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Prediction of live weight in beef heifers using a body volume formula

[*Predição do peso vivo em novilhas de corte usando a fórmula do volume corporal*]

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ABSTRACT

The objective of this study was to develop and evaluate linear, quadratic, and allometric models to predict live weight (LW) using the body volume formula (BV) in crossbred heifers raised in southeastern Mexico. The LW (426.25±117.49kg) and BV (338.05±95.38 dm^3) were measured in 360 heifers aged between 3 and 30 months. Linear and non-linear regression were used to construct prediction models. The goodness-of-fit of the models was evaluated using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), coefficient of determination (R^2), mean squared error (MSE), and root MSE (RMSE). In addition, the developed models were evaluated through cross-validation (*k*-folds). The ability of the fitted models to predict the observed values was evaluated based on the RMSEP, $R^{2,}$ and mean absolute error (MAE). The quadratic model had the lowest values of AIC (2688.39) and BIC (2700.05). On the other hand, the linear model showed the lowest values of MSE (7954.74) and RMSE (89.19), and the highest values of AIC (2709.70) and BIC (2717.51). Despite this, all models presented the same R^2 value (0.87). The cross-validation (k-folds) evaluation of fit showed that the quadratic model had better values of MSEP (41.49), R^2 (0.85), and MAE (31.95). We recommend the quadratic model to predictive of the crossbred beef heifers' live weight using the body volume as the predictor.

Keyword: body weight, crossbred heifers, body volume, humid tropics, mathematical models

RESUMO

O objetivo deste estudo foi desenvolver e avaliar os modelos linear, quadrático e alométrico para predizer o peso vivo (PV), usando-se a fórmula do volume corporal (VC) em novilhas mestiças criadas no sudeste do México. O PV (426,25±117,49kg) e o VC (338,05±95,38dm^3) foram medidos em 360 novilhas, com idade entre três e 30 meses. Regressões lineares e não lineares foram utilizadas para construir os modelos de predição. A adequação dos modelos foi avaliada utilizando-se o critério de informação de Akaike (AIC), o critério de informação bayesiano (BIC), o coeficiente de determinação (R^2), o quadrado médio do erro (QME) e a raiz do QME (RQME). Além disso, os modelos desenvolvidos foram avaliados por meio de validação cruzada (k-folds). A capacidade dos modelos ajustados em prever os valores observados foi avaliada com base no RQME, no R^2 e no erro médio absoluto (EMA). O modelo quadrático apresentou os menores valores de AIC (2688,39) e de BIC (2700,05). Por outro lado, o modelo linear apresentou os menores valores de QME (7954,74) e de RQME (89,19); esse modelo apresentou os maiores valores de AIC (2709,70) e de BIC (2717,51). Apesar disso, todos os modelos apresentaram o mesmo valor para o R^2 (0,87). A avaliação de ajuste por validação cruzada (k-folds) mostrou que o modelo quadrático teve melhores valores de RQME (41,49), R^2 (0,85) e EMA (31,95).

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Recomenda-se o modelo quadrático para predição do peso vivo de novilhas de corte mestiças utilizando-se o volume corporal como preditor.

Palavras-chave: modelos matemáticos, novilhas mestiças, peso corporal, trópicos úmidos, volume do corpo

INTRODUCTION

Live weight (LW) is one of the main information that assists in the decision-making process in cattle production systems, due to the direct relationship with the nutritional requirements of animals (Vieira *et al.,* 2013; Nutrient…, 2021). In addition, monitoring the weight development of ruminants makes it possible to identify the phases in which the animal has a greater capacity to convert the food consumed into body tissue and the best time for its commercialization (Fernandes *et al.,* 2012; Gurgel *et al.,* 2021a). Regarding management, LW measurement is important in establishing nutritional and animal health programs (Sabbioni *et al.,* 2020; Canul-Solís *et al.,* 2022).

