EQUATIONS FOR BODY WEIGHT ADJUSTMENTS IN BLACK BELLY EWE LAMBS †

[ECUACIONES PARA AJUSTES DE PESO CORPORAL EN CORDERAS BLACK BELLY]

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SUMMARY

Background. As body weight (BW) is rarely determined on fasted animals in most production systems, the need to develop accurate mathematical models for adjusting BW has been identified. **Objective.** To evaluate models for estimating shrunk body weight (SBW) and empty body weight (EBW) in Black Belly growing ewe lambs raised in tropical conditions. **Methodology.** Data of sixty Black Belly ewe lambs, between four to eight months of age with a mean BW of 26.55± 3.92 kg (± SD) were used. The SBW was estimated based on the BW without fasting (fed) and the EBW based on SBW through three models: 1. Linear; 2.-Linear without intercept and 3.- Exponential. The predictive capacity of the models was evaluated by cross-validation. **Results.** The correlation coefficients between BW and SBW and SB and EBW were high (r = 0.94; <0.0001). The coefficients of determination (r^2) for the equations between BW and SBW were 0.89 (P<0.001); and 0.86 (P<0.001) for the relationship between SBW and EBW. Based on the AIC (26.81) Eq. 2 described the relationship between BW and SBW better than Eq. 1, (AIC = 28.44) and Eq. 3 (AIC =28.35). The final model to estimate SBW as a function of BW was: SBW (kg): 0.96 (±0.001***) × BW. With respect to the SBW and EBW ratio, Equation 5, was better than the linear Eq. 4, (AIC = 33.01) and Eq. 6 (AIC = 33.35). The following model was: EBW (kg): 0.81 (± 0.06***) × SBW. The cross-validation of the equation of the relationship between BW and SBW showed that Eq. 1 had a higher r2 (0.87), and lower RMSEP and MAE than Eq. 2 and Eq. 3. Also, the equation of the relationship between SBW and EBW the cross-validation revealed that Eqs. 4 and 6 had the higher ^{r2} (0.82), and lower RMSEP and MAE and tended to be more accurate than Eq. 5. **Implications.** The results obtained in present study contributes to the development of mathematical models for more accurate body weight adjustments in tropical sheep. **Conclusion.** The equations developed and evaluated in the present study revealed that the linear relationship between BW and SBW, and the linear and exponential relationship between SBW and EBW can be used to body weight adjustments in growing Black Belly ewe lambs. It's worth noting that this confirms that the SBW can be calculated using an adjustment factor of 0.96 FBW.

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

RESUMEN

Antecedentes. Dado que el peso corporal (PV) rara vez se determina en animales en ayunas en la mayoría de los sistemas de producción, se ha identificado la necesidad de desarrollar modelos matemáticos precisos para ajustar el

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PV. **Objetivo.** Evaluar modelos para estimar el peso corporal reducido (PVR) y el peso corporal vacío (PVV) en corderas Black Belly en crecimiento criadas en condiciones tropicales. Se utilizaron datos de sesenta corderas Black Belly, de entre cuatro y ocho meses de edad, con un PV medio de 26,55± 3,92 kg (± DE). El PVR se estimó a partir del PV sin ayuno (lleno) y el PVV a partir del PVR mediante tres modelos: 1. Lineal; 2.-Lineal sin intercepto y 3.- Exponencial. La capacidad predictiva de los modelos se evaluó mediante validación cruzada. **Resultados.** Los coeficientes de correlación entre PV y PVR y PVR y PVV fueron altos (r = 0.94; <0.0001). Los coeficientes de determinación (r^2) para las ecuaciones entre PV y PVR fueron de 0.89 (P<0.001); y de 0.86 (P<0.001) para la relación entre PVR y PVV. Con base al AIC (26.81), la ecuación 2 describió la relación entre el peso corporal y el peso corporal mejor que la ecuación 1 (AIC = 28.44) y la ecuación 3 (AIC = 28.35). El modelo final para estimar el PVR en función del PV fue: PVR (kg): 0.96 (±0.001***) × PV. Con respecto a la relación PVR y PVV, la Ecuación 5, fue mejor que la Ecuación lineal 4, (AIC = 33.01) y la Ecuación 6 (AIC = 33.35). El modelo fue el siguiente PVV (kg): 0.81 (± 0.06***) × PVR. La validación cruzada de la ecuación de la relación entre PV y PVR mostró que la Ecuación 1 tenía un r2 más alto (0.87), y RMSEP y MAE más bajos que la Ecuación 2 y la Ecuación 3. También, la ecuación de la relación entre PV y PVR mostró que la Ecuación 2 tenía un r^2 más alto (0.87), y RMSEP y MAE más bajos que la Ecuación 3. También, la ecuación de la relación entre PVR y PVV la validación cruzada reveló que las Ecs. 4 y 6 tenían el r^2 más alto (0.82), y RMSEP y MAE más bajos y tendían a ser más exactas que la Ec. 5. **Implicaciones.** Los resultados obtenidos en el presente estudio contribuyen al desarrollo de modelos matemáticos para ajustes más precisos del peso corporal en ovinos tropicales. **Conclusiones.** La ecuaciones desarrolladas y evaluadas en el presente estudio revelaron que la relación lineal entre el PV y PVR, y la relación lineal y exponencial entre el PVR y el PVV pueden utilizarse para ajustar el peso corporal en corderas Black Belly en crecimiento. Cabe señalar que esto confirma que el PVR puede calcularse utilizando un factor de ajuste de 0.96 del PV.

