https://doi.org/10.52973/rcfcv-e361772 Revista Científica, FCV-LUZ / Vol. XXXV

Multiple linear regression to predict carcass tissue composition in hair lambs raised under commercial system

Regresión lineal múltiple para predecir la composición tisular de la canal en corderos de pelo criados bajo sistema comercial

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ABSTRACT

The aim of the present study was to predict the carcass tissue composition of hair lambs reared on a commercial system, based on the characteristics of commercial cuts using multiple linear regression. In the study, thirty crossbred male lambs (Pelibuey × Dorper/Katahdin), with an average live weight of 51.12 ± 0.97 kg, were used. After slaughter of lambs, the carcasses were stored in refrigeration at 4 °C for 24 hours. Subsequently, they were weighed and split longitudinally. The left half of carcasses was divided into eight cuts (shank, neck, shoulder, rib, flank, loin, sirloin, and leg), which were individually weighed (kg) and dissected into muscle, fat, and bone. Also, the total weight of muscle, total fat content, and total bone content in the complete carcass was determined. In general, total weight of muscle, total fat content, and total bone contentshowed moderate to high positive correlations ($0.32 \le r \le 0.87$; $P < 0.05$, $P < 0.001$) with the characteristics of commercial cuts. The best predictors of total muscle content were shoulder muscle content, shank weight, leg muscle content, and rib muscle content ($R^2 = 0.96$; MSE = 3.94; AIC = -1.28). The total fat content can be adequately predicted using rib fat content, loin fat content, and shoulder fat content (R^2=0.96; MSE=3.29; AIC=-7.71). While total bone content can be predicted from leg bone content, sirloin bone content, shoulder bone content, and shank bone content (R2 = 0.91; MSE = 0.75; AIC = -16.42). All linear regression equations were found to be significant ($P < .001$). It is concluded that the carcass tissue composition of hair lambs is highly correlated with characteristics of commercial cuts. Consequently, the regression equations obtained in the study had high accuracy. Therefore, they can be used by technicians, producers, and researchers to obtain information on the carcass composition of hair lambs reared on commercial systems.

Key words: Carcass muscle content; crossbred hair lambs; linear regression.

RESUMEN

El objetivo del presente estudio fue predecir la composición tisular de la canal de corderos de pelo criados en un sistema comercial, con base en las características de los cortes comerciales utilizando regresión lineal múltiple. En el estudio, se utilizaron treinta corderos machos cruzados (Pelibuey × Dorper/Katahdin), con un peso corporal promedio de 51,12 ± 0,97 kg. Después del sacrificio de los corderos, las canales se almacenaron en refrigeración a 4 °C durante 24 horas. Posteriormente, se pesaron y se dividieron longitudinalmente. La mitad izquierda de las canales se dividió en ocho cortes (brazo, cuello, hombro, costilla, falda, lomo, solomillo y pierna), las cuales se pesaron individualmente (kg) y se diseccionaron en sus componentes: músculo, grasa y hueso. Además, se determinó el contenido (kg) total de músculo, grasa y hueso en la canal completa. En general, el contenido total de músculo, contenido total de grasa y contenido total de hueso, mostraron correlaciones positivas moderadas a altas ($0,32 \le r \le 0,87$; $P < 0,05$, $P < 0,001$) con las características de los cortes comerciales. Los mejores predictores del contenido total de músculo fueron el contenido muscular del hombro, peso del brazo, contenido muscular de la pierna y contenido muscular de la costilla (R2 = 0,96; MSE = 3,94; AIC = -1,28). El contenido total de grasa, se puede predecir adecuadamente utilizando el contenido de grasa de la costilla, contenido de grasa del lomo y contenido de grasa del hombro (R2 = 0,96; MSE = 3,29; AIC = -7,71). Mientras que el contenido total de hueso, se puede predecir a partir del contenido de hueso de pierna, contenido de hueso del solomillo, contenido de hueso del hombro y contenido de hueso del hombro (R2 = 0,91; MSE = 0,75; AIC = -16,42). Todas las ecuaciones de regresión lineal resultaron significativas ($P < 0,001$). Se concluye que la composición del tejido de la canal de los corderos de pelo presenta una alta correlación con las características de los cortes comerciales. En consecuencia, las ecuaciones de regresión obtenidas en el estudio presentaron una alta precisión. Por lo tanto, pueden ser utilizadas por técnicos, productores e investigadores para obtener información sobre la composición de la canal de los corderos de pelo criados en sistemas comerciales.

