SHORT COMMUNICATION

Relationship between body weight and dorsal area in female buffaloes

Relación entre el peso corporal y el área dorsal en hembras de búfalo

Relação entre o peso corporal e a área dorsal em búfalas

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Abstract

Background: The body weight (BW) of animals at various growth stages is an important piece of information for the decision-making process. In the current "livestock 4.0" or precision livestock farming it becomes necessary to know if body measurements obtained from the dorsal view of an animal are related to its BW. **Objective:** To evaluate the relationship between BW and dorsal area (DA) of water buffaloes (*Bubalus bubalis*) reared in southeastern Mexico. **Methods:** The BW (340 ± 161.68 kg), hip width (HW), thorax width (TW), and body length (BL) were measured in 215 female Murrah buffaloes aged between 3 months and 5 years. The DA (m^2) was calculated using the mathematical formulae for the area of a trapezoid, considering HW, TW, and BL in the calculation. The relationship between BW and DA was assessed with correlation and regression models. **Results:** The correlation coefficient between BW and AD was 0.96 ($p<0.001$). The linear equation had the highest determination coefficient ($R^2 = 0.94$) along with the lowest mean square error (MSE = 1716.86), root MSE (RMSE = 41.43), Akaike Information Criterion (AIC = 1603.36), and Bayesian Information Criterion (BIC = 1610.10). Conversely, the allometric equation exhibited the highest values of MSE, RMSE, AIC, and BIC. Based on the quality of fit by the *k*-folds technique, the three

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proposed equations showed consistent adjustments, with more than 90% accuracy ($R^2 = 0.92$). The quadratic equation exhibited the lowest mean squared prediction error and mean absolute error. **Conclusion:** The DA can be used as a good predictor of BW in buffaloes, especially when incorporated into first and second-degree linear equations.

Keywords: *Growth; biometric measurements; body weight; Bubalus bubalis; buffalo; drone; live weight; livestock 4.0; mathematical models; precision livestock farming; weight prediction; unmanned aerial vehicle*.

Resumen

Antecedentes: El peso corporal (PC) de los búfalos durante varias etapas productivas es un dato importante para el proceso de toma de decisiones. En la presente "ganadería 4.0" o ganadería de precisión se hace necesario saber si las medidas corporales obtenidas de la vista dorsal de un animal están relacionadas con su PC. **Objetivo:** Evaluar la relación entre el PC y el área dorsal (AD) en búfalos de agua (*Bubalus bubalis*) criados en el sureste de México. **Métodos:** Se midió el PC (340 ± 161,68 kg), el ancho de cadera (AC), el ancho de tórax (AT) y la longitud corporal (LC) en 215 hembras de búfalos Murrah de edades comprendidas entre los 3 meses y los 5 años. El AD (m^2) se calculó utilizando las fórmulas matemáticas para calcular el área de un trapecio, considerando en el cálculo la AC, la AT y el LC. La relación entre el PC y el AD se evaluó mediante modelos de correlación y regresión. **Resultados:** El coeficiente de correlación entre PC y AD fue de 0,96 (p<0,001). La ecuación lineal mostró el mayor coeficiente de determinación ($R^2 = 0,94$) junto con los menores valores de error cuadrático medio (ECM = 1716,86), error cuadrático medio radical (ECMR = 41,43), criterio de información de Akaike (AIC = 1603,36) y criterio de información bayesiano (BIC = 1610,10). Por el contrario, la ecuación alométrica presentó los mayores valores de ECM, ECMR, AIC y BIC. La calidad del ajuste mediante la técnica de *K-folds* mostró que las tres ecuaciones propuestas tienen ajustes coherentes, con precisión superior al 90% ($R^2 = 0,92$). Entre ellas, la ecuación cuadrática exhibió valores más bajos de error cuadrático medio de predicción y error absoluto medio. **Conclusión:** El AD puede ser un buen predictor del PC en búfalas, especialmente cuando se incorpora a ecuaciones lineales de primer y segundo grado.