Palabras clave: peso corporal vacío; ovinos de pelo; requerimientos de ovinos; condiciones tropicales.

INTRODUCTION

It has been established that knowledge of animal weight and its relationship with growth performance is essential to improve the profitability of production systems (Herbster *et al*., 2020; Salazar-Cuytun *et al*., 2022). However, the real body mass of animals can be influenced by factors such as physiological state, gastrointestinal tract (GIT) content and feeding level, among others, which can lead to errors and behaviour that underestimate or underestimate the real body weight (BW) (Chay-Canul *et al*., 2014; Campos *et al*., 2017; Gionbelli *et al*., 2015; Mardhati *et al*., 2021). The use of full BW (FBW) as a growth index is uncertain when feed or water intake and GIT filling can be altered by dietary roughage levels, weather changes or feeding patterns (Owens *et al*., 1995). To avoid such problems, FBW can be measured 'shrunken' (*i.e*. after a period of feed and water withdrawal). The result is a reduction in the degree of variation in GIT content (Owens *et al*., 1995).

In this sense, the main feeding systems for ruminants have adopted some terms to indicate body weight adjustment in ruminants. Shrunk BW (SBW) is defined as 96% of full BW (FBW, kg) of animals (Cannas *et al*. (2004; Tedeschi *et al*. (2010). Also, SBW is defined as live body weight following overnight feed withdrawal (Lancaster, 2022). While the empty BW (EBW) can represent 10 to 20% of the BW of cattle and is obtained from the difference between BW at slaughter or SBW and the weight of the content of the gastrointestinal tract (Chay-Canul *et al*., 2014; Gionbelli *et al*., 2015; Salazar-Cuytun *et al*., 2022). The EBW represents the real mass of the animal and is taken as a basis for calculating nutritional requirements in feeding systems. Because, in most production systems, the BW of fasted animals is rarely determined, the need to develop accurate mathematical models for the adjustment of body weights has been identified (Chay-Canul *et al*., 2014; Gionbelli *et al*., 2015; Herbster *et al*., 2020; Salazar-Cuytun *et al*., 2022). In this context, in beef cattle, the BR CORTE system (2023) and the NRC system (1996) reported a constant relationship between EBW and SBW. Other studies have reported an exponential relationship, which could be different because the whole-body GIT content decreases as the animal grows (Costa e Silva *et al*., 2015). Also, Barcelos *et al*. (2020) reported that the exponential model observed in their study in sheep considered that the weight ratios and weight gain rates varied according to the weight of the animal. This study suggests an exponential relationship between SBW and EBW, with the decrease in GIT content proportional to the increase in BW. A exponential relationship between SBW and EBW has also been found in other ruminant species (Gionbelli *et al*., 2015). To do this, we need to evaluate different mathematical models to allow precise and accurate bodyweight adjustments for hair sheep breeds.