On the other hand, the high cost of acquiring and maintaining scales has been considered an obstacle to directly obtaining the live weight of animals (Salazar-Cuytun *et al.,* 2022; Canul-Solís *et al.,* 2022). In most cases, this leads to a subjective animal weight estimation, which leads to errors in live weight estimation and affects the profitability of production systems (Málková *et al.,* 2021). In this sense, biometric measurements are a viable option to predict live weight due to the strong positive correlation between these characteristics and the live weight of animals (Chay-Canul *et al.,* 2019; Gurgel *et al.,* 2021b).

Some studies were carried out to develop linear and multiple equations to estimate the live weight of ruminants through biometric measurements (Chay-Canul *et al.,* 2019; Salazar-Cuytun *et al.,* 2022; Canul-Solís *et al.,* 2022). Also, several authors concluded that thoracic perimeter is the most important biometric measure for predicting the live weight of animals (Chico-Alcudia *et al.,* 2022); however, the association of this parameter with other biometric measures can increase the accuracy and precision of predictive models (Málková *et al.,* 2021; Gurgel *et al.,* 2021b).

Another approach to the use of biometric measurements to predict the live weight of cattle is from the body volume (BV), obtained through the formula for calculating the volume of a cylinder, including body measurements of thoracic perimeter and body length (Paputungan *et al.,* 2015). Paputungan *et al.* (2018) reported that 96% of the weight variation of native Indonesian cattle is explained by the BV measure, a value higher than any other biometric measure used alone. Thus, the authors recommended estimating the LW of cattle using a first-degree linear regression model through BV as the only predictor measure. It is noteworthy that the authors did not test and evaluate a quadratic or allometric equation to estimate LW through BV.

Sheep studies have shown that a second-degree linear model provides more accurate estimates of LW using the BV measure (Salazar-Cuytun *et al.,* 2021, 2022). Thus, the tested hypothesis was that the LW of crossbred cattle presents a quadratic relationship with the measurement of BV and that a second-degree linear equation more accurately estimates the LW of these animals. Therefore, the objective of this study was to develop and evaluate linear, quadratic, and allometric mathematical models to predict LW using the BV formula in crossbred heifers raised in humid tropical conditions in Mexico.

MATERIALS AND METHODS

The animals were managed following the guidelines and regulations for animal experimentation set forth by the Academic Division of Agricultural Sciences at Universidad Juárez Autónoma de Tabasco (UJAT). All methods were performed according to *in vivo* animal research guidelines: ARRIVE 2.0 (Sert *et al.,* 2020).

The animals included in the present study belonged to four production units located in the state of Chiapas, southern Mexico. The predominant climate in this region is hot and humid, with abundant rains in summer.

For the development of the equations, a total of 360 crossbred (*Bos taurus* × *Bos indicus*) replacement heifers with different breed compositions, aged between 3 to 30 months were used. The heifers were grazed on African bermudagrass (*Cynodon nlemfuensis*) and Brachiaria humidicola pastures, without concentrate supplementation. Live weight (LW, kg) was recorded in each heifer using a digital livestock scale (Revuelta®, Nuevo León, Mexico), whereas thoracic perimeter (TP, cm), body length (BL, cm) was recorded using a flexible fiberglass tape measure (Truper®, SA de CV, San Lorenzo, Mexico) considering the anatomical references described by Bautista-Diaz *et al.* (2020) and Salazar-Cuytun *et al.* (2022).

Body volume (BV) was estimated using the formula to calculate the volume of a cylinder, by including the measurements of TP and BL in its composition.
The volume (dm^3) was thus calculated as follows:

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

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

Where r = circumference radius (cm); π = 3.1416; TP = thoracic perimeter (cm); and BL = body length (cm).

Additionally, three mathematical models were evaluated to predict the heifer's weight based on BV, namely:
1) First-degree equation (linear): LW (kg) = $\mu+\beta 1\times BV$;
2) Second-degree equation (quadratic): LW (kg) = $\mu+\beta 1\times \mathrm{BV} + \beta 2\times BV^2$; and
3) Allometric model: LW (kg) = $\mu\times BV^{\beta 1}$,
Where LW = live weight of the heifer (kg);
BV = Body volume (dm^3); " ", " β1" and " β2" = model parameters.