Palabras clave: *Bubalus bubalis; bufalo; crecimiento; dron; ganadería de precisión; ganadería 4.0; medidas biométricas; modelos matemáticos; peso vivo; peso en pie; predicción del peso; vehículo aéreo no tripulado.*

Resumo

Antecedentes: O peso corporal (PC) de búfalos durante as diversas etapas de produção é um dado importante para a tomada de decisão. Na atual "pecuária 4.0" ou pecuária de precisão, é necessário saber se as medidas corporais obtidas a partir da vista dorsal de um animal estão relacionadas à sua PC. **Objetivo:** Avaliar a relação entre o PC e a área dorsal (AD) em búfalos d'água (*Bubalus bubalis*) criados no sudeste do México. **Métodos:** O PC (340 ± 161,68 kg), largura do quadril (LQ), largura do tórax (LT) e comprimento corporal (CC) foram medidos em 215 búfalas Murrah com idades entre 3 meses e 5 anos. A AD (m^2) foi calculada usando as fórmulas matemáticas para calcular a área de um trapézio, considerando o LQ, LT e CC no cálculo. A relação entre PC e AD foi avaliada usando modelos de correlação e regressão. **Resultados:** O coeficiente de correlação entre PC e a AD foi de 0,96 (p<0,001). A equação linear demonstra o maior valor de coeficiente de determinação ($R^2 = 0,94$) junto com o menor erro quadrático médio (EQM = 1716,86), raiz do EQM (REQM = 41,43), Critério de Informação de Akaike (AIC = 1603,36) e Critério de Informação Bayesiano (BIC = 1610,10). Por outro lado, a equação alométrica exibe os maiores valores de EQM, REQM, AIC e BIC. A qualidade do ajuste usando a técnica de *k-folds* nos permitiu identificar que as três equações propostas mostraram ajustes consistentes, com uma precisão acima de 90% ($R^2 = 0,92$). Entre elas, a equação quadrática exibiu valores menores de erro quadrático médio de predição e erro médio absoluto. **Conclusão:** A AD pode ser um bom preditor de PC em búfalos, especialmente quando incorporada em equações lineares de primeiro e segundo grau.

Palavras-chave: *Bubalus bubalis; búfalo; crescimento; drone; medidas biométricas; modelos matemáticos; peso vivo; pecuária 4.0; pecuária de precisão; predição do peso; veículo aéreo não tripulado.*

Introduction

The technologies of image analysis are developing fast and can be used to quantitatively characterize the size, shape, and density of organisms or objects (Carabús *et al.*, 2016; Chay-Canul *et al.*, 2023). These technologies are being used in several fields, including human and veterinary medicine and forensic science (Chay-Canul *et al.*, 2023). They can be used in a faster and cheaper way to assess body weight, body mass and body composition of livestock (Gomes *et al.*, 2016; Martins *et al.*, 2020). For example, the measurement of thoracic width, hip width, and body length can be used to predict live weight of dairy cows using three-dimensional cameras (Martins *et al.*, 2020). Similarly, thoracic and hip widths have been included with BW in models for predicting muscle, fat and bone weights in Coopworth sheep using computed tomography to assess body composition; and multivariate regression methods, artificial neural networks, and regression trees, to predict the body composition (Shalaldeh *et al.,* 2023).

Knowing the body weight of animals is fundamental for decision-making in farms, as it is related to economic variables (Ramos Zapata *et al.*, 2023; Ruiz-Ramos *et al.*, 2023). It is necessary to determine whether body measurements obtained from the dorsal view of an animal are related to its body weight, taking advantage of the current "precision livestock farming" based on image analysis technologies, digital photography, and videos. To the best of our knowledge, no literature reports exist on the relationship between dorsal measurements, such as biometrically calculated dorsal area and body weight in buffaloes.

Buffaloes demonstrate greater adaptation to tropical climates, superior disease resistance, and better utilization of low-quality forage (Torres-Chable *et al.*, 2017; Ağyar *et al.*, 2022; Ramos-Zapata *et al.*, 2023). The main objective of the present study was to evaluate the correlation between body weight and dorsal area in buffaloes raised in tropical environments.

Materials and Methods

Buffaloes were managed according to the ethical guidelines and animal experimentation regulations of the Department of Agricultural Sciences of 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. The animals were raised in extensive production systems, which are predominant in the study area. The native pastures, consisting of trees, shrubs, grasses, herbs, and aquatic vegetation, are typical of the humid tropics of Mexico (Ramos-Zapata *et al.*, 2023). Water was provided *ad libitum* to the animals, and they did not receive any supplements (Ramos-Zapata *et al.*, 2023; Ruiz-Ramos *et al.*, 2023).

