EVALUATION OF MODELS TO ESTIMATE EMPTY BODY WEIGHT IN HAIR SHEEP RAISED IN A FEEDLOT SYSTEM †

[EVALUACIÓN DE MODELOS PARA ESTIMAR EL PESO CORPORAL VACÍO EN OVINOS DE PELO MANTENIDOS EN UN SISTEMA DE ALIMENTACIÓN INTENSIVA]

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SUMMARY

Background. The empty body weight (EBW) represents exactly the animal mass and is used as a base to calculate most of the nutrient requirements in most feeding systems. **Objective.** To evaluate models for estimating EBW in growing hair sheep in a feedlot system under tropical conditions. **Methodology.** One hundred fifteen male growing hair sheep lambs (Pelibuey, Black Belly, and Katahdin) between four to ten months of age with a mean shrunk body weight (SBW) of 34.50 ± 7.40 kg (± SD) were used. The relationship between SBW and EBW was assessed by means of three models: Eq. 1. Linear with intercept; Eq. 2.- Linear without intercept and Eq. 3.- Allometric. The predictive ability of models was evaluated by cross-validation. **Results.** The correlation coefficient among SBW and EBW was high (r = 0.98). The regression equations had high determination coefficients (r^2) of 0.97. Based on the evaluations Eq.1 had the performance compared with other models. The following final model was fitted to estimate the EBW as a function of SBW of growing castrated male hair sheep: EBW (kg): -2.39 (± 0.53***) + 0.95(± 0.02***) × SBW (kg). **Implications.** These results contribute to the development of mathematical models for more accurate weight adjustments in growing hair sheep in a feedlot system under tropical conditions**.** **Conclusion.** The equation developed and evaluated in the present study revealed that the linear relationship between SBW and EBW can be used to predict EBW in hair sheep, for that the use of this model can be safely applied to male hair sheep. In addition, it was found that the relation BW/EBW was on average 1.18 for males.

Key words: hair sheep; empty body weight; sheep requirements; tropical conditions.

RESUMEN

Antecedentes. El peso corporal vacío (PVV) representa exactamente la masa animal y se usa como base para calcular la mayoría de los requerimientos de nutrientes en la mayoría de los sistemas de alimentación. **Objetivo.** Evaluar modelos para la estimación del PVV en ovinos de pelo en crecimiento en un sistema de alimentación intensiva bajo condiciones tropicales. **Metodología.** Se utilizaron 115 corderos ovinos machos de pelo en crecimiento (Pelibuey, Black Belly y Katahdin) de cuatro a diez meses de edad con un peso corporal reducido (PVR) medio de 34.50 ± 7.40 kg (± SD). La relación entre PVR y PVV se evaluó mediante tres modelos: Eq. 1. Lineal con intersección; ecuación 2.- Lineal sin intercepto y Ec. 3.- Alométrico. La capacidad predictiva de los modelos se evaluó mediante validación cruzada. **Resultados.** Los coeficientes de correlación entre PVR y PVV fueron altos (r = 0,98). Las ecuaciones de regresión tuvieron altos coeficientes de determinación (r^2) de 0.97. Según las evaluaciones, el Eq.1 tuvo el rendimiento

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en comparación con otros modelos. El siguiente modelo final se ajustó para estimar el PVV en función del PVR de ovinos de pelo macho castrados en crecimiento: PVV (kg): -2.39 (± 0.53***) + 0.95 (± 0.02***) × PVR (kg). **Implicaciones.** Estos resultados contribuyen al desarrollo de modelos matemáticos para realizar ajustes de peso en ovinos de pelo en crecimiento en un sistema de alimentación intensiva bajo condiciones tropicales. **Conclusión.** La ecuación desarrollada y evaluada en el presente estudio reveló que la relación lineal entre PVR y PVV se puede utilizar para predecir PVV en ovinos machos de pelo, por lo que el uso de este modelo se puede aplicar de forma segura a ovinos de pelo. Además, se encontró que la relación PV/PVV fue en promedio de 1.18 para los machos.
Palabras clave: ovinos de pelo; peso corporal vacío; requerimientos de ovinos; condiciones tropicales.

