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Predicting body composition of hair-lambs based on body mass index

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ABSTRACT. The objective of this study was to evaluate the relationship between body mass index corrected (BMIc) for empty body weight and chemical components in hair sheep lambs. Thirty-eight weaned Pelibuey lambs (21 males and 17 females, with an average weight of 10.64 ± 2.46 kg) were used. The carcass was dissected into muscle and fat and ground together. The viscera and blood were mixed, ground, and one sample was collected from each animal. Crude protein and fat were determined in carcass and viscera samples. Correlation and regression were used to estimate the relationships between body composition and BMI. The correlation between BMIc and carcass crude protein (CCP) and visceral crude protein (VCP) was 0.80 and 0.50, respectively ($P < 0.0001$). BMIc showed a correlation of 0.71 and 0.70 with carcass fat (CF) and visceral fat (VF), respectively ($P < 0.0001$). The R^2 values ranged from 0.52 to 0.97 for equations involving BMIc and body chemical composition. For carcass chemical components, CCP, CF and CE (carcass energy) with BMIc and R^2 ranged from 0.64 (RSD: 0.10 kg) for CCP, 0.53 (RSD: 0.16 kg) for CF to 0.62 (RSD: 7.98) for CE. Visceral composition and BMIc had R^2 values ranging from 0.96 for VCP (RSD: 0.05 kg), 0.52 for VF (RSD: 0.09 kg) to 0.55 (RSD: 4.34 kg) for VE (visceral energy). BMIc can be used to moderately predict body chemical composition in weaned Pelibuey lambs.

Introduction

In lambs, studying body composition has become important due to the demand for better meat quality in sheep farming (Anderson et al., 2016). Consequently, the need for improved meat quality has resulted in a growing interest in accessing accurate data to calculate carcass and body chemical composition. This is essential for assessing nutritional requirements and physiological growth (Morales-Martínez et al., 2020), because weight gain and body composition are directly related (Herath et al., 2020). Body composition studies involve analyses and measures of body properties, such as size, surface area and density (Costa-Moreira et al., 2015). The growing interest in body composition has led to the search for methods allowing to determine body composition of animals *in vivo* (Fonseca et al., 2017; Morales-Martínez et al., 2020). Since body mass gain occurs in a temporal sequence at different rates, it provides essential information to estimate changes in tissue body composition under different physiological conditions (prenatal, postnatal to weaning, weaning to puberty and puberty to maturity) (Pearce et al., 2009; Salazar-Cuytún et al., 2020a). The so far commonly applied approaches (live weight and body condition) are not very suitable due to the internal pattern of fat accumulation and because the body condition assessment technique is not applicable at early growth stages (Morales-Martínez et al., 2020). Furthermore, there is a need to develop an approach where body chemical composition could be assessed cross-sectionally and information on individuals could be collected over time.

In this regard, body mass index (BMI) is a coefficient that allows measuring body composition and carcass characteristics of sheep (Chavarría-Aguilar et al., 2016; Salazar-Cuytún et al., 2020b) and other animals. There are studies concerning body fat reserves determined by the body condition score in pre-pubertal sheep (Chavarría-Aguilar et al., 2016). Nevertheless, no information is available regarding BMI during the growing period in sheep. In order to provide information on body chemical composition for accurate comparisons, it is necessary to study the relationship between BMI and body chemical components at different stages and ages. Therefore, the objective of this study was to investigate the relationship between corrected body mass index (BMIc) and body chemical components in weaned Pelibuey lambs.

Material and methods

Experimental site, animals, and collection of biometric measurements (BM)

The study was conducted in accordance with the guidelines and regulations for ethical animal experimentation of the Universidad Juarez Auntónoma Tabasco (PFI: UJAT-DACA-2015-IA-02) and the NOM-033-SAG/ZOO-1995 Official Mexican Standard. The experiment was carried out at the El Rodeo commercial farm (17°84′N, 92°81′W) in Tabasco, Mexico. Thirty-eight Pelibuey lambs (21 males and 17 females), weaned at 56 days of age, weighing 10.64 ± 2.46 kg body weight (BW), were used. The lambs and their dams were managed in a feedlot system in individual pens, with free access to feed and water. However, the offspring did not have direct access to the ewes' feeders. The lambs were slaughtered on the day of weaning.