On the other hand, Lancaster (2022) concluded that the existing models might have significant limitations and are affected by some combination of factors such as sex and breed; for this is necessary to develop/evaluate robust equations to account for these factors. Also, the prediction equations may need to be re-evaluated periodically as cattle genetics change and the adaptations of production systems. Because the equations for body weight (BW) adjustments (shrunk and empty body weights) are necessary for accurately estimating the nutritional requirements of farm animals is required to develop equations for those purposes under different production systems (Salazar-Cuytun *et al*., 2022). This study aimed to evaluate models for estimating shrunk body weight (SBW) and empty body weight (EBW) in Black Belly growing ewe lambs raised in tropical conditions.

MATERIALS AND METHODS

Experimental site

The handling of the animals was carried out following the guidelines and standards for ethical experimentation with animals of the Academic Division of Agricultural Sciences of the Universidad Juárez Autónoma de Tabasco (project ID: CIEI: Folio 1173-2022).

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). In the experiment, sixty growing Black Belly ewe lambs between four and six months of age with a mean body weight (BW) of 26.55± 3.75 kg (SD) were used. Ewe lambs were housed in raised-slatted floor pens (6 x 4 m) with a feeding group (15 animals per pen) and fed a total mixed ration ad libitum at 08:00 and 15:00 daily. The experimental diet was a total mixed ration (80:20 ratio of concentrate to pasture) consisting of ground maize, soybean meal, star grass hay, and a premix of vitamins and minerals. The diet was designed to meet the metabolizable energy (ME) and metabolizable protein (MP) requirements for developing sheep (250 g/d) based on the Agricultural and Food Research Council formulae (AFRC, 1993). The animals were confined for fattening at various ages and weights, but they remained in the feedlot for at least 40 days in group pens. Animals were slaughtered when their commercial BW was achieved (around 25-40 kg). Prior to fasting, the animal's BW was recorded the day before.

Slaughter procedures

The shrunk BW (SBW) was recorded prior to sacrifice after removing food and water for 24 h. The animals were slaughtered following the Official Mexican Standards (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 is the difference between the SBW and the contents of the GIT. The weight of the internal organs and the hot carcass (HCW) were recorded, later they were kept at a temperature of 4°C for 24 h, to obtain the cold carcass weight (CCW).

Data analyses

The statistical analysis and validation of the model were performed in the Python environment using various packages. The descriptive analysis was described using the “pandas” package (McKinney, 2010). According to the recommendations by Salazar-Cuytun *et al*. (2022), three models were tested to estimate SBW as a function of BW (Eq. 1-3) and EBW as a function of SBW (Eq. 4-5).

Eq. 1.- Linear with intercept:
$\text{SBW (kg)} = \beta 0+\beta 1\times BW\ (kg)$

Eq. 2.- Linear without intercept:
$\text{SBW (kg)} = \beta 1\times BW\ (kg)$

Eq. 3.- Exponential:
$\text{SBW (kg)} = \beta 0\times BW^{\beta 1}$

Eq. 4.- Linear with intercept:
$\text{EBW (kg)} = \beta 0+\beta 1\times SBW\ (kg)$

Eq. 5.- Linear without intercept:
$\text{EBW (kg)} = \beta 0\times SBW\ (kg)$

Eq. 6.- Exponential:
$\text{EBW (kg)} = \beta 0\times SBW^{\beta 1}$

where BW= body weight (kg); SBW = shrunk body weight (kg); EBW = empty body weight (kg); " $\beta 0$ ", " $\beta 1$" = model parameters.

Using the "lmfit" package, the models were fitted (Newville *et al.*, 2014). The residuals of the models were plotted using the "matplotlib" package (Hunter, 2007). The Akaike information criterion (AIC), Bayesian information criterion (BIC), coefficient of determination (r^2), mean squared error (MSE), and root of MSE (RMSE) were used to evaluate the regression models' fit; these parameters were computed using the scikit-learn package (Pedregosa *et al.*, 2011).

Internal model validation

The predictive ability of the three EBW prediction models was evaluated using k-fold validation (k = 10). By randomly dividing the set of observation values into k non-overlapping folds of approximately the same size. The first fold was treated as a validation set and the model was fitted to the remaining k – 1 folds (training data). The ability of the fitted model to predict the actual observed values was evaluated using the MSE, r^2, and the mean absolute error (MAE). Where MAE is used as an alternative to root mean square error of prediction (RMSEP) because it is less sensitive to outliers and is related to the mean absolute difference between observed and predicted results. Lower RMSEP and MAE values were used to indicate a better fit. The "scikit-learn" package (Pedregosa *et al*., 2011) was used for the validation of k-folds, which allowed the comparison of numerous multivariate calibration models.

