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ANIMAL PRODUCTION

Can body volume predict of body weight in Pelibuey ewe lambs?

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ABSTRACT: In traditional sheep production systems in tropical regions, the evaluation and monitoring of animal growth are not commonly practiced. This is primarily attributed to the limited adoption of technology and the high costs associated with acquiring livestock scales. The present study developed equations to predict body weight of Pelibuey ewe lambs using a Body Volume (BV) formula. BW and BV were obtained from 85 ewe lambs. The models evaluated were as follows: 1) linear, 2) quadratic, 3) cubic, 4) allometric, 5) exponential and 6) logarithmic. In addition, the models' predictive ability for BW was assessed by k-fold (k=10) cross-validation. The BW and BV were 20.60 ± 8.73 kg and 17.54 ± 7.89 dm^3, respectively. The quadratic model showed the highest r^2 and the lowest values of mean square error, root mean square error, and bayesian information criterion, while the k-fold cross-validation technique also had the highest r^2 and the lowest values of mean squared prediction error and mean absolute error. The quadratic model was the best performing mathematical model for predicting BW of growing Pelibuey ewe lambs using BV.
Key words: body weight estimation, Pelibuey ewe lambs, mathematical models, regression models.

O volume corporal pode predizer o peso corporal em borregas Pelibuey?

RESUMO: Nos sistemas tradicionais de produção de ovinos em regiões tropicais, a avaliação e monitoramento do crescimento dos animais não são práticas comuns. Isso se deve principalmente à adoção limitada de tecnologia e aos altos custos associados à aquisição de balanças para animais. O presente estudo teve como objetivo desenvolver equações para prever o peso corporal (PC) de borregas Pelibuey usando uma fórmula de Volume Corporal (VC). Foram obtidos dados de PC e VC de 85 borregas. Os modelos avaliados foram os seguintes: 1) linear, 2) quadrático, 3) cúbico, 4) alométrico, 5) exponencial e 6) logarítmico. Além disso, a capacidade preditiva dos modelos para o PC foi avaliada por meio de validação cruzada *k-fold* (k=10). O PC e VC foram 20,60 ± 8,73 kg e 17,54 ± 7,89 dm^3, respectivamente. O modelo quadrático apresentou o maior r^2 e os menores valores de erro do quadrático médio, raiz do erro do quadrático médio e critério de informação bayesiano, enquanto a técnica de validação cruzada *k-fold* também teve o maior r^2 e os menores valores de erro quadrático médio de predição e erro médio absoluto. O modelo quadrático foi o melhor desempenho matemático para predizer o PC de cordeiras Pelibuey em crescimento usando o VC.
Palavras-chave: borregas Pelibuey, estimativa de peso corporal, modelos de regressão, modelos matemáticos.

INTRODUCTION

In the traditional sheep production systems in tropical regions, it is not common to evaluate and monitor animal growth. Because of the limiting technologic adoption and the expensive prices of livestock scales, which 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; SALAZAR-CUYTUN et al., 2022). Trained technicians are also needed to calibrate and maintain weighing equipment. This is often not available in rural areas (MÁLKOVÁ et al., 2021, SALAZAR-CUYTUN et al., 2021; SALAZAR-CUYTUN et al., 2022). Consequently, the limitations of weighing equipment in traditional production systems lead to animals being sold by negotiation or visual assessment, resulting in high body weight (BW) estimation errors, ultimately affecting producers' economic gains (MÁLKOVÁ et al., 2021; SALAZAR-CUYTUN et al., 2021; SALAZAR-CUYTUN et al., 2022; GURGEL et al., 2023).