Palabras clave: Contenido muscular de la canal; corderos de pelo cruzados; regresión lineal.

Recibido: 18/08/2025 Aceptado: 05/01/2026 Publicado: 14/01/2026

INTRODUCTION

Currently, the Latin America and the Caribbean region concentrate 6.5 % of the sheep (*Ovis aries*) inventory reported worldwide, being approximately 77.0 million sheep. Specifically, Mexico has 11 % of this sheep inventory, contributing 22 % of the sheep total economic value in the region [1]. In the tropical regions of the country, sheep production systems include crosses and purebreds, mainly hair breeds (e.g. Pelibuey, Blackbelly, Katahdin and Dorper), and provides around 25 % of sheep meat national production [2]. Pelibuey is one of the most predominant sheep breeds, which has shown a significant increase in meat production under intensive management, improving profitability of the production units [3].

In lamb commercial production, carcass evaluation is crucial for assessing the yield, quality, and profitability of this productive sector. Thus, the yield of high value cuts determines the economic value of carcasses [4]. Meat yield and carcass composition, in terms of muscle, fat and bone content, are determinants of carcass quality due to the variability in these characteristics [5]. The muscle content affects tenderness and flavor, while fat content influences the flavor, texture, and juiciness of meat. Meanwhile, bone content influences flavor and texture, but to a lesser extent [6]. Therefore, the commercial value of lamb carcasses is determined by yield and distribution pattern of the muscle, as well as the quality of the meat [7].

The total or partial dissection of carcass into muscle, fat and bone is the most accurate technique to determinate the carcass tissue composition, but it is an expensive, time-consuming method, and produces carcass losses [5, 8]. In this context, modelling has great potential to help in decision-making in lamb production under controlled systems. Total or partial dissection is a useful tool capable of predicting quantitative variables of interest with high precision and accuracy, such as carcass tissue composition [9].

In sheep, linear regression models have been used for this purpose [10, 11, 12, 13, 8]. In general, the authors determined that prediction of carcass composition from dissection of some cuts is a potential option over the method of analyzing the whole carcass. However, the equations developed are based on measurements from growing lambs with slaughter weights less than 30 kg, so they may not be appropriate for predicting the carcass composition of lambs with higher slaughter weights [7].

Therefore, the aim of the present study was to predict the carcass tissue composition of hair lambs raised under commercial system, based on the characteristics of commercial cuts (weight, yield, and proportions of muscle, fat, and bone) using multiple linear regression and decision tree methods. One important aspect in this study is the use of measurements of lambs with weights higher than those commonly reported in literature (~50 kg).

MATERIALS AND METHODS

Study site and animals

The present study was carried out using 30 crossbred male lambs (Pelibuey × Dorper/Katahdin), with a mean body weight of 51.12 ± 0.97 kg, which were reared on a commercial sheep farm, located in the municipality of Timucuy of the State of Yucatan, Mexico (20º 48' 38” N and 89º 30' 49” W) at 14 masl. The lambs age ranged from 200 to 230 days (d) at slaughter. Animal management has been described by Portillo-Salgado *et al*. [14].

Lambs were handled according to the regulations for ethical animal experimentation of the Faculty of Veterinary Medicine and Zootechnics of the Universidad Autónoma de Yucatán, México (Approval number: 6324.19-114 05-2022).

