***Arq. Bras. Med. Vet. Zootec.*, v.76, n.4, e13170, 2024**

http://dx.doi.org/10.1590/1678-4162-13170
Original Article - Zootechnics

Prediction of body weight of Brown Alpine goats by measuring body volume

[*Predição do peso corporal de cabras da raça Alpina por meio da medida do volume corporal*]

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ABSTRACT

The objective was to estimate the body weight (BW) of Brown Alpine goats by means of body volume (BV) measurements. We used 132 pieces of information with measurements of BW, body length (BL) and thoracic perimeter (TP) from 22 goats evaluated fortnightly, between March and May 2023. Based on this information, the BV of the animals was calculated. Three mathematical models were evaluated - a linear model, a quadratic model, and an exponential model - with the measurement of BV. The goodness of fit of the equations was evaluated using the coefficient of determination (R^2), mean square error (MSE) and root of the MSE (RMSE). The predictive ability of the models was evaluated by k-fold cross-validation (k = 10). A high positive correlation between BW and TP (r = 0.95) and BL (r = 0.94) was observed. The correlation between BW and BV was higher than the other correlations (r = 0.98). The linear model showed the lowest values of MSE (9.49) and RMSE (3.08). In the cross-validation, the linear and quadratic models presented estimates of the mean BW and the standard deviation of this weight similar to the real data, and high R^2 values (0.95) of the data predicted by the observed ones. The analysis of the coefficient of correlation and concordance (CCC) also showed that these models have accuracy and precision (CCC > 0.95). Thus, the linear and quadratic models estimate the body weight of Brown Alpine goats with precision and accuracy.

Keywords: body length, Live weight, modeling, thoracic perimeter

RESUMO

Objetivou-se estimar o peso corporal (PC) de cabras da raça Alpina por meio da medida do volume corporal (VC). Foram utilizadas 132 informações, com medições de PC, comprimento corporal (CC) e perímetro torácico (PT), de 22 cabras avaliadas quinzenalmente, entre março e maio de 2023. Com base nessas informações, o VC dos animais foi calculado. Três modelos matemáticos foram avaliados – um modelo linear, um modelo quadrático e um modelo exponencial – com a medição do VC como único preditor. A qualidade de ajuste das equações foi avaliada usando-se o coeficiente de determinação (R^2), o erro do quadrado médio (EQM) e a raiz do EQM (REQM). A capacidade preditiva dos modelos foi avaliada por meio de validação cruzada k-fold *(k = 10). Foi observada uma alta correlação positiva entre o PC e o PT (r = 0,95) e o CC (r = 0,94). A correlação entre o PC e o VC foi maior do que as outras correlações (r = 0,98). O modelo linear mostrou os menores valores de EQM (9,49) e REQM (3,08). Na validação cruzada, os modelos linear e quadrático apresentaram estimativas do PC médio e do desvio padrão desse peso semelhantes aos dados reais e altos valores de R^2 (0,95) dos dados predistos em relação aos observados. A análise do coeficiente de correlação e concordância (CCC) também mostrou que esses modelos têm precisão e acurácia (CCC > 0,95). Assim, os modelos linear e quadrático estimam o peso corporal de cabras da raça Alpina com precisão e acurácia.*

Palavras-chave: comprimento corporal, modelagem, peso vivo, perímetro torácico

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Submitted: November 6, 2023. Accepted: January 2, 2024.

INTRODUCTION

Goat farming is an activity that has a high socio-cultural and economic importance, especially in the Northeast of Brazil, being a relevant source of income for the region (Ferreira *et al.*, 2016; Pereira *et al.*, 2021). It is estimated that about 90% of the Brazilian goat herd is in the Northeast region of Brazil, which stands out to produce these animals, mostly in an extensive system, by small producers. These producers generally have little technology and low investment in infrastructure, a factor that makes it impossible to control performance based on the periodic weighing of the animals (Yáñez *et al.*, 2004; Conrado *et al.*, 2015).

Body weight (BW) is an essential parameter for monitoring the development of goats, controlling herd productivity, and aiding decision-making within production systems, given its direct relationship with the nutritional requirements of animals (Gurgel *et al.*, 2021a). In addition, this parameter allows the monitoring of the growth curve of the animals, which makes it possible to identify phases in which the animal has a lower feed conversion and the best moment for its commercialization (Silva *et al.*, 2011; Gurgel *et al.*, 2021b; Souza *et al.*, 2021).