Calculation of corrected body mass index

Twenty-four hours before slaughter, BW was registered, and subsequently empty BW (EBW) was calculated for each lamb. Height at withers (WH) and body length (BL) were measured, and BMIc was calculated according to Salazar-Cuytún et al. (2020b):

$$BMIc = [EBW / WH / BL] / 10,$$

where: EBW – empty body weight (kg), WH – height at withers (m), and BL – body length (m).

To calculate BMIc, live weight was replaced with empty live weight (EBW) according to Salazar-Cuytún et al. (2020b).

Slaughtering

The lambs were slaughtered and processed in accordance with the Official Mexican Standard NOM-033-ZOO-1995, established for the humane processing of meat animals. Twenty hours before slaughter, the feeds were removed and shrunk BW (SBW) was recorded.

Hot carcass weights were recorded and divided along the dorsal midline into two halves and cooled for 24 h at 1 °C. The gastrointestinal tract (GIT) was weighed full and empty. Empty BW (EBW) was calculated as slaughter body weight minus GIT content. Internal organs, blood, and internal fat deposits were weighed separately for each lamb. The constituents of the body, blood, and viscera (liver, heart, kidneys, lungs and trachea, rumen, reticulum, omasum, abomasum and small and large intestines, spleen and reproductive system) were mixed and grounded (4-mm screen, Torrey; Mexico). At the end of the process, two samples (carcass and viscera weighing 0.5 kg) were collected from each animal for storage and preservation at −20 °C for subsequent laboratory analysis.

Chemical analyses

The samples (carcass and viscera) were freeze-dried to determine: dry matter (DM), crude protein (CP) (method 984.13) and fat (method 920.39) contents according to AOAC (1990). Energy content was calculated assuming caloric values of 39.2 and 23.6 MJ/kg for fat and protein, respectively (ARC, 1980). Total body chemical composition (BW, fat, and energy) was calculated as the sum of carcass chemical composition plus visceral chemical composition.

Statistical analyses

The PROC CORR procedure from SAS (2002) was used to calculate the correlation coefficients from values significantly different from zero. The regression procedure was used to estimate the relationships between BMI and body composition using the PROC GLM SAS procedure (2002).

Linear and multiple (quadratic) regressions were evaluated. Goodness-of-fit of the regression models were assessed using the root mean square prediction error (RMSE). The following were tested in the evaluation of the regression models: the null hypothesis (H_0) that b_0 was equal to zero and b_1 was equal to one, and the alternative hypothesis (H_A). Acceptance of the null hypothesis meant that the model accurately explained the variation in the dataset.

The final values of protein, fat and energy contents were compared with the predicted values for the models (Figure 1). The precision and accuracy of the models was evaluated against predicted values by evaluating R^2 of the linear regression of Y (i.e., observed) on X (i.e., predicted) using the Model Evaluation System (MES) (Tedeschi, 2006).

MSEP (RMSEP). The average inaccuracy of the model was represented by the mean bias (MB), as described by Cochran and Cox (1957). The proportion of variation explained by the Y = X relationship was used to indicate the goodness-of-fit using the modelling efficiency factor (MEF) (Loague and Green, 1991; Mayer and Butler, 1993), and the model coefficient of determination (CD) was applied to assess the variance in the predicted data. The bias correction factor (Cb), as a component of the correlation coefficient of concordance (CCC) (Lin, 1989), was used as an index of reproducibility to account for accuracy and precision. The models assumed high accuracy and precision when the coefficients were > 0.80, low when they were < 0.50, and moderate when they ranged between 0.51 and 0.70.

