Body mass index and body chemical components in Pelibuey ewes

Índice de masa corporal y composición química corporal en ovejas Pelibuey

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ABSTRACT. The present study determined the relationship between body mass index (BMI) and chemical components in Pelibuey ewes. The BMI was determined in 28 ewes. At slaughter, internal organs and blood were weighed, then were mixed and grounded. The half-carcasses were dissected into subcutaneous and intermuscular fat, muscle, and bone. The muscle and fat of each animal were ground together, and one sample of the mixture was taken. The carcass and viscera samples were freeze-dried and further analysed for crude protein (CP), fat (F), and ash (A). The relationship between BMI and body composition were estimated using correlation coefficients (r) and regression models. The r between BMI and carcass crude protein and visceral crude protein were 0.51 and 0.48, respectively ($p < 0.001$), and between BMI and carcass F and visceral F were 0.82 and 0.71, respectively ($p < 0.0001$). The r^2 of the models relating to BMI and body chemical components ranged from 0.62 to 0.97. There was a quadratic relationship between total body CP, and A. The chemical carcass components (CP, F, and carcass energy [CE]) showed a linear relationship with BMI, with an r^2 ranging from 0.67 to 0.96. It was concluded that BMI could be used as predictors of body chemical composition in non-pregnant and non-lactating Pelibuey ewes. The use of empty body weight for calculating BMI yielded more accurate estimates of the chemical components of the body of adult sheep.
Key words: Body condition, body energy status, body measurements, sheep.

RESUMEN. El presente estudio tuvo como objetivo determinar la relación entre el índice de masa corporal (IMC) y los componentes químicos del cuerpo en ovejas Pelibuey. El IMC se determinó en 28 ovejas. Al sacrificio, se pesaron los órganos internos y la sangre de cada oveja y posteriormente se mezclaron y molieron. Las medias canales se diseccionaron en grasa subcutánea e intermuscular, músculo y hueso. El músculo y la grasa de cada animal se mezclaron y molieron, y se tomó una muestra. Las muestras de canal y vísceras se liofilizaron y se analizaron para proteína cruda (PC), grasa (G) y cenizas (C). Las relaciones entre el IMC y la composición corporal se estimaron mediante coeficientes de correlación (r) y modelos de regresión. Los r entre el IMC y la PC de canal y la PC visceral fueron 0.51 y 0.48, respectivamente ($p < 0.001$), y entre el IMC y la G en canal y la G visceral fueron 0.81 y 0.71, respectivamente ($p < 0.0001$). El r^2 de los modelos que relacionan el IMC y la composición química del cuerpo variaron de 0.62 a 0.97. Se encontró una relación cuadrática entre la PC y la C total del cuerpo. Los componentes químicos de la canal (CP, G y energía de la canal [EC]) mostraron una relación lineal con el IMC, con un r^2 entre 0.67 y 0.96. Por lo tanto, el IMC puede usarse como un predictor moderadamente preciso de la composición corporal en ovejas de pelo no gestantes y no lactantes. El uso del peso vivo vacío para calcular el IMC (IMCc) generó estimaciones más precisas de los componentes químicos del cuerpo en ovejas adultas.
Palabras clave: Condición corporal, estado de energía del cuerpo, medidas corporales, oveja.

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INTRODUCTION

Hair sheep are well adapted to tropical climatic changes and the variation in forage availability throughout the year (Chay-Canul *et al.* 2011). However, these changes induce periods of weight loss in animals (Chay-Canul *et al.* 2017), which give rise to variations in the proportion of their tissues; as well as in the chemical composition of the body and the carcass (Chay-Canul *et al.* 2017). Pelibuey sheep is a breed that shows fat depot variations due to the accumulation of a large fat quantity in their internal cavity (Chay-Canul *et al.* 2016, Morales-Martinez *et al.* 2020).

The body of livestock has four chemical components in decreasing amounts: water, protein, fat, and minerals (Maeno *et al.* 2013, Tedeschi *et al.* 2017, Tedeschi 2019, Chay-Canul *et al.* 2019). However, there is a lack of in-depth information about body composition for farm animals. The evaluation of the body chemical composition of productive animals is essential because this knowledge can aid in the assessment of energy and protein requirements and could improve feeding efficiency (Maeno *et al.* 2013, Tedeschi *et al.* 2017, Tedeschi 2019). However, due to the sophisticated equipment required by other methods to evaluate body chemical composition (Eisenmann *et al.* 2004, Achamrah *et al.* 2018, Chay-Canul *et al.* 2019), it is necessary to find a similar non-invasive method that allows evaluating internal body energy reserves *in vivo*.

