RELATIONSHIP BETWEEN BODY VOLUME AND BODY WEIGHT IN PELIBUEY EWES †

[RELACIÓN ENTRE VOLUMEN CORPORAL Y PESO CORPORAL EN OVEJAS PELIBUEY]

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SUMMARY

Background. In terms of animal management, the measurement of body weight (BW) is important in the design of nutrition and health programs. **Objective.** The objective of the present study was to evaluate the relationship between body volume (BV) and BW in Pelibuey ewe lambs and ewes. **Methodology.** For the model development, the BW and body volume (BV) were recorded in 406 Pelibuey ewe lambs and ewes ranging from two months to one years in age. All animals were clinically healthy, with a BW = 37.62 ± 10.63 kg. The BV was calculated using the heart girt (HG) and the body length (BL). BV was calculated according to the mathematical formulas for calculating the volume of a cylinder, considering biometric measurements in the calculation. The relationship between BV and BW was assessed by linear (Eq. 1), quadratic (Eq. 2) and allometric equation (Eq. 3). The goodness of fit of the regression models was assessed by the Akaike information criterion (AIC), Bayesian information criterion (BIC), coefficient of determination (R^2), mean square error (MSE) and root mean square error (RMSE). **Results.** The correlation coefficient (r) between BW and BV was 0.89 ($P < 0.001$). The quadratic model had the higher value of coefficient of determination ($R^2 = 0.81$, and the lower MSE (4.17), RMSE (2.04), AIC (1163.64) and BIC (1175.66) values. The predictive ability of the three live weight prediction models was evaluated using *k*-folds validation ($k = 10$). **Implications.** The quadratic model had the higher coefficient of determination and lowest values were found for the mean square error (MSE) and mean absolute error (MAE). This model is practical and predicts with high accuracy the BW of the animals. **Conclusion.** Based on the evaluation approaches used in the present study and the close relationship between BW and BV in Pelibuey ewe lambs and adult ewes, the quadratic model was the mathematical model that had the best performance according to the goodness-of-fit evaluation.

Keywords: body volume; mathematical equations; Pelibuey ewes; prediction.

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RESUMEN

Antecedentes. En términos de manejo animal, la medición del peso corporal (PV) es importante en el diseño de programas de nutrición y salud. **Objetivo**. El objetivo del presente estudio fue evaluar la relación entre el volumen corporal (VC) y el PV en ovejas Pelibuey. **Metodología**. Para el desarrollo de los modelos, se registró el PC y el VC en 406 ovejas Pelibuey, con un rango de edad de dos meses a un año. Todos los animales estaban clínicamente sanos, con un peso corporal = 37.62 ± 10.63 kg. El VCCc se calculó utilizando el perímetro torácico (PT) y la longitud del cuerpo (LC). El VC se calculó de acuerdo con las fórmulas matemáticas para calcular el volumen de un cilindro, considerando medidas biométricas en el cálculo. La relación entre VC y PV se evaluó mediante ecuaciones lineales (Ec. 1), cuadráticas (Ec. 2) y alométricas (Ec. 3). La bondad de ajuste de los modelos de regresión se evaluó mediante el criterio de información de Akaike (AIC), el criterio de información bayesiano (BIC), el coeficiente de determinación (R^2), el error del cuadrado medio (ECM) y la raíz del ECM (RECM). **Resultados.** El coeficiente de correlación (r) entre PV y VC fue de 0.89 (P <0.001). El modelo cuadrático tuvo el valor más alto de coeficiente de determinación (R^2 = 0.81, y los valores más bajos de ECM (4.17), RECM (2.04), AIC (1163.64) y BIC (1175.66). La capacidad predictiva de los tres modelos de predicción de peso vivo se evaluó mediante la validación de k-folds (k = 10). **Implicaciones.** El modelo cuadrático tuvo un alto coeficiente de determinación y valores más bajos para el ECM y el error absoluto medio (EAM). Este modelo es práctico y predice el PV de los animales con una alta precisión **Conclusión.** Basado en los enfoques de evaluación utilizados en el presente estudio y la estrecha relación entre PV y VC en ovejas Pelibuey, el modelo cuadrático fue el modelo matemático que tuvo el mejor desempeño de acuerdo con la evaluación de bondad de ajuste.