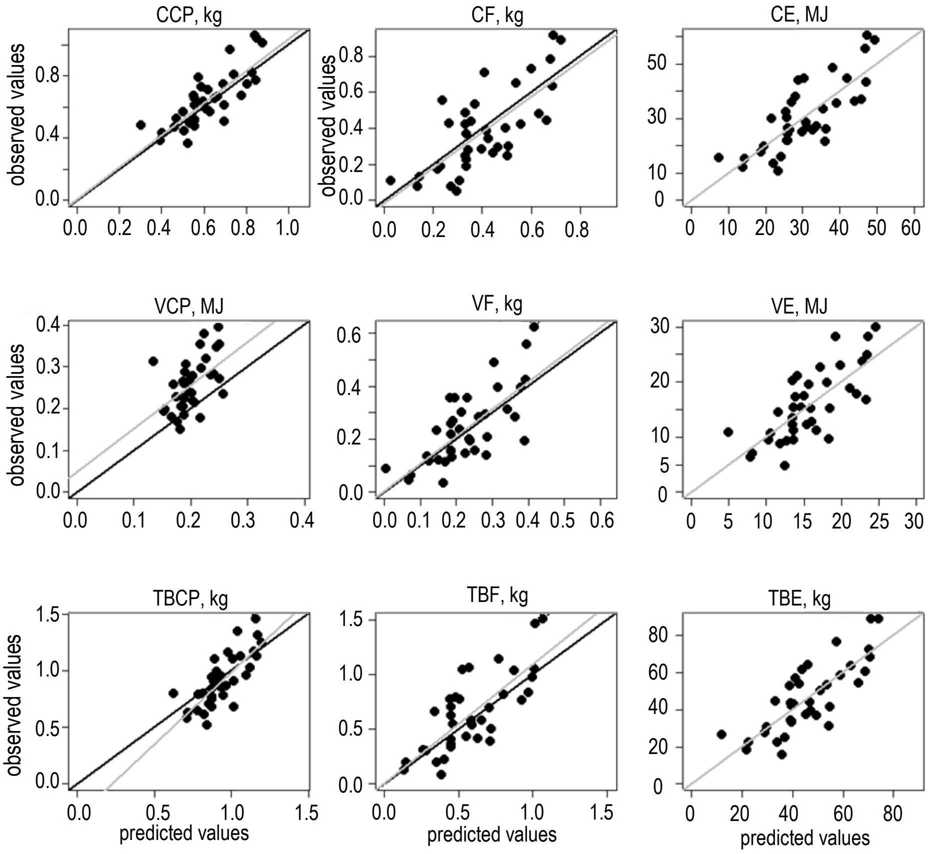

Figure 1. Body chemical composition of Pelibuey lambs, observed versus predicted

CCP – carcass crude protein, CF – carcass fat, CE – carcass energy, VCP – visceral crude protein, VF – visceral fat, VE – visceral energy, TBCP – total body crude protein, TBF – total body fat, TBE – total body energy

The MES system evaluates the predictive capacity of the equations to account for the distance between predicted and actual values using statistics such as the coefficient of determination (R^2), mean square error (MSE), standard deviation (SD), root mean square error of prediction (MSEP) and root

Results

There was no sex effect for any of the evaluated variables ($P > 0.05$). The animals were contemporaries, had the same origin, and were reared under similar conditions.

Table 1. Descriptive analysis of data recorded in Pelibuey lambs (n = 38)

Variable	Mean ± SD	CV	Minimum	Maximum
BMI	7.45 ± 1.07	14.36	5.23	9.40
BMIc	6.68 ± 0.98	14.67	4.46	8.56
CCP	0.64 ± 0.17	26.56	0.37	1.06
CF	0.38 ± 0.22	57.89	0.05	0.91
CE	30.52 ± 12.85	42.10	10.66	60.39
VCP	0.25 ± 0.06	24.00	0.15	0.39
VF	0.24 ± 0.13	54.16	0.03	0.62
VE	15.78 ± 6.04	38.27	4.79	29.88
TBCP	0.90 ± 0.22	24.44	0.51	1.45
TBF	0.63 ± 0.35	55.55	0.08	1.51
TBE	46.30 ± 18.62	40.21	15.45	88.57

BMI – body mass index (kg/m^2), BMIc – body mass index corrected (kg/m^2), CCP – carcass crude protein (kg), CF – carcass fat (kg), CE – carcass energy (MJ), VCP – visceral crude protein (kg), VF – visceral fat (kg), VE – visceral energy (MJ), TBCP – total body crude protein (kg), TBF – total body fat (kg), TBE – total body energy (MJ), SD – standard deviation, CV – coefficient of variation

Table 2. Correlation coefficients of body composition variables in Pelibuey lambs

	BMI	BMIc	TBCP	TBF	TBE	CCP	CF	CE	VCP	VF	VE
BMI	1	0.97	0.79	0.75	0.79	0.80	0.71	0.78	0.53	0.70	0.73
BMIc		1	0.76	0.76	0.80	0.80	0.73	0.79	0.50	0.72	0.74
TBCP			1	0.80	0.89	0.96	0.78	0.85	0.81	0.78	0.88
TBF				1	0.98	0.86	0.98	0.98	0.51	0.93	0.90
TBE					1	0.92	0.96	0.98	0.62	0.92	0.93
CCP						1	0.84	0.91	0.68	0.82	0.85
CF							1	0.98	0.51	0.84	0.82
CE								1	0.57	0.87	0.85
VCP									1	0.51	0.68
VF										1	0.97
VE											1