INTRODUCTION

The production of meat from sheep is a prominent activity in tropical regions because it has a high potential for generating economic income in agribusiness (Barcelos *et al.,* 2020). Hair sheep are well adapted to the climatic and management conditions of tropical regions (Pereira *et al.,* 2017). However, its nutritional requirements are a controversial issue due to the scarce available information (Chay-Canul *et al.,* 2016). A better understanding of the nutritional requirements of growing hair sheep would allow the development of better feeding strategies and reduce costs in the formulation of diets (Pereira *et al.,* 2017). For that, estimating the nutritional requirements of hair sheep, knowledge about the animal's weight and its relationships with growth performances is essential (Herbster *et al.,* 2020). Different measures are used to evaluate the nutritional effects in growing sheep, such as body weight (BW), fasting BW (FBW) and weight gain (Gionbelli *et al.,* 2015; Herbster *et al.,* 2020).

Moreover, the result of weighting cattle does not represent the true weight of its body. Approximately 10 to 20% of the body weight of cattle is from the gastrointestinal tract content (Gionbelli *et al.,* 2015). The empty BW (EBW) is defined as the difference between BW at slaughter and the contents of the gastrointestinal tract. The EBW represents exactly the animal mass and is used as a base to calculate most of the nutrient requirements in most feeding systems. However, fasting animals are rarely weighed in beef cattle production systems (Gionbelli *et al.,* 2015). For that, the development of methods and mathematical models are necessary to apply accurate adjustments to the weights of the animals as a function of their body weights collected in field conditions (Chay-Canul *et al.,* 2014; Gionbelli *et al.,* 2015; Herbster *et al.,* 2020).

Body weight adjustments represent an indispensable tool for estimating animal performance in feeding trials, nutritional requirement studies and production systems. The decision-making in the production system is often based on the weight gain of the animals. In this regard, accurate body measurement of weight is crucial in assessing animal performance and assisting the strategic management of a herd such as formulating diets, weight gain projections and carcass yield (Barcelos *et al.,* 2020; Herbster *et al.,* 2020). Although most of the sheep raised in tropical conditions worldwide are hair breeds, little information is available on their nutritional requirements (Chay-Canul *et al.,* 2011; Chay-Canul *et al.,* 2014; Barcelos *et al.,* 2020). This research aimed at evaluating models for estimation of the EBW in growing hair sheep in a feedlot system under tropical conditions.

MATERIALS AND METHODS

Experimental site

Animals were handled in compliance with the guidelines and regulations for ethical animal experimentation of the División Académica de Ciencias Agropecuarias of the Universidad Juárez Autónoma de Tabasco (ID project PFI: UJAT-DACA-2015-IA-02).

The experiment was carried out at the Southeastern Center for Ovine Integration (Centro de Integración Ovina del Sureste [CIOS]; 17° 78" N, 92° 96" W; 10 masl). One hundred fifteen male growing hair sheep lambs (40 Black Belly, 30 Pelibuey and 45 Katahdin) from four to ten months of age with a mean shrunk body weight (SBW) of 34.50 ± 7.40 kg (± SD) were used in the experiment. Lambs were placed in raised-slatted floor pens (6 × 4 m) with a feeding group (15 animals per pen) in a feedlot system and were fed *ad libitum* daily at 08:00 and 15:00 with a total mixed ration. The experimental diet was a total mixed ration (80:20 concentrate to forage ratio) comprising ground maize, soybean meal, star grass hay, vitamins and minerals premix. The diet was formulated to meet the metabolizable energy (ME) and metabolizable protein (MP) for growing sheep (250 g/d) according to the equations of the Agriculture and Food Research Council (AFRC, 1993). The animals were confined for fattening at different ages and weights, however, they remained for at least 40 days in the feedlot in grouped pens. Animals were slaughtered when they reached the commercial BW (around 25-40 kg). The animal´s BW was recorded on the previous day, before fasting.

Slaughter procedures

Before slaughtering, the shrunk BW (SBW) was recorded after feed and water were withdrawn for 24

h. Animals were slaughtered humanely following the Mexican Official Norms (NOM-08-ZOO, NOM-09-ZOO, and NOM-033-ZOO) established for the slaughter and processing of meat animals. The gastrointestinal tract (GIT) content was recorded as the difference in weight of the GIT before and after emptying and flushing with running water. The EBW was computed as the difference between SBW at slaughter and contents of the GIT. The data recorded at slaughter included the weight of internal organs and that of the hot carcass (HCW), then the carcass was chilled at 6°C for 24 h, after which the cold carcass weight (CCW) was recorded.