Palabras Clave: volumen corporal; ecuaciones matemáticas; oveja Pelibuey; predicción.

INTRODUCTION

In hair sheep of the Pelibuey breed, the use of biometric measures (BM) has made it possible to establish the degree of association of a certain body measure with some characteristic of productive interest, such as the estimation of the weight of the carcass tissues (Bautista-Díaz *et al*., 2017; 2020), body weight of growing replacement ewe lambs (Chay-Canul *et al*., 2019; Canul-Solís *et al*., 2020), body condition and fattening (Salazar-Cuytún *et al.*, 2020a,b). It has been established that the body conformation, fat deposition in the body may differ between animals of different sex and breeds and these aspects may interfere with the correlation between some MB and the body weight (BW) of sheep (Wamatu and Alkhtib, 2021).

In this sense, hair breeds are commonly used in sheep production systems in the Mexican tropics, characterized by low inputs and poor technology adoption (Chay-Canul *et al*., 2019). Under these conditions, the constant evaluation of the growth replacement ewe lambs represents a great challenge for small producers, even more with BW measurement, due to the high cost of direct measurement equipment, such as livestock scales (Chay-Canul *et al., 2019;* Canul-Solis *et al*., 2020*).* In this regard, the use of scales limits the accurate determination of BW of animals under extensive sheep management conditions (Málková *et al*., 2021). Estimating ewe lamb BW based on defined body measurements to provide a fast, easy, and more accurate in comparison with the traditional visual method for determining BW in production systems when the normal use of scales is limited such as in rural areas where farmers rarely use weighing scales (Málková *et al*., 2021; Wamatu and Alkhtib, 2021). In addition, scale calibration and maintenance require skilled technicians who are rarely found in rural areas for that, farmers, therefore, rely on estimating weights of livestock without recourse to validated weighing methods (Chay-Canul *et al*., 2019; Sabbioni *et al*., 2020; Canul-Solís *et al*., 2020; Málková *et al* 2021; Wamatu and Alkhtib, 2021).

In terms of management, the measurement of BW is important in the design of animal nutrition and health programs (Sabbioni *et al*., 2020). Specifically, in meat sheep breeds, the BW is essential in choosing the optimal slaughter moment and the optimal carcass end point (Bautista-Díaz *et al*., 2017; Bautista-Díaz *et al*., 2020; Canul-Solis *et al*., 2020; Sabbioni *et al*., 2020). Some authors evaluated the use of BM as an alternative, practical and low-cost method that allows small producers to estimate the BW of Pelibuey sheep in farm conditions. The method of BM, consists in the development of mathematical equations from some BM, which are taken directly from the animals, such as the circumference of the heart girt (HG), the hip width (HW), body length (BL) and the withers height (WH). However, previous studies demonstrated that HG and HW presents the higher correlation with BW in adult Pelibuey ewes (Chay-Canul *et al*., 2019; Canul-Solís *et al*., 2020). This BMs has certain advantages over other, such as being easier to measure during routine handling practices, due to the fact that no special facilities are required and it entails less handling of the animal (Chay-Canul *et al*., 2019).

New technologies based on digital image analysis (DIA) are successfully used to improve the management of most types of animal production (Le Cozler *et al*., 2019). This technology may be adapted to farm conditions and can be used to estimate the BW of farm animals (Le Cozler *et al*., 2019). Currently, inexpensive and portable equipment such as depth cameras allows obtaining 3D image technology to estimate animal BW, this technology is also suitable for collecting information about animal body volume and body area and use to predict the BW of domestic animals (Le Cozler *et al*., 2019). Our research group are initiate in works related to DIA and we require evaluating how the body volume of animals is related to BW. However, as far as we know, there is no study that evaluated the relationship between body volume and BW in Pelibuey sheep. Therefore, in the present study we evaluate the relationship between body volume (BV) and BW in Pelibuey ewe lambs and ewes.