Data collection

When the lambs they reached the fixed body weight (~50 kg) were slaughtered, which was determined using an electronic scale with a capacity of 50 ± 0.01 kg (Torrey®, SR-50/100; Mexico), after a fasting period of 16 hours (h), during which they received only clean water ad libitum. The animals were slaughtered humanely by electrical stunning (Reysan Atlactic®, TSQ003; Spain) and exsanguination by cutting the jugular vein, following the Official Mexican Standards [15, 16, 17] established for the humane slaughter of animals used for meat production.

After evisceration, carcasses were weighed and cooled at 4 °C for 24 h in a cold chamber (Torrey®; Mexico). After this period, carcasses were weighed again using an electronic scale with a capacity of 50 ± 0.01 kg (Torrey®, SR-50/100; Mexico) and split longitudinally with a commercial saw. The left half of the carcass was divided into eight complete commercial cuts: shank, neck, shoulder, rib, flank, loin, sirloin, and leg, as described by Esenbuga *et al*. [18] (TMC: total muscle content; TFC: total fat content; TBC: total bone content; SHWE: shank weight; SHYI: shank yield; SHMC: shank muscle content; SHFC: shank fat content; NEWE: neck weight; NEYI: neck yield; NEMC: neck muscle content; NEBC: neck bone content; SOWE: shoulder weight; SOMC: shoulder muscle content; SOFC: shoulder fat content; SOBC: shoulder bone content; RIWE: rib weight; RIYI: rib yield; RIMC: rib muscle content; RIFC: rib fat content; RIBC: rib bone content; FLWE: flank weight; FLYI: flank yield; FLFC: flank fat content; LOWE: loin weight; LOYI: loin yield; LOMC: loin muscle content; LOFC: loin fat content; LOBC: loin bone content; SIWE: sirloin weight; SIMC: sirloin muscle content; SIFC: sirloin fat content; SIBC: sirloin bone content; LEWE: leg weight; LEYI: leg yield; LEMC: leg muscle content; LEFC: leg fat content; LEBC: leg bone content). Each commercial cut was dissected into muscle, fat, and bone, and individually weighed using a digital scale with a capacity of 20 kg ± 0.1 gram (g) (Torrey®, L-PCR-20; Mexico) to estimate their tissue composition. Finally, the weights of each tissue per commercial cut were doubled to determine the total weight of muscle (TMC), fat (TFC), and bone (TBC) in the complete carcass.

Statistical analysis

Initially, the normal distribution of the variables evaluated was analyzed according to the Shapiro-Wilk test. Data were analyzed using descriptive statistics (means, standard deviations, minimum and maximum values, and coefficients of variation) and Pearson correlation (r) analysis using the SPSS 25.0 statistical package (IBM® SPSS, Armonk, NY, USA).

Multiple linear regressions were also employed to predict the carcass tissue composition of hair lambs (total muscle, fat, and bone content) from characteristics of carcass cuts (weight, yield, and proportions of muscle, fat, and bone) using the stepwise analysis. The criteria used for selecting the best-fitting model included the adjusted coefficient of determination (R^2), mean square error (MSE), Akaike information criterion (AIC), Bayesian Information Criterion (BIC), and significance level [19]. The multiple linear regression models were:

$$Y_i = \beta_0 + \beta_{i1}X_1 + \beta_{i2}X_2 + \beta_{i3}X_3 + \cdots + +\beta_{ip}X_pD + \varepsilon_i$$

where: Yj = dependent variables (total muscle, fat, and bone content); β_0 = intercept; β_1, β_2, $\beta_3 \ldots \beta_n$ = coefficients that correspond to the independent variables X_1, X_2, $X_3 \ldots X_p$ (characteristics of carcass cuts), the subscript i refers to the cases (in this case animals used), and ej = residual error.

RESULTS AND DISCUSSION

The results of the Shapiro-Wilk normal distribution test showed that most variables met this assumption, except for SHFC, SHBC, SOWE, SOYI, SOMC, LOBC, SIMC, SIFC, LEYI, and LEMC ($P < 0.05$). On the other hand, no high correlations (> 0.80) were observed between the independent variables, thus meeting the multicollinearity assumption [5].