Body mass index (BMI) is an indirect and non-invasive method commonly used to identify obesity (Doak *et al.* 2013) or as an indicator of energy status in humans (Okorodudu *et al.* 2010, Kinge 2016, Ortega *et al.* 2016). Due to the relationship between BMI and adiposity, BMI has been proposed for use in farm animals (Ptáček *et al.* 2018, Salazar-Cuytún *et al.* 2020). In recent years, relationships between BMI and several parameters in farm animal were reported: milk and meat productivity of goats and sheep's (Randby *et al.* 2015, Ptáček *et al.* 2018), hormone production in the adipose tissues of adult goats and growing kids (Vilar-Martínez *et al.* 2009, Habibu *et al.* 2016), body condition score of prepuberal sheep (Monteiro *et al.* 2010), and in adult Pelibuey ewes (Chavarría-Aguilar *et al.* 2016, Salazar-Cuytún *et al.* 2020). Most recent studies showed the potential of BMI as an alternative tool to predict body composition in sheep (Ptáček *et al.* 2018). Nevertheless, there is no information about the relationship of BMI with the chemical body composition in sheep. The present study aimed to investigate the relationship between BMI and body chemical components to predict CP, Fat, Energy, and Ash in Pelibuey ewes.

MATERIALS AND METHODS

Experimental location, animals, and measurements

The experiment was carried out at the El Rodeo commercial farm (17° 84" N, 92° 81" W) located at 14 km along the Villahermosa-Jalapa highway in Tabasco, Mexico. Twenty-eight non-pregnant and non-lactating Pelibuey ewes between 3 and 4 years old were selected. A trained technician visually observed each ewe and assigned a body condition score (BCS) of 1-5, with 1 = emaciated and 5 = obese, according to the technique described in Russell *et al* (1969). The ewes had a mean BW of 41.01 $\pm$ 8.43 kg and a mean BCS of 2.2 $\pm$ 1.29. The ewes were grouped in confinement, in pens of roofed buildings with concrete floor and no walls. The diet composition was 66% forage and 34% concentrate, with an estimated of metabolizable energy of 12 MJ/kg^{-1} DM and 10% CP (AFRC 1993). Withers height, body length, and weight of each ewe were measured 24 hours before slaughter. The biometric data used to calculate BMI were previously reported by Chavarria-Aguilar *et al* (2016). The BMI was calculated as follows:

$$BMI(kg\ m^{-2}) = (BW\ (kg)/WH\ (m)/BL\ (m))/10$$

Where BMI: body mass index (kg m^{-2}), BW: body weight (kg), WH: withers height (m), BL: body length (m).

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Slaughter procedures, samples, and chemical analysis

The ewes were humanely slaughtered following the Mexican Official Norms (NOM-08-ZOO, NOM-09-ZOO, and NOM-033-ZOO) established for the slaughter and processing of meat animals. Before slaughter, shrunk BW (SBW) was measured 24 h after feed and water withdrawal. After slaughter, the carcass, internal organs, blood, and internal fat depots of each ewe were weighed. The gastrointestinal tract (GIT) was weighed both full and empty. The empty BW (EBW) was calculated as the slaughter body weight less GTI content. The body constituents, including the blood, were mixed with the viscera (liver, heart, kidneys, lungs and trachea, rumen, reticulum, omasum, abomasum, small and large intestines, spleen, and uterus) and ground to pass a 4-mm screen (Torrey, Mexico). One sample (0.5 kg) was collected from each animal. After refrigeration at 1 °C for 24 h, the left half of carcasses were dissected entirely and separated into three main components (fat, muscle and bone), separating subcutaneous and superficial intermuscular fat from muscle and bone as much as possible. The three components were weighed separately. The muscle and fat were ground to pass a 4-mm screen (Torrey, Mexico), and a sample (approx. 1 kg) was taken from each animal. The ground carcass and viscera samples were frozen (-20 °C) and stored for subsequent laboratory analyses (Chay-Canul *et al.* 2019). The ground samples were freeze-dried to determine dry matter (DM), CP (method 984.13), fat (method 920.39), and ash (method 942.05) according to AOAC (1990). The gross energy contents of carcass and viscera were calculated, assuming caloric values of 39.2 and 23.6 MJ/kg^{-1} for fat and protein, respectively (ARC 1980). Total body chemical components (CP, fat, ash, and gross energy) was considered as the sum of the carcass chemical composition plus the visceral chemical composition.