Descriptive statistics were obtained using the description function of the "Psych" package in R software. The relationship between LW and BV was evaluated by linear and multiple regressions, using the *LM function* in R software. In addition, the following allometric equation was fitted: Y = a + bX, where Y represents LW, X represents BV, and *a* and *b* are parameters. The parameters of the allometric model were estimated by non-linear regressions using the *NLS function* of R software. Residual analysis was included to identify outliers, which were detected by plotting the studentized residuals against the values predicted by the equation. Outliers were removed if the value of the studentized residuals was outside the range of −2.5 to 2.5. The models and their residuals were plotted in the *ggplot2 package* of R software. The quality-of-fit of the regression models was evaluated using the Akaike Information Criterion (AIC); Bayesian Information Criterion (BIC); mean square error (MSE); root MSE (RMSE).

The predictive capacity of the three models for LW was evaluated by cross-validating *k*-folds (*k* = 10) according to Steyerberg and Harrel (2016), and Canul-Solis *et al.* (2020). 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 *k*-folds cross-validation was performed using the *scikit-learn package* (Pedregosa *et al.*, 2011).

RESULTS

The LW ranged from 182.00 to 704.00 kg, whereas BV ranged from 129.95 to 562.49 dm^3, averaging 426.25 ± 117.18 kg and 338.05 ± 95.78 dm^3, respectively (Table 1). LW and BV were significantly positive and strongly correlated (r=0.93; P<0.001).

The quadratic model had the lowest values of AIC (2688.39) and BIC (2700.05). On the other hand, the linear model showed the lowest values of MSE (7954.74) and RMSE (89.19), and the highest values of AIC (2709.70) and BIC (2717.51). Despite this, all models presented the same value for the coefficient of determination (R2 =0.87) (Table 2), as demonstrated in Figure 1, which shows that all LW prediction equations using BV in crossbred heifers present the same variation.

The quality-of-fit using the k-folds technique (cross-validation) allowed us to identify that the three proposed models showed an adequate fit considering the internal validation (Table 3). Of these, the quadratic model had lower values of mean square error of prediction (MSEP = 41.49) and mean absolute error (MAE = 31.95), also, a higher coefficient of determination (R^2= 0.85).

DISCUSSION

The present study proposed to develop and evaluate mathematical models based on BV to predict LW in crossbred beef heifers. The correlation coefficient between BV and LW (r = 0.93) is similar to that found in various previous studies. Paputungan *et al.* (2015) reported a correlation between LW and BV in crossbred Indian cows, above 0.97. Also, Paputungan *et al.* (2018) determine a correlation between LW and BV in Indonesian Local-Bali grade cattle, above 0.96 regardless of the age of the animals. Several studies on other animal species have identified a high correlation between LW and BV (Takaendengan *et al.*, 2012; Salazar-Cuytun *et al.*, 2021, 2022). These findings reveal that the BV as a predictor variable can be a consistent parameter for predicting the LW of production animals. The practical implications are that the BV may represent better the body mass of the animal, which is directly related to nutrient requirements of maintenance (Chay-Canul *et al.*, 2019).

All models tested were able to predict the weight of animals. As these proved to be equally accurate (Table 2), either of them can be used to predict the LW of crossbred heifers using BV measurement. However, the predictive capacity of the three models for LW was evaluated by cross-validation of *k*-folds (k = 10). This approach was performed by randomly dividing the set of observation values into non-overlapping k-folds of approximately the same size (Steyerberg and Harrel, 2016; Canul-Solis *et al.*, 2020). The first fold is treated as a validation set and the model fits the remaining k-1 folds (training data). This procedure allowed the estimation of higher values of R^2 and lower values of MSPE and MAE for the quadratic model (Table 3). Therefore, the quadratic model was the best-performing mathematical model according to the adequacy assessment to predict the LW of beef heifers using BV calculated from TP and BL data (Fig. 1).