Data analyses

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 described function of the "pandas" package (McKinney, 2010). The relationship between SBW and EBW was assessed according to recommendations by Barcelos *et al.* (2020) we tested three models to estimate EBW as a function of SBW. The following models were tested:

Eq. 1.- Linear with intercept: EBW (kg) = $\mu + \beta 1 \times SBW$ *(kg)*

Eq. 2.- Linear without intercept: EBW (kg) = $\beta 1 \times SBW$ *(kg)*

Eq. 3.- Allometric: EBW (kg) = $\mu \times SBW^{\beta 1}$

where EBW = empty body weight (kg); SBW = the shrunk body weight (kg); " μ ", " $\beta 1$" = model parameters.

The models were fitted using the "lmfit" package (Newville *et al.*, 2014). 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 EBW 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 remaining 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

Mean (± SD), minimum and maximum weights of animals are shown in Table 1. The SBW ranged from 21.00 to 58.50 kg, while the EBW ranged from 17.83 to 51.78 kg. The correlation coefficients among SBW and EBW was high (r = 0.98).

The regression equations had high determination coefficients (r^2) of 0.97 (Table 2, Figure 1). The Eq. 1 described the relationship between SBW and EBW (AIC = 45.42), better than the linear models without intercepts (AIC = 61.89). But, was only slightly better than that nonlinear model (AIC = 48.26). Based on the AIC evidence ratio, the linear model had a 99% probability of showing the best fit on the linear models without intercepts. While compared with nonlinear model versus only the 80% of probability of showing the best fit. The following final model was fitted to estimate the EBW as a function of SBW of growing castrated male hair sheep was: EBW (kg): -2.39 (±0.53***) + 0.95 (± 0.02***) × SBW.

Although the cross-validation indicated that Eq. 1 and Eq. 3 had a similar r^2 (0.96), the RMSEP and MAE were slightly lower for Eq. 1 than Eq. 3. As indicated by the cross-validation and Eq. 1 tended to be slightly more accurate (less RMSEP and MAE) than Eq. 3 (Table 3).

Table 1. Descriptive statistics of SBW and EBW in hair sheep.

Variable	*n*	Mean	Median	Minimum	Maximum	SD
SBW (kg)	115	34.50	33.15	21.00	58.50	7.40
EBW (kg)	115	30.55	29.41	17.83	51.78	7.16

SBW: shrunk body weight BW; EBW: empty body weight; SD: Standard Deviation.

Table 2. Prediction equations of EBW using the SBW in hair sheep.

No.	Equations	r^2	MSE	RMSE	AIC	BIC	*P*-Value
1	EBW (kg): -2.39 (± 0.53***) + 0.95(± 0.02***) × SBW	0.97	1.45	1.20	45.42	50.91	<0.0001
2	EBW (kg): 0.88 (± 0.01***) × SBW	0.97	1.69	1.30	61.89	64.63	<0.0001
3	EBW (kg): 0.69 (± 0.04***) × $SBW^{1.06(\pm 0.02***)}$	0.97	1.49	1.22	48.26	53.75	<0.0001

SBW: shrunk body weight; EBW: empty body weight; 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. *= P < 0.05; **= P < 0.01; ***=*P* < 0.001.

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

Model	r^2	RMSEP	MAE
1	0.96	1.19	0.91
2	0.80	2.69	2.44
3	0.96	1.21	0.92

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

DISCUSSION

The nutritional guidelines for small ruminants, such as the Small Ruminant Nutrition System (SRNS) (Cannas *et al.,* 2004; Tedeschi *et al.,* 2010; Mendes *et al.,* 2021) are continuously being updated with data that were unavailable for some of the parameters required by these models in order to predict the performance of hair sheep breeds, including mature weight, body weight adjustments, maturity index for determination of standards in nutritional requirements (Chay-Canul *et al.,* 2014). However, in tropical conditions, the nutritional requirements recommended by international committees may not be adequate to meet the physiological needs at different stages of the animal's life. On the other hand, several authors have been reported that one of the limiting factors for evaluating production efficiency (e.g., feed efficiency) in hair sheep during growth is the difficulty in obtaining reliable estimates of weight variation (Chay-Canul *et al.,* 2014; Gionbelli *et al.,* 2015; Pereira *et al.,* 2017).

