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Relationship between body weight and hip width in dairy buffaloes (*Bubalus bubalis*)

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Abstract

The objective of the present study was to evaluate the relationship between body weight (BW) and hip width (HW) in dairy buffaloes (*Bubalus bubalis*). HW was measured in 215 Murrah buffaloes with a BW of 341 ± 161.6 kg, aged between three months and five years, and raised in southeastern Mexico. Linear and non-linear regressions were used to construct the 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). Additionally, the developed models were evaluated through internal and external cross-validation (*k*-folds) using independent data. The ability of the fitted models to predict the observed values was assessed based on the root mean square error of prediction (RMSEP), R^2, and mean absolute error (MAE). The relationship between BW and HW showed a high correlation coefficient ($r = 0.96$, $P < 0.001$). The chosen fitted model to predict BW was: -176.33 ($\pm$ 40.83***) + 8.74 ($\pm$ 1.79***) × HW + 0.04 ($\pm$ 0.01*) × HW^2, because it presented the lowest MSE, RMSE, and AIC values, which were 1228.64, 35.05 and 1532.41, respectively. Therefore, with reasonable accuracy, the quadratic model using hip width may be suitable for predicting body weight in buffaloes.

Due to its potential as a source of milk, dairy products and meat, buffalo (*Bubalus bubalis*) breeding has gained ground in Mexico in the last 5 years in the livestock industry (Mota-Rojas *et al.*, 2022). Their climate adaptability, increased resistance to tropical livestock illnesses and improved use of lower quality fodder compared to cattle are advantages of these animals (Torres-Chable *et al.*, 2017). In Mexico, water buffalo have been introduced in regions with warm and humid climates, mainly in the states of Veracruz, Tabasco, Chiapas and Campeche, regions that naturally have large swamps (Peralta-Torres *et al.*, 2020). Although farmers believe that buffalo farming is a viable business, there is a knowledge gap in science regarding the factors that affect animal productivity (Hernández-Herrera *et al.*, 2018).

The production and quality of buffalo milk have stood out as a promising alternative in the dairy industry. These animals are known for their adaptability to different environments and their ability to produce nutrient-rich milk, particularly with high levels of fat, protein and total solids, giving it a creamy texture and distinctive flavor (Rangel *et al.*, 2011; Ahmad and Saleem, 2020). Furthermore, the composition of buffalo milk is notably different from cow's milk, making it an excellent choice for the production of special cheeses and yogurts (Sales *et al.*, 2021).

Body weight (BW) is an important factor within production systems as it influences several other economic characteristics (Ramos-Zapata *et al.*, 2023; Ruiz-Ramos *et al.*, 2023). However, the buffalo production chain is characterized by poor infrastructure investment, generally including the lack of a scale to determine the animal's weight. Biometric measurements of buffalo can be used to estimate BW in a simple and inexpensive way (Ramos-Zapata *et al.*, 2023; Ruiz-Ramos *et al.*, 2023). In this sense, Herrera-López *et al.* (2018) and Alejandro-Zarate *et al.* (2023)

found that hip width (HW) is highly related to BW in crossbred heifers. Mathematical models created using biometric data can be safely used to predict BW (Chico-Alcudia *et al*., 2022).

This measurement has an advantage over others since it is simpler to produce and requires less handling of the animal, making it a valuable substitute that can be used without special facilities for restraint and handling of cattle. It can be easily used in any routine practice (Herrera-López *et al*., 2018). In view of this, we examined the hypothesis that HW can be used to predict BW in dairy buffaloes reared in tropical environments. Therefore, the objectives of this study were to understand the relationship between HW and BW and to develop equations to predict BW based on HW in replacement dairy buffaloes reared in tropical environments.

Materials and methods

The buffalo were managed in accordance with the ethical guidelines and animal experimentation regulations of the Department of Agricultural Sciences of the Universidad Juárez Autónoma de Tabasco (approval code: UJAT-2012-IA-18) on a commercial farm located in Isla, Veracruz State, Mexico.

The climate of the region is warm and humid with summer rains and a mean annual temperature and rainfall of 25°C and 2750 mm, respectively. Body weight (BW, kg) and hip width (HW, cm) data were obtained for 215 Murrah buffaloes aged 3 months to 5 years. The animals were raised in extensive pasture production systems with native trees, shrubs, grasses, herbs, and aquatic vegetation (Ramos-Zapata *et al*., 2023). Water was provided *ad libitum*. None of the animals received supplements (Ramos-Zapata *et al*., 2023; Ruiz-Ramos *et al*., 2023). The BW was recorded by weighing the animals on a fixed platform scale with a capacity of 2000 kg and an accuracy of 0.5 kg, while HW was recorded using a 65 cm forceps (Haglöf®).

