Using the 9th–11th rib section to predict carcase tissue composition in Blackbelly sheep

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Abstract
The study aimed at developing predictive equations to estimate carcase tissue composition in Blackbelly sheep using the 9th–11th rib section and to evaluate its accuracy and precision. Twenty male growing Blackbelly sheep with a bodyweight (BW) of 29 ± 3 kg were slaughtered. Data from carcase and non-carcase components were recorded. Thereafter, the left half carcase was weighed and dissected to record weights of fat (CF), muscle (CM), and bone (CB). Also, the 9th–11th section was dissected for muscle, fat and bone (MRib, FRib, BRib, respectively). The MRib and FRib were moderate to highly correlated (p < .001) with CM and the r values ranged from 0.47 to 0.82, while the FRib and the CF were positive correlated (r = 0.68, p < .001). Also the left half carcase weight (LHCW) was positively correlated (p < .001) with carcase tissues and the r values ranged from 0.57 for CF to 0.93 CM. Regression equations developed for predicting CM, CF and CB in Blackbelly sheep using the 9th–11th rib section had an r² that ranged from 0.61 to 0.90. Predictions had moderate to high precision (r² > 0.59 and ≤ 0.92). All equations had high accuracy (> 0.96), moderate to high reproducibility index and concordance (CCC > 0.74 and ≤ 0.96) and moderate to high efficiency of prediction (from 0.58 to 0.91). Overall, results showed that the 9th–11th rib section could accurately be used as an option for predicting carcase tissue composition in Blackbelly sheep.

Introduction
Total physical separation (by dissection) of carcases into meat fat and bone is the most accurate method for determining carcase tissue composition and this knowledge contributes with valuable information for ensuring agribusiness profitability (Barba et al. 2018; Bautista-Díaz et al. 2020; Gomes et al. 2021). Total carcase dissection is not practical because it is time-consuming, produces carcase losses and requires specialised staff (Prados et al. 2016; Morales-Martínez et al. 2020; Bautista-Díaz et al. 2020). For that, developing accurate models for predicting the amount of bone, muscle, and fat in sheep could contribute to improve meat production (Morais et al. 2016). These models provide data that could allow farmers to select...
animals with maximum growth potentials, feed efficiency, body weight gains, and improved production of high-quality carcases (Morais et al. 2016).

In hair sheep breeds, dissection of some carcase cuts could be used as predictors of overall carcase tissue composition (Bautista-Díaz et al. 2020). However, these type of studies are scarce. In this context, in cattle, Hankins and Howe (1946) used equations to estimate carcase composition based on composition of the 9th–11th rib section. This technique is widely used due to its low cost and have been evaluated in Bos indicus cattle and their crosses as a tool to estimate carcase traits (Prados et al. 2016; Silva et al. 2016). In fact, recently, this technique has been used to determine body chemical composition in hair sheep (Sousa et al. 2020).

Until now, some studies have indicated that carcase tissue composition (contents of fat, muscle, and bone) differs depending on age, genetics, production system, diet, and growth stage (Sousa et al. 2019; Sousa et al. 2020). Hair sheep breeds are normally used in sheep production systems in the tropics. Among these breeds, Pelibuey and Blackbelly are used as maternal breeds but little is known about their carcase characteristics (Almeida 2017; Chay-Canul et al. 2019; Bautista-Díaz et al. 2020). In the specific case of Blackbelly sheep, scarce research have been performed to determine carcase characteristics. The hypothesis of this study was that the 9th–11th rib section tissue composition obtained by dissection could be used to predict carcase tissue composition from Blackbelly sheep. No equations have been reported on that use the 9th–11th rib section for predicting carcase traits in Blackbelly sheep, consequently, the rationale of present study was to develop predictive equations for carcase tissue composition in Blackbelly sheep using the 9th–11th rib section and evaluate its accuracy and precision.

Materials and methods

Animals were handled in compliance with the guidelines and regulations for ethical animal experimentation of the División Académica de Ciencias Agropecuarias of the Universidad Juárez Autónoma de Tabasco (ID project PFI: UJAT-DACA-2015-IA-02).

