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Corresponding authors:
Antonio Leandro Chaves Gurgel,
Email: antonioleandro09@gmail.com;
Alfonso Juventino Chay-Canul,
Email: alfonso.chay@ujat.mx

Predicting live weight using body volume formula in lactating water buffalo

Remedio Ramos-Zapata[1], Camila Dominguez-Madrigal[1], Ricardo-A. García-Herrera[1], Enrique Camacho-Perez[2], Jesús Manuel Lugo-Quintal[3], Thobela Louis Tyasi[4], Antonio Leandro Chaves Gurgel[5], Luís Carlos Vinhas Ítavo[6] and Alfonso Juventino Chay-Canul[1]

[1]División Académica de Ciencias Agropecuarias, Universidad Juárez Autónoma de Tabasco, Villahermosa, Tabasco, México; [2]Facultad de Ingeniería, Universidad Autónoma de Yucatán, Mérida, Yucatán, México; [3]Tecnológico Nacional de México, Instituto Tecnológico de Progreso, Progreso, Yucatán, México; [4]Department of Agricultural Economics and Animal Production, University of Limpopo, Sovenga, Limpopo, South Africa; [5]Campus Professora Cinobelina Elvas, Universidade Federal do Piauí, Bom Jesus, Piauí, Brasil and [6]Faculdade de Medicina Veterinária e Zootecnia, Universidade Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brasil

Abstract

Live weight (LW) is an important piece of information within production systems, as it is related to several other economic characteristics. However, in the main buffalo-producing regions in the world, it is not common to periodically weigh the animals. We develop and evaluate linear, quadratic, and allometric mathematical models to predict LW using the body volume (BV) formula in lactating water buffalo (*Bubalus bubalis*) reared in southeastern Mexico. The LW (391.5 ± 138.9 kg) and BV (333.62 ± 58.51 dm^3) were measured in 165 lactating Murrah buffalo aged between 3 and 10 years. 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). LW and BV were significantly positively and strongly correlated ($r = 0.81$; $P < 0.001$). The quadratic model had the lowest values of MSE (2788.12) and RMSE (52.80). On the other hand, the allometric model showed the lowest values of BIC (1319.24) and AIC (1313.07). The Quadratic and allometric models had lower values of MSEP and MAE. We recommend the quadratic and allometric models to predict the LW of lactating Murrah buffalo using BV as a predictor.

Currently, buffalo farming is an important livestock activity in Mexico because it represents a potential source of milk, dairy products, and meat (Hossein-Zadeh, 2016; Mota-Rojas *et al.*, 2022). The buffalo offers several important advantages over cattle, such as better adaptation to the type of climate, greater resistance to tropical cattle diseases, and better use of low-quality forage (Torres-Chable *et al.*, 2017; Ağyar *et al.*, 2022). In Mexico, the water buffalo (*Bubalus bubalis*) was introduced in regions with a hot and humid climate, mainly in the states of Veracruz, Tabasco, Chiapas, and Campeche, due to the fact that in these areas there are large wetlands, which are the natural habitat of these animals (Peralta-Torres *et al.*, 2020).

Although buffalo farming is perceived by producers as a profitable business, there is still much to be explored in terms of animal production parameters (Hernández-Herrera *et al.*, 2018). In particular, the growth rate is an important parameter in animal production, as it characterizes the adaptability and economic suitability of livestock production (Ağyar *et al.*, 2022). Animals that grow faster in terms of body weight must also initiate early physiological functioning of reproduction and milk production (Thiruvenkadan *et al.*, 2009; Gurgel *et al.*, 2020). However, the uncontrolled increase in weight and body size of the animal leads to reproductive problems and increases production costs, due to the greater energy demand for its maintenance (Melo *et al.*, 2020). This problem is even more marked in buffalo culture, where adult males can reach a body weight of 800 kg, while adult females 600 kg (Luna-Palomera *et al.*, 2021).

Live weight is, therefore, the most important information within production systems, as it is related to several other economic characteristics (Agudelo-Gómez *et al.*, 2015; Ağyar *et al.*, 2022). However, in the main buffalo-producing regions in the world, the systems are characterized by low investments in infrastructure, and it is common not to periodically weigh the animals due to the absence of a livestock scale (Agudelo-Gómez *et al.*, 2015; Işik and Gül, 2016; Melo *et al.*, 2020; Ağyar *et al.*, 2022). Biometric measurements of buffalo can be used to estimate body weight in a simple and low-cost way (Ağyar *et al.*, 2022). According to Agudelo-Gómez *et al.* (2015), buffalo body morphometric traits can be used to predict the ability for commercial exploitation and when applied in breeding selection programs may contribute to creating an appropriate functional type.

The measurement of body volume (BV), obtained through the formula for calculating the volume of a cylinder, including body measurements of heart girth (HG) and body length (BL) (Paputungan *et al.*, 2015), has been used in mathematical equations to predict the body weight accurately of animal's production (Paputungan *et al.*, 2018; Salazar-Cuytun *et al.*, 2021, 2022). However, according to our research, no studies were found using the volume measurement to predict the body weight of buffalo. In this context, we hypothesized that BV can be used as the only predictor of LW in buffalo.