For the statistical analysis and internal validation of the model, the data were processed in the Python environment as follows: descriptive statistics were obtained using the 'description' function of the 'pandas' package. The ratio between HW and BW 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 BW, X represents HW, 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 BW was evaluated by cross-validating k-folds ($k = 4$). This approach involved randomly dividing the set of observation values into non-overlapping k-folds of approximately the same size. The first fold was treated as a validation set, and the model fit 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

The 215 animals evaluated had a body weight (BW, mean ± SD) of 341 ± 162 kg, ranging from 58 to 654 kg, while the hip width (HW) was 47.5 ± 12.3 cm, with a minimum of 22 cm and a maximum of 68 cm. The BW and HW were positively and highly correlated ($r = 0.97$; $P < 0.001$).

The regression equations describing the estimation of BW according to the three models are presented in Table 1, and the data are plotted in Fig. 1. This figure illustrates external validation, which consisted of evaluating observed vs. predicted values of the three proposed models. The quadratic model was superior to the linear and allometric models in terms of MSE, RMSE, and AIC values. The quadratic model had the lowest MSE (1228.64) and RMSE (35.05). This model also had the lowest AIC (1532.41), although a larger BIC (1542.52). However, the coefficient of determination ($R^2 = 0.95$) was the same for all models.

The linear model exhibited smaller values than the allometric model but greater values than the quadratic model. The quadratic model displayed improved goodness-of-fit scores in relation to the validation criteria, presenting better predictive performance. 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). Among these, the quadratic and allometric models had lower values of MSEP (34.59) and MAE (2686) and a high coefficient of determination ($R^2 = 0.95$). The quadratic model showed a high predictive capacity for body weight using HW as the only predictor in dairy buffaloes (Fig. 1).

Discussion

The findings revealed a robust positive correlation between BW and HW in dairy buffaloes reared in tropical environments aged 3 months to 5 years. Franco *et al*. (2017) reported $r = 0.88$ and $R^2 = 0.83$ between BW and HW in Holstein crossbred heifers; these authors concluded that although HW was highly correlated with BW, it showed a low R^2 with a high coefficient of variation in

Table 1. Regression equations to estimate body weight (kg) of replacement dairy buffaloes kept under humid tropical conditions

No.	Equation	R^2	MSE	RMSE	AIC	BIC	*P*-value
1	BW (kg): −266.25 (± 96.10***) + 12.78 (± 0.19***) × HW	0.95	1252.45	35.39	1535.55	1542.29	<0.0001
2	BW (kg): −176.33 (± 40.83***) + 8.74 (± 1.79***) × HW + 0.04 (± 0.01*) × HW^2	0.95	1228.64	35.05	1532.41	1542.52	<0.0001
3	BW (kg): 0.27 (± 0.30***) × $HW^{1.83\ (\pm 0.03^*)}$	0.95	130.72	36.16	1544.74	1551.48	<0.0001

BW, body weight; HW, hip width; *N*, number of observations; R^2, Coefficient of determination; 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: *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

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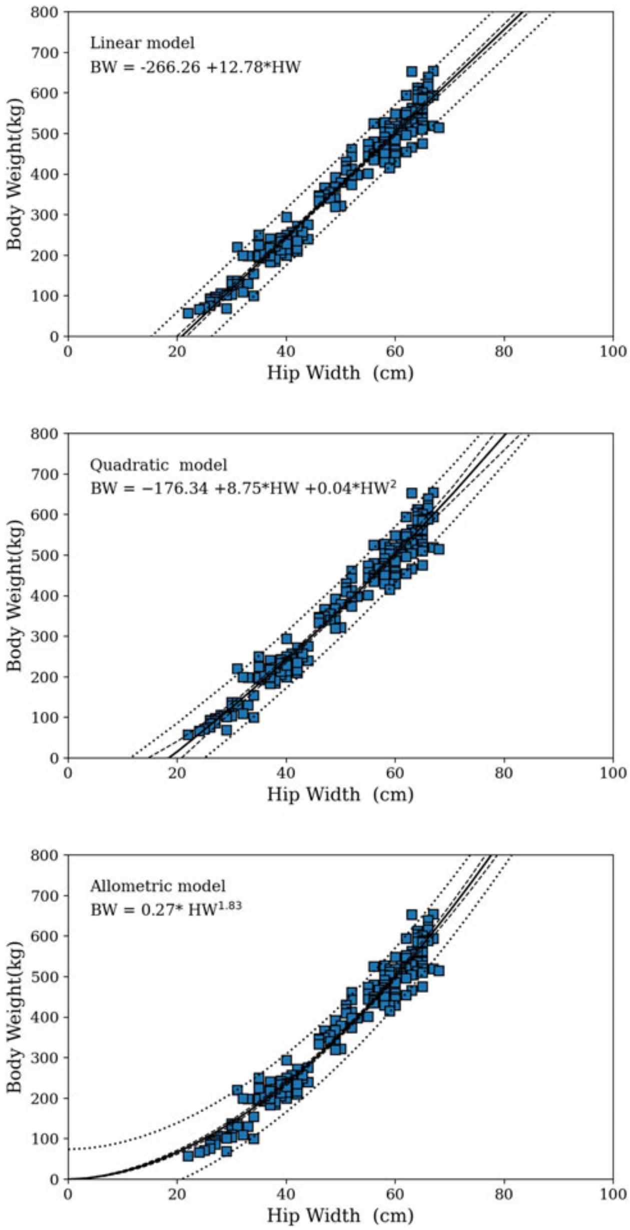