The experiment was carried out at the Southeastern Centre for Ovine Integration (Centro de Integración Ovina del Sureste [CIOS]; 17° 78’ N, 92° 96’ W; 10 masl). Twenty male growing Blackbelly lambs with six months of age with a mean body weight (BW) of 29.07 ± 2.88 kg (± SD) were used in the experiment. Lambs were placed in raised-slatted floor cages with a feeding group system. The experimental diet was a total mixed ration (80:20 concentrate to forage ratio) comprising ground maize, soybean meal, star grass hay, vitamins and minerals premix and had a crude protein (CP) level of 15% DM (AFRC 1993).

Animals were fasted for 24 h and the shrunk BW (SBW) was recorded before slaughtering. Animals were slaughtered according to the Mexican Official Standard NOM-033-SAG/ZOO-2014. Data recorded at slaughtering included carcase and non-carcase components. After chilling at 4°C for 24 hours, carcases were carefully split longitudinally with a band saw to obtain left and right halves and then these were weighed. The 9th–11th rib section was removed from the left side of the carcase as described by Sousa et al. (2020). Thereafter, the remaining left half carcase was weighed and manually deboned to obtain weights for fat (CF), muscle (CM), and bone (CB). Same procedure was applied when 9th–11th rib section weighed and then dissected. Carcases sectioning and deboning was performed by the same specialised technicians. Dissected tissues of the left half carcase plus the obtained in 9th–11th rib section, were adjusted as whole carcases (Bautista-Díaz et al. 2020).

Data analyses

Data were processed and analysed using the PROC MEANS procedure from SAS (SAS Inst. Inc., Cary, NC, 2010). Pearson correlation analysis was conducted using the SAS PROC CORR. Regressions among variables were calculated using the SAS PROC REG. To predict the carcase tissue composition, entire carcase tissue weights as dependent variable were used. The predictors (i.e. independent variables) were the weight of the 9th–11th rib section (WRib, kg), muscle in the 9th–11th rib section (MRib, kg), fat in the 9th–11th rib section (FRib, kg), bone in the 9th–11th rib section (BRib, kg) and left half-carcases weight (LHCW, kg). The stepwise procedure was used to select the variables for predictive equations, only variables that were significant at p < .05 were selected for the development of the predictive equations. Also the residual plots were used to identify possible outliers.

After developing the models, their performance and adequacy were tested using the following criteria: determination coefficient (r2); F test, parameters identity (β0 = 0 and β1 = 1) of predicted regressions from the observed data; concordance correlation coefficient (CCC); root mean square error of prediction (RMSEP); and decomposition of the mean square error of
prediction (MSEP) into mean error, systematic bias, and random error according to Tedeschi (2006) and Morales-Martínez et al. (2020). The analyses were performed using the Model Evaluation System software version 3.2.2 (Tedeschi 2006).

Results

Descriptive statistics of data measured in Blackbelly sheep is shown in Table 1. Body weight ranged from 23.5 to 32.9 kg. Carcase muscle weight ranged from 6.79 to 10.9 kg and CF varied from 0.77 to 2.08 kg. With regard to the 9th–11th rib section, WRib ranged from 0.12 to 0.27 kg.

The MRib and FRib were correlated with CM and the r values ranged from 0.47 to 0.82. While FRib positively correlated (p < 0.001) with CF (r² = 0.68; p < 0.001). However, BRib with CM and CF showed non-significant correlations (Table 2). Finally, LHCW was positively correlated (p < 0.001) with carcase tissues and the r values ranged from 0.57 for CF to 0.93 CM. The equations for predicting CM, CF and CB in Blackbelly sheep using the 9th–11th rib section, had a r² ranging from 0.61 to 0.90 and included LHCW, Frrib and BRib (Table 3). Finally, LHCW accounted for 15% to 86% of the variation in CF and CM, respectively (Table 3).

