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Prediction of live weight in growing hair sheep using the body volume formula

[Predição do peso vivo de ovelhas deslanadas em crescimento usando a fórmula do volume corporal]

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ABSTRACT

Due to the conditions in which traditional sheep production systems operate, the evaluation of animal growth from live weight (LW) is limited by the high cost of the livestock scale as well as the sophisticated maintenance required. In this scenario, in recent years, biometric measurements have been investigated as an accurate indirect method to predict the LW of farm animals. Therefore, the present study was undertaken to examine different models for predicting the body weight of growing lambs using the body volume (BV) formula. Body volume, heart girth (HG) and body length (BL) data of 290 lambs aged between two and eight months were recorded. Body volume was calculated from HG and BL data using a formula that calculates the volume of a cylinder. The estimation of LW from the BV formula was achieved through regression equations using three mathematical models (linear, quadratic and exponential). The mean values of LW, HG, BL and BV of the lambs were 29.12±12.04kg, 70.00±11.69cm, 38.40±6.43cm and 23.93±9.90dm^3, respectively. The correlation coefficient between LW and BV was r = 0.96 (P<0.001). The quadratic model showed the highest coefficient of determination (0.93) and the lowest prediction error (3.29kg). Under the experimental conditions adopted in this study, it is possible to predict the live weight of growing lambs using the body volume formula.

Keywords: biometric measurements, mathematical equations, prediction models

RESUMO

Devido às condições dos sistemas tradicionais de produção de ovinos, a avaliação do crescimento animal a partir do peso vivo (PV) é limitada pelo alto custo da balança pecuária, bem como pela sofisticada manutenção necessária. Assim, nos últimos anos, as medidas biométricas (MB) têm sido avaliadas como um método indireto e preciso para predizer o PV de animais de criação. Portanto, o objetivo desta pesquisa foi avaliar diferentes modelos de predição do PV de cordeiros em crescimento utilizando-se a fórmula do volume corporal (VC). Foram registrados dados de PV, perímetro torácico (PT) e comprimento corporal (CC) de 290 cordeiros entre dois e oito meses de idade. O VC foi calculado com base nos dados PT e CC, sendo usada uma fórmula que calcula o volume de um cilindro. A previsão do PV a partir da fórmula VC foi estimada por meio de equações de regressão, utilizando-se três modelos matemáticos (linear, quadrático e exponencial). Os valores médios do PV, PT, CC e VC dos cordeiros foram 29,12±12,04kg, 70,00±11,69cm, 38,40±6,43cm e 23,93±9,90 (dm^3), respectivamente. O coeficiente de correlação entre PV e VC foi r=0,96 (P<0,001). O modelo quadrático apresentou o maior coeficiente de determinação (0,93) e o menor erro de predição (3,29kg) Nas condições do presente estudo, conclui-se que é possível predizer o peso vivo de cordeiros em crescimento por meio da fórmula de volume corporal.

Palavras-chave: equações matemáticas, medidas biométricas, modelos de predição

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INTRODUCTION

Because of the conditions in which traditional sheep production systems operate, the evaluation of animal growth, which could be achieved using direct-measurement equipment such as livestock scales, often represents a challenge for producers due to its high cost (Chay-Canul *et al*., 2019; Canul-Solís *et al*., 2020; Salazar-Cuytun *et al*., 2021). Coupled with this, the calibration and maintenance of measurement equipment require trained technicians, who are not commonly available in rural areas (Málková *et al*., 2021; Salazar-Cuytun *et al*., 2021). As a result, the limitations of measuring equipment in traditional production systems cause the animals to be sold through negotiation or based on visual assessment, which leads to high errors in the estimation of body weight (BW), ultimately affecting the economic gains of producers (Kumar *et al*., 2018; Paputungan *et al*., 2018; Salazar-Cuytun *et al*., 2021).