Body weight (BW, kg), hip width (HW, cm), thoracic width (TW, cm), and body length (BL, cm) data were obtained from 215 female Murrah buffaloes aged 3 months to 5 years. The BW was recorded by weighing the animals on a 2000 kg capacity fix-platform scale with 0.5 kg accuracy; while HW, TW, and BL were recorded using a 65 cm calliper (Haglöf®, Sweden) and a flexible fiberglass measuring tape (Truper®).

The HW, TW, and BL were used to estimate dorsal area (DA, m^2). This estimation was derived through a formula used to calculate the area of a trapezoid, as outlined below:

$$DA = \frac{TW + HW}{2} \times BL$$

Thus, three mathematical models were evaluated to predict body weight of buffaloes through the dorsal area:

(1) Linear equation model (Eq. 1): $BW\ (kg) = \mu + \beta 1 \times DA$;

(2) Quadratic equation model (Eq. 2): $BW\ (kg) = \mu + \beta 1 \times DA + \beta 2 \times DA^2$; and

(3) Allometric model (Eq. 3): $BW\ (kg) = \mu \times DA^{\beta 1}$.

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Where BW represents body weight (kg), DA is the dorsal area (m^2), and β1 and β2 represent the model parameters.

For the statistical analysis and internal validation of the model, data were processed in the Python environment, as follows: descriptive statistics were generated with the 'description' function from the 'pandas' package. The ratio between DA and BW was calculated using linear (Eq. 1), quadratic (Eq. 2), and allometric (Eq. 3) equations implemented via the 'lmfit' package. The allometric equation $Y = aX ** b$ was fitted, where Y represents BW, X represents DA, and a and b are the model parameters. Both the models and their residuals were visualized using the 'matplotlib' package. The goodness-of-fit of the regression models was assessed using the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), the coefficient of determination (R^2), mean square error (MSE), and root MSE (RMSE). The latter three parameters were computed using the 'scikit-learn' package.

The predictive performance of the three models was assessed through a *k*-fold cross-validation. This technique involves randomly partitioning the dataset into k non-overlapping folds of roughly equal size. One-fold serves as the validation set while the model is trained on the remaining k-1 folds (training data). The effectiveness of the model for predicting actual observations was gauged using metrics such as MSE, R^2, and mean absolute error (MAE). The MAE offers an alternative to mean squared prediction error (MSPE), being less influenced by outliers and reflecting the average absolute deviation between observed and predicted values. Lower values of root MSPE and MAE indicate a stronger fit. For the k-fold cross-validation procedure we used the "scikit-learn" package to facilitate the comparison of multiple multivariate calibration models.

Results

The descriptive analysis of BW and DA is summarized in Table 1. The BW ranged from 58.00 to 654.00 kg, with a mean of 340.83 ± 161.68 kg. The DA ranged from 1.20 to 9.57 m^2, with a mean of 5.29 m^2. A strong correlation was observed between BW and DA, with 0.96 correlation coefficient ($p<0.001$).

The regression equations for predicting BW through DA are presented in Table 2, and the data are illustrated in Figure 1. The linear equation had the highest R^2 value (0.94) along with the lowest MSE (1716.86), RMSE (41.43), AIC (1603.36), and BIC (1610.10). On the

Table 1. Minimum and maximum values of body weight (BW) and dorsal area (DA) of buffaloes.

Variable	Description	Mean	SD	Minimum	Maximum
BW	body weight (kg)	340.83	161.68	58.00	654.00
DA	Dorsal area (m^2)	5.29	2.22	1.20	9.57

Table 2. Regression equations to estimate body weight (kg) of buffaloes.

No.	Equation	R^2	MSE	RMSE	AIC	BIC	P-value
1	BW (kg): -31.21 (± 7.30***) + 70.25 (±1.27***) × DA	0.94	1716.86	41.43	1603.36	1610.10	<0.0001
2	BW (kg): -43.57(± 18.31***) + 75.69 (± 7.49***) × DA - 0.49 (± 0.67*) × DA^2	0.93	1720.56	41.48	1604.81	1614.92	<0.0001
3	BW (kg): 54.36 (± 2.56***) × $DA^{1.09\ (\pm 0.02*)}$	0.93	1729.40	41.58	1713.31	1611.67	<0.0001

BW: body weight; DA: dorsal area; 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: *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$

other hand, the allometric equation presented the highest MSE, RMSE, AIC and BIC values. However, the allometric equation yielded R^2 values equivalent to the quadratic equation (0.93).

