Prediction of carcase characteristics using neck traits from hair-sheep ewes

Flor de María Rivera-Alegria, Francisco G. Ríos-Rincón, Ulises Macías-Cruz, Ricardo A. García-Herrera, José Herrera-Camacho, Mohammed Benaouda, Juan C. Angeles-Hernández, Alfonso L. Muñoz-Benítez, Einar Vargas-Bello-Pérez and Alfonso J. Chay-Canula

ABSTRACT

The objective of this study was to develop predictive equations for carcase composition using neck tissue composition as predictors in multiparous Pelibuey ewes (n=50, body weight = 39 ± 7 kg and body condition score = 2.56 ± 0.98 points) were used to develop predictive equations for carcase tissue composition and weight from neck composition traits applying multiple linear regression. The accuracy of the model was evaluated considering the values of determination coefficient (r²) and root mean square error (RMSE). Carcase and neck traits showed a positive relationship (p < .01) and the correlation coefficient (r) ranged from 0.44 to 0.78, being stronger for hot (HCW) and cold (CCW) carcase weights with neck traits. Except for neck bone weight, all neck traits resulted to be suitable predictor variables for carcass muscle and fat. The relationship between carcase composition and neck tissue from Pelibuey ewes (n=50, body weight = 39 ± 7 kg and body condition score = 2.56 ± 0.98 points) were used to develop predictive equations for carcase muscle (MW) and fat (FW) weight as r² values ranged from 0.63 to 0.74. In the equation for carcase bone weight, only neck muscle weight was a predictor. However, r² value was low (r² = 0.29; p < .0001). Overall, results suggest that carcase and neck traits showed a positive relationship. The weight of the neck and its content of muscle and fat could be used to predict the composition of the carcase tissue in non-pregnant and non-lactating multiparous Pelibuey ewes.

HIGHLIGHTS

- The relationship between carcass composition and neck tissue from Pelibuey ewes was evaluated.
- Except for neck bone weight, all neck traits resulted to be suitable predictor variables for carcass muscle and fat.
- The neck traits can be used to predict carcass tissue composition in multiparous Pelibuey ewes.

Introduction

Knowledge on carcase tissue composition contributes with valuable information for ensuring economic viability and sustainability of agribusinesses as well as optimising production system decisions and profitability increases (Gomes et al. 2021). Several studies have established that the total physical separation (by dissection) of the carcasses into meat, fat and bone is the most accurate method to estimate carcase tissue composition (Argüello et al. 2001; Santos et al. 2017). However, this technique is not practical because it is time consuming, produces carcase losses and requires specialised staff (Morales-Martínez et al. 2020). Dissection is an invasive, expensive, and labour-intensive method, which makes it impracticable at most research institutions (Chay-Canul et al. 2019a). Thus, indirect methods are preferred over direct methods as they are easier and cheaper to implement without losses in carcase commercial value and suitable to be performed by producers, slaughterhouses, and
researcher (Santos et al. 2017; Alfonso et al. 2019; Morales-Martínez et al. 2020). Therefore, there is a need for methods that can be used to determine carcase composition without a full carcase dissection.

In small ruminants, dissection of some carcase cuts could be used as predictors of overall carcase tissue composition (Santos et al. 2017; Barcelos et al. 2021). For example, in goats, carcase composition was predicted from the tissue composition of primal cuts (Argüello et al. 2001). Santos et al. (2017) found that tissue compositions of rib and shoulder are suitable indicators for fat, bone and meat contents in sheep and goat carcases, while the tissue compositions of shank and neck showed low relationship. However, some authors (Kempster et al. 1986) reported in lambs that predictions of carcase, muscle, and fat are highly accurate when estimated using neck traits. It should be noted that the neck represents an easy cut to obtain and dissect, which has little commercial value (Ruiz-Ramos et al. 2016). Therefore, the hypothesis of this study was that neck tissue composition obtained by dissection could be used to predict the carcase tissue composition in Pelibuey ewes. The objective of this study was to develop predictive equations for carcase composition using neck tissue composition from Pelibuey ewes.

Materials and methods

Experimental site and animals

Animals included in the present study were managed in compliance with the ethical guidelines and regulations for animal experimentation of the División Académica de Ciencias Agropecuarias of the Universidad Juárez Autónoma de Tabasco (Approval code: UJAT-DACA-2015-IA-02). Animals were raised at the Sheep Integration Centre of the Southeastern (Centro de Integración Ovina del Sureste; 17° 78” N, 92° 96” W; 10 masl), located at Villahermosa-Teapa road, Mexico.