Statistical analyses

The correlation coefficients between variables were analysed according to the PROC CORR procedure of SAS. Correlation coefficients were tested as non-zero values. The relationships between BMI and body composition were estimated by regression models with the PROC GLM procedure SAS. We assessed linear and multiple regressions (quadratic). The goodness of fit of the regression models was evaluated by the root of the mean square prediction error (RMSE). Alternatively, the empty body weight (EBW) was used in calculate BMI to reduce the variation due to GIT content. The regression models were evaluated according to the null hypothesis ((H_0) that b_0 is equal to zero and b1 is equal to one, and the alternative hypothesis (H_A). A non-rejection of the null hypothesis means that the model accurately explains variation in the dataset. The precision was assessed by the evaluation of the r^2 of the linear regression of Y (observed) on X (predicted), as described by Fonseca *et al.* (2017). Also, several statistics were used to assess the predictability of the equations, including the coefficients of determination (r^2), mean square error (MSE), standard deviation (SD), mean squared error of prediction (MSEP), and root of the MSEP (RMSEP), which account for the distance between predicted values and true values (Tedeschi 2006). The mean bias (MB), as described by Cochran and Cox (1957), was used as a representation of the average inaccuracy of the model. The modeling efficiency factor (MEF), which represents the proportion of variation explained by the line Y = X, was used as an indicator of goodness of fit (Loague and Green 1991; Mayer and Butler 1993). The coefficient of model determination (CD) was used to assess variance in the predicted data. The bias correction factor (Cb), a component of the concordance correlation coefficient (CCC; Lin 1989), was used as an indicator of deviation from the identity line, and the CCCs were also used as a reproducibility index to account for accuracy and precision. High accuracy and precision were assumed when the coefficients were > 0.80, and low accuracy and precision when the coefficients were < 0.50, while the values ranged from 0.51 to 0.79 imply a moderate accuracy and precision. The Model Evaluation System was used to all calculations (Tedeschi 2006).

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Table 1. Descriptive analysis of the body composition data recorded in Pelibuey ewes (n = 28).

Variable	Description	Mean (± SD)	CV	Minimum	Maximum
BMI	Body mass index (kg·m^{-2})	10.84 ± 2.01	18.54	8.18	14.91
BMIc	BMI corrected (kg·m^{-2})	9.20 ± 1.95	21.19	6.49	13.43
TBCP	Total body crude protein (kg)	3.35 ± 0.68	20.30	2.17	4.65
TBF	Total body fat (kg)	8.88 ± 4.96	55.86	1.39	20.17
TBA	Total body ash (kg)	0.17 ± 0.03	17.65	0.12	0.23
TBE	Total body energy (MJ)	427.27 ± 205.48	48.09	115.55	892.57
CCP	Carcass crude protein (kg)	2.40 ± 0.57	23.75	1.52	3.39
CF	Carcass fat (kg)	4.34 ± 2.64	60.83	0.73	10.47
CA	Carcass ash (kg)	0.12 ± 0.03	25.00	0.08	0.17
CE	Carcass energy (MJ)	226.76 ± 112.21	49.48	69.60	488.60
VCP	Visceral crude protein (kg)	0.95 ± 0.17	17.89	0.65	1.49
VF	Visceral fat (kg)	4.54 ± 2.45	53.96	0.66	9.70
VA	Visceral ash (kg)	0.05 ± 0.01	20.00	0.04	0.07
VE	Visceral energy (MJ)	200.52 ± 97.96	48.85	45.90	404.00

SD: standard deviation; CV: coefficient of variation.

RESULTS

The mean, minimum and maximum values of the variables are presented in Table 1. The chemical body components that showed a higher variation were total body energy (TBE), carcass energy (CE), and visceral energy (VE). The correlation coefficients (r) between variables are shown in Table 2. BMI was moderately correlated ($p < 0.001$) with carcass crude protein (CCP; r = 0.51) and visceral crude protein (VCP); r = 0.48). It showed from moderate to high correlations ($p < 0.001$) with carcass fat (CF; r = 0.81) and visceral fat (VF; r = 0.71). However, the correlation between BMI was not significant ($p > 0.05$) with total body fat (TBF), TBE, and CA.

Table 3 shows the regression equations describing the relationship between BMI and body chemical components in Pelibuey ewes. The coefficient of determination (r^2) for the equations involving BMI and body chemical components ranged from 0.62 to 0.97. There was a quadratic relationship between total body crude protein and total body ash (RSD = 0.572 and 0.027, respectively). Meanwhile, total body fat and total body energy adjusted to a linear trend (RSD = 3.11 and 129.3, respectively). Regarding chemical carcass components, CCP, CF, and CE had a linear relationship with BMI, with an r^2 ranging from 0.67 (RSD = 66.27) for CE to 0.96 (RSD = 0.511) for CCP. The regression equations describing the relationship between BMI and visceral composition had r^2 values ranging from 0.23 for visceral crude protein (VCP; RSD = 0.14 kg) to 0.97 for visceral ash (VA; RSD = 0.008 kg). Finally, for VF and VE, the r^2 values ranged from 0.63 for VF (RSD: 1.76) to 0.64 for VE (RSD: 611.47). Because the intercepts of equations 1, 3, 5, 7, and 11 were not significant ($p > 0.05$), we fitted a linear regression through the origin. Table 4 shows the regression equations describing the relationship between BMI corrected (using the empty body weight for calculating BMI, BMIc) and body chemical components in Pelibuey ewes. The coefficient of determination (r^2) for the equations involving BMI and body chemical components ranged from 0.58 to 0.69, and for carcass and visceral components, the r^2 ranged from 0.37 to 0.98.