Descriptive statistics of the characteristics of commercial cuts evaluated in the study are shown in TABLE I. In general, the characteristics of the commercial cuts analyzed showed moderate variation (CV < 20 %), which is justified by the homogeneous management conditions used in the commercial production system where the lambs were raised. The greatest variation was observed in SHFC (CV = 22.7 %), LOFC (CV= 21.9 %), and LOBC (CV= 22.9 %). The variations observed in fat content in cuts (e.g. shoulder and loin) are possibly explained by the use of crossbred lambs. That is, some breeds, such as Katahdin, experience rapid growth and accumulate back fat at an early age, compared to the Pelibuey breed, which grows more slowly and tends to accumulate less fat [19]. Similarly, Díaz *et al.* [20] observed high variation (CV > 43 %) in fat measurements in Manchego-breed lambs compared to other carcass measurements.

In the present study, the average TMC, TFC, and TBC were 12.92 ± 0.97, 6.48 ± 0.77 and 5.32 ± 0.43 kg, respectively. This means that the carcass tissue composition of hair lambs slaughtered at 50 kg was 52.3 % muscle, 26.2 % fat, and 21.5 % bone. In their study, Gastelum-Delgado *et al.* [13] reported that proportions of muscle, total fat and bone in growing Blackbelly lambs with average body weight of 29.1 kg were 68.1, 9.34, and 22.4 %, respectively. The variations observed between studies are because in hair lambs it has been reported that as the slaughter weight increases, the percentage of fat increases and the percentage of bone decreases [11]. For their part, Keçici *et al.* [21] reported that the mean carcass tissue composition of Kivircik lambs with an average slaughter weight of 27.51 kg was 49.60 % muscle, 21.07 % bone, and 21.87 % total fat.

TABLE I
Descriptive statistics of the characteristics of carcass cuts of hair lambs reared under commercial system