Indirect methods, such as biometric measurements, can be a low-cost and easy-to-adoption alternative for estimating the BW of small ruminants (Gurgel *et al.*, 2023a). These measurements can be made using instruments such as a hypometer and a measuring tape (Costa *et al.*, 2020; Bautista-Díaz *et al.*, 2020). In addition, the use of regression models based on biometric measurements can be a solution to estimate the weight of animals, since these measurements have a high positive correlation with BW (Conrado *et al.*, 2015; Chay-Canul *et al.*, 2019; Gurgel *et al.*, 2021, 2023a).

In production animals, the measurement of body volume (BV) can be incorporated into mathematical equations to predict BW (Gurgel *et al.*, 2023b), providing more precise and accurate estimates than any biometric measurement used alone (Paputungan *et al.*, 2018; Salazar-Cuytun *et al.*, 2021, 2022). Currently, although there are studies that use the BV measurement to estimate the BW of sheep (Salazar-Cuytun *et al.*, 2022; Gurgel *et al.*, 2023b), cattle (Castillo-Sanchez *et al.*, 2022), and buffaloes (Ramos-Zapata *et al.*, 2023), studies using this approach in dairy goats are limited. Therefore, we hypothesize that body volume (BV) can be a variable incorporated into mathematical equations to accurately predict BW in Brown Alpine goats. Thus, the objective was to estimate the live weight of Brown Alpine goats by measuring body volume.

MATERIAL AND METHODS

The study was carried out at Capril BeP at Serrote Farm, located in the municipality of Piau, located in the Zona da Mata Mineira, Minas Gerais, Brazil (altitude 446 meters, latitude 21° 30' 3" South and longitude: 43° 19' 35" West). The region's climate is classified as Tropical Altitude, with an average annual temperature of 21°C, a maximum of 27.9°C, and a minimum of 15.3°C, in addition to a rainfall annual of 1,581 mm.

The project was approved by the Committee on Ethics in the Use of Animals of the Federal Institute of Southeast Minas Gerais (CEUA protocol Nº 05/2023). For the experiment, 22 Brown Alpine goats were selected, which were accommodated individually in stalls equipped with drinkers and feeders. The goats were born between 2020 and 2023 and were of different ages and in different physiological stages ranging from the post-weaning period to pregnant, non-pregnant, and lactating. The feed provided to the goats consisted of a diet composed of corn silage as a source of roughage, bran concentrate, and a mineral mixture with 87 g/kg of phosphorus.

The experiment was conducted from March to May 2023, a period in which all animals were weighed every 15 days, resulting in six samples by a goat, totaling 132 evaluations/information. After weighing, measurements of body length (BL) - from the acromion of the scapula to the end of the ischium - and thoracic perimeter (TP) were obtained using a tape measure, following the method described by Gurgel *et al.* (2023a).

With this information in hand, the body volume (BV) was then calculated as described by Paputungan *et al.* (2018):

$$r\ (cm) = TP / 2\pi,$$

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

Where: r = radius of the circle (cm); π = 3.1416...; TP = thoracic perimeter (cm); and BL = body length (cm).

Three mathematical models were developed to predict the body weight (BW) of goats based on BV, namely:

(1) First-degree linear equation (linear): BW (kg) = β0 + β1 × BV;
(2) Linear equation of the second-degree (quadratic): BW (kg) = β0 + β1 × BV + β2 × BV^2;
(3) Exponential equation: BW (kg) = β0 × *exp*$^{(β1 × BV)}$,
Where BW = body weight (kg); BV = body volume (dm^3); β0 = intercept of the models; β1 and β2 = slope coefficients of the models.

Statistical analyzes were performed using the SAS 9.4 statistical program (SAS Inst. Inc., Cary, NC). A descriptive statistical analysis was performed using PROC SUMMARY. Pearson's correlation coefficients between variables were estimated using PROC CORR. PROC REG was used to estimate the parameters of the linear equations. The Gauss-Newton method was performed using PROC NLIN to estimate the parameters of the exponential equation. Outliers were tested by evaluating studentized residuals against values predicted by the model, residuals outside the range of -2.5 to 2.5 were removed. The goodness of fit of the equations was evaluated using the coefficient of determination (R^2), mean square error (MSE), and root of the MSE (RMSE).