In sheep, several authors have developed equations for estimating BW mainly using biometric measurements such as heart girth (HG), body length (BL), withers height, hip width and rump height (CHAY-CANUL et al., 2019; CANUL-SOLÍS et al., 2020). These researchers

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reported a high correlation between the two body measurements. This led them to conclude that HG is the most important biometric measurement for estimating BW in animals. However, to improve the accuracy of BW prediction, HG and BL data have been combined by SALAZAR-CUYTUN et al. (2021) to calculate animal body volume (BV) by adaptation of the cylinder volume formula. In this method, HG and BL represent the circumference and height, respectively, of the cylinder shape (SALAZAR-CUYTUN et al., 2021; SALAZAR-CUYTUN et al., 2022; GURGEL et al., 2023). Despite the advantages that the BV formula could offer producers and researchers in estimating the BW of livestock (SALAZAR-CUYTUN et al., 2021; GURGEL et al., 2023), it has been poorly studied in hair sheep breeds at different physiological stages and under different management conditions (SALAZAR-CUYTUN et al., 2021; GURGEL et al., 2023).

In this scenario, it was hypothesised that BV could be a predictor of BW in hair sheep at different physiological stages. Therefore, the present study was conducted to predict BW of growing Pelibuey ewe lambs using the BV formula calculated from HG and BL data.

MATERIALS AND METHODS

The animals were reared at the Sheep Integration Centre of the Southeast (Centro de Integración Ovina del Sureste; 17° 78" N, 92° 96" W; 10 m asl), located on the Villahermosa-Teapa road, Mexico.

Data on body weight (BW), heart girth (HG) and body length (BL) were obtained from 85 clinically healthy Pelibuey ewe lambs between the ages of two and eight months. BW was recorded by weighing the animals on a 100 kg capacity, 10 g accuracy fixed platform scale, while HG and BL were recorded using a flexible fibreglass tape measure (Truper®), following the anatomical references described by SALAZAR-CUYTUN et al. (2021).

The volume of the body was estimated using the formula for calculating the volume of a cylinder, by including the measurements of the HG and the BL in its composition. The volume (m^3) was thus calculated as follows:

Radius (cm) = HG/ 2π

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

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

The PROC MEANS procedure in SAS (SAS 2010) was used for descriptive statistical analysis. The same software also estimated correlation coefficients between variables using PROC CORR (SAS Ver. 9.3, 2010) and performed regressions using PROC REG, PROC GLM and PROC NLIN (SAS Ver. 9.3, 2010). All variables were tested for normal distribution using the Shapiro-Wilk test with PROC UNIVARIATE of SAS (SAS Inst. Inc., Cary, NC, 2010). The assumptions of the regression analysis were checked and were normal distribution (normality plots), homogeneity of variance (residual plots), multicollinearity (variance inflation factors and tolerance) and autocorrelation (Durbin-Watson [DW] test). Regressions were performed using PROC REG (SAS Inst. Inc., Cary, NC, 2010). The STEPWISE and Mallow's Cp options were used in the SELECTION statement to select the variables included in the model. The regression models used to estimate the relationship between BW and BV in Pelibuey ewe lambs are shown in table 1.

In addition, cross-validation of k-folds (k = 10) was used to assess the predictive ability of the models for BW. This is done by randomly dividing the set of observations into non-overlapping k-folds of approximately equal size. The model was then fitted to the remaining k-1 folds (training data), with the first fold being treated as the validation set. The MSE, R^2 and MAE are used to assess the ability of the fitted model to predict the actual observations. The MAE refers to the mean absolute difference between observed and predicted results and is an alternative to the mean squared prediction error (MSPE), which is less sensitive to outliers. A better fit is indicated by lower values of root MSPE and MAE. The k-fold cross-validation, which allowed the comparison of many multivariate calibration models, was performed using the 'scikit-learn' package.

Table 1 - Regression models to describe the relationship BW and BV in Pelibuey ewe lambs.

No.	Models	Mathematical equations
1	Linear	$y = \beta_0 + \beta_1 * x$
2	Quadratic	$y = \beta_0 + \beta_1 * x + \beta_2 * x^2$
3	Cubic	$y = \beta_0 + \beta_1 * x + \beta_2 * x^2 + \beta_3 * x^3$
4	Power	$y = \beta_0 * x\ \beta_1$
5	Exponential	$y = \beta_0 + \beta_1 (\beta_{2,1} + \beta_{p+1} x_{i,} 1) + e_i$
6	Logirithmic	$y = \beta_0 + \beta_1 * \ln(x)$

β_0 - β3: model parameters; y: body weight; x: body volume.