Salazar-Cuytun *et al.* (2021, 2022) and reported that the LW of lambs was better adjusted by a linear equation of the second degree as a function of the measurement of BV. Likewise, Gurgel *et al.* (2021b) observed that the association of several biometric measures promotes better estimates of the live weight of Santa Inês sheep. These authors also reported that the square of the TP measurement provides better predictions of the LW of the lambs. In contrast, Paputungan *et al.* (2015, 2018) recommended the use of a first-degree linear regression model to predict LW from body volume (LW = a + b × BV) in native Indonesian cattle. It is noteworthy that these authors did not test other equations to estimate the LW through the BV.

Table 1. Descriptive statistics of LW and body volume in crossbred heifers raised in tropical humid conditions

	N	Mean ± SD	Minimum	Maximum	CV (%)
LW (kg)	390	426.25±117.18	182.00	704.00	27.49
TP (cm)	390	177.49±18.09	133.00	209.00	10.19
BL (cm)	390	87.90±11.36	60.00	130.00	12.93
BV (dm^3)	390	338.05±95.78	129.95	562.49	28.33

LW: live weight; TP: thoracic perimeter; BL: body length; BV: body volume; N: number of observations; SD: standard deviation; CV: coefficient of variation.

Table 2. Live weight prediction equations using body volume in crossbred heifers raised in tropic humid conditions

	Equation	N	R^2	MSE	RMSE	AIC	BIC	P-value
1	LW (kg) = 41.41 (± 8.32***) + 1.14 (± 0.02***) × BV	390	0.87	7954.72	89.19	2709.74	2717.51	<0.0001
2	LW (kg) = -57.68 (± 21.80***) + 1.80 (± 0.13***) × BV - 0.009 (± 0.001***) × BV^2	390	0.87	8070.05	89.83	2688.39	2700.05	<0.0001
3	LW (kg) = 2.51 (± 0.30***) × $BV^{0.88\ (\pm 0.02^*)}$	390	0.87	7987.46	89.37	2702.50	2710.28	<0.0001

LW: live weight; BV: body volume; N: number of observations; R^2: determination coefficient; MSE: mean square error; RMSE: Root MSE; AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion.
Values in parentheses are the parameter estimates' standard errors (SE). The * indicates: *: P < 0.05; ***: P < 0.001