To evaluate the equations for predicting body composition from BMI the null hypothesis was accepted with an intercept = 0 and slope = 1 (Table 5). The results for equations 1 and 3 had low precision (r^2 = 0.32 and 0.26, respectively), a low reproducibility index and concordance with the observed data (CCCs = 0.48 and 0.42, respectively; < 0.50), and a low efficiency of prediction (MEF = 0.23 to 0.30). Meanwhile, equations 2 and 4 presented moderate precision (r^2 = 0.61; Table 5), high accuracy (Cb > 0.80; Table 5), and moderate CCCs (0.76) and MEFs (0.61). For all equations, the CDs ranged from 1.60 to 3.06, indicating high variability in the predicted data (Table 4). The partition of the MSEP (% MSEP) indicated that the largest proportion (> 94%) of the error was associated with random error (Table 5). In general, the equations overpredicted the body chemical com-

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Table 2. Correlation coefficients between the evaluated variables in adult Pelibuey ewes.

	BMI	BMIc	TBCP	TBF	TBA	TBE	CCP	CF	CA	CE	VCP	VF	VA	VE
BMI		0.85	0.54**	0.79	0.47*	0.79	0.51**	0.82	0.50**	0.82	0.48**	0.71	0.20ns	0.72
		0.0005	0.0030	<.0001	0.0155	<.0001	0.0058	<.0001	0.0065	<.0001	0.0098	<.0001	0.3131	<.0001
BMIc	0.85	1	0.79	0.81	0.76	0.83	0.77	0.78	0.79	0.82	0.61	0.80	0.38	0.81
	<.0001		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0006	<.0001	0.0458	<.0001
TBCP	0.54**	0.79	1	0.68	0.93	0.72	0.98	0.64	0.93	0.71	0.75	0.68	0.49	0.69
	0.0030	<.0001		<.0001	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001	<.0001	0.0085	<.0001
TBF	0.79	0.81	0.68	1	0.64	1.00	0.67	0.97	0.66	0.98	0.50**	0.97	0.32ns	0.97
	<.0001	<.0001	<.0001		0.0003	<.0001	0.0001	<.0001	0.0001	<.0001	0.0072	<.0001	0.0776	<.0001
TBA	0.47*	0.76	0.93	0.64	1	0.68	0.93	0.57	0.96	0.64	0.66	0.67	0.59	0.68
	0.0155	<.0001	<.0001	0.0003		<.0001	<.0001	0.0014	<.0001	0.0002	0.0001	0.0001	0.0008	<.0001
TBE	0.79	0.83	0.72	1.00	0.68	1	0.71	0.97	0.70	0.98	0.53**	0.97	0.36ns	0.97
	<.0001	<.0001	<.0001	<.0001	<.0001		<.0001	<.0001	<.0001	<.0001	0.0038	<.0001	0.0610	<.0001
CCP	0.51**	0.77	0.98	0.67	0.93	0.71	1	0.61	0.95	0.68	0.61**	0.69	0.41	0.70
	0.0058	<.0001	<.0001	0.0001	0.0001	<.0001		0.0005	<.0001	<.0001	0.0005	<.0001	0.0302	<.0001
CF	0.82	0.78	0.64	0.97	0.57	0.97	0.61	1	0.60**	0.99	0.53**	0.70	0.28ns	0.90
	<.0001	<.0001	0.0002	<.0001	0.0014	<.0001	0.0005		0.0007	<.0001	0.0036	<.0001	0.1509	<.0001
CA	0.50**	0.79	0.93	0.66	0.96	0.70	0.95	0.60**	1	0.67	0.57**	0.69	0.48**	0.70
	0.0065	<.0001	<.0001	0.0001	<.0001	<.0001	<.0001	0.0007		0.0001	0.0014	<.0001	0.0299	<.0001
CE	0.82	0.82	0.71	0.98	0.64	0.98	0.68	0.99	0.67	1	0.56**	0.90	0.31ns	0.91
	<.0001	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001	0.0001		0.0018	<.0001	0.1134	<.0001
VCP	0.48**	0.61	0.75	0.50**	0.66	0.53**	0.61**	0.53**	0.57**	0.56**	1	0.43*	0.66	0.46*
	0.0098	0.0006	<.0001	0.0072	0.0001	0.0036	0.0005	0.0036	0.0014	0.0018		0.0220	0.0001	0.0130
VF	0.71	0.80	0.68	0.97	0.67	0.97	0.69	0.70	0.69	0.90	0.43*	1	0.38ns	0.99
	<.0001	<.0001	<.0001	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0220		0.0432	<.0001
VA	0.20ns	0.38	0.49	0.32ns	0.59	0.36ns	0.49**	0.28ns	0.48**	0.31ns	0.66	0.38ns	1	0.40ns
	0.3131	0.0458	0.0085	0.0776	0.0008	0.0610	0.0302	0.1509	0.0299	0.1134	0.3131	0.0001		0.0341
VE	0.72	0.81	0.69	0.97	0.68	0.97	0.70	0.90	0.70	9.91	0.46*	0.99	0.40ns	1
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0130	<.0001	0.0341	

[1]Correlations followed by no superscript indicate p < 0.0001; **p < 0.001; *p < 0.05; ns: non-significant BMI: body mass index; TBCP: total body crude protein (kg); TBF: total body fat (kg); TBA: total body ash (kg); TBE: total body energy (MJ); CCP: carcass crude protein (kg); CF: carcass fat (kg); CA: carcass ash (kg); CE: carcass energy (MJ); VCP: visceral crude protein (kg); VF: visceral fat (kg); VA: visceral ash (kg); VE: visceral energy (MJ).