MATERIALS AND METHODS

Animal care

The animals were treated in accordance with the guidelines and regulations for animal experimentation of the Academic Division of Agricultural Sciences, Universidad Juárez Autónoma de Tabasco.

Animals, diets, and handling

The experiment was carried out at the Centro de Integracion Ovina del Sureste (CIOS) located at 17° 78" N, 92° 96" W, at an altitude of 10 masl, at km 25 + 3 of the Villahermosa-Teapa Road in the town of Alvarado Santa Irene 2nd Section in the state of Tabasco, Mexico. The regional climate is warm-humid, with an average minimum and maximum temperature of 18.5° and 36° C, respectively, and an annual precipitation of 2299.5 mm (CONAGUA, 2019).

For the models development, the BW and BV were recorded in 406 in Pelibuey ewe lambs and ewes ranging from two months to one years in age. All animals were clinically healthy, with a BW = 37.62 ± 10.63 kg. The BW of each animal was determined using a digital scale (EQB model, Torrey, Mexico). The BV was calculated using the heart girt (HG) and the body length (BL) which were recorded using a flexible tape fiberglass (Truper®, Truper S.A. de C.V., San Lorenzo, Mexico) as described as described by Bautista-Díaz *et al*. (2020, Table 1). Body volume was calculated according to the mathematical formulas for calculating the volume of a cylinder, considering biometric measurements in the calculation:

Radius (m) = HG/ 2π

Volume (m^3) = $\pi \times r^2 \times$ BL

Where: radius of the circumference (m); π = 3.1416; HG = heart girt (m) and BL = body length (m).

Statistical analysis

For the statistical analysis and the internal model validation of the research the data was read into the Python environment using several packages, which are mentioned as follows. Descriptive statistics were obtained using the describe function of the "pandas" package (Mckinney, 2010). The relationship between Volume and BW was assessed by linear (Eq. 1), quadratic (Eq. 2) and allometric equation (Eq. 3) using the "lmfit" package (Newville *et al*., 2014). The allometric equation was fitted: Y = aX**b, where Y represents BW, X represents BV and a and b are parameters of the model. The models and their residuals were plotted with "matplotlib" package (Hunter, 2007). The goodness of fit of the regression models was assessed by the Akaike information criterion (AIC), Bayesian information criterion (BIC), coefficient of determination (R^2), mean squared error (MSE) and root of MSE (RMSE), the las three parameters were obtained using the "scikit-learn" package (Pedregosa *et al*., 2011)

Internal model validation

The predictive ability of the three models for live weight prediction was evaluated using *k*-folds validation (k = 10). This approach was performed by randomly dividing the set of observation values into *k* non-overlapping folds of approximately equal size. The first fold is treated as a validation set, and the model is fit to the remanding $k - 1$ folds (training data). The ability of the fitted model to predict the actual observed values was evaluated by the MSE, R^2 and mean absolute error (MAE). MAE is an alternative to the root mean square error of prediction (RMSEP) that is less sensitive to outliers, and it is related to the average absolute difference between observed and predicted outcomes. Lower values of RMSEP and MAE indicate a better fit. The *k*-folds validation was carried out in the *"scikit-learn" package* (Pedregosa *et al*., 2011), which allowed for the comparison of numerous multivariate calibration models.

RESULTS AND DISCUSSION

The means, maximum and minimum values of BW and BV are presented in Table 1. The BW ranged from 16.80 to 61.40 kg, and the BV from 0.01 to 0.07 m^3. The correlation coefficient between BW and BV was r= 0.89. The fitted regression equations are listed in Table 2 and Figure 1. Three models were fitted to explore the relationship between BW and BV in Pelibuey ewes, the linear (Eq. 1), quadratic (Eq. 2) and allometric model (Eq. 3). The quadratic model had the highest value of coefficient of determination, and the lowest values of MSE, RMSE, Akaike information criterion (AIC) and Bayesian information criterion (BIC). While the linear model had the lowest R^2 and the highest MSE, RMSE, AIC and BIC values. Also, during cross-validation process using *k*-folds validation ($k = 10$), the quadratic model had the highest R^2 and the lowest values for the RMSEP and MAE (Table 3).