The predictive ability of the models was assessed by k-fold cross-validation (k = 10), which randomly divides the set of observation values into non-overlapping “k” folds of approximately the same size (Steyerberg and Harrell, 2016; Chico-Alcudia *et al.*, 2022). The criteria for evaluating the adequacy of the models were: coefficient of determination (R^2); F-test for the identity of the parameters (β0 = 0 and β1 = 1) of the regression of the predicted data by the observed ones; coefficient of correlation and concordance (CCC); square root mean square prediction error (SRMSPE); mean square decomposition of the prediction error (MSPE) into mean error, systematic bias and random error (Tedeschi, 2006).

RESULTS

The BW average of the Brown Alpine goats was 45.68 kg, with a standard deviation of ±13.86 kg and the average BV was 38.64 kg, with a standard deviation of ±11.72 kg (Table 1).

Table 1. Descriptive statistics of live weight, thoracic perimeter, body length and body volume of Brown Alpine goats

Variables	N	Average ± SD	Minimum	Maximum	SEM
Body weight (BW, kg)	132	45.68 ± 13.86	13.40	71.20	1.19
Body length (BL, cm)	132	68.98 ± 7.14	47.00	80.00	0.61
Thoracic perimeter (TP, cm)	132	82.25 ± 10.84	51.00	99.00	0.93
Body volume (BV, dm^3)	132	38.64 ± 11.72	11.31	59.28	1.00

N: number of observations; SD: standard deviation; SEM: standard error of the mean.

The database revealed a wide variation, with a minimum value of 13.4 kg and a maximum of 71.2 kg for the BW, and the BV showed a minimum of 11.31 dm³ and a maximum of 59.28 dm³ (Table 1). The BW exhibited a strong positive correlation with TP (r = 0.95) and BL (r = 0.94). However, the correlation between BW and BV was even stronger than the others (r = 0.98), indicating a highly positive and consistent relationship between these variables (Figure 1 and Table 2).

Table 2. Pearson correlation coefficients between body weight (BW), thoracic perimeter (PT), body length (BL), and body volume (BV) of Brown Alpine goats

	BW	TP	BL	BV
BW	1.00	0.95*	0.94*	0.98*
TP	-	1.00	0.94*	0.99*
BL	-	-	1.00	0.96*
BV	-	-	-	1.00

*P <0,001.

The intercepts of the equations were 1.099, 1.798, and 15.169 for the linear, quadratic, and exponential models, respectively. The estimated values for the slopes were 1.154 for the linear equation, 1.104 for the quadratic equation, and 0.027 for the exponential equation. The first-degree linear equation showed the lowest values of MSE (9.49) and RMSE (3.08). On the other hand, the exponential equation exhibited the highest values of MSE (15.09) and RMSE (3.88). However, according to the exponential model, the BV explains 99% of the variation in the BW of the Brown Alpine goats. In the linear and quadratic models, the BV explained 95% of the variation in the BW (Table 3).

Table 3. Body weight (BW) prediction equations using body volume (BV) in Brown Alpine goats.

Models		N	R^2	MSE	RMSE	P-value
Linear	BW (kg) = 1.099 (±0.916) + 1.154 (±0.227) × BV	132	0.95	9.49	3.08	<0.0001
Quadratic	BW (kg) = 1.798 (±1.982) + 1.104 (±0.125) × BV + 0.0007 (±0.002) × BV^2	132	0.95	9.55	3.09	<0.0001
Exponential	BW (kg) = 15.169 × $exp^{(0.027\times BV)}$	132	0.99	15.09	3.88	<0.0001

N: number of observations; R^2: coefficient of determination; MSE mean square prediction error; RMSE: square root of the mean square of the prediction error.

In the cross-validation (k = 10), the linear and quadratic equations presented mean estimates of the BW and standard deviation of this variable similar to the real data (β0 = 0 and β1 = 1), while the exponential equation generated significantly different predictions of these data (P <0.05). Furthermore, all equations exhibited high regression determination coefficients (greater than 92%) between predicted and observed data (Table 4). The CCC also demonstrated that these models have precision, accuracy, and reproducibility (CCC > 0.95).