BMI – body mass index (kg/m^2), BMIc – body mass index corrected (kg/m^2), TBCP – total body crude protein (kg), TBF – total body fat (kg), TBE – total body energy (MJ), CCP – carcass crude protein (kg), CF – carcass fat (kg), CE – carcass energy (MJ), VCP – visceral crude protein (kg), VF – visceral fat (kg), VE – visceral energy (MJ); [1] correlations without a superscript indicate $P < 0.001$, with superscripts: **$P < 0.01$, *$P < 0.05$, ns – not significant

The average, minimum and maximum values of the variables are presented in Table 1; total body energy (TBE), carcass energy (CE), and visceral energy (VE) were the chemical components of the body that showed the highest variation. The correlation coefficients (r) between the variables are shown in Table 2. The relationship (r) between BMIc with carcass crude protein (CCP) and visceral crude protein (VCP) was 0.80 and 0.50, respectively ($P < 0.0001$), while for BMIc with carcass fat (CF) and visceral fat (VF), they were 0.73 and 0.72, respectively ($P < 0.0001$). In contrast, the correlations befat (TBF), and total body energy (TBE) had r values of 0.76, 0.80 and 0.76, respectively ($P > 0.0001$).

Table 3 shows the regression equations for the relationship between BMIc and body chemical components in Pelibuey lambs. Regarding the relationship between carcass chemical components (CCP, CF and CE) with BMIc, the R^2 value ranged from 0.53 (RSD: 0.16) for CF to 0.64 (RSD: 0.10) for CCP. The regression equations between visceral composition and BMIc resulted in R^2 values ranging from 0.52 for VF (RSD: 0.09) to 0.96 for VCP (RSD: 0.05). The coefficient of determination for the equations that included BMIc and body chemical composition ranged from 0.59 (RSD: 0.05) for TBF to 0.97 (RSD: 0.15) for TBCP; all equations were fitted to a linear trend. Moreover, since the intercepts of equations 4 and 7 were not significant, we fitted a linear regression through the origin.

On the other hand, equations 1, 2, and 3, devel-oped to predict lamb carcass composition (Table 4), had R^2 indicating moderate precision ($> 0.53 \leq 0.63$), and the Cb > 0.95 suggesting high accuracy (Table 4). However, the CCC indicated a moderate reproducibility index ($> 0.69 \leq 77$). The null hypothesis for intercept = 0 and slope = 1 (Table 4) was adopted for all equations. The CD ranged from 1.56 to 1.79, indicating high variability in the predicted data

Table 3. Regression equations for predicting body composition in Pelibuey lambs

Equation no.	Equation	n	MSE	RSD	R^2	*P*
1	CCP = −0.32 (± 0.12*) + 0.14 (0.01***) × BMIc	38	0.01	0.10	0.64	<0.0001
2	CF = −0.73 (± 0.17***) + 0.17 (± 0.03***) × BMIc	38	0.02	0.16	0.53	<0.0001
3	CE = −38.57 (± 9.14***) + 10.29 (± 1.34***) × BMIc	38	63.71	7.98	0.62	<0.0001
4	VCP = 0.03 (± 0.001***) × cBMI	38	0.002	0.05	0.96	<0.0007
5	VF = −0.44 (0.11***) + 0.10 (± 0.01***) × BMIc	38	0.009	0.09	0.52	<0.0001
6	VE = −16.55 (± 4.98**) + 4.81 (± 0.73***) × BMIc	38	18.91	4.34	0.55	<0.0001
7	TBCP = 0.14 (± 0.003***) × cBMI	38	0.02	0.15	0.97	<0.0001
8	TBF = −1.24 (± 0.27***) + 0.27 (± 0.03***) × BMIc	38	0.05	0.22	0.59	<0.0001
9	TBE = −55.11 (± 12.95***) + 15.10 (± 1.90***) × BMIc	38	127.91	11.31	0.64	<0.0001

CCP – carcass crude protein (kg), CF – carcass fat (kg); CE – carcass energy (kg), VCP – visceral crude protein (kg), VF – visceral fat (kg), VE – visceral energy (MJ), TBCP – total body crude protein (kg), TBF – total body fat (kg), TBE – total body energy (MJ), R^2 – coefficient of determination, MSE – mean square error, RSD – residual standard deviation, *P* – *P*-value; *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; [1] values in parentheses are SE of the estimated parameter, intercepts that did not differ from 0 were removed from the final equation