This study aimed to develop and evaluate linear, quadratic, and allometric mathematical models to predict live weight using the BV formula in lactating water buffalo reared in tropical environments.

Material and methods

The buffalo 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-2012-IA-18) on a commercial farm located in Isla in the state of Veracruz, México. The climate of the region is hot-humid with rain in summer and average annual temperature and rainfall of 25°C and 2750 mm, respectively. Additional management and experimental details are provided in the online Supplementary File.

Live weight (LW, kg), HG (cm), and BL (cm) data were obtained from 165 lactating Murrah buffalo aged 3–10 years. The animals were reared in production systems based on extensive grazing, and were provided water *ad libitum.* LW was recorded by weighing the animals on a fixed platform scale with a capacity of 2000 kg and precision of 0.5 kg, whereas HG and BL were recorded using a flexible fiberglass tape measure (Truper®).

BV was estimated using the formula to calculate the volume of a cylinder, by including the measurements of HG and BL in its composition (Paputungan *et al.*, 2015). The calculation was as follows:

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

$$\text{Body volume (dm}^3) = \frac{\pi \times r^2 \times \text{BL}}{1000},$$

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

Additionally, three mathematical models were evaluated to predict the Murrah buffalo LW based on BV, namely:

(1) Linear equation (Eq. 1): LW (kg) = $\mu + \beta1 \times \text{BV}$;
(2) Quadratic equation (Eq. 2): LW (kg) = $\mu + \beta1 \times \text{BV} + \beta2 \times \text{BV}^2$; and
(3) Allometric equation (Eq. 2): LW (kg) = $\mu \times \text{BV}^{\beta1}$,

where LW = live weight of the heifer (kg); BV = Body volume (dm^3), 'β1' and 'β2' = model parameters.

Statistical analysis

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. The ratio between BV and LW was determined by linear (Eq. 1), quadratic (Eq. 2) and allometric (Eq. 3) equations using the 'lmfit' package. 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. 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.

The predictive capacity of the three models for LW was evaluated by cross-validating k-folds ($k = 4$). 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, which allowed a comparison of numerous multivariate calibration models.

Results and discussion

The descriptive analysis of the LW and body measurements is presented in full in online Supplementary Table S1. The observed LW ranged from 314.00 to 722.50 kg, with a mean value of 487.17 ± 89.61 kg. This is higher than that reported by Del Pilar *et al.* (2002) for Philipine carabao-Murrah crossbred female buffalo (391 kg), but lower than those of Dhillod *et al.* (2017) and Kumar *et al.* (2019) for female Murrah buffalo reared in India (556 and 516 kg, respectively). Variations in LW, even in animals belonging to the same genetic group and gender could be due to the age range, origin of the animals, and different management practices in different production systems (Del Pilar *et al.*, 2002).

The mean ± standard deviation estimated for body measurements were: HG (201.35 ± 14.99), BL (102.26 ± 11.89) and BV (333.62 ± 58.51). In general, the mean values of body measurements found in this study are consistent with those reported in female Murrah crossbred buffalo raised in Brazil (Melo *et al.*, 2018, 2020) and India (Dhillod *et al.*, 2017). Melo *et al.* (2018) phenotypically describe the females of this buffalo breed as animals with long and wide chests, medium to long rumps, medium height, deep animals and long diagonal lines, which contribute positively to their reproductive and productive abilities. In addition, body measurements are used as a criterion to determine the required area and layout of barn planning in the transition from traditional water buffalo farming to modern water buffalo farming (Kocaman *et al.*, 2017).

Regression equations describing the estimation of LW by the three models are shown in Table 1 and the data are plotted in Figure 1. LW and BV were significantly, positively and strongly

Table 1. Regression equations to estimate live weight (kg) in lactating buffalo reared in Mexican humid tropical conditions

No.	Equation	R^2	MSE	RMSE	AIC	BIC	*P*-value
1	LW (kg): 75.05 (± 24.05***) + 1.24 (± 0.07***) × BV	0.65	2794.22	52.86	1313.32	1319.53	<0.0001
2	LW (kg): 7.07 (± 116.64***) + 1.65 (± 0.68***) × BV − 0.001 (± 0.001***) × BV^2	0.65	2788.12	52.80	1314.96	1324.28	<0.0001
3	LW (kg): 3.61 (± 1.030***) × $BV^{0.84\ (\pm 0.04^*)}$	0.65	2789.34	52.81	1313.07	1319.24	<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: *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

correlated ($r = 0.81$; $P < 0.001$). The quadratic model had the lowest values of MSE (2788.12) and RMSE (52.80). On the other hand, the allometric model showed the lowest values of BIC (1319.24) and AIC (1313.07). Despite this, all models presented the same value for the coefficient of determination ($R^2 = 0.65$) as demonstrated in Figure 1, which shows that all LW prediction equations using BV in crossbred heifers present the same variation.