Table 4. Internal assessment (k =10) of the adequacy of live weight prediction models using body volume in Brown Alpine goats

Models	Average	SD	R^2	P-value	CCC	RMSE	Decomposition of MSE (%)		
							ME	SA	RE
Linear	45.68	13.52	0.950	0.999	0.975	3.06	0.00	0.00	100.00
Quadratic	45.60	13.48	0.950	0.943	0.974	3.06	0.08	0.01	99.91
Exponential	45.04	12.46	0.923	0.005	0.955	3.95	2.63	4.83	92.54
Observed data	45.68	13.86	-	-	-	-	-	-	-

SD = standard deviation; R² = coefficient of determination; P-value = probability value associated with the simultaneous F-test for the identity of the parameters (β0 = 0 and β1 = 1) of the regression of the observed data by the predicted ones; CCC = coefficient of correlation and concordance; RMSE = square root of the mean square of the prediction error; MSE: mean square prediction error; ME = mean error; SA: systematic addiction; RE = random error.

The RMSE analysis revealed that the linear and quadratic models showed a better ability to accurately predict the exact value of the goat BW, with an RMSE of 3.06 kg. The mean square decomposition of the prediction error indicated that more than 99% of the deviations in the linear and quadratic equations were attributed to random errors, suggesting the absence of average or systematic deficiency in these models. On the other hand, the exponential equation showed approximately 4.83% and 2.63% of the deviations associated with a systematic bias and an average bias, respectively (Table 4).

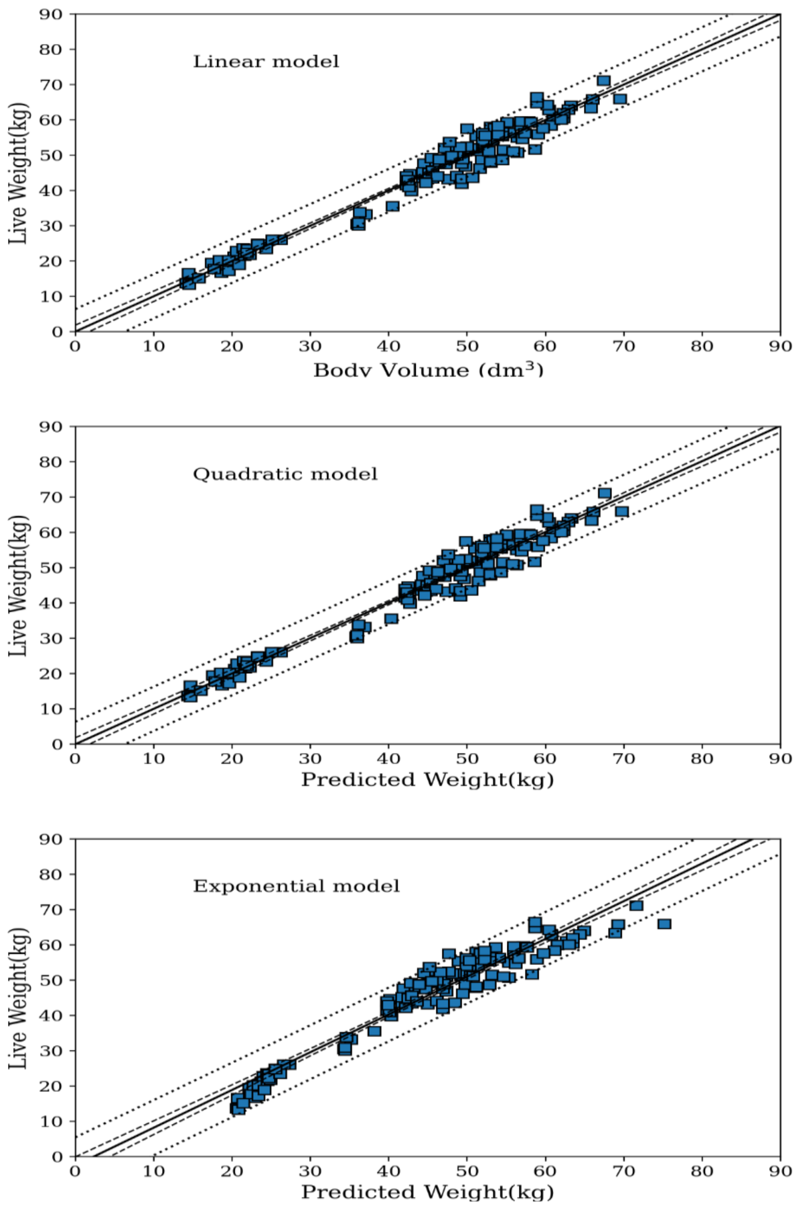

Figure 1. Observed values and predicted by linear, quadratic, and exponential models of body weight of Brown Alpine goats.

