Indian Journal of Animal Sciences **94** (7): 637–641, July 2024/Article
https://doi.org/10.56093/ijans.v94i7.148186

Prediction models for live body weight and body compactness of Criollo sheep in Huancavelica Region, Peru

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Received: 7 February 2024; Accepted: 24 June 2024

ABSTRACT

This study aimed to identify the phenotypic correlations between live weight (LW), zoometric characteristics, and indices in Criollo sheep to develop prediction equations for LW and body compactness. The independent variables included live weight (LW), body length (BL), withers height (WH), chest depth (CD), chest width (CW), chest circumference (CC), muscle circumference (MC), loin width (LW), and loin length (LL). Additionally, body volume (BV), body index (BI), and body compactness (BC) were determined based on zoometric measurements. The evaluations involved 111 male and female sheep aged between 4 and 6 years, data collection took 3 months, from March-May, 2023. The correlations between the characteristics and LW were positive and statistically significant, except for MC. Criollo sheep were classified as brachylines based on the BI value of 69.16±7.20. Substantial and strong correlations were found between BI, BC1, BC2, BC3, and live weight. Prediction equations were developed to estimate live weight using chest circumference, with the quadratic equation proving the most efficient. When body volume was considered a predictor, the cubic equation (R^2=0.46) demonstrated better accuracy in predicting live weight. The multiple regression equation incorporating live weight and body length achieved a superior fit (R^2=0.99) in predicting the body compactness of sheep. This equation is recommended for its accuracy, practicality, and ease of use.

Keywords: Body volume, Characteristics, Characterization, Criollo sheep, Productive relationships, Zoometric índices

The sheep population in Peru is 9,523,198 animals. Criollo sheep make up 81% of the total population, followed by the Corriedale breed with 11%, followed by other breeds with 4%. (INEI 2012). Understanding the characteristics and indices of Criollo sheep is important for several reasons (Whannou *et al*. 2021). Firstly, Criollo sheep have adapted to specific marginal environments and harsh climates, making them well-suited for certain ecological niches and providing a sustainable resource for local communities (Vivas *et al*. 2020). Secondly, their unique genetic makeup and long-standing adaptation to local conditions may yield valuable insights into genetic resilience and potential contributions to breeding programs focused on enhancing productivity and adaptability in sheep populations (Salinas-Rios *et al*. 2021). Therefore, assessing the zoometric characteristics and indices of Criollo sheep is essential for informed breeding and conservation strategies that can preserve their valuable genetic traits.

While there is existing knowledge on biometric measurements and weight estimation in various species and breeds, relying solely on data from other breeds may not accurately represent the specific characteristics and body composition of Criollo sheep. Criollo sheep exhibit distinct morphological traits resulting from their unique genetic heritage and adaptation to local conditions (Silva-Jarquin 2019; Ormachea *et al*. 2020). Therefore, it is crucial to determine specific zoometric indices for Criollo sheep that accurately reflect their physical attributes and allow for precise weight estimation tailored to this breed.

Therefore, the objectives of this study were to comprehensively characterize and correlate the zoometric characteristics and indices of Criollo sheep (*Ovis aries*) and to predict live weight and body compactness indices.

MATERIALS AND METHODS

Study area: The study was conducted at the Municipal Slaughter House in the district, province, and region of Huancavelica, Peru. The geographical location is a temperate-arid zone. The location coordinates were south latitude and 74°58’21” west longitude, at an altitude of 3704 meters. The study was performed during the rainy

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season between the months of February and March 2023, with an annual maximum temperature of 16°C (61ºF), a minimum temperature of 2°C (36ºF), and an average annual precipitation of 784 mm.

Animals and distribution: Peruvian Creole sheep, consisting of 56 males (50.45%) and 55 females (49.55%), were utilized in the present study. The age of each individual was determined by dental chronology. It was observed that 65.77% of the animals had 6 teeth, with a distribution of 39 males and 34 females in this group. The remaining 34.23% had 4 teeth, distributed in 17 males and 21 females. The animals were raised in a co-grazing system with cattle, sheep, alpacas, and llamas, and their diet primarily consisted of high-altitude natural grasslands and crop stubble, supplemented occasionally with barley and/or oat hay. All procedures related to animal care and handling were approved by LETTER N° 005-GRJ-DRA-AAC-PERÚ-2023. This follows the protocols and ethics in the use of animals, for animal welfare purposes.