RESULTS

The SBW ranged from 18.50 to 35.70 kg, while the EBW ranged from 12.50 to 30.77 kg (Table 1). The correlation coefficients among BW and SBW and SB and EBW were high (r = 0.94; <0.0001).

The regression equations between BW and SBW had high determination coefficients (r^2) of 0.89 (P<0.001, Table 2, Figure 1). While for the relationship between SBW and EBW, the r^2 was 0.86 (P<0.001, Table 2, Figure 2). Based on the AIC (26.81) and BIC (28.89) Eq. 2 described the relationship between BW and SBW, better than the linear models with intercepts (Eq. 1, AIC = 28.44, BIC= 32.60) and the exponential model (Eq. 3, AIC = 28.35, BIC= 32.50). Based on the AIC evidence ratio, the linear model without intercept had a 69 and 68% probability of showing the best fit on the linear models without intercepts and exponential models, respectively. The following final model was fitted to estimate the SBW as a function of BW of Black Belly growing ewe lambs: SBW (kg): 0.96 (± 0.001***) × BW. It's worth noting that this confirms that the SBW can be calculated using an adjustment factor of 0.96 FBW.

Regarding the SBW and EBW relationship, also the AIC evidence ratio showed that Eq. 5 described the relationship between BW and SBW, better than the linear models with intercepts (Eq. 4, AIC = 33.01, BIC= 37.16) and the exponential model (Eq. 6, AIC = 33.35, BIC= 37.51). The linear model without intercept presented a 65 and 69% probability of showing the best fit on the linear models without intercepts and exponential models, respectively. The following final model was fitted to estimate the EBW as a function of SBW of Black Belly growing ewe lambs: EBW (kg): 0.81 (± 0.06***) × SBW.

The cross-validation of the equation of the relationship between BW and SBW showed that Eq. 1 had a higher r^2 (0.87), and lower RMSEP and MAE than Eq. 2 and Eq3. (Table 3). Also, the equation of the relationship between SBW and EBW the cross-validation revealed that Eqs. 4 and 6 had the higher r^2 (0.82), and lower RMSEP and MAE and tended to be more accurate (less RMSEP and MAE) than Eq. 5 (Table 3). For that, the better equations were Eq.1, Eq.4 and, Eq. 6.

Table 1. Descriptive statistics of BW, SBW, and EBW in Blackbelly ewe lambs.

Variable	*n*	Mean	SD	Minimum	Maximum
BW (kg)	60	26.55	3.92	19.55	36.45
SBW (kg)	60	25.69	3.90	18.50	35.70
EBW (kg)	60	20.71	3.53	12.50	30.77

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	SBW (kg): 0.67 (± 1.22*) + 0.94(± 0.04***) × BW	0.89	1.56	1.25	28.44	32.60	<0.0001
2	SBW (kg): 0.96 (± 0.001***) × BW	0.89	1.54	1.24	26.81	28.89	<0.0001
3	SBW (kg): 1.07 (± 0.17***) × BW $^{0.97\ (\pm\ 0.04^{***})}$	0.89	1.56	1.25	28.35	32.50	<0.0001
4	EBW (kg): -0.96 (± 1.36***) + 0.84 (± 0.04***) × SBW	0.86	1.69	1.30	33.01	37.16	<0.0001
5	EBW (kg): 0.81 (± 0.06***) × SBW	0.86	1.68	1.29	31.74	33.82	<0.0001
6	EBW (kg): 0.73 (± 0.12***) × SBW$^{1.03(\pm\ 0.05^{***})}$	0.86	1.70	1.30	33.35	37.51	<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