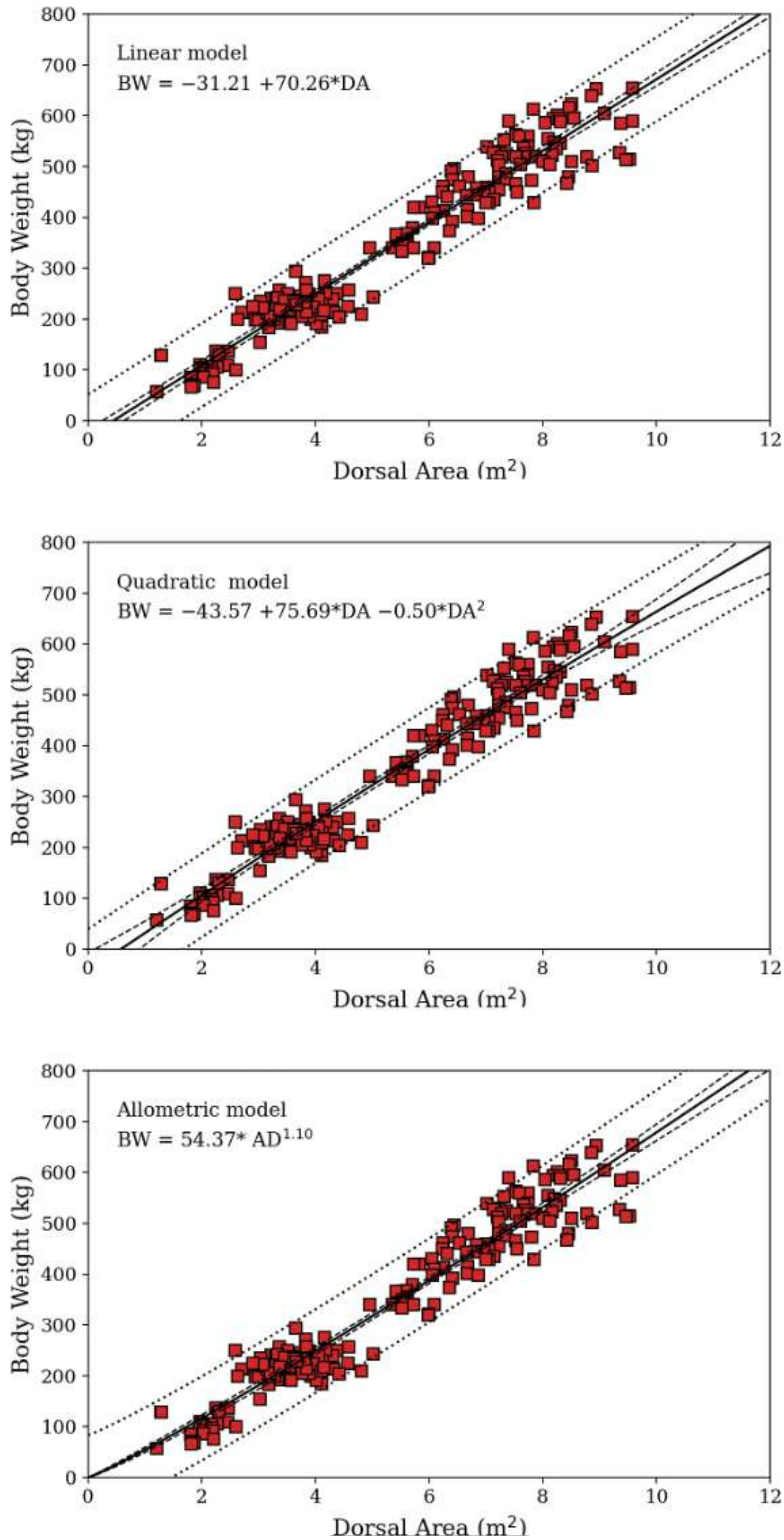

Figure 1. Relationship between body weight and dorsal area of buffaloes.