Table 4. Mean and descriptive statistics of the accuracy and precision of equations for predicting body composition in Pelibuey lambs

Variable[1]	Eq. 1 [CCP]	Eq. 2 [CF]	Eq. 3 [CE]	Eq. 4 [VCP]	Eq. 5 [VF]	Eq. 6 [VE]	Eq. 7 [TBCP]	Eq. 8 [TBF]	Eq. 9 [TBE]
Mean	0.62	0.41	30.50	0.20	0.23	15.73	0.94	0.58	45.84
SD	0.14	0.17	10.16	0.03	0.10	4.75	0.14	0.25	14.92
Maximum	0.88	0.72	49.49	0.26	0.42	24.61	1.20	1.07	74.11
Minimum	0.30	0.03	7.34	0.13	0.01	4.91	0.62	0.14	12.26
R^2	0.63	0.53	0.62	0.24	0.53	0.55	0.58	0.59	0.64
CCC	0.77	0.69	0.75	0.23	0.69	0.71	0.67	0.68	0.78
Cb	0.96	0.95	0.97	0.54	0.94	0.96	0.88	0.89	0.95
MEF	0.61	0.52	0.66	0.23	0.54	0.54	0.54	0.55	0.64
CD	1.56	1.78	1.59	1.56	1.94	1.82	2.54	1.93	1.56
Regression analysis									
Intercept (β_0)									
estimate	0.02	−0.02	0.03	0.06	0.04	0.03	−0.27	0.01	0.05
SE	0.08	0.07	4.20	0.06	0.04	2.50	0.17	0.10	6.13
P-value (β_0 = 0)	0.83	0.82	0.99	0.28	0.91	0.99	0.12	0.95	0.99
Slope (β_1)									
estimate	1.01	0.98	0.99	0.96	1.03	1.00	1.25	1.08	1.00
SE	0.13	0.16	0.13	0.28	0.16	0.15	0.18	0.16	0.13
P-value (β_1 = 1)	0.92	0.92	0.99	0.89	0.85	0.99	0.17	0.59	0.99
MSEP source, %									
MSEP									
mean bias	5.60	2.03	0.01	53.59	0.60	0.01	4.19	5.76	0.02
systematic bias	0.08	0.03	0.00	0.03	0.46	0.00	5.07	0.81	0.00
random error	94.37	97.94	99.99	64.85	98.93	99.99	90.74	93.43	99.98
Root MSEP									
estimate	0.11	0.16	7.76	0.08	0.09	4.23	0.15	0.24	11.00
% of the mean	16.80	40.40	25.43	29.76	41.52	26.80	16.70	36.40	23.75

[1] observed evaluation data set; CCC – concordance correlation coefficient, R^2 – coefficient of determination, Cb – bias correction factor, MEF – modelling efficiency, CD – coefficient of model determination, SE – standard error, MSEP – mean square error of the prediction, Eq – equation, CCP – carcass crude protein, CF – carcass fat, CE – carcass energy, VCP – visceral crude protein, VF – visceral fat, VE – visceral energy, TBCP – total body crude protein, TBF – total body fat, TBE – total body energy

(Table 4). The partition of MSEP (% MSEP) indicated that the error was mostly (> 94%) associated with random error (Table 4). In equations 1, 2, and 3, RMSEP accounted for 16.80 to 40.40% of the observed carcass chemical composition.

Regarding the equations developed to predict visceral composition using BMIc as a predictor, the null hypothesis for intercept = 0 and slope = 1 (Table 4) was adopted for all equations. Equation 4 presented the lowest precision (R^2 = 0.24), moderate accuracy (Cb = 0.54) and low reproducibility index (CCC = 0.23), while both equations 5 and 6 showed moderate precision, high accuracy (Cb > 0.94) and moderate correlation coefficient (CCC = 0.69 and 0.71, respectively); the prediction efficiency (MEF) for both equations was 0.54. The CD ranged from 1.56 to 1.94, indicating high variability in the predicted data (Table 4). The partition of MSEP (% MSEP) indicated that the main error rate (> 64%) was associated with random error (Table 4).