Table 2 - Descriptive statistics of BW and biometric measurements recorded in growing hair lambs.

Variable	N	Mean ± SD	Minimum	Maximum	CV (%)
BW (kg)	85	20.60 ± 8.73	6.22	38.00	42.37
HG (cm)	85	64.17 ± 11.20	43.00	86.00	17.45
BL (cm)	85	33.56 ± 4.96	24.00	55.00	14.77
BV (dm^3)	85	17.54 ± 7.69	5.98	35.16	43.84

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

RESULTS AND DISCUSSION

Descriptive statistics, mean body weight and biometric measurements of growing Pelibuey ewe lambs are shown in table 2. The overall BW and BV were 20.60 ± 8.73 kg and 17.54 ± 7.89 dm^3, respectively. The coefficients of variance were 42.37% and 43.84% for BW and BV, respectively. Although, BW and BV showed high variability (>20%), this is desirable to obtain a diverse database to improve the completeness of the generated equations (SAZALAR-CUYTUN et al., 2023). The BW and BV equations can be used to generate a wide range of equations. The BW and biometric values obtained in this study are consistent with those reported for lambs in other physiological states (SALAZAR-CUYTUN et al., 2021; SALAZAR-CUYTUN et al., 2022; GURGEL et al., 2023). Correlations showed a positive and significant relationship ($P < 0.001$) between BW and BV (r=0.94). SALAZAR-CUYTUN et al. (2021) reported a correlation coefficient (r) of 0.89 between BW and BV ($P < 0.001$) in adult Pelibuey sheep. Conversely, SALAZAR-CUYTUN et al. (2022) identified a correlation coefficient (r) of 0.96 between BW and BV in male growing sheep ($P < 0.001$). More recently, a positive and strong correlation (r = 0.97; $P < 0.001$) between BW and BV in recently weaned Santa Inês lambs was found by GURGEL et al. (2023). A positive and strong relationship between BW and BV is suggested by previous work. However, the relationship is variable in relation to the physiological condition under investigation.

The models fitted to study the relationship between BW and BV in growing Pelibuey ewe lambs were as follows: 1) linear (equation 1), 2) quadratic (equation 2), 3) cubic (equation 3), 4) allometric (equation 4), 5) exponential (equation 5) and 6) logarithmic (equation 6) (Table 3; Figure 1).

It was observed that the quadratic model had the highest coefficient of determination (r^2=0.91) and the lowest values of MSE (7.12), RMSE (2.67), AIC (159.20) and BIC (166.30) (Table 4). In addition, during the k-fold cross-validation (k = 10), the quadratic model had the highest r^2 (0.87) and the lowest RMSPE (2.71) and MAE (2.19) (Table 5). Therefore, for predicting BW of growing Pelibuey

Table 3 - Body weight prediction equations in Pelibuey ewe lambs through a body volume formula.

No	Models	Equation
1	Linear	BW (kg): $1.67(\pm 0.80^*) + 1077.40\ (\pm 41.63^*) \times BV$
2	Quadratic	BW (kg): $-1.95(\pm 1.70^*) + 1560.25(\pm 206.53^*) \times BV - 13254.54(\pm 5560.06^*) \times BV^2$
3	Cubic	BW (kg): $3.58(\pm 4.18^*) + 484.81(\pm 772.18^*) \times BV + 46025.30\ (\pm 41405.47^*) \times BV^2 - 979518.69\ (\pm 678061.74^*) \times BV^3$
4	Allometric	BW (kg): $784.96(\pm 123.04^*) \times BV^{0.90(\pm 0.04^*)}$
5	Exponential	BW (kg): $8.64(\pm 0.52^*) \times Exp^{46.28(\pm 2.52^*) \times BV}$
6	Logarithmic	BW (kg): $90.65(\pm 2.94^*) + 16.88\ (\pm 16.88^*) \times Ln\ (BV)$

BW: body weight; BV: body volume; Values in parentheses are the standard errors (SE) of the parameter estimates. The * indicates: *: $P < 0.05$.