Variable	Description	Mean ± SD	Minimum	Maximum	CV (%)
Shank					
SHWE	Weight; kg	3.69 ± 0.22	3.28	4.36	6.17
SHYI	Yield; %	13.86 ± 0.85	12.15	15.96	6.15
SHMC	Muscle content; kg	2.26 ± 0.17	2.02	2.53	7.92
SHFC	Fat content; kg	0.67 ± 0.15	0.52	1.12	22.72
SHBC	Bone content; kg	0.74 ± 0.10	0.39	0.88	14.00
Neck					
NEWE	Weight; kg	1.10 ± 0.14	0.86	1.46	13.33
NEYI	Yield; %	4.14 ± 0.53	3.17	5.36	12.98
NEMC	Muscle content; kg	0.46 ± 0.08	0.30	0.58	18.83
NEFC	Fat content; kg	0.26 ± 0.04	0.18	0.33	18.87
NEBC	Bone content; kg	0.28 ± 0.03	0.22	0.34	10.92
Shoulder					
SOWE	Weight; kg	4.34 ± 0.42	3.76	6.13	9.87
SOYI	Yield; %	15.90 ± 0.97	13.56	17.35	6.15
SOMC	Muscle content; kg	1.92 ± 0.32	1.44	2.92	16.71
SOFC	Fat content; kg	1.54 ± 0.29	1.06	1.99	18.96
SOBC	Bone content; kg	0.98 ± 0.15	0.69	1.22	15.46
Rib					
RIWE	Weight; kg	1.90 ± 0.18	1.48	2.28	9.94
RIYI	Yield; %	7.13 ± 0.70	5.77	8.87	9.84
RIMC	Muscle content; kg	0.76 ± 0.11	0.51	0.99	15.08
RIFC	Fat content; kg	0.65 ± 0.13	0.46	0.98	19.99
RIBC	Bone content; kg	0.55 ± 0.09	0.42	0.73	16.13
Flank					
FLWE	Weight; kg	1.80 ± 0.25	1.19	2.38	14.33
FLYI	Yield; %	6.77 ± 0.96	4.61	8.71	14.17
FLMC	Muscle content; kg	0.79 ± 0.07	0.69	0.91	9.12
FLFC	Fat content; kg	0.97 ± 0.13	0.77	1.27	14.29
Loin					
LOWE	Weight; kg	2.76 ± 0.45	2.68	3.94	16.26
LOYI	Yield; %	10.36 ± 1.63	6.40	14.52	15.78
LOMC	Muscle content; kg	1.34 ± 0.13	1.11	1.64	10.03
LOFC	Fat content; kg	0.92 ± 0.20	0.59	1.46	21.88
LOBC	Bone content; kg	0.67 ± 0.15	0.46	1.18	22.94
Sirloin					
SIWE	Weight; kg	1.88 ± 0.20	1.43	2.33	11.14
SIYI	Yield; %	7.05 ± 0.78	4.85	8.55	11.17
SIMC	Muscle content; kg	0.71 ± 0.07	0.57	0.80	10.33
SIFC	Fat content; kg	0.62 ± 0.05	0.46	0.69	8.15
SIBC	Bone content; kg	0.46 ± 0.04	0.39	0.53	9.55
Leg					
LEWE	Weight; kg	7.04 ± 0.26	6.42	7.60	3.82
LEYI	Yield; %	26.52 ± 1.42	23.42	31.73	5.36
LEMC	Muscle content; kg	4.66 ± 0.42	4.13	5.68	9.14
LEFC	Fat content; kg	0.83 ± 0.13	0.51	1.01	15.91
LEBC	Bone content; kg	1.61 ± 0.14	1.36	1.90	8.97
Totals					
TMC	Total muscle content; kg	12.92 ± 0.97	11.24	15.20	7.57
TFC	Total fat content; kg	6.48 ± 0.77	5.23	8.13	11.98
TBC	Total bone content; kg	5.32 ± 0.43	4.56	6.12	8.17

SD: standard deviation; CV: coefficient of variation TMC: total muscle content; TFC: total fat content; TBC: total bone content; SHWE: shank weight; SHYI: shank yield; SHMC: shank muscle content; SHFC: shank fat content; NEWE: neck weight; NEYI: neck yield; NEMC: neck muscle content; NEBC: neck bone content; SOWE: shoulder weight; SOMC: shoulder muscle content; SOFC: shoulder fat content; SOBC: shoulder bone content; RIWE: rib weight; RIYI: rib yield; RIMC: rib muscle content; RIFC: rib fat content; RIBC: rib bone content; FLWE: flank weight; FLYI: flank yield; FLFC: flank fat content; LOWE: loin weight; LOYI: loin yield; LOMC: loin muscle content; LOFC: loin fat content; LOBC: loin bone content; SIWE: sirloin weight; SIMC: sirloin muscle content; SIFC: sirloin fat content; SIBC: sirloin bone content; LEWE: leg weight; LEYI: leg yield; LEMC: leg muscle content; LEFC: leg fat content; LEBC: leg bone content

The Pearson correlation matrix between carcass tissue composition and characteristics of commercial cuts of hair lambs is represented in TABLE II.

The results showed that TMC showed high correlations (P < 0.001) with characteristics associated with muscle as SOMC (r = 0.86), LOMC (r = 0.83), LEMC (r = 0.78), RIMC (r = 0.70), SOWE (r = 0.66), NEMC (r = 0.63). Likewise, it had moderate correlations (P<0.05) with LEYI (r = 0.55), LOBC (r = 0.55), LEWE (r = 0.54), NEWE (r = 0.53), RIWE (r = 0.53), LOWE (r = 0.53), SHWE (r = 0.52), and LOYI (r = 0.51).