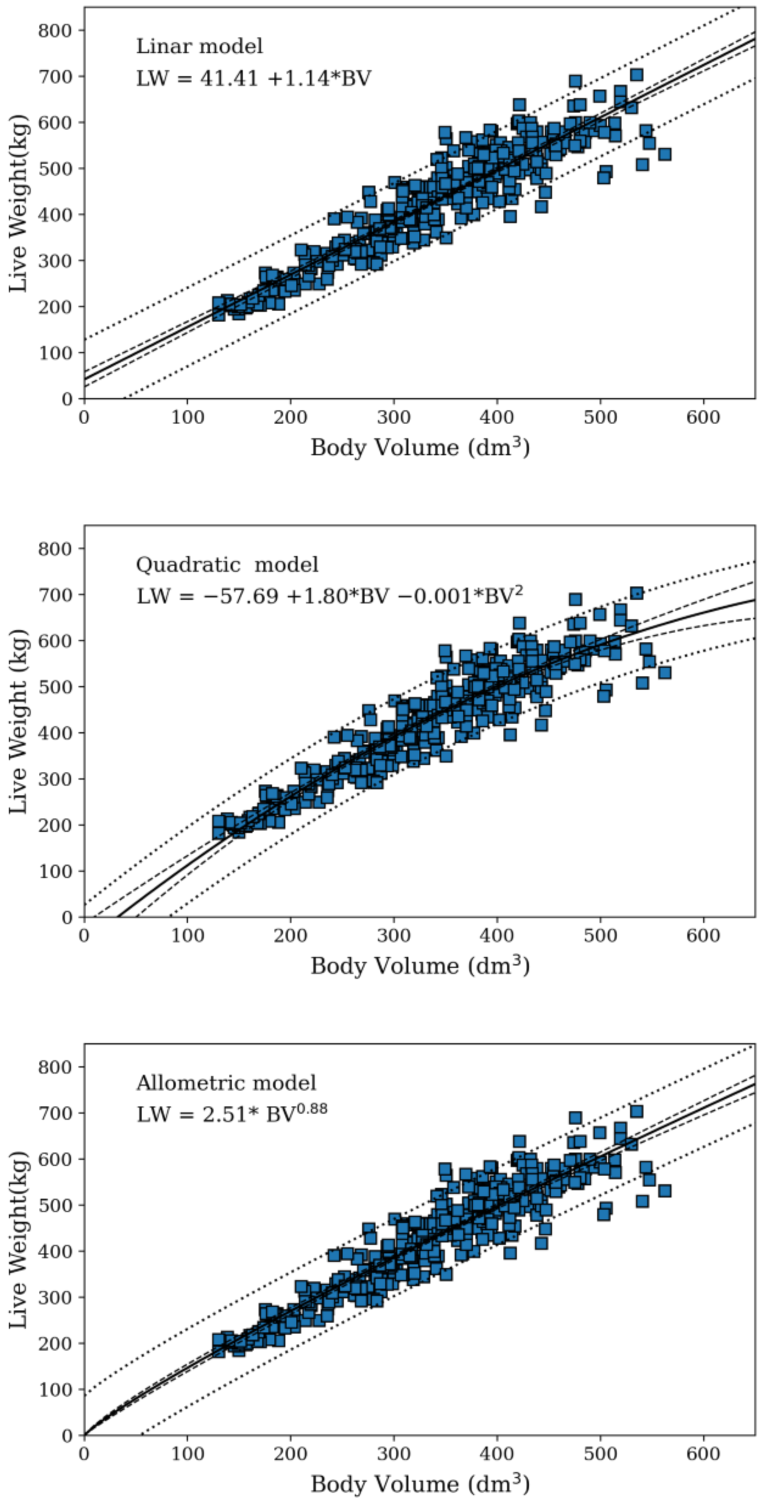

Figure 1. Live weight (LW) prediction equations using the body volume formula (BV) in crossbred heifers raised in tropical humid conditions (n = 360).

Table 3. Internal k-folds cross-validation of the proposed models using body volume in crossbred heifers raised in tropical humid conditions

Model	N	R^2	MSPE	MAE
Linear	390	0.84	42.80	32.75
Quadratic	390	0.85	41.49	31.95
Exponential	390	0.84	42.36	32.32

N: number of observations; R^2: coefficient of determination; MSPE: mean squared prediction error; MAE: mean absolute error.

The results confirm that the second-degree linear equation (quadratic) can be safely used to estimate the LW of crossbred heifers by means of the BV measurement. However, it should be considered that this equation was developed from data from heifers kept in tropical pastures. Therefore, its application is limited to animals raised under such conditions (Tedeschi, 2006). For this, if we want to use the equation in other types of animals, breeds, or production systems, it would be necessary to evaluate its functionality under these specific conditions. Because body conformation and body fat deposition may differ between animals of different sexes and breeds - aspects that may interfere with the correlation between BV and LW in ruminant animals (Paputungan *et al.,* 2018; Salazar-Cuytun *et al.,* 2021; Chico-Alcudia *et al.,* 2022). For this reason, models should 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; Chico-Alcudia *et al.,* 2022).

CONCLUSION

The BV can be used as a predictor of the LW of the crossbred beef heifers kept in tropical pastures. We recommend the quadratic model to predictive of the crossbred beef heifers' live weight using the body volume as the predictor.

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