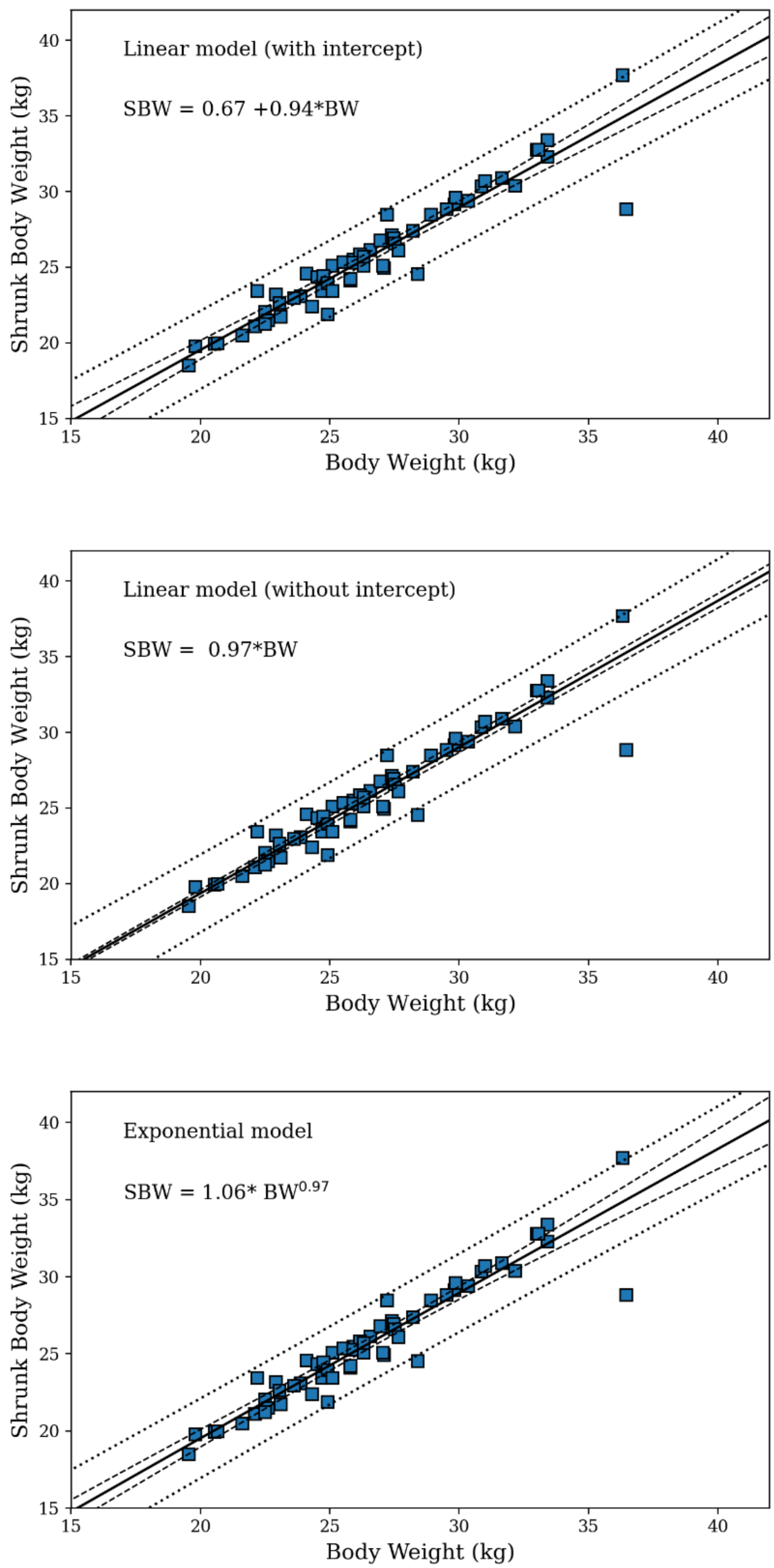

Figure 1. Linear and exponential relationship between BW and SBW in Blackbelly ewe lambs.