Table 3. Regression equations describing the relationship of BMI with carcass and body chemical composition in Pelibuey ewes.

Equation no.	Equation	n	MSE	RSD	r^2	P value
1	TBCP (kg) = 0.44 (± 0.05***) × BMI - 0.011 (± 0.0004*) × BMI^2	28	0.327	0.572	0.97	< 0.0001
2	TBF (kg) = -12.09 (± 3.27**) + 1.94 (± 0.29***) × BMI	28	9.69	3.11	0.62	< 0.0001
3	TBA (kg) = 0.024 (± 0.0025***) × BMI - 0.0007 (± 0.002**) × BMI^2	28	0.0007	0.027	0.97	< 0.0111
4	TBE (MJ) = -442.00 (± 136.00**) + 80.22 (± 12.39***) × BMI	28	16716	129.3	0.62	< 0.0001
5	CCP (kg) = 0.218 (± 0.008***) × BMI	28	0.26	0.511	0.96	< 0.0001
6	CF (kg) = -7.26 (± 1.62***) + 1.07 (± 0.14***) × BMI	28	2.39	1.54	0.67	< 0.0001
7	CA (kg) = 0.016 (± 0.002***) × BMI - 0.0004 (± 0.0001**) × BMI^2	28	0.0005	0.02	0.97	< 0.0001
8	CE (MJ)= -264.96 (± 69.71**) + 45.38 (± 6.32***) × BMI	28	4391	66.27	0.66	< 0.0001
9	VCP (kg) = 0.51(± 0.15**) + 0.03 (± 0.01**) × BMI	28	0.022	0.14	0.23	0.01
10	VF (kg) = -35.13 (± 10.79**) + 6.32 (± 1.92**) × BMI - 0.23(± 0.08**) × BMI^2	28	3.10	1.76	0.63	< 0.0001
11	VA (kg) = 0.008 (± 0.0008***) × BMI - 0.0003 (± 0.00007***) × BMI^2	28	0.00007	0.008	0.97	< 0.0001
12	VE (MJ) = -1391.04 (± 424.68**) + 253.76 (± 75.91**) × BMI - 9.54(± 3.29**) × BMI^2	28	3778.80	61.47	0.64	< 0.0001

R^2: determination coefficient; MSE: mean square error; RSD: residual standard deviation; P: P-value, *p < 0.05, **p < 0.01, ***p < 0.001; BMI: body mass index; TBCP: total body crude protein (kg); TBF: total body fat (kg); TBA: total body ash (kg); TBE: total body energy (MJ); CCP: carcass crude protein (kg); CF: carcass fat (kg); CA: carcass ash (kg); CE: carcass energy (MJ); VCP: visceral crude protein (kg); VF: visceral fat (kg); VA: visceral ash (kg); VE: visceral energy (MJ). [1]Values in parentheses are the standard errors (SEs) of the parameter estimates. Intercepts not different from zero were removed from the final equation.

ponents by around 14.88 to 33.58%.

On the other hand, the equations (5 to 8) for predicting carcass composition from BMI had an r^2 indicating low to moderate precision (0.25 to 0.66) and moderate to high accuracy (Cb > 0.61; Table 5). Nonetheless, the CCCs were 0.31, 0.80, 0.44 and 0.80 for equations 5, 6, 7 and 8, respectively. The CDs ranged from 0.43 to 2.68, indicating high variability in the predicted data (Table 5). Except for equation 5, the partition of the MSEP (% MSEP) indicated that the largest proportion (> 91%) of the error was associated with random error (Table 5). In general, the equations overpredicted the carcass chemical composition (ranged from 17.30 to 34.41%).

Finally, for equations developed to predict visceral composition from BMI, the null hypothesis was accepted in all of them (Table 5). Equations 9 and 11 had low precision (r^2 of 0.23 and 0.08, respec-

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Table 4. Regression equations developed for the relationship of BMIc with and body chemical composition in Pelibuey ewes.