Regarding the body weight adjustments, a few previous studies have reported data about BW adjustments for growth in hair sheep (Herbster *et al.,* 2020). That is required to develop equations to predict EBW of hair sheep at different physiological states (Chay-Canul *et al.,* 2014). Variations in the contents of the GIT of animals are a major source of error in the measurement of the SBW. It has been reported that the gut fill and thus the relationship of EBW to BW may be affected by various factors including the physiological state, the level of production, maturity, size and age, temperature (particularly regarding water intake), activity, fasting and physical and chemical characteristics of the diet (ARC, 1980; Owens *et al.,* 1995; Chay-Canul *et al.,* 2014; Herbster *et al.,* 2020). It has been reported that the relationship between EBW and SBW can be affected by several factors, including effects of the animal itself (physiological state, level of production, and maturity) and others of the chemical composition of the diet (fiber content of the diet, the level of concentrate), among others (ARC, 1980; Campos *et al.,* 2017). In the present study, it was observed that the GIT filling was reduced, probably the fact that the animals were in intensive fattening with high grain fattening and low in fiber (80:20, concentrate: hay), could have an impact on the transit rate of the digesta, which caused the rumen of these animals to increased transit rate and therefore the filling percentage of the GIT was less.

The EBW is the most accurate body measurement used to express the nutrient requirements of ruminants. For this reason, regression equations have been developed to estimate the EBW from the BW or FBW (Cannas *et al.,* 2004). The fixed ratio of 0.851 × SBW (Cannas *et al.,* 2004; NRC, 2007) may incur in estimation errors, especially when used for hair sheep with different patterns of growth relative to wool sheep. For this reason, regression equations have been developed to estimate EBW from BW or SBW (Cannas *et al.,* 2004; Chay-Canul *et al.,* 2014). Cannas *et al.* (2004) and Tedeschi *et al.* (2010) defined SBW as 96% of full BW (FBW, kg). Chay-Canul *et al.* (2014) fitted a linear equation to estimate the EBW to hair ewes raised under tropical conditions and reported a reduction of 19% of SBW. It is important to report variations in the contents of the GIT of ruminants as important sources of error in the measurement of SBW. Regadas-Filho *et al.* (2013) studied Santa Inés growing sheep and recorded a GIT fill of approximately 20% of the SBW. Baião (2006) reported, that for growing Santa Inés ewes, an EBW that corresponded to 87% of SBW, resulting in a GIT fill of 13%. Duarte-Vera *et al.* (2012) used EBW data from studies of Pelibuey sheep and reported that the EBW was 81.4% of the SBW, and stated that GIT fill was 18%, which is greater than that for wool sheep. Mendes *et al.* (2021) found a linear relationship between SBW and EBW (EBW (kg) = 0.547 (± 0.564) + 0.827 (± 0.016) × SBW) in crossbreed Dorper × Santa Ines lambs, resulting in a GIT fill of 17%.

Similarly, Hebster *et al.* (2020) fixed a linear equation to predict EBW in hair sheep raised in tropical conditions (EBW = −1.4944 (± 0.3639) + 0.8816 (± 0.018) × FBW), indicating a 12% GIT fill. In the present study, the weight of the gastrointestinal content corresponds to 5% of the SBW of the animals, which proves that the level of concentrate in the diet has a significant effect on the filling of the gastrointestinal tract. In addition, it was found that the relation BW/EBW was on average 1.18, which is similar to that reported by Chay-Canul *et al*., (2016).