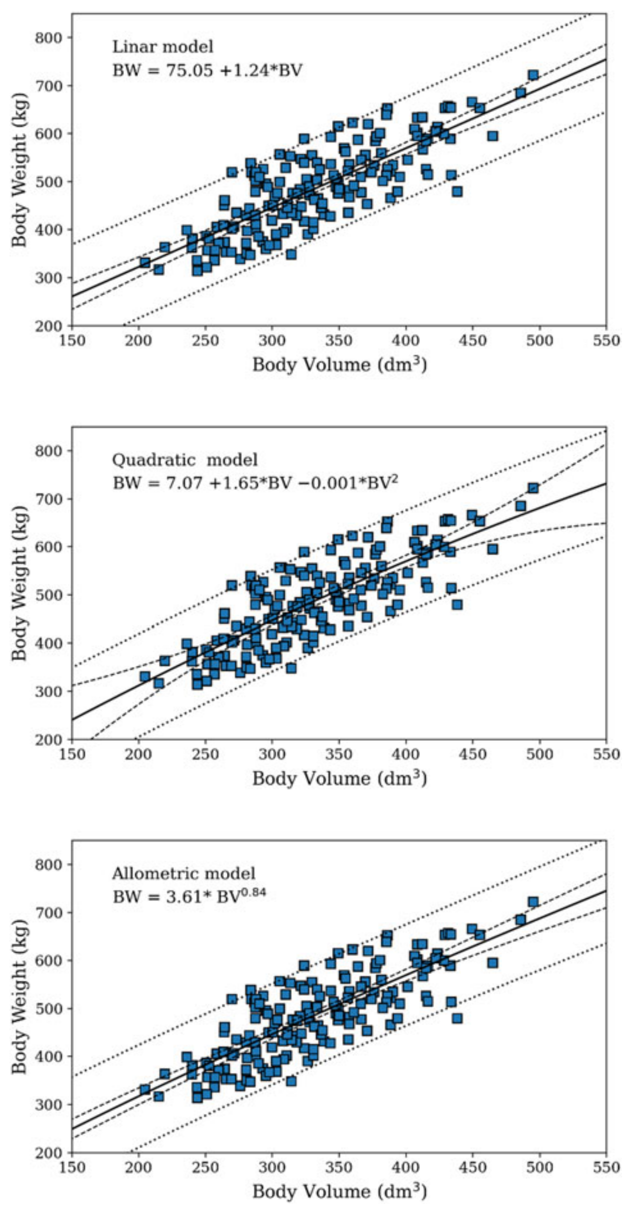

Fig. 1. Body weight (LW) prediction equations using the body volume formula (BV) in lactating buffalo raised in tropical humid conditions ($n = 165$).

Although several studies with buffalo of different breeds, gender and age kept in different production systems showed positive and significant correlations between LW and body measurements (Del Pilar *et al.*, 2002; Johari *et al.*, 2009; Luz *et al.*, 2013; Melo *et al.*, 2018; Ağyar *et al.*, 2022), there are no studies in the literature in which BV was used to estimate LW in this species. Furthermore, Ağyar *et al.* (2022) reported that although LW estimation through biometric measurements is widely used in several animal species, there are no studies in which LW is estimated from buffalo body measurements, although the importance of weight estimation is well known.

Due to the scarcity of such studies on buffalo, we discuss different animal species. In this sense, Paputungan *et al.* (2015) reported that 96% of the weight variation of Indonesia's native cattle is explained by the BV measure, a value higher than any other biometric measure used alone. Salazar-Cuytun *et al.* (2021) found a correlation coefficient greater than 0.85 between body weight and volume in Pelibuey ewes. Salazar-Cuytun *et al.* (2021) also reported a correlation coefficient of 0.96 between body weight and volume in growing hair sheep lambs. In these studies, the authors recommended estimating the LW of sheep by a second-degree linear equation, using the measure of BV as a single predictor (Salazar-Cuytun *et al.*, 2021, 2022).

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 2). Of these, the quadratic and allometric models had lower values of MSEP and MAE. However, the models showed a low coefficient of determination ($R^2 = 0.45$). It should be noted that the interpretation of the value of R^2 only is often wrong, as these criteria measure the precision and not the accuracy of the equation (Tedeschi, 2006). The values of BIC, AIC, and RMSE admit the existence of a model, among a set of evaluated models, that minimizes errors (Bozdongan, 1987; Tedeschi,

Table 2. Internal *k*-folds cross-validation of the proposed models

Model	*N*	R^2	MSPE	MAE
Linear	165	0.43	53.43	43.26
Quadratic	165	0.43	53.39	43.48
Allometric	165	0.43	53.39	43.34

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

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2006). Thus, smaller values denote more accurate estimates. The interpretation of this set of criteria that assess the quality of fit of the models made it possible to identify that the quadratic and allometric models provide more precise and accurate estimates of the body weight using BV as the only predictor.

In conclusion, therefore, the hypothesis tested that BV can be used as a sole predictor of LW in buffalo is confirmed by our results. Nevertheless, we encourage further studies to predict the LW of buffalo using the BV measure. The models described here present high errors and low coefficients of determination, possibly due to the high variability in the age of the animals that composed the database (3–10 years). Nevertheless, we can recommend the quadratic and allometric models to predict the live weight of of lactating Murrah buffalo using BV as a predictor.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0022029923000249.

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