In the case of sheep, several authors have developed equations to estimate BW from biometric measurements such as heart girt (HG), body length (BL), withers height, hip width, and rump height, mainly (Kumar *et al*., 2018; Chay-Canul *et al*., 2019; Huma and Iqbal, 2019; Worku, 2019; Canul-Solís *et al*., 2020; Gurgel *et al.*, 2021). These researchers concluded that HG is the most important biometric measurement for the estimation of the animals' LW, since a high relationship was found between both body measurements. However, to improve the accuracy of prediction of LW, Paputungan *et al*. (2018) and Salazar-Cuytun *et al*. (2021) combined HG and BL data to calculate the body volume (BV) of the animals by adapting the formula used to calculate the volume of a cylinder. In this method, HG and BL represent the circular line and the height of the cylinder shape, respectively (Paputungan *et al*., 2018; Salazar-Cuytun *et al*., 2021). Despite the advantages the BV formula could offer to producers and researchers in estimating the LW of farm animals (Takaendengan *et al*., 2012; Paputungan *et al*., 2015, 2018; Le Cozler *et al*., 2019), it has been poorly explored in hair sheep breeds at different physiological stages (Salazar-Cuytun *et al*., 2021). In this scenario, we hypothesize that body volume can be used to predict the live weight of hair lambs at different physiological stages. Therefore, the present study was carried out to predict the BW of growing hair lambs using the BV formula calculated from HG and BL data.

MATERIAL AND METHODS

The animals included in the present study were managed in compliance with the ethical guidelines and regulations for animal experimentation of División Académica de Ciencias Agropecuarias at Universidad Juárez Autónoma de Tabasco (approval code: UJAT-DACA-2015-IA-02). The animals were raised at the Sheep Integration Center of the Southeastern (Centro de Integración Ovina del Sureste; 17° 78" N, 92° 96" W; 10m asl), located on the Villahermosa-Teapa road, Mexico.

Live weight, HG and BL data were obtained from 290 clinically healthy hair lambs (Pelibuey and its crosses with Blackbelly and Katahdin) aged between two and 10 months. Live weight was recorded by weighing the animals on a fixed platform scale with a capacity of 300 kg and precision of 10 g, whereas HG and BL were recorded using a flexible fiberglass tape measure (Truper®), considering the anatomical references described by Bautista-Díaz *et al*. (2020).

Body volume was estimated using the formula to calculate the volume of a cylinder, by including the measurements of HG and BL in its composition.

The volume (m^3) was thus calculated as follows:

$$\text{Radius (cm)} = HG/\ 2\pi$$

$$\text{Volume } (dm^3) = (\pi \times r^2 \times BL)/1000,$$

where r = circumference radius (cm); π = 3.1416; HG = heart girth (cm); and BL = body length (cm).

For the statistical analysis and internal validation of the model, the data were read in the Python environment as follows: descriptive statistics were obtained using the description function of the "pandas" package (Mckinney, 2010). The ratio between BV and LW was determined by linear (Eq. 1), quadratic (Eq. 2) and allometric (Eq. 3) equations using the "lmfit" package (Newville *et al*., 2014). The following allometric equation was fitted: Y = aX ** b, where Y represents LW, X represents BV and a and b are parameters of the model. The models and their residuals were plotted with the "matplotlib" package (Hunter, 2007). The goodness-of-fit of the regression models was evaluated using the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), the coefficient of determination (R^2), the mean square error (MSE) and the root MSE (RMSE). The last three parameters were obtained using the "scikit-learn" package (Pedregosa *et al*., 2011).

The predictive capacity of the three models for LW was evaluated by cross-validating *k*-folds (*k* = 10). This approach was undertaken by randomly dividing the set of observation values into non-overlapping k-folds of approximately the same size. The first fold is treated as a validation set, and the model fits the remaining *k*-1 folds (training data). The ability of the fitted model to predict the actual observed values was evaluated using MSE, R^2, and the mean absolute error (MAE). The mean absolute error is an alternative to the mean squared prediction error (MSPE) that is less sensitive to outliers and is related to the mean absolute difference between observed and predicted results. Lower values of root MSPE and MAE indicate a better fit. The *k*-folds cross-validation was performed using the "scikit-learn" package (Pedregosa *et al*., 2011), which allowed a comparison of numerous multivariate calibration models.