Ewes were kept in confinement, within group pens with roofed building and concrete flooring. The feeding consisted of mixed diet including: 66% grass hay, 19% cracked corn, 11% soybean meal, 3% cane molasses and 1% minerals expressed as dry matter basis. The chemical composition was 82.50% dry matter, 9.3% crude protein, 1.20% ether extract, 53.10% neutral detergent fibre, 31.10% acid detergent fibre expressed as dry matter basis, and 12 MJ of metabolisable energy/kg DM (AFRC 1993; Chay-Canul et al. 2019a, 2019b).

Slaughtering of animals

Data of carcase traits from 50 non-pregnant and non-lactating multiparous Pelibuey ewes with an age of 2–3 years, average body weight (BW) of 38.64 ± 6.80 kg and body condition score (BCS) of 2.56 ± 0.98 points from a 5-point scale (Russel et al. 1969), were used. Before slaughtering, both individual BW and BCS of ewes were recorded after a 24-h fasting period. Slaughtering was humanely performed by disgorge-ment following the Mexican Official Norms NOM-08-ZOO, NOM-09-ZOO, and NOM-033-SAG/ZOO established for slaughtering meat-producing animals. Lamb bodies were bled, skinned and eviscerated to allow hot carcase weight, and then these carcases were stored at 1 °C for 24 h to record cold carcase weight and dissection them. Cold carcase was split at the dor-sal midline and the left half was weighed and dis-sected to record weights of fat (CFW), muscle (CMW), and bone (CBW). The same procedure was applied when neck was weighed and then dissected (weights of neck fat [NFW], muscle [NMW] and bone [NBW]). Dissected tissues of the left carcase were adjusted as whole carcase (Ruiz-Ramos et al. 2016). Note that a highly experienced group of persons carried out the dissection process manually with a knife in the same day.

Statistical analysis

The final database included dependent variables (i.e. CMW, CFW, and CBW) and four independent variables or predictors (i.e. overall neck weigh and its tissue components [NMW, NFW, and NBW]). All statistical analyses were performed with the R Software version 3.3.1 (R Core Team 2018).

Initially, variables were subjected to a descriptive analysis using the describe function of PSYCH package (Revelle 2020). Then, an exploratory analysis was car-ried out to assess the relationships among dependent and independent variables applying a pairwise Pearson’s correlation analysis with the CORR function. To facilitate the interpretation of correlation results, they were displayed in a correlogram plot using the CORRPLOT package (Taiyun and Viliam 2017).

Regression models were fitted using the lm func-tion. Linear and quadratic relationships were tested. However, because the quadratic term was not signifi-cant (p < .05) and only the r^2 did not improve considerably (2% approximately), we used the linear trend. Forward and backward stepwise procedures for multiple regression analysis were used to select the best models. The stepwise process added and pruned explanatory
variables in models to reach a balance between model simplicity (parsimony) and predictive performance. The fit goodness of the models was determined using Akaiké Information Criterion (AIC) and Bayesian Information Criterion (BIC), adjusted determination coefficient ($r^2_{adj}$) and root mean square error (RMSE). Models with the lowest AIC and BIC, RMSE and highest $r^2_{adj}$ were defined as the best models. Additionally, in order to improve the accuracy of estimations of each model derived from the stepwise process, a multicollinearity test was performed. The multicollinearity in multiple regressions models was explored using the Variance Inflation Factor (VIF). The VIF measures the correlation and strength of correlation between the predictor variables in a regression model; hence, as the VIF increases, the degree of dependence between predictors becomes stronger. A model was not selected when the VIF value in their predictors was higher than 5. In addition, graphical multicollinearity was explored by plotting the uncertainty (CI = 95%) of the coefficient estimates to each model in order to identify significant models ($p < .05$) with larger standard error estimates. Calculation of VIF and plots was carried out using the ‘JTOOLS’ package (Long 2020).

Model validation

The predictive ability of models selected was evaluated using $k$-fold validation methods, with $k = 10$ ($k = 10$). The $k$ groups were randomly made and this was repeated three times. This approach involves randomly dividing the set of observation into $k$ non-overlapping folds of approximately equal size. Each fold is treated as a validation set, and the model was fitted on the remaining $k – 1$ fold (training data). The performance of the fitted model in predicting out the actual observations was evaluated using the RMSE, $r^2$ and mean absolute error (MAE). The lowest values of RMSPE and MAE indicated the best predictions. For validation, RMSPE and MAE were the average of cross-validation. The $k$-folds validation was implemented in the ‘Classification and Regression Training’ package (Kuhn 2019). This package allows comparing numerous multivariate calibration models under a unified framework.

Results and discussion

In tropical regions of Mexico, Pelibuey sheep are the most important maternal breeds for lambs production and thus, they play an important role in meat production (Chay-Canul et al. 2019a). Nutritional requirements for this sheep breed have not been completely defined as in wool breeds; this is partially explained by the lack of information regarding dietary energy and protein retention in carcases (Rodríguez-Valenzuela et al. 2017; Chay-Canul et al. 2019a, 2019b). Determination of carcase tissue composition in adult ewes is very important to define nutritional requirements with accuracy; however, entire carcase dissection is an impractical, time-consuming, and costly method (Barcelos et al. 2021; Gomes et al. 2021). In this regard, results of the current study seem to be the first evidences on the possibility of predicting carcase tissue composition in adult Pelibuey ewes from neck tissue composition.