Data collection: One day prior to animal slaughter, the weight of each animal was recorded using a 150 kg capacity livestock scale (Model PCE-HS N, sensitivity ±0.01 g). Zoometric measurements were determined according to Birteeb *et al*. (2024) using a graduated tape measure in centimeters. These measurements included: body length (BL), the distance from the point of encounter to the ischium on the same side; withers height (WH), the distance from the base of the floor to the withers; chest depth (CD), the distance from the withers to the elbow; chest width (CW), a measurement taken with a square from both the left and right flanks; chest circumference (CC), taken over the fifth thoracic vertebra and the sternum behind the elbow line; muscle circumference (MC), measured at the middle part of the leg; loin amplitude (LA), the distance from the rump to the ischium; and loin length (LL), the distance from the iliac tuberosity to the ischium.

In addition, body volume (BV), calculated as the product of body length and thoracic circumference (Koritiaki *et al*. 2013), and body compactness indices: BC1, calculated as the ratio of live weight to body length multiplied by 100 (Costa *et al*. 2006), BC2, calculated as the ratio of live weight to thoracic circumference multiplied by 100 (Costa *et al*. 2006), BC3, which relates live weight to withers height multiplied by 100 (Flórez *et al*. 2020), and the body index (BI), calculated as the ratio of body length to thoracic circumference multiplied by 100 (Flórez *et al*. 2020).

Statistical analysis: The Pearson correlation coefficients between the traits and body compactness indices were categorized using the scale suggested by (Wang *et al*. 2022). According to this scale, correlations were classified as low when r was equal to or less than 0.30, moderate when r was greater than 0.30 but less than 0.70, and high when r was equal to or greater than 0.71.

To predict live weight (LW) and body compactness indices (BC1, BC2, and BC3), equations of first, second, and third-order polynomials were used. Following the approach proposed by (Araújo *et al*. 2021), the Pearson correlation coefficients with the highest values between live weight and the studied zoometric traits were selected for further multiple linear regression analysis of the first degree. The selection of prediction models was based on the significance of linear, quadratic, and cubic coefficients using the Student's t-test at significance levels of 0.1%, 1%, and 5%.

RESULTS AND DISCUSSION

Phenotypic correlations: Positive and moderately high correlations (P<0.001) were observed between BL, WH, CD, CW, CC, LW, LL, and LW (Table 1). The CC and CW showed the highest correlations with LW (0.59 *vs.* 0.53).

Table 1. Pearson phenotypic correlations between zoometric characteristics and live weight in Peruvian Criollo sheep (n = 111) from the high Andean zone of the Huancavelica region (Peru), considering the entire set of animals (both gender and age)

Characteristic	BL	WH	CD	CW	CC	MC	LW	LL
Live weight (LW)	0.43 ***	0.30 **	0.35 ***	0.53 ***	0.59 ***	-0.005 ns	0.35 ***	0.41 ***
Body length (BL)		0.34 ***	0.50 ***	0.35 ***	0.39 ***	-0.001 ns	0.27 **	0.30 **
Withers height (WH)			0.50 ***	0.30 **	0.22 *	0.17 ns	0.26 **	0.26 **
Chest depth (CD)				0.40 ***	0.42 ***	0.05 ns	0.34 ***	0.33 ***
Chest width (CW)					0.70 ***	0.26 **	0.55 ***	0.49 ***
Chest circumference (CC)						0.18 ns	0.61 ***	0.60 ***
Muscle circumference (MC)							0.09 ns	0.05 ns
Loin width (LW)								0.47 ***
Loin length (LL)								

ns, No significant; *, P<0.05; **, P<0.01; ***, P<0.001.