Predictions of carcase tissue composition (Table 4) had a precision of r² > 0.59 ≤ and ≤ 0.92 (Table 4). All equations presented high accuracy (bias correction factor > 0.96; Table 4), moderate to good reproducibility index and concordance with the observed data (CCC > 0.74 and ≤ 0.96). With regard to MEF, equations show low to moderate values (0.58–0.91). The CD fluctuated from 1.08 to 1.68, indicating a great variability in the predicted values (Table 4). In all equations, the highest component of MSEP (> 84%) was associated with the random error and the null hypothesis (intercept = 0 and slope = 1) was accepted.

Diagnostic plots for the regression equations revealed that values of residual were low, uniformly and randomly distributed (Figure 1). The symmetric distribution of residuals around zero in all constructed equations confirmed that constructed models did not underestimated nor overestimated predictions of carcase tissue composition in fattening Blackbelly sheep using the 9th–11th rib section.

Discussion

Until now, this is the first study reporting the use of the 9th–11th rib section to predict carcase tissue composition of Blackbelly sheep. The Blackbelly sheep is a genetic resource that is well-adapted to the environmental conditions from the humid tropics of Mexico and could be considered an important alternative to increase sheep production in humid tropical regions around the world (Almeida 2017). Hair sheep breeds are important for meat production in tropical regions and characterising carcase tissue composition is vital to promote economic efficiency in these production systems. Moreover, in these regions, native breeds, have an important genetic and cultural value, and are a source of income, employment, and food security for low-income farmers (Almeida 2017, Yildirim et al. 2014; Gomes et al. 2021). In this regard, Sabbioni et al. (2018) mentioned that the conservation of biodiversity has become an important topic in animal husbandry,

Table 2. Correlations coefficients from the 9th–11th rib section and carcase tissue composition in fattening Blackbelly sheep.

| Variable | Description | Mean ± SD | Minimum | Maximum |
|----------|-------------|-----------|---------|---------|
| BW       | Body weight (kg) | 29.1 ± 2.88 | 23.5 | 32.9 |
| LHCW     | Left half-carcases weight (kg) | 6.47 ± 0.78 | 4.80 | 8.20 |
| CM       | Carcase muscle (kg) | 8.74 ± 1.21 | 6.79 | 10.92 |
| CF       | Carcase fat (kg) | 1.29 ± 0.38 | 0.77 | 2.08 |
| CB       | Carcase bone (kg) | 2.91 ± 0.39 | 2.19 | 3.98 |
| WRib     | Weight of 9th–11th rib section (kg) | 0.18 ± 0.04 | 0.12 | 0.27 |
| MRib     | Muscle in 9th–11th rib section (kg) | 0.11 ± 0.02 | 0.07 | 0.16 |
| FRib     | Fat in 9th–11th rib section (kg) | 0.01 ± 0.01 | 0.004 | 0.03 |
| BRib     | Bone in 9th–11th rib section (kg) | 0.05 ± 0.01 | 0.03 | 0.09 |

SD = Standard deviation

Table 1. Descriptive analyses of the data measured in live animals (n = 20) fattening Blackbelly sheep.

| Variable | Description | Mean ± SD | Minimum | Maximum |
|----------|-------------|-----------|---------|---------|
| BW       | Body weight (kg) | 29.1 ± 2.88 | 23.5 | 32.9 |
| LHCW     | Left half-carcases weight (kg) | 6.47 ± 0.78 | 4.80 | 8.20 |
| CM       | Carcase muscle (kg) | 8.74 ± 1.21 | 6.79 | 10.92 |
| CF       | Carcase fat (kg) | 1.29 ± 0.38 | 0.77 | 2.08 |
| CB       | Carcase bone (kg) | 2.91 ± 0.39 | 2.19 | 3.98 |
| WRib     | Weight of 9th–11th rib section (kg) | 0.18 ± 0.04 | 0.12 | 0.27 |
| MRib     | Muscle in 9th–11th rib section (kg) | 0.11 ± 0.02 | 0.07 | 0.16 |
| FRib     | Fat in 9th–11th rib section (kg) | 0.01 ± 0.01 | 0.004 | 0.03 |
| BRib     | Bone in 9th–11th rib section (kg) | 0.05 ± 0.01 | 0.03 | 0.09 |

SD = Standard deviation
for that the first step to determine the potential use of local breeds for production is to explore their relevant productive traits.