Equation No.	Equation	n	MSE	RSD	r^2	P value
13	TBCP (kg) = 0.82 (± 0.39*) + 0.27 (± 0.04***) × BMIc	28	0.181	0.43	0.62	<.0001
14	TBF (kg) = -10.17 (± 2.67***) + 2.07 (± 0.28***) × BMIc	28	8.40	2.89	0.67	<0.0001
15	TBA (kg) = 0.06 (± 0.01***) + 0.01 (± 0.001***) × BMIc	28	0.0004	0.02	0.58	<0.0111
16	TBE (MJ) = -379.52 (± 106.17**) + 87.66 (± 11.29***) × BMIc	28	13215	114.95	0.69	<0.0001
17	CCP (kg) = 0.26 (± 0.007***) × BMIc	28	0.13	0.37	0.97	<.0001
18	CF (kg) = -5.43 (± 1.52***) + 1.06 (± 0.16***) × BMIc	28	2.74	1.65	0.62	<0.0001
19	CA (kg) = 0.01 (± 0.0003***) × BMIc	28	0.0002	0.02	0.98	<.0001
20	CE (MJ) = -205.03 (± 60.56 **) + 46.92 (± 6.44 ***) × BMIc	28	4299.96	65.57	0.67	<0.0001
21	VCP (kg) = 0.47 (± 0.12***) + 0.05 (± 0.01**) × BMIc	28	0.02	0.13	0.37	0.0006
22	VF (kg) = -4.73 (± 1.37**) + 1.08 (± 0.14***) × BMIc	28	2.20	1.48	0.65	<0.0001
23	VA (kg) = 0.03 (± 0.008***) + 0.001 (± 0.0008***) × BMIc	28	0.00007	0.009	0.97	0.0458
24	VE (MJ) = -174.49 (± 53.43**) + 40.74 (± 5.68***) × BMIc	28	3347.74	57.85	0.66	<0.0001

R^2: determination coefficient; MSE: mean square error; RSD: residual standard deviation; P: P-value, *p < 0.05, **p < 0.01, ***p < 0.001; BMI: body mass index; TBCP: total body crude protein (kg); TBF: total body fat (kg); TBA: total body ash (kg); TBE: total body energy (MJ); CCP: carcass crude protein (kg); CF: carcass fat (kg); CA: carcass ash (kg); CE: carcass energy (MJ); VCP: visceral crude protein (kg); VF: visceral fat (kg); VA: visceral ash (kg); VE: visceral energy (MJ). [1]Values in parentheses are the standard errors (SEs) of the parameter estimates. Intercepts not different from zero were removed from the final equation.

Table 5. Mean and descriptive statistics of the accuracy and precision of the equations for predicting body composition of Pelibuey ewes.

Variable[1]	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	Eq. 6	Eq. 7	Eq. 8	Eq. 9	Eq. 10	Eq. 11	Eq.12
Mean	3.43	8.93	0.175	427.26	3.03	4.33	0.12	226.7	0.83	5.44	0.05	201.18
SD	0.38	3.90	0.016	161.62	0.56	2.15	0.01	91.43	0.06	2.26	0.002	78.28
Maximum	4.11	16.83	0.202	753.89	4.17	8.69	0.15	411.55	0.95	8.28	0.05	296.43
Minimum	2.86	3.78	0.149	214.11	2.29	1.49	0.10	106.19	0.75	1.175	0.04	46.26
r^2	0.32	0.61	0.26	0.61	0.25	0.66	0.28	0.66	0.23	0.62	0.08	0.63
CCC	0.48	0.76	0.42	0.76	0.31	0.80	0.44	0.80	0.22	0.73	0.15	0.78
Cb	0.84	0.97	0.80	0.97	0.61	0.97	0.80	0.97	0.45	0.92	0.53	0.97
MEF	0.30	0.61	0.23	0.61	-1.26	0.66	0.22	0.66	-0.26	0.46	0.08	0.63
CD	3.05	1.60	3.06	1.61	0.43	1.49	2.68	1.50	1.61	1.01	1.96	1.56
Regression analysis												
Intercept (β_0)												
Estimate	-0.13	-0.03	-0.00014	-0.01	0.84	-0.001	-0.002	-0.070	-0.157	-0.114	0.00003	-0.155
SE	1.00	1.49	0.05	70.16	0.52	0.666	0.037	34.01	0.396	0.771	0.0328	31.92
P-value (β_0 = 0)	0.89	0.98	0.99	0.99	0.11	0.998	0.95	0.99	0.69	0.88	0.99	0.99
Slope (β_1)												
Estimate	1.01	0.99	0.96	1.00	0.51	1.001	0.967	1.0002	1.325	0.855	1.003	0.99
SE	0.29	0.15	0.31	0.15	0.16	0.138	0.298	0.139	0.473	0.131	0.651	0.14
P-value (β_1 = 1)	0.96	0.99	0.91	0.99	0.008	0.991	0.91	0.99	0.49	0.27	0.99	0.98
MSEP source, % MSEP												
Mean bias	2.19	0.026	4.98	0.00	56.9	0.001	8.26	0.000	38.32	26.12	0.06	0.01
Systematic bias	0.008	0.001	0.039	0.00	10.3	0.000	0.04	0.000	1.10	3.30	0.000	0.001
Random error	97.69	99.97	94.976	100.0	32.6	99.99	91.69	100.0	60.57	70.56	99.93	99.98
Root MSEP												
Estimate	0.55	2.99	0.026	124.58	0.83	1.49	0.021	63.83	0.18	1.76	0.008	58.09
% of the mean	16.26	33.58	14.88	29.15	27.6	34.41	17.30	28.15	22.05	32.43	16.38	28.87