In addition, Barcelos *et al.* (2020) found that the relationship between SBW and EBW was better described by a nonlinear model (AIC = 12.5) than by linear models with (AIC = 13.7) or without (AIC = 26.2) intercepts. They fitted the following final model to estimate the EBW as a function of SBW for growing castrated male hair sheep: EBW = 0.507 (± 0.052) × SBW 1.135(±0.028). The nonlinear model observed by these authors considered that the weight ratios and weight gain rates varied according to the animal's weight. Even after solid-fasting for more than 16 h, the

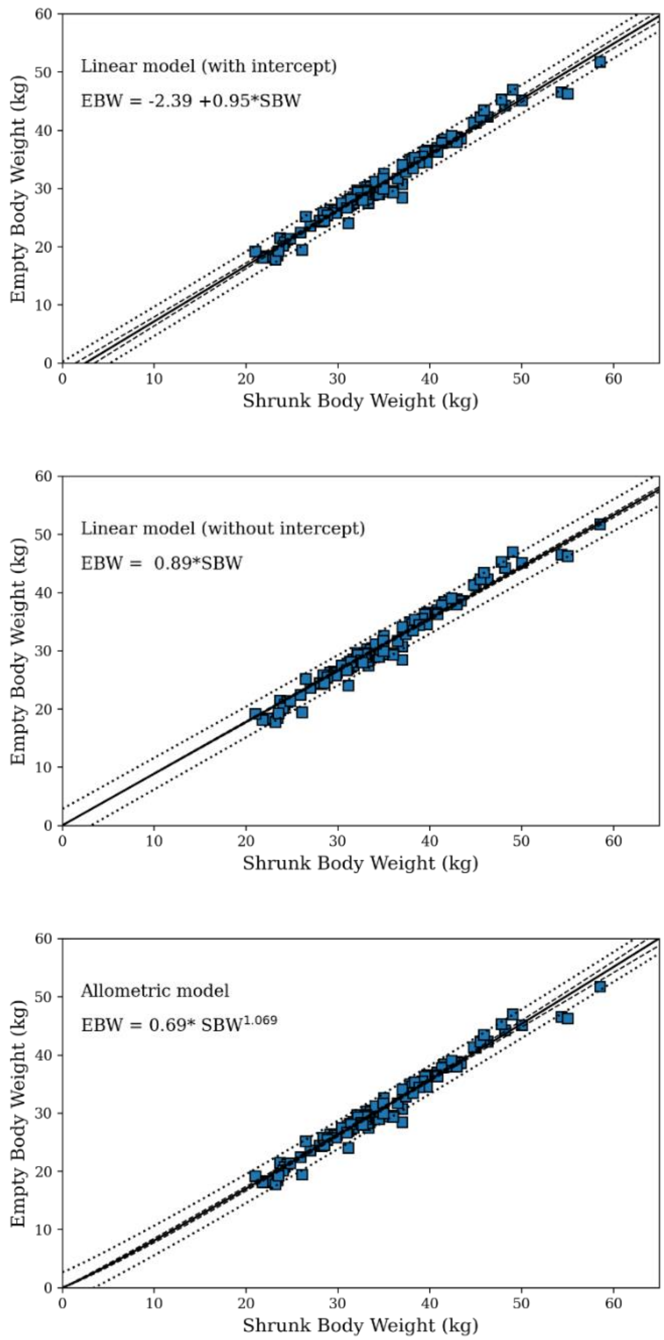

Figure 1. Linear and nonlinear relationship between EBW and SBW in hair sheep.

animals still had ingested in their gastrointestinal tracts (GIT). Barcelos *et al.* (2020) suggest a nonlinear relationship between SBW and EBW, with the decreased GIT content proportional to the increased body weight. A nonlinear relationship between SBW and EBW was also found for other ruminant species. The equations developed and evaluated via cross-validation in the present study revealed that the linear relationship between SBW and EBW can be used to predict EBW in hair sheep, for that the use of these models can be safely applied to hair sheep. Results from the present study are specific to a growing hair sheep in feedlot systems, but this builds a starting point for studying animals in other physiological states and under different management conditions.

CONCLUSION

The current study indicates that the weight of gastrointestinal contents was approximately 5% of SBW in hair sheep under tropical conditions. In addition, it was found that the relation BW/EBW was on average 1.18 for males. The equation developed and evaluated in the present study revealed that the linear relationship between SBW and EBW can be used to predict EBW in male hair sheep. These results contribute to the development of mathematical models for more accurate weight adjustments in growing hair sheep in a feedlot system under tropical conditions.

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Compliance with ethical standards and Statement of animal rights. In this study animals were handled according to the guidelines and regulations for animal experimentation of the Academic Division of Agricultural Sciences of the Universidad Juárez Autónoma de Tabasco (ID project PFI: UJAT-DACA-2015-IA-02).

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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