Table 2. Pearson correlations between zoometric characteristics and body compactness indices in Peruvian Criollo sheep from the Huancavelica region, Peru

Characteristic	BV	BI	BC1	BC2	BC3
Live weight (LW)	0.63 ***	-0.23 *	0.85 ***	0.75 ***	0.87 ***
Body length (BL)	0.81 ***	0.42 ***	-0.11 ns	0.20 *	0.27 **
Withers height (WH)	0.33 ***	0.06 ns	0.12 ns	0.16 ns	-0.17 Ns
Chest depth (CD)	0.54 ***	-0.007 ns	0.07 ns	0.04 ns	0.09 Ns
Chest width (CW)	0.64 ***	-0.39 ***	0.38 ***	0.09 ns	0.39 ***
Chest circumference (CC)	0.86 ***	-0.67 ***	0.41 ***	-0.07 ns	0.50 ***
Muscle circumference (MC)	0.11 Ns	-0.17 ns	-0.009 ns	-0.15 ns	-0.10 Ns
Loin width (LW)	0.54 ***	-0.38 ***	0.21 *	-0.09 ns	0.25 **
Loin length (LL)	0.55 ***	-0.35 ***	0.26 **	0.008 ns	0.29 **
Body volume (BV)[1]		-0.20 *	0.22 *	0.08 ns	0.48 ***
Body index (BI)[2]			-0.49 ***	0.23 ns	-0.27 **
Body compactness 1 (BC1)[3]				0.73 ***	0.80 ***
Body compactness 2 (BC2)[4]					0.69 ***
Body compactness 3 (BC3)[5]					

[1] BV=(BL × CC); [2]BI=(BL/CC) × 100; [3]BC1=(LW/BL) × 100; [4] BC2=(LW/CC) × 100; [5] BC3=(LW/WH) × 100.

Therefore, selecting animals with higher mature weights would likely result in an increase in these two characteristics and consequently in the size of the animal (Costa *et al*. 2006). Correlation estimates in Criollo sheep have been reported as 0.90 (Ormachea *et al*. 2020), 0.98 (16, 5), 0.98 (males) and 0.91 (females), 0.78 (Montesinos *et al*. 2012), 0.83 (De la Rosa *et al*. 2012), and 0.99 (Dantas *et al*. 2016). In cattle, the correlation is 0.90 and 0.91 (Contreras *et al*. 2020), in goats ranges from 0.89 to 0.93 (Fonseca *et al*. 2021). Therefore, the CC is the characteristic most strongly correlated with LW.

The positive and significant correlations between LW and the other characteristics are high, which could be attributed to the small sample size considered in this study. Ventura-León *et al*. (2023) mentioned that the correlation coefficient obtained from the sample is a slightly biased estimator that may underestimate the population correlation coefficient, which may have occurred in this study due to the use of bivariate random variables.

Among the correlations, LW and LL showed the highest coefficients of correlation with CC (0.61 vs. 0.60), which could potentially allow for indirect selection of sheep with higher LW or LL by selecting for CC. Furthermore, CC showed a high positive correlation with CW (R^2=0.70, P<0.001), highlighting the importance of these two characteristics in selection programs aimed at improving meat production.

The characteristics most strongly correlated with body volume (BV) were body length (BL) and chest circumference (CC) with positive, high, and significant coefficients (0.81 *vs.* 0.86, respectively) (P<0.001; Table 2). In line with this, Ormachea *et al*. (2023) also obtained a significant positive correlation (0.92) between BV and CC. Furthermore, positive, moderately high, and significant correlations (P<0.001) were found between live weight (LW), with WH, CD, CW, LW, LL, and BV. Ormachea *et al*. (2023) reported a correlation estimate of 0.96 between LW and BV. Fonseca *et al*. (2021) reported a correlation value of 0.90 between LW and BV in growing Saanen goats. In the present study, the correlation between these two characteristics (R^2=0.63) was the most suitable for predicting the live weight of the sheep. This finding is consistent with McMgregor (2017), who suggested that body volume is the ideal characteristic for predicting weight and carcass traits in Angora goats.

The body compactness indices BC1, BC2, and BC3 showed very high and significant correlations (P<0.001) with live weight (LW). These results confirms the correlations of LW with BC1 and BC2 in sheep, which were reported as 0.97 and 0.97, respectively by Costa *et al*. (2006). In goats, Fonseca *et al*. (2021) obtained correlations between LW and body compactness of 0.86

Table 3. Prediction equations for live weight (LW) and body compactness in Peruvian Criollo sheep in Huancavelica, Peru