Meanwhile, TFC showed high correlations (P < 0.001) with RIFC (r = 0.87), LOFC (r = 0.86), FLFC (r = 0.71), SHFC (r = 0.68), SOWE (r = 0.68), and LEFC (r = 0.65). TFC had also moderate correlations (P < 0.05) with RIWE (r = 0.58), FLWE (r = 0.58), LOWE (r = 0.58), SOFC (r = 0.55), LOYI (r = 0.54), FLYI (r = 0.53), and NEWE (r = 0.52).

Finally, high correlations (P < 0.001) were observed between TBC with LEBC (r = 0.75), RIBC (r = 0.73), SOBC (r = 0.68), NEBC (r = 0.62), and SIBC (r = 0.61), as well as moderate correlations (P < 0.05) with SOWE (r = 0.58).

Other authors have also reported high correlation coefficients between carcass tissue composition and characteristics of commercial cuts, but their studies were in other breeds of hair sheep and with lower weight animals. For example, Camacho *et al*. [11] showed that characteristics of rib cut presented high correlations with the percentage of muscle and fat, and the leg for the percentage of bone in Canarian hair lambs. Similarly, in Galician lambs, the muscle content of the carcass was highly correlated with the muscle content of the leg, rib, and shoulder. Likewise, the bone and fat content of these cuts was highly correlated with the bone and intermuscular and subcutaneous fat content of the carcass.

In Santa Inês sheep, muscle proportion had negative and moderate correlations with traits related to commercial cuts as loin, rib, neck, and shoulder, as well as bone proportion with neck and loin [8]. In that study, fat proportion showed relatively high correlation coefficients with neck and loin weight. Recently, Gastelum-Delgado *et al*. [13] reported that muscle, fat and bone content in carcass of growing Blackbelly lambs presented positive and moderate to high correlations with most of the shoulder cut components. Therefore, due to their greater ease of obtaining, the shoulder, rib, and leg are viable cuts for predicting muscle, fat, and bone content of the carcass of lambs.

TABLE II

Pearson's correlations (r) between carcass tissue composition and characteristics of carcass cuts of hair lambs reared under commercial system

Description	TMC	TFC	TBC
SHWE	0.530*	0.201	-0.243
SHYI	0.419*	0.067	-0.164
SHMC	0.485*	0.225	-0.167
SHFC	0.322*	0.680**	0.264
NEWE	0.533*	0.529*	0.290
NEYI	0.499*	0.462*	0.318*
NEMC	0.634**	0.089**	0.135
NEBC	0.010	0.275	0.630**
SOWE	0.669**	0.683**	0.587*
SOMC	0.868**	0.376*	0.461*
SOFC	0.288	0.559*	-0.019
SOBC	-0.249	0.219	0.687**
RIWE	0.537*	0.583*	0.228
RIYI	0.481*	0.495*	0.273
RIMC	0.700**	-0.118	-0.151
RIFC	0.442*	0.876**	0.147
RIBC	-0.053	0.096	0.733**
FLWE	-0.203	0.587*	-0.024
FLYI	-0.252	0.537*	-0.008
FLFC	-0.265	0.710**	0.072
LOWE	0.539*	0.589*	0.453*
LOYI	0.516*	0.549*	0.486*
LOMC	0.833**	0.392*	0.318*
LOFC	0.143	0.866**	0.307
LOBC	0.550*	0.037	0.454*
SIWE	0.458*	0.458*	0.038
SIMC	0.420*	0.364*	-0.120
SIFC	0.004	0.479*	0.208
SIBC	0.447*	0.393*	0.613**
LEWE	0.544*	0.167	0.154
LEYI	0.553*	0.228	0.363*
LEMC	0.783**	0.041	0.059
LEFC	0.235	0.654**	-0.363
LEBC	-0.066	-0.174	0.750**