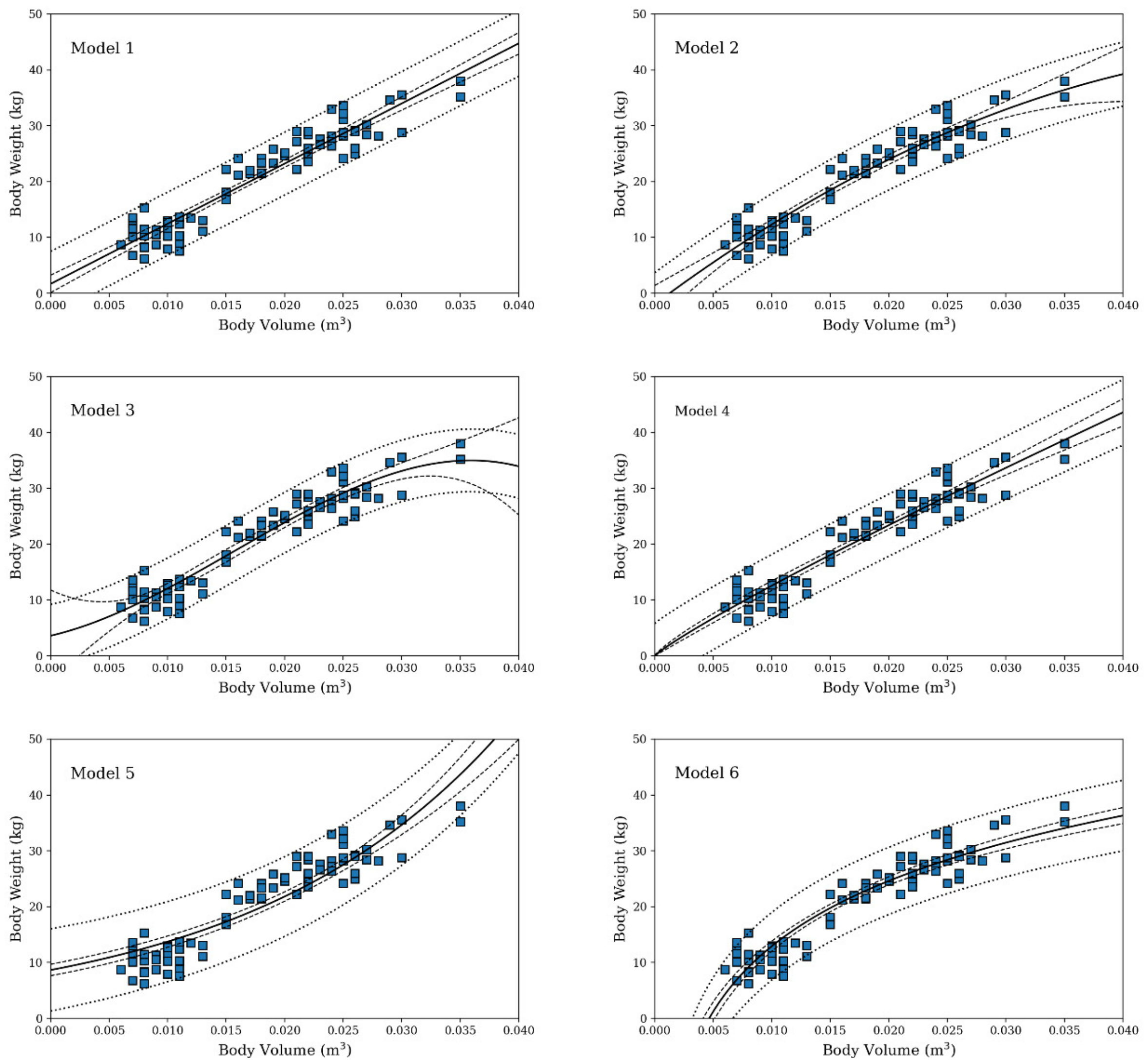

Figure 1 - Relationship between live weight and body volume in growing Pelibuey ewe lambs.

ewe lambs using BV calculated from HG and BL data, the quadratic model was the best performing mathematical model according to the goodness of fit evaluation.