Sheep’s body composition is an important aspect when defining nutritional requirements (Costa et al. 2013) and contents of water, protein, fat and minerals are influenced by factors such as genotype, age, gender, growth rate, and nutrition (Bautista-Díaz et al. 2017; Morales-Martínez et al. 2020). The use of indirect methods to predict carcass components offers the option to increase quantitative determinants for carcass composition (Barba et al. 2018; Bautista-Díaz et al. 2020; Gomes et al. 2021). It helps follow animal’s growth and development for meat production as well as allowing efficient herd management (Barba et al. 2018; Gomes et al. 2021).

The use Hankins and Howe (1946) method, where the 9th–11th rib section is used to predict carcass tissue composition, is a non-destructive method and presents high values of correlation between contents of body protein, fat and ash (0.83, 0.91 and 0.53, respectively) and the composition of the empty body (Menezes et al. 2015). In this regard, Menezes et al. (2015) found a positive relationship between percentages of tissues in the carcass (muscle, fat and bone) with the tissues dissected from the 9th–11th rib section of Texel ewe lambs, similarly to what was observed in the present study.

### Table 3. Regression equations to predict carcass tissue composition in Blackbelly sheep using the 9th–11th rib section.

| No. | Equation | $r^2$ | MSE | RMSE | p-Value |
|-----|----------|-------|-----|------|---------|
| 1   | $CM (kg) = 0.89 \pm (0.66^*) + 1.11 \times LHCPW + 24.49 \times FRib$ | 0.90 | 0.12 | 0.34 | <.0001 |
| 2   | $CF (kg) = -0.19 \pm (0.41^*) + 0.16 \times LHCPW + 20.57 \times FRib$ | 0.61 | 0.05 | 0.22 | .0007 |
| 3   | $CB = 0.58 \pm (0.54^*) + 0.28 \times LHCPW + 9.32 \times BRib$ | 0.80 | 0.02 | 0.14 | <.0001 |

CM: Carcase muscle (kg); CF: Carcase fat (kg); CB: Carcase bone (kg); MRib: Muscle in the 9th–11th rib section (kg); FRib: Fat in 9–11 rib section (kg); BRib: Bone in the 9th–11th rib section (kg); LHCPW: left half-carcases weight (kg); MSE: mean square error; RMSE: root mean square error.

Values within parentheses are the SE of the parameter estimates.

### Table 4. Mean and descriptive statistics of the accuracy and precision of the equations for predicting carcass tissue composition in Blackbelly sheep using the 9th–11th rib section.

| Variable | Eq. 1 | Eq. 2 | Eq. 3 |
|----------|-------|-------|-------|
| Mean     | 8.52  | 1.21  | 2.88  |
| SD       | 1.02  | 0.25  | 0.30  |
| $r^2$    | 0.92  | 0.59  | 0.79  |
| CCC      | 0.96  | 0.74  | 0.86  |
| Cb       | 0.99  | 0.96  | 0.96  |
| MEF      | 0.91  | 0.58  | 0.76  |
| CD       | 1.08  | 1.68  | 1.30  |

Regression analysis

| Intercept ($b_0$) | Estimate | SE | p-value ($b_0 = 0$) |
|-------------------|----------|---|---------------------|
| Eq. 1              | 0.004    | 0.01 | 0.07 |
| Eq. 2              | 0.64     | 0.25 | 0.36 |
| Eq. 3              | 0.99     | 0.96 | 0.85 |

| Slope ($b_1$)     | Estimate | SE | p-value ($b_1 = 1$) |
|-------------------|----------|---|---------------------|
| Eq. 1              | 0.99     | 0.99 | 1.08 |
| Eq. 2              | 0.07     | 0.20 | 0.12 |
| Eq. 3              | 0.99     | 0.98 | 0.71 |

MSEP source, % MSEP

| Mean bias | 0.00     | 0.17 | 15.24 |
| Systematic bias | 0.00 | 0.000 | 0.69 |
| Random error | 99.99 | 99.82 | 84.06 |
| Root MSEP | 0.29 | 0.20 | 0.16 |