Table 1. Descriptive analyses of BW (kg) and BV (m^3) in Pelibuey ewes.

Varia-bles	N	Mean ± SD	Min.	Max.
BW (kg)	406	37.62 ± 10.63	16.80	61.40
BV (m^3)	406	0.04 ± 0.01	0.01	0.07

BW: body weight; Body volume (m^3); N: number of observations; SD: standard deviation.

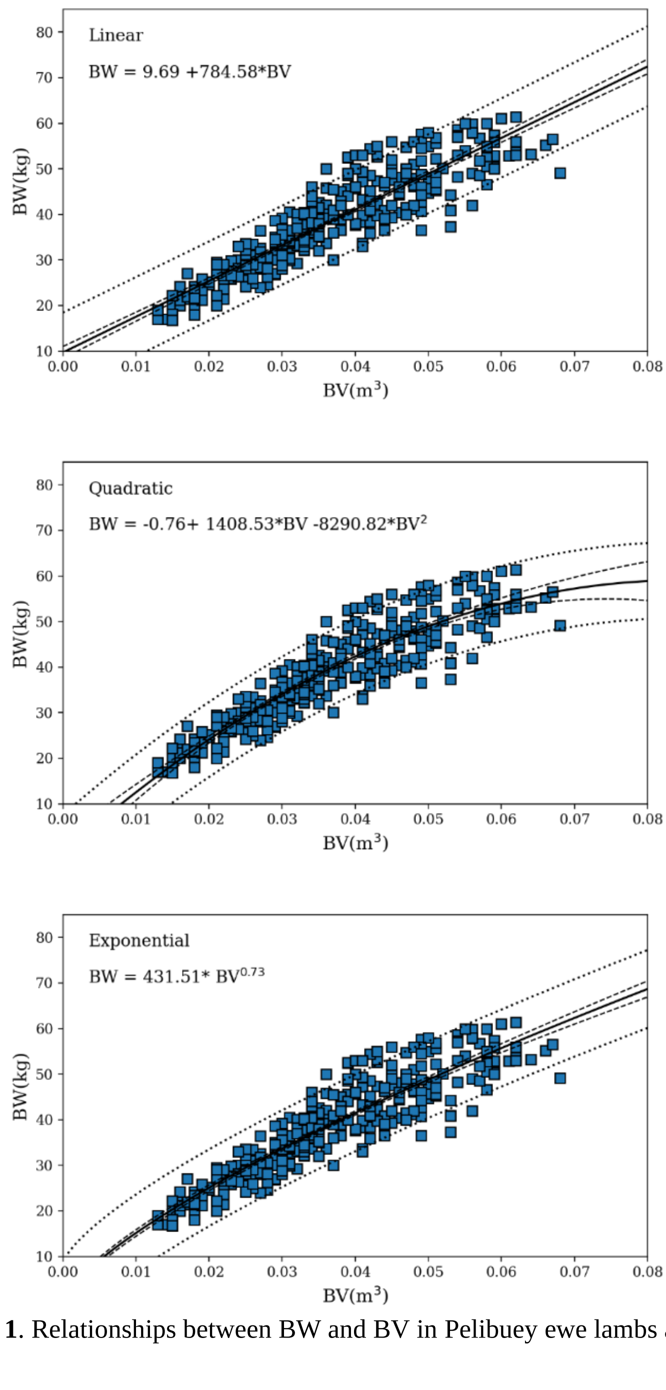

Figure 1. Relationships between BW and BV in Pelibuey ewe lambs and ewes.

Table 2. Prediction equations of BW in Pelibuey ewes using the body volume.