Prediction equations using BMIc, null hypothesis intercept = 0 and slope = 1 were used to assess body composition (Table 4). The results for equations 7, 8 and 9 presented moderate precision (R^2 = 0.58, 0.59 and 0.64 respectively), high accuracy (Cb = 0.88, 0.89 and 0.95, respectively) and moderate reproducibility index (CCC = 0.58, 0.59 and 0.64, respectively); the CD ranged from 1.56 to 2.54 for equations 9 and 7, respectively (Table 4). The partition of MSEP (% MSEP) indicated that the main error rate (> 90%) was associated with random error (Table 4). In equations 7, 8, and 9, RMSEP accounted for 16.70 to 36.40% of the observed body chemical composition.

Discussion

Various studies have shown that the body composition of sheep is an important factor in determining nutritional requirements because it is composed of water, protein, fat, and minerals (Costa et al., 2014). These components vary in proportion, influenced, among others, by factors such as genotype, age, sex, growth rate, and nutrition

(Morales-Martínez et al., 2020). In adult hair sheep, the accumulation patterns of fat tissue are less affected by genetic factors and maturity (Anderson et al., 2016). On the contrary, in growing lambs, the maturity of an individual determines the proportions of different tissues (muscle, fat, and bone) that make up the body (Carrasco et al., 2009). The present study found that at 56 days of age, hair lambs had a lower proportion of fat tissue compared to muscle tissue, which was present in higher quantity. These results were consistent with the growth stage of the lambs during the evaluation.

However, it is worth noting that even when fat tissue was present in a lower proportion, it was the most variable tissue in the body of those animals. Recently, Salazar-Cuytún et al. (2020b) showed 56% variation for the same component in the body of adult sheep, and the variation in the present study was 55% in lambs. Despite the high variation in lamb body fat, the model obtained for this body component was able to predict tissue with moderate precision and high accuracy. In this context, several authors attributed this variation to factors such as growth and individual variation; therefore, it is of great importance to determine and control fat depositions during the growth stage (Morales-Martínez et al., 2020). As various factors can contribute to such variation in body tissues, it is recommended that the mathematical models obtained for animals in a certain physiological condition, or of similar ages and weights, should not be used in a generalised way, as they may generate inaccurate estimates. The percentage of particular body tissues can vary considerably between individuals (Loya-Olguin et al., 2019). Considering the known studies that involve BMI as a predictor of body chemical composition in lambs in the tropics, the equations generated were more appropriate, because they provided information on the age and weights of hair lambs, even if they tended to overestimate said components.

In the present study, the lambs were slaughtered on the day of weaning, thus the effect of sex on their growth was not considered, because male growth significantly exceeds the females' only at the post-weaning stage. It is at this stage when the growth is observed to a greater or lesser extent in all tissue components, generally being the largest in adipose tissue (Lauces et al., 2007; Macedo and Arredondo, 2008).

The body chemical composition of the lambs was assessed and it was found that the models generated at this stage described the body components (fat and protein) better than the models generated for adult sheep. The value of the protein component in lambs ranged from 0.51 to 0.57 compared to 0.25–0.32 in mature sheep, and for the fat component, the values ranged from 0.50 to 0.59 compared to 0.61–0.66 in adult sheep using BMI, respectively. The models obtained in the present study showed higher precision than those obtained in adult ewes (Salazar-Cuytún et al. 2020b). Due to their higher prediction efficiency, except for the fat component (carcass fat, visceral fat, and total fat), the models better explained the protein component in lambs. This could be due to the fact that dynamics of tissue formation in recently weaned lambs was different compared to adult ewes. In lambs, the protein and fat show differences because lamb body shape is constantly changing, especially before reaching maturity (Moro et al., 2019), and energy is used for priority tissue synthesis, i.e. protein and bone rather than fat (Maeno et al., 2013). Therefore, a higher proportion of protein and very little fat was observed at this stage (Lauces et al., 2007).

On the contrary, the fat component showed a better fit in ewes, with R^2 values of 0.62 to 0.67 with BMIc and 0.50 to 0.51 in lambs. This could be due to the fact that lambs at growing stage (Moro et al., 2019). Although sheep's body tissues have an identical growth rate, muscles and bones mature early, while fat is a late-maturing tissue, with subcutaneous and pelvic-renal fat being the ones that develop the latest and at a higher rate (Lauces et al., 2007). In addition, the Pelibuey breed is characterised by late maturation compared with other hair sheep breeds such as Dorper or Katahdin (Macías-Cruz et al., 2010). In general, the statistical indices of model evaluation in the current study had better values for growing lambs and showed less variability when estimating the body chemical composition compared to the models evaluated in ewes (Salazar-Cuytún et al., 2020b).