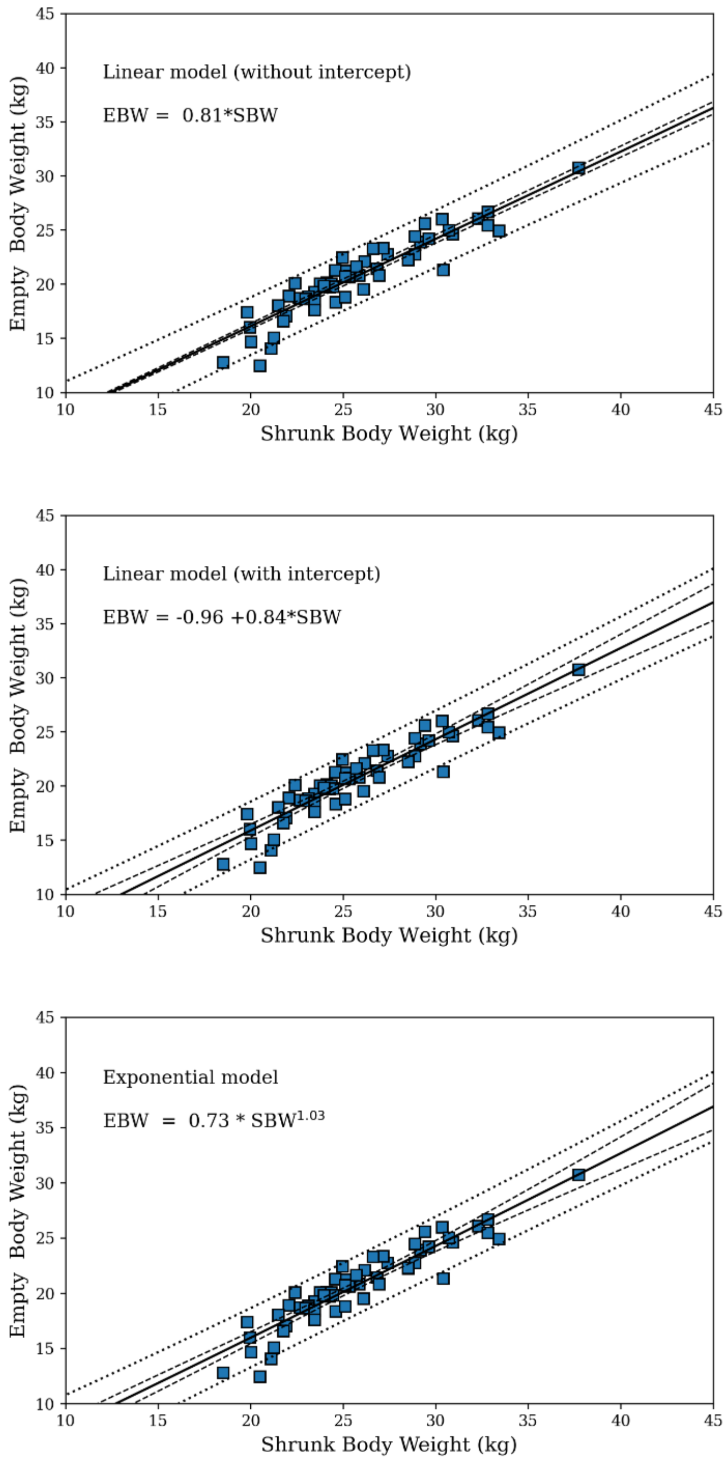

Figure 2. Linear and nonlinear relationship between SBW and BW in Blackbelly ewe lambs.

DISCUSSION

Concerning the development of equations for body weight adjustments, a few previous studies have reported for hair sheep breeds (Chay-Chay-Canul *et al.*, 2014; Herbster *et al.*, 2020; Salazar-Cuytun *et al.*, 2022). In this sense, in Latin America only exist studies from hair sheep breeds from Brazil (Herbster *et al.*, 2020; Barcelos, 2020; Gurgel *et al.*, 2023). Previous studies reported that in Latin America the most common breeds of sheep are the hair sheep breeds and are considered genetic resources for meat production in this region (Chay-Canul *et al*., 2016).

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

Model	r^2	RMSEP	MAE
1	0.87	1.29	0.90
2	0.73	1.60	1.24
3	0.82	1.31	1.03
4	0.82	1.28	1.03
5	0.72	1.55	1.29
6	0.82	1.28	1.03

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

Several factors, including effects of the animal itself (physiological state, level of production, and maturity) and others of the chemical composition of the diet (dietary fibre content, level of concentrate), among others, have been reported to influence the relationship between EBW and SBW (ARC, 1980; Chay-Canul *et al*., 2014; Campos *et al*., 2017; Salazar-Cuytun *et al*., 2022). For this, equations must be developed to estimate the EBW of hair sheep in various physiological conditions (Chay-Canul *et al*., 2014; Campos *et al*., 2017; Salazar-Cuytun *et al*., 2022).