No.	Equations	N	R^2	MSE	RMSE	AIC	BIC	*P*-Value
1	BW (kg): 9.68 (± 0.66*) + 784.57 (± 17.68*) × BV	406	0.79	4.38	2.09	1204.34	1212.35	<0.0001
2	BW (kg): -0.76(± 1.68*) + 1408.53 (± 94.83*) × BV- 8290.82 (± 1240.18*) × BV^2	406	0.81	4.17	2.04	1163.64	1175.66	<0.0001
3	BW (kg): 431.51 (± 23.79***) × $BV^{0.73\ (\pm 0.02*)}$	406	0.80	4.25	2.06	1181.71	1189.72	<0.0001

BW: body weight; HW: hip width; AIC: Akaike information criterion; MSE= mean square error, RMSE = Root of MSE, BIC: Bayesian information criterion. Values in parentheses are the standard errors (SEs) of the parameter estimates. The * denotes: *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

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

Model	n	R^2	RMSEP	MAE
Linear	406	0.79	4.39	3.46
Quadratic	406	0.81	4.22	3.29
Exponential	406	0.80	4.28	3.38

RMSEP: root mean square error of prediction; R^2: coefficient of determination; MAE: mean absolute error

In the present study, we evaluated the possibility of using BV to predict the BW of Pelibuey ewes. The positive linear correlation (r = 0.89) and highly significant (*P* <0.001) found between BW and BV in this study supports the possibility of using BV to predict BW in Pelibuey ewes. The goodness of fit of the three models calculated by the *k*-folds cross validation technique is shown in Table 3. The three proposed models showed an adequate goodness of fit based on the internal validation. However, the quadratic model had the high coefficient of determination and lower values for the mean square error (MSE) and mean absolute error (MAE). The quadratic model was the one that presented the best fit (Table 2). The equation was BW (kg): -0.76 (± 1.68 *) + 1408.53 (± 94.83 *) × BV- 8290.82 (± 1240.18 *) × BV^2 (P <0.0001, R^2 = 0.81, MSE = 4.17, RMSE = 2.04, n = 406). This model gave the best fits compared to the linear and allometric model, showing lower AIC and BIC values (1163.64 and 1175.66). The RMSE represented about 5.42% of the mean BW. Canul-Solis *et al*. (2020) compared different mathematical equations to predict BW using hip width (HW) in Pelibuey sheep and determined that the linear model (BW (kg), - 19.17 (± 0.86 ***) + 3.46 (± 0.05 ***) × HW) showed the best performance according to the goodness of fit evaluation: P <0.0001, R^2 = 0.96; AIC = 3342.0; BIC = 3355.1). Sabbioni *et al.* (2020) mentioned that the choice of the model to use depends largely on several factors, where the most important is the comfort of use, which is reflected in the number of measurable variables. The quadratic model showed the best performance according to the goodness-of-fit evaluation and internal validation (Table 3). This model may be used both in experimental and commercial farms. This mathematical model is practical and predicts with high accuracy animal´s BW. It has been reported that in farms where the scale option does not exist, then farmers consistently underestimate animal´s BW by using subjective methods such as visual assessment. Therefore, it is a necessary to development an accurate and inexpensive method in order to improve management decisions and economic profits, because the visual estimation of BW is very inaccurate and leads to high errors. The present model could not be extrapolated to different breeds and sex of sheep.

On the other hand, methods to estimate BW based on image technologies are then of increasing interest for many research groups, breeding organization, farmers and advisors. Ultimately, 3D imaging enables accurate and simplified estimation of BW, especially because it allows calculation of volume, which is strongly correlated with BW of lactating Holstein cows (Le Cozler *et al*., 2019). Nevertheless, more automation (e.g. image preparation and measurement) is required to fully benefit from this tool. Unlike previous studies that used only linear traits as parameters, 3D imaging can create new models using volume and area (Le Cozler *et al*., 2019).

CONCLUSION

Based on the evaluation approaches used in the present study and the close relationship between BW and BV in Pelibuey ewe lambs and adult ewes, the quadratic model was the mathematical model that had the best performance according to the goodness-of-fit evaluation. This model is practical and predicts with high accuracy animal´s BW. This will support farmers to achieve more accurate decisions in order to improve their economic profits, especially when they use of scales is limited.

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Compliance with ethical standards and Statement of animal rights. All applicable international, national and/or institutional guidelines on the care and use of animals were followed.

Conflict of interest. The authors declare that they have no conflicts of interest.

Data availability. Data are available with the corresponding author of this publication upon reasonable request.

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