Independent variable	Equation	R^2
CC	$LW = 1.71 + 0.41^{***}CC$	0.3520
$CC + CC^2$	$LW = 95.41 – 2.014^{*}CC + 0.016^{**} CC^2$	0.3963
CW + CC	$LW = - 0.68 + 0.58^{*}CW + 0.30^{**}CC$	0.3800
BV[1]	$LW = 11.75 + 0.0052^{***}BV$	0.4014
$BV + BV^2 + BV^3$	$LW = 253.56 – 0.162^{**}BV + 0.000038^{**}BV^2 -2.88^{**}E\text{-}9BV^3$	0.4594
BL + CW + CC + BV	$LW = 6.19 + 0.55^{*}CW + 0.004^{***}BV$	0.4214
LW	$COMPC\ 1 = 15.09 + 1.42^{***}LW$	0.7120
LW + CC + BL	$COMPC\ 1 = 64.18 + 1.85LW^{***}- 1.186^{***}BL$	0.9948
LW	$COMPC\ 2 = 16.32 + 0.80^{***}LW$	0.5704
$LW+ LW^2$	$COMPC\ 2 = - 5.81 + 2.11^{***}LW – 0.019^{*}LW^2$	0.5894
LW + CC + BL	$COMPC\ 2 = 46.62 + 1.312^{***}LW – 0.583^{***}CC -0.040^{*}BL$	0.9856
LW	$COMPC\ 3 = 10.12 + 1.37^{***}LW$	0.7506
$LW + LW^2$	$COMPC\ 3 = - 22.10 + 3.28^{***}LW – 0.028LW^2$	0.7686
LW + CC + BL	$COMPC\ 3 = 20.30 + 1.46^{***}LW – 0.246^{*}BL$	0.7664

[1]Corporal volume (BL x CC); COMPC 1 (LW/BL) x 100; COMPC 2 (LW/CC) x 100; COMPC 3 (LW/WH) x 100.

and 0.95, respectively. These authors also indicated that higher body compactness is associated with greater muscle development and fat accumulation (kg/cm), and that LW is the best characteristic for predicting body compactness in goats.

Equations for the prediction of live weight and body compactness: The quadratic equation is given here.

$$LW = 95.41-2.014 * CC + 0.016 * CC2\ (R^2=0.40)$$

Where, CC as the explanatory variable, demonstrated a better option for predicting live weight compared to simple linear regression (Table 3). The combination of CW and CC in the multiple regression equation did not contribute significantly (R^2=0.38) to live weight prediction. Body volume (BV) provided a better fit for the data in predicting live weight with the cubic regression equation (R^2=0.46) compared to the simple linear regression equation (R^2=0.40).

The multiple regression equation including CW and BV showed a slight increase in R^2 (0.42) in predicting live weight. This demonstrates that in the present study, performing more than one measurement leads to minimal benefits in the accuracy of the estimates, which does not justify the additional work and time required.

Body compactness is a characteristic used to assess the amount of tissue deposited in the animal's body, serving as an indicator of carcass conformation (Osório and Osório 2005). In present study, the multiple regression equations used is presented below.

$$COMPC\ 1 = 64.18 + 1.85 * LW - 1.186 * BL\ (R^2 = 0.99) \text{ and}$$
$$COMPC\ 2 = 46.62 + 1.312 * LW - 0.583 * CC - 0.040 * BL$$

It provided the best fit (R^2 = 0.99) for the data on body compactness in sheep. This behaviour was not observed when predicting body compactness 1 and 2 (R^2 = 0.71 vs. R2 = 0.57) considering only LW. This study demonstrates that using multiple regression equations based on multiple characteristics leads to increased accuracy in the estimates. This result is in conformity with the study in Criollo cattle (Contreras *et al*. 2020), where thoracic circumference, wither height, and body length included in the prediction model showed higher precision (R^2=1.0) compared to the simple linear regression equation that only considered thoracic circumference (R^2=0.93).

Conclusively, the chest circumference and chest width were the measurements that could be used to predict live weight in Peruvian Criollo sheep, although with some restriction due to moderately high correlation values. Additionally, body volume could be used to estimate live weight, as there was a high correlation between these characteristics. Live weight alone would be sufficient to predict body compactness in the animals. However, the inclusion of live weight, thoracic circumference, and body length in a multiple regression equation allows for the prediction of sheep compactness without any limitations.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude for the support provided by the research group in Pastures and Forages of the Professional School of Animal Science at the National University of Huancavelica, Peru for data collection.

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