[1]Obs: observed evaluation data set; CCC: concordance correlation coefficient; Cb: bias correction factor; MEF: modelling efficiency; CD: coefficient of model determination; MSEP: mean square error of the prediction.

tively), a low reproducibility index in concordance with the observed data (CCCs = 0.22 and 0.15, respectively; < 0.50) and low efficiency prediction (MEF = -0.23 to 0.08). However, equations 10 and 12 presented moderate precision (r^2 > 0.62; Table 6), high accuracy (Cb > 0.92) and moderate CCCs (> 0.73) and MEFs (> 461; Table 5). The partition of the MSEP (% MSEP) indicated that the largest proportion (> 60%) of the error was associated with random error (Table 5). In general, the equations overpredicted the body chemical components around 16.38 to 32.43%.

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Table 6. Mean and descriptive statistics of the accuracy and precision of the equation's whit BMIc for predicting body composition of Pelibuey ewes.

Variable[1]	[Eq. 13]	[Eq. 14]	[Eq. 15]	[Eq. 16]	[Eq.17]	[Eq. 18]	[Eq. 19]	[Eq. 20]	[Eq. 21]	[Eq. 22]	[Eq. 23]	[Eq. 24]
Mean	3.30	8.88	0.15	4.27	2.39	4.32	0.09	226.78	0.93	5.21	0.04	200.44
SD	0.52	4.05	0.01	171.73	0.50	2.07	0.01	91.92	0.01	2.11	0.00	79.81
Maximum	4.45	17.63	0.19	797.75	3.49	8.81	0.13	425.11	1.14	9.77	0.04	372.65
Minimum	2.57	3.26	0.15	189.39	1.69	1.45	0.06	99.48	0.79	2.28	0.04	89.91
r^2	0.62	0.67	0.56	0.69	0.59	0.62	0.61	0.67	0.37	0.64	0.00	0.66
CCC	0.76	0.80	0.56	0.82	0.77	0.77	0.43	0.80	0.54	0.76	0.00	0.80
Cb	0.96	0.98	0.74	0.98	0.99	0.97	0.55	0.98	0.86	0.95	0.00	0.97
MEF	0.61	0.67	0.22	0.69	0.57	0.62	-0.63	0.67	0.36	0.56	-1.30	0.66
CD	1.64	1.49	1.33	1.43	1.23	1.61	0.54	1.48	2.76	1.22	0.76	1.50
Regression analysis												
Intercept (β_0)												
Estimate	-0.007	0.003	-0.006	0.01	0.34	0.01	0.02	-0.01	-0.02	-0.32	n/s	0.03
SE	0.51	1.33	0.03	59.16	0.33	0.73	0.01	33.50	0.24	0.75	n/s	30.02
P-value ($\beta_0 = 0$)	0.98	0.99	0.83	0.99	0.31	0.99	0.07	0.99	0.94	0.67	0.00001	0.99
Slope (β_1)												
Estimate	1.01	1.00	1.15	1.00	0.85	1.00	1.00	0.99	1.03	0.93	n/s	1.00
SE	0.15	0.13	0.19	0.12	0.13	0.15	0.15	0.13	0.26	0.13	n/s	0.13
P-value ($\beta_1 = 1$)	0.92	0.99	0.44	0.99	0.31	0.99	0.99	0.99	0.88	0.62	0.00001	0.99
MSEP source, % MSEP												
Mean bias	1.13	0.00	42.41	0.00	0.03	0.01	75.97	0.00	2.02	17.64	56.67	0.00
Systematic bias	0.03	0.00	1.31	0.00	3.92	0.00	0.00	0.00	0.08	0.75	0.00	0.00
Random error	98.83	100.0	56.27	100.0	96.04	99.99	24.02	100.0	97.63	81.59	43.32	100.00
Root MSEP												
Estimate	0.41	2.79	0.02	110.77	0.36	1.59	0.03	63.18	0.13	1.58	0.01	55.75
% of the mean	12.50	31.47	17.34	25.92	15.06	36.74	34.82	27.86	14.03	30.41	34.39	27.81

[1]Obs: observed evaluation data set; CCC: concordance correlation coefficient; Cb: bias correction factor; MEF: modelling efficiency; CD: coefficient of model determination; MSEP: mean square error of the prediction.