Figure 1. Body weight (BW) prediction equations using the Hip width (HW) in replacement dairy buffaloes raised in tropical humid conditions ($n = 215$).

relation to other body measurements. However, our relationship between BW and HW was high, with a higher value ($r = 0.97$), which is similar to that reported in tropical replacement heifers (Herrera-López *et al.*, 2018; Alejandro-Zarate *et al.*, 2023). This higher relationship may be due, at least in part, to the age (and hence size) range of our study population. The body weight of adult female Murrah buffaloes is highly correlated with body measurements (Ruiz-Ramos *et al.*, 2023). Possibly, HW is a good predictor variable of BW because it indicates the development of the skeletal structure in animals, and this body measurement is located in the hindquarters, exactly where the highest body weight of the animal is concentrated (Bretschneider *et al.*, 2014; Herrera-López *et al.*, 2018). Thus, a wider hip would be expected to support a greater accumulation of muscle and fat in this body region, positively favoring the change in BW, as suggested by the developed equation. Therefore, anatomical measurements as indicators of skeletal size may reflect the true size of replacement females (heifers) and consequently their BW (Herrera-López *et al.*, 2018).

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

Model	*N*	R^2	MSPE	MAE
Linear	215	0.94	35.06	27.83
Quadratic	215	0.96	34.59	26.86
Allometric	215	0.94	35.73	27.94

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

The size or frame of the cow is an important trait for dairy cattle, as these dimensions can influence milk yield and intake capacity (Williams *et al.*, 2018). For cows of different size but equivalent milk yield, the smaller the animal, the greater her gross efficiency. An animal's weight is defined by the quantity of tissues, including the skeleton, which is in turn affected by both long-term growth and short-term changes in energy balance during lactation. An animal's frame is dictated by its skeletal size, which increases as the animal ages, as our results show. According to Ruiz-Ramos *et al.* (2023), withers height, rump height, body height, heart girth, abdominal girth, pelvic girth and body length are all parameters that can be used in models to measure the body weight of mature female Murrah buffaloes.

After confirming the correlation between variables, the development of mathematical equations becomes feasible with the goal of elucidating the relationship between predicted and predictor variables. Biometric measurements, as highlighted by Gurgel *et al.* (2023), have been extensively employed for estimating body weight in ruminant animals. Hence, selecting the mathematical model that most accurately captures this relationship is pivotal, given that the association between live weight and biometric measurements does not consistently follow a linear pattern (Salazar-Cuytun *et al.*, 2022; Ramos-Zapata *et al.*, 2023). Consequently, a critical phase in modeling studies involves the thorough evaluation of the equations (Tedeschi, 2006).

The model evaluation is performed to assess the degree of robustness based on predefined criteria. It is crucial to emphasize that a combination of statistical methods must be employed to collectively evaluate whether the equation is suitable for its intended purpose, considering specific conditions (Gurgel *et al.*, 2023). The use of isolated measures (e.g., R^2) is often misinterpreted, as these criteria primarily measure precision rather than accuracy, as highlighted by Tedeschi (2006). The values of BIC, AIC, and RMSE indicate a model within a set of evaluated models that minimizes errors (Tedeschi, 2006).

The analysis of this set of criteria, which assesses the quality of model fit, revealed that the quadratic and allometric models provide more precise and accurate estimates of body weight when using HW as the sole predictor. Similarly, Ramos-Zapata *et al.* (2023) explored the hypothesis that body volume measurement could be used as the sole predictor of BW in buffaloes, recommending quadratic and allometric models. Despite our research confirming the tested hypothesis, we encourage further studies to predict buffalo BW, incorporating HW measurement. In these new studies, it would be crucial to develop equations considering the age and physiological stage of the animals, aiming to enhance predictions.

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In conclusion, the quadratic model utilizing hip width as a predictor variable proves to be a viable method for estimating body weight with satisfactory precision in dairy buffaloes.

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