Various models have been used to predict body composition to improve precision in estimating body components, with more emphasis in predicting body fat deposits such as carcass fat and internal fat in beef and sheep (Ribeiro and Tedeschi, 2012; Morales-Martínez et al., 2020). Khojastehkey et al. (2016), assessed body size of new-born lambs and body measurements (length and height) and reported a correlation between measured body size and estimated size equal to r = 0.48 ($P < 0.01$). In the present study, body mass index could be used as an indicator of lamb body chemical components (R^2 = 0.51 to 0.63), and because of this association, the body chemical composition can be estimated using measurements such as weight, length, and height of the body.

The proposed index (BMI) has recently been applied in hair sheep (Salazar-Cuytún et al., 2020a; b) and includes measures related to body size and mass to associate the body chemical composition with the amount of body fat. Similar trends in the prediction equations were found only in adult sheep (no-pregnant and non-lactating, aged 2 to 4 years) between BMI and body chemical components, ranging from 0.37 to 0.97 compared to those obtained in the present study 0.52–0.97 (Salazar-Cuytún et al., 2020b).

In lambs, the relationship between the chemical components of the carcass, (protein, fat and energy), with BMIc presented a low range of association; the variation ranged from 0.64 (RSD = 0.10), 0.53 (RSD = 0.16) to 0.62 (RSD = 7.98) and was lower in lambs compared to adult sheep: 0.97 (RSD = 0.37), 0.67 (RSD = 1.65) and 0.66 (RSD = 65.67), respectively. However, although the range is lower in lambs than in adult ewes, it should be noted that the equations presented less variation and, therefore, better described the relationship between carcass chemical components and BMI in lambs. This may indicate that 56-day-old lambs show less variation in their body tissues.

Ehrhardt et al. (2003) reported the same amount of fatty tissue in pre-ruminant lambs when evaluating two different feeding plans (high and low), as well as different weight (15 kg and 20 kg) and age (38 vs 115 days) at slaughter. It was found that the feeding factor did not influence the accumulation patterns of fat tissue at this stage of growth. In contrast, the current study found different amounts of fat tissue at 56-day-old weaned lambs. With such different results, we can confirm that fat tissue is the most complex to measure, and it can show different accumulation patterns even at the same growth stage. Moreover, energy intake, as in adults, is not the only factor that influences the accumulation patterns of body tissues. Therefore, an increase in weight or size in the growth stage does not necessarily mean an increase in the proportion of body fat (Costa-Silva et al., 2019).

Strengths and limitations of the study. One of the strengths of the present study is the possibility to predict *in vivo* body chemical composition of lambs. In addition, an evaluation of the prediction models (comparison of predicted results with the actual measurements of the body chemical composition) is also presented; therefore, the precision and accuracy of the predictions obtained each model prediction were useful for determination of the better models.

In general, although the precision and accuracy of the models were moderate to high, this information would undoubtedly contribute to generating new information on prediction methods for livestock assessment using BMI. This is the first step towards predicting body chemical composition in growing lambs, because the existing information on the use of BMI as a predictor of chemical components in hair sheep is limited, the obtained models allowed us to make valid conclusions about the body chemical composition in hair sheep. In addition, it should be noted that the evaluation of body chemical composition in growing animals is complex because their tissue proportions are constantly changing, and therefore, the results of the current study are only applicable in the weight ranges evaluated.

Overall, BMI as a measure of body composition has been validated with greater precision in adult individuals. Since both lean mass and fat mass are highly correlated with BMI, thus it can act as an indicator for both of these parameters (Wells, 2001). However, this index has limitations in young individuals because lean mass and fat mass are still developing; however, body size can be estimated in growing individuals based on body measurements such as length and height (Khojastehkey et al., 2016). For this purpose, it is necessary to evaluate the usefulness of BMI in young animals in order to make more appropriate comparisons (Pearce et al., 2009; Salazar-Cuytún et al., 2020b). Moreover, further studies are required for other breeds of hair sheep in different physiological states, as well as under other management conditions, to validate the present results.

Conclusions

BMIc shows a good relationship with body chemical components and can therefore be used to predict body chemical composition in 56-day-old hair lambs, within the weight range used under the experimental conditions of the current study.

Conflict of interest

The Authors declare that there is not conflict of interest.

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