DISCUSSION

To the best of our knowledge, the present study is the first to evaluate the relationship between the BMI and body chemical components of adult sheep. The determination of the body chemical composition of productive animals can aid in the assessment of energy and protein requirements and improve feeding efficiency (Tedeschi *et al*. 2017, Tedeschi 2019). Given the positive relationships found by Chavarría-Aguilar *et al*. (2016) between BMI and BCS (r^2 = 0.80) and body energy reserves (total body fat), the present study explored BMI as a predictor of the body chemical composition of Pelibuey ewes. The calculation of BMI in sheep involves the measurement of mass (body weight) and body size and shape (withers heights and body length) (Salazar-Cuytún *et al*. 2020). Body weight was found to be a function of body size (skeletal development), body fat (BCS), and gut fill in lactating dairy cows (Yan *et al*. 2009). Notably, these variables would be ideal for the assessment of body chemical composition because they can be easily measured (body size) or estimated. Besides, Muliyono *et al*. (2009) reported that body size could be estimated from chest deep, and that shape could be described from several body measurements in sheep. Body size and shape together could provide a better description of an animal's body conformation, and their inclusion in the estimation of BMI could generate a more accurate estimate (Yan *et al*. 2009, Muliyono *et al*. 2009). However, there is a lack of information about the relationship between body chemical composition, body size measurements, and weight in sheep (Chay-Canul *et al*. 2017, Salazar-Cuytún *et al*. 2020).

In a previous study, Yan *et al*. (2009) found that body size measurements and BCS were able to accurately predict empty body masses as well as lipid, crude protein, dry matter, water, and total gross energy contents in lactating dairy cows. Also, Sanson *et al*. (1993) found a high correlation between body weight (BW) and BCS (r = 0.89) in western-range ewes. However, these latter authors reported that the inclusion of both BW and BCS in regression models did not increase their accuracy and BW was the single best predictor. Even so, BCS was highly related to carcass lipids and was suggested as a possible descriptor of available energy reserves in ewes and cows. In the present study, the inclusion of BMI in the equation for estimating the body chemical composition of ewes showed good results (Table 3). Maeno *et al*. (2013) studied the accretion rates of chemical components in the body of

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domestic animals (cattle, goats, pigs, sheep, dogs, mice and rats) using allometric equations ($Y = aX^b$) describing the relationships of empty body weight (EBW), fat-free weight (FFW) and protein (PRO) with the weights of each chemical component (water, fat, and ash). The allometric growth coefficients (slope values) for PRO and water (WAT) did not differ ($p > 0.2$) among farm animals, although FAT and ASH showed differences ($p < 0.01$). The highly positive relationship found between PRO, WAT, and FFW in the evaluated farm animals, enabling the following equations to be generated: $PRO = 0.1513\ FFW^{1.085}$ and $WAT = 0.8303\ FFW^{0.972}$. However, these equations did not fit the data for laboratory animals (dogs, mice, and rats). Those relationships in farm animals confirm that protein and water weights could be estimated from equations. These results have practical implications for the estimation of body composition. It reduced the time and cost of laboratory analysis. Besides, it confirms that models to predict body composition can be built from these components due to their high association with the weight and size of many animals. It is important to highlight that these predictive equations are not generalized to animals of different sex, species, or physiological state. Meanwhile, in the present study, the eleven equations generated to estimate the body chemical composition of a single species (sheep) were able to predict body composition based on BMI to a certain extent.

In humans, Maynard *et al.* (2001) reported moderate to high correlations between BMI and the percentage of body fat (PBF) and total body fat (TBF), which had r values ranging from 0.64 to 0.85 and 0.83 to 0.94, respectively. Also, these correlations indicated that BMI accounted for 41 to 88% of the variation in PBF and TBF. These results coincide with those found in the present study, wherein a moderate association was found between BMI and TBF ($r = 0.79$). However, the equations for estimating body chemical composition showed a low to moderate precision ($r^2 = 0.08$ to 0.66; Table 5); hence, our equations were not better than those used in humans and dogs to estimate body fat (Speakman *et al.* 2001).

In the present study, the regression equations 2, 6, and 10 developed to explain the relationship of BMI with the fatty component, or TBF, CF, and VF, respectively, presented a moderate relationship ($r^2 = 0.62$ to 0.67) and high variability. These results could be explained for the variation in body tissues (fat and muscle) according to the animal age, sex, and climatic condition or food availability in tropical conditions (Tedeschi *et al.* 2013, Bautista-Díaz *et al.* 2017). Overall, the results of the present study support the use of body measurements such as live weight and body size (BMI) as indicators of body chemical composition in Pelibuey ewes. This relationship has already been confirmed in humans and other animals. However, the results should not be considered applicable to both sexes or all species and physiological states, and this method should be evaluated under different management and physiological conditions. Also, Tables 4 and 6 shows that the use of empty body weight as part of a corrected body mass index (BMIc) improves the values of the estimation of the body chemical composition. It showed a better adjustment of the coefficient of regression value (r^2), meaning that the linear relationship between the predicted and observed values were improved, and the MSEP values were low, which resulted in the best models in the evaluation, with the exception for visceral ash. Therefore, we suggest the use of empty body weight to make more accurate estimates of body chemical components of adult sheep.

CONCLUSIONS

The present study showed that BMI could be used as predictors of body chemical composition in non-pregnant and non-lactating Pelibuey ewes. The use of empty body weight for calculating body mass index (BMI) yielded more accurate estimates of the chemical components of the body of adult sheep. The BMI as a predictor of body composition should be evaluated in animals with different physiological states raised under different management systems.

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