These results agreed with those reported by SALAZAR-CUYTUN et al. (2021; 2022) who recommended a quadratic model to predict live weight in adult Pelibuey ewes and in growing male crosses with Blackbelly and Katahdin. SALAZAR-CUYTUN et al. (2021) decided that the quadratic model was the best performing mathematical model according to the goodness of fit evaluation, with a prediction error of 2.04 kg, based on the evaluation approaches used and the close relationship between BW and BV in Pelibuey ewe lambs and adult ewes. SALAZAR-CUYTUN et al. (2022) also concluded that the quadratic model had the highest coefficient of determination (0.93) and the lowest prediction error (3.29 kg). The RMSE of the present study was 2.77 kg, which is approximately 13.44% of the observed mean BW. Nevertheless, GURGEL et al. (2023) concluded that the linear models were the most suitable for predicting live weight at weaning in Santa Ines lambs using BV measurement as the only predictor. Due to its simplicity of interpretation and ease of estimation, we recommend the use of the first-degree linear model.

Table 4 - Predictive performance of regression models obtained in this study.

No	r2	MSE	RMSE	AIC	BIC
1	0.89	7.67	2.77	162.90	167.60
2	0.91	7.12	2.67	159.20	166.30
3	0.91	6.93	2.63	159.03	168.45
4	0.89	7.50	2.73	161.17	165.89
5	0.83	12.34	3.51	200.03	204.75
6	0.88	8.79	2.96	173.54	178.25

r^2: Coefficient of determination, MSE: mean square error; RMSE: Root MSE; AIC: Akaike information criterion; BIC: Bayesian Information Criterion.

In farm animals, incorporating BV measurements into mathematical equations has emerged as a method to predict BW, offering more accurate estimates than relying solely on individual biometric measurements (PAPUTUNGAN et al., 2018). While studies have utilized BV measurements to estimate BW in adult sheep (SALAZAR-CUYTUN et al., 2022), cattle (CASTILLO-SANCHEZ et al., 2022), and buffaloes (RAMOS-ZAPATA et al., 2023), this approach remains less common in young animals. Considering that body conformation and fat deposition can vary among animals of different sexes, categories and breeds, these factors may influence the correlation between certain biometric measurements and BW in sheep (SALAZAR-CUYTUN et al., 2021; SALAZAR-CUYTUN et al., 2022).

For these reasons, models need to be developed for animals in different physiological states and sexes, as well as in various management scenarios. This is crucial for enhancing decision-making processes and maximizing the economic benefits associated with determining and monitoring BW in livestock (SALAZAR-CUYTUN et al., 2021; SALAZAR-CUYTUN et al., 2022; GURGEL et al., 2023). According to SALAZAR-CUYTUN et al. (2021; 2022), the practical implication of utilizing BV to predict BW lies in the enhancement of indirect BW estimation in growing sheep. This is because the internal organs are located within the abdominal cavity, resulting in a higher percentage of weight being accounted for in the estimation process.

CONCLUSION

The result showed that the quadratic regression model correctly predicted body weight using body volume in growing Pelibuey ewes. Body volume could be used as the sole predictor of body weight in growing Body weight ewes reared in the tropics.

Table 5 - Internal *k*-folds cross-validation of the proposed models.

Model	N	r^2	MSPE	MAE
Linear	85	0.85	2.83	2.27
Quadratic	85	0.87	2.71	2.19
Cubic	85	0.87	2.72	2.20
Allometric	85	0.86	2.82	2.24
Exponential	85	0.72	3.46	2.86
Logarithmic	85	0.84	2.99	2.37

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

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

BIOETHICS AND BIOSECURITY COMMITTEE APPROVAL

The animals included in this study were treated in accordance with the ethical guidelines and regulations for animal experimentation of the Division of Agricultural Sciences of the University of Juárez Autónoma de Tabasco (approval code: UJAT-DACA-2015-IA-02).

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