RESULTS AND DISCUSSION

Table 1 shows the descriptive statistics of LW and the biometric measurements recorded in growing hair lambs. The mean values of LW, HG, BL and BV were 29.12±12.04kg, 70.00±11.69cm, 38.40±6.43cm and 23.93±9.90 dm^3, respectively. The mean values of LW and the biometric measures described in this study agree with those reported in lambs of other breeds raised in tropical regions of other countries (Taye *et al*., 2011; Younas *et al*., 2013; Worku, 2019).

Table 1. Descriptive statistics of LW and biometric measurements recorded in growing hair lambs

Variable	N	Mean ± SD	Minimum	Maximum	CV (%)
LW (kg)	290	29.12 ± 12.04	6.08	6200	41.36
HG (cm)	290	70.00 ± 11.69	43.00	97.00	16.71
BL (cm)	290	38.40 ± 6.43	24.00	55.00	16.74
BV (dm^3)	290	23.93 ± 9.90	593	52.94	41.37

LW: live weight; HG: heart girth; BL: body length; BV: body volume; N: number of observations; SD: standard deviation; CV: coefficient of variation.

The correlations indicated a positive and significant association (P<0.001) between LW and the biometric measurements (r=0.95 for HG and r=0.85 for BL). Likewise, LW showed a positive and significant correlation (P<0.001) with BV (r=0.96). Several studies with cattle (Paputugan *et al*., 2015, 2018), sheep (Taye *et al*., 2011; Iqbal *et al*., 2014; Chay-Canul *et al*., 2019; Worku, 2019) and goats (Adhianto *et al*., 2020; Dakhlan *et al*., 2021; Peña-Avelino *et al*., 2021; Ouchene-Khelifi and Ouchene, 2021) identified a high correlation between live weight and heart girth. In adult sheep, Kumar *et al*. (2018) found a genetic correlation of 0.51±0.13 between LW and HG, as well as a heritability of 0.61±0.16, confirming that LW can be estimated under field conditions using HG as a predictor. On the other hand, Paputugan *et al*. (2015) reported a correlation of r=0.72 between LW and BV in Ongole crossbred cows. This group of researchers also found a correlation of r≥0.90 between BV and HG in local Bali cattle of different ages.

Three models were fitted to explore the relationship between LW and BV in growing lambs, as follows: 1) linear (Eq. 1), 2) quadratic (Eq. 2) and 3) allometric (Eq. 3) (Table 2; Figure 1). Salazar-Cuytun *et al*. (2021) found a correlation coefficient (r) of 0.89 between LW and BV (P <0.001) in Pelibuey lambs and sheep. Likewise, these authors reported that these variables better fitted a quadratic model, which showed the highest coefficient of determination (R^2=0.81) and the lowest values of MSE (4.17), RMSE (2.04), AIC (1163.64) and BIC (1175.66). These results agree with those obtained in the present study, since although the three developed models showed a similar coefficient of determination (r^2=0.93), the quadratic model exhibited lower values of MSE (9.74), RMSE (3.12), AIC (663.27) and BIC (674.28). Moreover, during the *k*-fold cross-validation process (k = 10), the quadratic model had the highest r^2 (0.92) and the lowest RMSPE (3.11) and AME (2.33) (Table 3). Therefore, the quadratic model was the mathematical model with the best performance according to the evaluation of goodness-of-fit to predict the LW of growing hair lambs using BV calculated from HG and BL data. Although the results agree with those reported by Salazar-Cuytun *et al*. (2021), it should be noted that their models were developed in Pelibuey lambs and sheep. In this respect, it has been established that body conformation and body fat deposition may differ between animals of different sexes and breeds — aspects that may interfere with the correlation between some biometric measurements and LW in sheep (Wamatu and Alkhtib, 2021; Salazar-Cuytin *et al*., 2021). For this reason, models must be developed for animals of different physiological conditions and sexes, in different management scenarios, to improve decision-making and the economic benefits provided by determining and monitoring the LW of domestic animals (Sherwin *et al*., 2021; Málková *et al*., 2021; Salazar-Cuytun *et al*., 2021).