TMC: total muscle content; TFC: total fat content; TBC: total bone content; SHWE: shank weight; SHYI: shank yield; SHMC: shank muscle content; SHFC: shank fat content; NEWE: neck weight; NEYI: neck yield; NEMC: neck muscle content; NEBC: neck bone content; SOWE: shoulder weight; SOMC: shoulder muscle content; SOFC: shoulder fat content; SOBC: shoulder bone content; RIWE: rib weight; RIYI: rib yield; RIMC: rib muscle content; RIFC: rib fat content; RIBC: rib bone content; FLWE: flank weight; FLYI: flank yield; FLFC: flank fat content; LOWE: loin weight; LOYI: loin yield; LOMC: loin muscle content; LOFC: loin fat content; LOBC: loin bone content; SIWE: sirloin weight; SIMC: sirloin muscle content; SIFC: sirloin fat content; SIBC: sirloin bone content; LEWE: leg weight; LEYI: leg yield; LEMC: leg muscle content; LEFC: leg fat content; LEBC: leg bone content;
**P < 0.001; *P < 0.05

Prediction of carcass tissue composition using multiple linear regression

The results of multiple linear regression using the stepwise procedure (TABLE III) showed the significance level; next to each regression coefficient, the standard errors are shown in parentheses, of the independent variables in regression equations predicting the dependent variables (TMC, TFC, and TBC). The TMC can be adequately predicted using the SOMC (R2 = 0.73; P < 0.001 [Eq.1]). However, predictive accuracy was improved by adding other characteristics related to muscle tissue such as SHWE, LEMC, and RIMC, since the R2 increased to 0.96 [Eq.4].

TABLE III

Regression equations to predict carcass tissue composition using characteristics of carcass cuts of hair lambs reared under commercial system

Eq. No.	Equations	R^2	adj. R^2	MSE	AIC	BIC	*P*-value
Total muscle content; kg							
[1]	TMC = 7.85 + 2.63 (±0.38***) × SOMC	0.751	0.735	12.214	30.25	32.92	< 0.001
[2]	TMC = 1.82 + 2.41 (±0.27***) × SOMC + 1.78 (±0.43**) × SHWE	0.883	0.867	7.181	18.67	22.23	< 0.001
[3]	TMC = 1.10 + 1.93 (±0.26***) × SOMC + 1.36 (±0.36**) × SHWE + 0.67 (±0.21**) × LEMC	0.932	0.917	5.051	11.00	15.45	< 0.001
[4]	TMC = 1.37 + 1.51 (±0.21***) × SOMC + 0.96 (±0.27**) × SHWE + 0.76 (±0.15***) × LEMC + 2.09 (±0.52**) × RIMC	0.969	0.960	3.941	-1.28	4.05	< 0.001
Total fat content; kg							
[5]	TFC = 3.08 + 5.21 (±0.71***) × RIFC	0.767	0.752	7.872	20.76	23.43	< 0.001
[6]	TFC = 2.76 + 3.07 (±0.83**) × RIFC + 1.84 (±0.53**) × LOFC	0.869	0.852	4.463	12.34	15.91	< 0.001
[7]	TFC = 1.84 + 2.21 (±0.49***) × RIFC + 2.00 (±0.30***) × LOFC + 0.86 (±0.14***) × SOFC	0.981	0.962	3.291	-7.71	-3.26	< 0.001
Total bone content; kg							
[8]	TBC = 1.66 + 2.27 (±0.49***) × LEBC	0.570	0.543	1.835	10.91	13.58	< 0.001
[9]	TBC = - 0.371 + 2.05 (±0.31***) × LEBC + 5.16 (±1.03***) × SIBC	0.838	0.816	1.349	-4.66	-1.10	< 0.001
[10]	TBC = - 0.22 + 1.69 (±0.32***) × LEBC + 4.59 (±0.95***) × SIBC + 0.70 (±0.32*) × SOBC	0.880	0.854	0.944	-8.04	-3.59	< 0.001
[11]	TBC = - 0.59 + 1.59 (±0.25***) × LEBC + 3.64 (±0.80**) × SIBC + 0.90 (±0.25**) × SOBC + 1.03 (±0.32**) × SHBC	0.933	0.912	0.751	-16.42	-11.08	< 0.001