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

Model	N	R^2	MSPE	MAE
Linear	215	0.92	41.00	32.95
Quadratic	215	0.92	40.957	32.93
Allometric	215	0.92	41.16	33.08

N: number of observations; MSPE: mean squared prediction error; R^2: coefficient of determination; MAE: mean absolute error. 0.001

Discussion

Biometric measurements of buffaloes offer a straightforward and cost-effective means to estimate body weight (Ramos-Zapata *et al.*, 2023; Ruiz-Ramos *et al.*, 2023). In their assessment of female water buffalo reared in southeastern Mexico, Ruiz-Ramos *et al.* (2023) found a strong correlation between several body measurements and live weight, including height at withers, height at rump, thoracic perimeter, abdominal perimeter, and body length. Similarly, Ramos-Zapata *et al.* (2023) explored the relationship between pelvic width, pelvic thickness, and body length in lactating Murrah buffaloes. They computed body volume using a formula for cylinder volume. Their findings suggest that body volume could serve as a reliable predictor of BW in buffaloes.

Although measurements of chest circumference, body volume, and body length are efficient and cost-effective methods for accurately estimating BW of livestock (Chico-Alcudia *et al.*, 2022; Gurgel *et al.*, 2023a; 2023b; Ramos-Zapata *et al.*, 2023) these assessments do not allow for direct weight determination in the field. This implies the need to remove animals from pasture and transport them to handling facilities, resulting in stress and increased labour (Peng *et al.*, 2024). In this context, the adoption of digital image analysis technology offers an alternative solution by enabling weight estimation through the capture of dorsal images of buffaloes using unmanned aerial vehicles. This approach not only reduces stress on animals but also optimizes animal handling, saving time and resources.

Our results show that DA is highly correlated with BW of buffaloes and could be used to predict BW accurately. Accordingly, digital aerial photography can be used to calculate DA using biometric measurements, obtaining a good relationship with BW. To the best of our knowledge, the present study is the first using DA as a tool for estimating body weight in buffaloes.

Unmanned aerial vehicles (UAVs) or aerial drones are used to obtain valuable information for decision-making (Batistoti *et al.*, 2019; Fernandes *et al.*, 2023). This technology involves image capture through drones equipped with high-definition cameras to create models based on patterns among correlated variables (Peng *et al.*, 2024). Modeling studies are fundamental for estimating BW of livestock animals through image capture. These studies seek to establish relationships between predictive and predicted variables thus increasing the precision and accuracy of the methods.

For the development (Table 2) and validation (Table 3) phases, linear equations of first and second degree provided more precise estimates of buffalo BW. These models exhibited higher coefficients of determination and lower errors, indicating a linear relationship between BW and DA. Canul-Solís *et al.* (2023), working with growing Pelibuey sheep, and Chico-Alcudia *et al.* (2022) using crossbred beef heifers, reported that a second-degree linear model provides more precise estimates of BW based on chest circumference. Similarly, Gurgel *et al.* (2023b) recommended the use of body volume in a first-degree linear equation as the sole predictor of BW at weaning for Santa Inês sheep. Lastly, Ramos-Zapata *et al.* (2023) suggested to use a second-degree linear model to predict BW of lactating buffalo based on body volume.

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The present study is pioneer for establishing a relationship between DA and BW of buffaloes under extensive production systems in the humid tropics of Mexico. These farms are characterized by low level of technology and producers rarely perform regular weighing of the animals, which hinders decision-making. The estimation of BW by dorsal image is a significant improvement since the combination of machine learning techniques with modeling studies allows for calculating BW with no stress to the animals and less labor. However, future studies should explore this technique on other breeds, types of animals, and production systems as models have limited applicability to the specific conditions in which they were developed (Gurgel *et al.*, 2023a; Canul-Solís *et al.*, 2023).

Conclusion

The dorsal area is strongly correlated with body weight of buffaloes kept in humid tropical conditions. Therefore, the dorsal area can be a good predictor of body weight in buffaloes, especially when included in first and second-degree linear equations.

Declarations

Funding

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Conflicts of interest

The authors declare they have no competing interests regarding the work presented in this report.

Author contributions

AGV, AACT, ECP, JHC, DMR, RAGH and AJCC conducted the experiment, collected the samples, and wrote the manuscript; JRCS and AJCC conceived and designed the study and wrote the manuscript; ALCG, LCVI and TPDS wrote and reviewed the manuscript; All authors read and approved the manuscript.

Use of artificial intelligence (AI)

No AI or AI-assisted technologies were used during the preparation of this work.

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