Table 2. Live weight prediction equations using body volume in growing hair lambs

No.	Equation	N	R2	MSE	RMSE	AIC	BIC	P-value
1	LW (kg): 1.11 (± 0.50*) + 1.17 (± 0.02***) × BV	290	0.93	10.84	3.29	693.20	70054	<0.0001
2	LW (kg): -2.84(± 0.83***) + 1.58 (± 0.07***) × BV - 0.008 (± 0.001***) × BV^2	290	0.93	9.74	3.12	663.27	674.28	<0.0001
3	LW (kg): 1.56 (± 0.10***) × $BV^{0.93\ (\pm 0.02*)}$	290	0.93	10.48	3.23	683.58	690.92	<0.0001

LW: live weight; BV: body volume; AIC: Akaike Information Criterion; MSE: mean square error; RMSE: Root MSE; BIC: Bayesian Information Criterion. Values in parentheses are the standard errors (SE) of the parameter estimates. The * indicates: *: P<0.05; **: P<0.01; ***: P<0.001

On the other hand, Paputungan *et al*. (2018) determined higher and more consistent coefficients of determination (from r = 0.92 to r = 0.96), using BV as the only predictor variable in local Bali cattle, compared with simple regression models using the independent variables of HG and BL. Likewise, in horses, Takaendengan *et al*. (2012) reported that LW could be predicted with high precision from BV with a coefficient of determination of r^2 = 0.92, which is higher than that obtained in the model in which only HG was used (r^2 = 0.90). The foregoing shows that the animals' LW could be predicted with greater precision from the BV formula that comprises HG and BL instead of a single biometric measurement.

Table 3. Internal k-folds cross-validation of the proposed models

Model	N	r^2	MSPE	MAE
Linear	290	0.91	3.29	2.55
Quadratic	290	0.92	3.11	2.33
Exponential	290	0.91	3.22	2.47

MSPE: mean squared prediction error; r^2: coefficient of determination; MAE: mean absolute error

In terms of management, determining LW is important in the design of animal nutrition and health programs (Sabbioni *et al*., 2020). In the specific case of sheep meat breeds, live weight is essential to choose the ideal time for slaughter and the optimal carcass endpoint (Bautista-Díaz *et al*., 2017, 2020; Canul -Solís *et al*., 2020; Sabbioni *et al*., 2020). Some authors evaluated the use of biometric measurements as an alternative, practical and low-cost method that allows small producers to estimate the body weight of Pelibuey sheep in farming conditions. This approach consists of the development of mathematical equations from some biometric measurements that are taken directly on the animal (Chay-Canul *et al*., 2019; Canul-Solís *et al*., 2020). Multiple studies have reported variations in the ability of producers and veterinarians to accurately estimate the live weight of cattle visually, and most people underestimate the live weight of animals, which could lead to an increased risk of development of antibiotic and anthelmintic resistance (Málková *et al*., 2021; Sherwin *et al*., 2021; Salazar-Cuytun *et al*., 2021).