TMC: total muscle content; TFC: total fat content; TBC: total bone content; SOMC: shoulder muscle content; SHWE: shank weight; LEMC: leg muscle content; RIMC: rib muscle content; RIFC: rib fat content; LOFC: loin fat content; SOFC: shoulder fat content; LEBC: leg bone content; SIBC: sirloin bone content; SOBC: shoulder bone content; SHBC: shank bone content; R^2 = coefficient of determination; adj. R^2 = adjusted R2; MSE = Mean square error; AIC = Akaike information criterion; BIC = Bayesian Information Criterion, *P < 0.05; **P < 0.01; ***P < .001; ns: non-significant

For the prediction of TFC, the accuracy of prediction was similarly high (R2 = 0.75 to 0.96; P < 0.001). The RIFC was the most important predictor and alone explained R2 = 0.75 of the variation explained in TFC [Eq.5]. Adding the LOFC [Eq.6] and SOFC [Eq.7] increased R2 by 0.85 and 0.96, respectively.

The prediction of TBC was less accurate than that of muscle and fat (R2 = 0.54 to 0.91; P < 0.001). In the observed equations, LEBC, SIBC, SOBC, and SHBC were the important predictors in that order. The proportion of variation explained for first equation that included only LEBC was 0.54 [Eq.8]. However, the R2 value increased by adding the rest of the selected variables into the equations [Eq.9 to 11].

As expected, cut characteristics highly correlated with muscle, fat, and bone content were the best predictors. Although the accuracy of the equations obtained were high, it is important to consider the number and type of variables involved and their practicality for field application as a selection criterion for evaluating the prediction equations [22]. For example, Díaz *et al*. [20] determined that kidney knob channel fat proportion was included in prediction equation of muscle and fat (weight and proportion) in suckling lambs; however, this variable is not suitable to use in the abattoir, restricting its use to experimental purposes. Under this criterion, in our study, the last equations could be impractical due to the greater number of predictor variables. Therefore, it is recommended to use the equations for each tissue, with at least two variables, which offer acceptable accuracy (R2 > 80 %).

In another study [13] with this same purpose, neck muscle, neck fat, and neck weight were the variables that most accurately predict the total weights of muscle, bone, and fat of Blackbelly lambs, respectively. For their part, Camacho *et al*. [11] observed that in Canarian lambs with a body weight of 15 kg, the rib was the carcass cut with the greatest predictive capacity for muscle and fat percentages; meanwhile, the leg cut allowed for the most accurate prediction of carcass bone percentage.

Keçici et al. [21] aimed to test the possibility of using carcass measurements and joint tissue composition to predict the carcass tissue composition of Kıvırcık male lambs. Their results determined that, when joint dissection (e.g. flank, neck, and shoulder) and various carcass traits (e.g. cold carcass weight, carcass length, tail percentage, and hind limb length) were combined, carcass tissue composition was predicted more accurately (65–90 %), especially for muscle and total fat weights.

CONCLUSION

The results demonstrates that the significant relationship found between the tissue composition and characteristics of commercial cuts of carcass allows to develop reliable prediction equations ($0.54 \leq R^2 \leq 0.96$) for the muscle, fat, and bone content of carcass in hair male lambs reared in commercial systems. Shoulder muscle content was the most important variable influencing total muscle content. While rib fat content was the predominant variable influencing total fat content. Finally, leg bone content was the best predictor variable for total bone content. Consequently, the regression equations obtained in the study can be used by technicians, producers, and researchers to obtain information on the carcass composition of hair lambs reared on commercial systems.

ACKNOWLEDGEMENT

The authors would like to acknowledge to Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI) -Mexico (Project 6029324), for the postdoctoral fellowship awarded to the first author. Also, the author s also gratefully thanks the owner of the “Libertad” sheep ranch for providing the lambs raised for this study.

Conflicting interest

The authors declare no conflict of interest regarding the publication of this manuscript

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