, as well as characteristics not considered, such as the state of pregnancy and body condition of the animals, which can affect the live weight of the animal (Serin et al. 2010). In conclusion, the present study found a model that efficiently predicts live weight based on morphometric measurements of Thoracic Girth (TG), Withers Height (WH), and Rump Width (RW) in Creole goats in Peru.

In conclusion, goat farmers in Peru can use this predictive model to implement breeding programs and facilitate the commercialization of adult Creole goats over four years old. Further studies are needed to improve the predictive model, which includes factors such as body condition scores, age, breed, and physiological state of the animals to build more accurate models; approaches such as machine learning will allow these factors to be used to generate more robust models for body weight prediction. In addition, the possibility of generating regional models should be explored, with a greater number of animals from specific areas, for greater representativeness and usefulness of these models to local farmers.

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