% of the mean | 3.47 | 16.70 | 5.88 |

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.
Quantifying animal growth processes involves changes in the animal’s body composition because of the differential growth of body parts. Within each body tissue, development may be early, moderate, or late depending on its location, which causes changes in body composition as animal grows up (Owens et al. 1993; Sousa et al. 2019). In lambs, increases in body weight lead to changes in body composition resulting in a reduction in protein and increases in body fat deposition (Barcelos et al. 2020). According to Almeida (2017), Blackbelly sheep is a slow-growing breed, and these animals do not reach ideal weights until 2 years of age, having weights of around 41–60 kg in males. In the present study, animals were young and lightweight, their BW hardly represented 55% of their breed’s mature body weight, and together with growth stage, and these factors probably affected carcass tissue composition. In this regard, Carvalho et al. (2016) reported that an increase in BW can determine alterations in the carcass characteristics and traits of commercial interest such as the muscle/bone and muscle/fat ratios, with the former being increased along with slaughter weight. Also, Carvalho et al. (2016) reported that the proportion of muscle decreased in the rib, whereas in other cuts it remained constant when the BW at slaughter increased in Texel lambs.

With regard to the use of the 9th–11th rib section for body composition prediction, Sousa et al. (2020) showed that the 9th–11th rib section allowed accurate predictions of water, ether extract and energy contents in carcasses of Brazilian Somali lambs. In addition, ether extract content of the 9th–11th rib section was the variable that better described variation of carcass ether extract in hair sheep breeds (Sousa et al. 2020). Sousa et al. (2020) concluded that breed and sex affected deposition of chemical components in carcasses and empty bodies from hair sheep. In this sense, the lack of body protein stabilisation affects the prediction of crude protein contents in carcasses and empty bodies in growing hair sheep (Souza et al. 2013). The equations obtained for predicting carcass tissue composition in growing Blackbelly sheep, had moderate precision \((r^2 > 0.59 \leq \text{and} \leq 0.96)\), high accuracy \((>0.96)\), and moderate to high reproducibility \((0.58–0.91)\) showed low to moderate concordance between observed values. Based on that, the obtained models were able to predict carcass tissue composition in growing Blackbelly sheep with moderate to high precision and high accuracy and reproducibility.

The use of the 9th–11th rib section for predicting physical and chemical carcass composition in beef cattle have been widely used around the world due to practical reasons (Silva et al. 2016). In Mexico, studies on the use of the 9th–11th rib section to predict carcass tissue composition are scarce. The present study opens the possibility to continue elucidating the relationship between the 9th–11th rib section and carcass tissue composition in hair sheep breeds and their crosses in tropical regions. Therefore, future studies using the 9th–11th rib section, should include different breeds, body weights, and different physiological or growth stages to determine accuracy prediction of carcass tissue. It is important to highlight that this study had a small sample size. Also, future studies should include other hair sheep breeds with different sex, different physiological states and different production managements.

Conclusion

The 9th–11th rib section can be used as an alternative trait to predict carcass tissue composition in Blackbelly sheep as they can provide moderate \((r^2 > 0.59 \leq \text{and} \leq 0.92)\) and high accuracy \((\text{bias correction factor} >0.96)\) predictions. The dissection of the 9th–11th rib section is a semi-invasive technique that allows to identify carcass traits in different ruminant’s species. Results from the present study are specific to a hair sheep breed and predictive equations may not be extrapolated to other breeds, but this builds a starting point for studying other sheep breeds from tropical production systems.

Compliance with ethical standards

Animals were handled in compliance with the guidelines and regulations for ethical animal experimentation of the División Académica de Ciencias Agropecuarias of the Universidad Juárez Autónoma de Tabasco (ID project PFI: UJAT-DACA-2015-IA-02).

Statement of animal rights

All applicable international, national and/or institutional guidelines for the care and use of animals were followed.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by SEC, SVJ, DNAA, TAAA, and AJCHC. DNAA, TAAA, ALMB and SKLP contributed new reagents or analytical tools. ATPV, EVBP and AJCHC writing and editing the draft. The
first draft of the manuscript was written by SEC and AJCHC and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Disclosure statement
No potential conflict of interest was reported by the author(s).

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

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