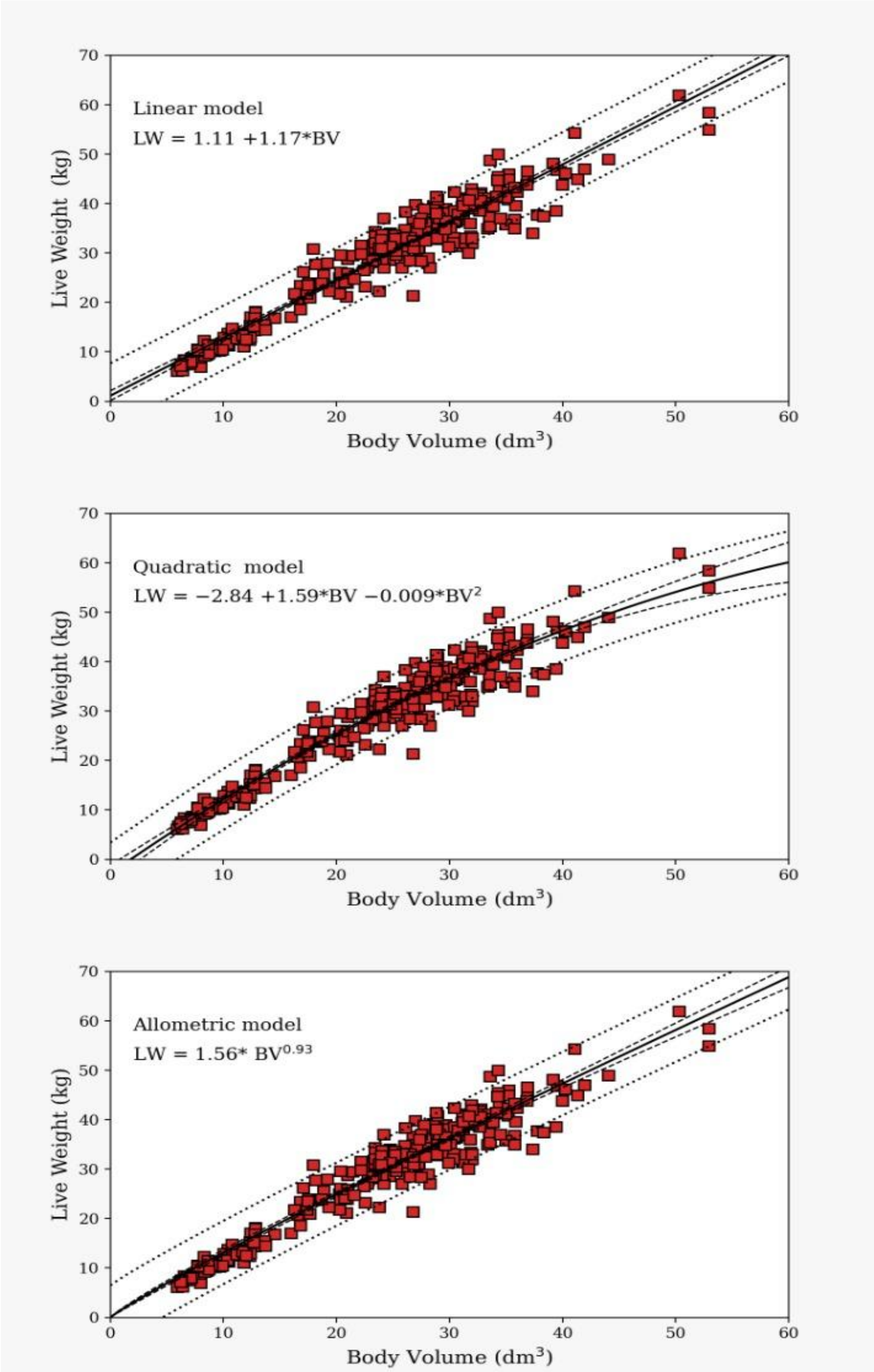

Figure 1. Relationship between live weight and body volume in growing Pelibuey lambs.

The practical implication of this study is the use of the most important biometric measurements, from the anatomical point of view, in a mathematical formula to improve the indirect estimation of live weight in growing sheep, since the internal organs are housed in the abdominal cavity. Therefore, the weight percentage considered in the estimate is higher.

CONCLUSIONS

This study revealed that there is a high relationship between LW and BV in growing hair lambs. The quadratic model showed the highest coefficient of determination and the lowest values of MSE, RMSE, AIC and BIC among the models. Cross-validation analysis confirms the obtained results, in which the quadratic model had the highest r^2 and the lowest values of RMSPE and MAE.

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