DISCUSSION

The high variability observed in the measured variables can be attributed to the age diversity of the evaluated animals. Our database included young non-pregnant or lactating goats, which resulted in a high range of data, with a minimum value of 13.4kg and a maximum value of 71.2kg of BW for the goats. These observations corroborate studies of Grandis *et al.* (2018), who highlight the influence of environment, genetics, and animal weight on biometric measurements. In addition, animal breed, sexual status, age, and nutritional management also play a significant role (Paputugan *et al.*, 2018; Gurgel *et al.*, 2020; Campos *et al.*, 2022). This diversity in the database is necessary, as it contributes to improving the predictive capacity and scope of the generated equations (Gomes *et al.*, 2021; Salazar-Cuytun *et al.*, 2023).

Significant correlations were identified between the analyzed variables, in line with the findings by Conrado *et al.* (2015) for Canindé goats, which reported positive correlations between BW, TP, and BL. Furthermore, Gurgel *et al.* (2021c) observed a strong correlation between BW and biometric measurements in Santa Inês lambs. These authors also found that the thoracic perimeter was the variable that presented the best correlation with the BW, which is an important performance measure due to its high relationship with the respiratory and digestive capacity of the animals (Gurgel *et al.*, 2021c). However, when we observe the correlation established between the BW and BV, a higher positive correlation is visible when compared to the correlation with the TP and BL biometric measurements. Several studies carried out on cattle (Paputugan *et al.*, 2018; Castillo-Sanchez *et al.*, 2022), sheep (Salazar-Cuytun *et al.*, 2022; Gurgel *et al.*, 2023b) and buffaloes (Ramos-Zapata *et al.*, 2023) have identified a significant correlation between BW and BV. In this regard, Salazar-Cuytun *et al.* (2021) stated that the BV of production animals must be used in BW prediction equations that provide more accurate estimates than any isolated biometric measurements.

There are several statistical techniques available to assess the precision and accuracy of models (Tedeschi, 2006; Gurgel *et al.*, 2023a). However, no technique used in isolation can provide an adequate assessment of the models' performance (Tedeschi, 2006). Therefore, the most appropriate approach to evaluate the predictive performance of a model is the combination of several methods (Gurgel *et al.*, 2023a). In the present study, the developed equations were submitted to k-fold cross-validation (Steyerberg and Harrell, 2016; Chico-Alcudia *et al.*, 2022), revealing that only the exponential equation produced predictions of the BW of the goats that differed from the actual data.

Therefore, both first-degree and second-degree linear equations have been shown to be precise and accurate in estimating the BW of Brown Alpine goats. Studies that used isolated biometric measurements, such as TP, or body volume (BV) as predictors of BW, demonstrated that linear and quadratic equations are efficient in predicting the BW of production animals (Salazar-Cuytun *et al.*, 2021, 2022; Chico-Alcudia *et al.*, 2022; Castillo-Sanchez *et al.*, 2022; Ramos-Zapata *et al.*, 2023). It is noteworthy that, following the principle of parsimony, it is recommended to choose the simplest model, such as the first-degree linear model (Canul-Solis *et al.*, 2020).

CONCLUSION

The linear models proved to be highly adequate in predicting the live weight of Brown Alpine goats using the measurement of body volume. Among the tested models, we recommend the first-degree linear equation model due to its ease of use and interpretation.

ACKNOWLEDGMENTS

The authors would like to thank the Federal Institute of Education, Science, and Technology of Southeast Minas Gerais – Campus Rio Pomba and the Federal University of Piauí – *Campus* Professora Cinibelina Elvas for supporting the project. Thanks also to Capril BeP at Serrote Farm for providing the infrastructure to conduct this research.

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