Previous studies have developed regression equations to estimate the SBW from BW of FBW, Cannas *et al*. (2004) and Tedeschi *et al*. (2010) defined SBW as 96% of FBW (kg). Similarly, Barcelos *et al*. (2020) fitted the following final model to estimate the SBW as a function of BW: SBW = 0.938× BW. They reported that a linear without intercept model resulted from the best relationship between SBW and BW and showed that SBW accounted for 93.82% of the BW, representing a fitted relationship of 6.18% of fasting losses. In the current study, based on regression tools and the cross-validation technique, we found that the linear model with intercept provided the best equation to describe the relationship between SBW and BW, accounting for approximately 4% of fasting losses. Similar results were found in studies applying nutritional models to small ruminants, where SBW was defined as 96% of total sheep BW (Cannas *et al*., 2004; Tedeschi *et al*., 2010).

Regarding EBW, Cannas *et al*. (2004) used live animal traits such as SBW and described EBW as EBW = 0.851×SBW (kg) for sheep of different breeds, however, this may incur estimation errors, especially when used for hair sheep with different patterns of growth relative to wool sheep (Chay-Canul *et al*., 2014). In Pelibuey ewes, Chay-Canul *et al*. (2014) fitted a linear equation to estimate the EBW and reported a reduction of 19% of SBW. Also, Mendes *et al*. (2021) found a linear relationship between SBW and EBW (EBW (kg) = 0.547 + 0.827 × SBW) in crossbreed Dorper × Santa Ines lambs, resulting in a GIT fill of 17%. Similarly, Herbster *et al*. (2020, 2022) fixed a linear equation to predict EBW in hair sheep raised in tropical conditions (EBW = −1.4944 + 0.8816 × FBW), indicating a 12% GIT fill. Recently, Salazar-Cuytun *et al*. (2022) in hair sheep raised in feedlot systems found that 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 the present study, we found that the in development of the equations the relationship between SBW and EBW the linear model without intercept described the greatest relationship between BW and SBW, better than the linear models with intercepts (AIC = 33.01, BIC= 32.50) and the exponential model (AIC = 33.35, BIC= 37.51). However, the cross-validation revealed that equations with intercepts and exponential model had the higher r^2 (0.82), and lower RMSEP and MAE and tended to be more accurate (less RMSEP and MAE) than the linear model without intercept. Similarly, Barcelos *et al*. (2020) found that the relationship between SBW and EBW was better described by an exponential 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: $EBW = 0.507 \times SBW^{1.135}$. The nonlinear model observed by these authors considered that the weight ratios and weight gain rates varied according to the animal's weight, similar to those found in the current study. Even after solid fasting for more than 16 h, the animals still had ingested in their gastrointestinal tracts (GIT). Barcelos *et al*. (2020) suggests an exponential relationship between SBW and EBW, with the decreased GIT content proportional to the increased body weight. A exponential relationship between SBW and EBW was also found in the current study and other ruminant species.

CONCLUSION

The equations developed and evaluated in the present study revealed that the linear relationship between BW and SBW was the better equation. While the relationship between SBW and SBW can be used the linear model with intercept or exponential model to predict EBW Black Belly growing ewe lambs. It's worth noting that this confirms that the SBW can be calculated using an adjustment factor of 0.96 FBW. The present study contributes to the development of mathematical models for more accurate body weight adjustments in tropical sheep.

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Compilance with ethical standards and Statement of animal rights. All applicable international, national and/or institutional guidelines on the care and use of animals were followed. 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: CIEI: Folio 1173-2022) and the Mexican regulations NOM-08-ZOO, NOM-09-ZOO, and NOM-033-ZOO.

Conflict of interest. The authors declare that there is no conflict of interest.

Data availability. Data are available with the corresponding author of this publication upon reasonable request.

Authors contribution statement (CRediT). S. Vázquez-Jiménez: Investigation; Methodology, and Writing – original draft. **D. Vidal-Ramírez**: Investigation; Methodology, and Writing – original draft. **R. Salazar-Cuytun**: Software, Supervision, Validation, Visualization, and Writing – original draft. **I. Vázquez-Martínez**: Validation, Visualization, and Writing – original draft**. E. Camacho-Pérez**: Data curation, Formal Analysis, and Writing – original draft. **A. L. C. Gurgel**: Conceptualization, Data curation, Writing – original draft, and Writing – review & editing. **G. A. Muñoz-Osorio**: Conceptualization, Data curation, Writing – original draft, and Writing – review & editing. **A. J. Chay-Canul**: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Writing – original draft, and Writing – review & editing.

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