Descriptive analysis results are shown in Table 1. Slaughter BW was 38.6 ± 7.6 kg, while HCW and CCW were 17.58 ± 4.75 kg and 16.95 ± 4.59 kg, respectively. The average neck weight was 0.57 ± 0.17 kg and its NMW was a little less than twice (0.31 versus 0.18 kg) the NBW and four times higher than the NFW (0.08 versus 0.31 kg). Both CFW and NFW showed a greater variation (CV > 79%) among animals. Other studies in Pelibuey ewes report a slightly heavier hot and cold carcase, which is due to a higher slaughter weight (41–42 kg); however, their carcases continue to show a higher proportion of muscle than fat and bone (Bautista-Díaz et al. 2017; Chay-Canul et al. 2019a). It is

| Table 1. Descriptive analysis of the data on carcase composition (kg), neck traits in Pelibuey ewes (n = 50). |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Abbreviation | Definition | Mean ± SD | CV % | Median | Skew | Kurtosis |
|---------------|-----------|-----------|------|--------|------|---------|
| BW | Body weight (kg) | 38.64 ± 7.56 | 19.59 | 37.51 | 0.99 | 0.36 |
| HCW | Hot carcase weight (kg) | 17.58 ± 4.75 | 27.01 | 16.4 | 1.16 | 0.68 |
| CCW | Cold carcase weight (kg) | 16.95 ± 4.59 | 27.11 | 15.82 | 1.13 | 0.72 |
| CMW | Carcase muscle (kg) | 9.98 ± 2.08 | 20.87 | 9.70 | 0.03 | 0.03 |
| CFW | Carcase fat (kg) | 3.13 ± 2.49 | 79.50 | 2.23 | 1.20 | 0.49 |
| CBW | Carcase bone (kg) | 3.86 ± 0.42 | 11.09 | 3.79 | 0.72 | 0.70 |
| NW | Neck weight (kg) | 0.57 ± 0.17 | 27.93 | 0.54 | 0.79 | 0.11 |
| NMW | Neck muscle (kg) | 0.31 ± 0.09 | 30.00 | 0.30 | 0.89 | 0.82 |
| NFW | Neck fat (kg) | 0.08 ± 0.07 | 93.44 | 0.06 | 2.16 | 5.86 |
| NBW | Neck bone (kg) | 0.178 ± 0.05 | 29.55 | 0.17 | 0.65 | 1.83 |
| SD: standard deviation; CV: coefficient of variation. | | | | | | |
widely known that, in adult sheep, the growth of bones slows or stops while the intake of dietary nutrients is used to deposit muscle mass and to a lesser degree fat (Barcelos et al. 2021). The amount of fat deposited in the body of the sheep depends largely on the physiological state, environment and excess dietary energy consumed (Ruiz-Ramos et al. 2016; Chay-Canul et al. 2019b). Therefore, the muscle was expected to be the predominant tissue in carcasses and necks, as well as the highest variation in amount of fat.

Pearson's correlation coefficients ($r$) results are shown in Figure 1. All carcase traits were positively correlated ($p < .01$; $0.44 < r < 0.78$) with NW, NMW and NFW, while NBW positively correlated ($p > .05$) only with the CBW. Most of these correlations were classified from moderate to high. These good relationships among carcase and neck tissue traits suggest that neck tissue traits could be used as predictor variables of the carcase tissue composition. Until now, there is no antecedent of the relationship between neck and carcase tissue composition in multiparous hair breed ewes, but Martínez-Avalos et al. (1987) reported, in discard Pelibuey ewes, a moderate correlation of neck weight with CMW and CBW. In goat kids, Santos et al. (2017) also observed high positive correlation ($r = \geq 0.76 \leq 0.94$) of neck weight with CMW, CBW and intermuscular fat weight.

The predictive equations developed and their respective cross-validation tests are shown in Tables 2 and 3. For CMW, two models explained ($p < .01$) between 63 (Equation (2)) and 64% (Equation (3)) of the observed variation compared to another model that explained only 56% (Equation (1)). Equation (2), which includes neck weight and NFW as predictors, was the best model to predict CMW because it had lower values of RMSE (1.22 versus $\geq 1.39$) and MAE (1.00 versus $\geq 1.10$) than the other equations, based on cross-validation test. Although Equation (3) had a slightly higher $r^2_{adj}$ than Equation (2), this was not selected because it is less practical (include three predictor variables), and its prediction errors were the highest (RMSPE = 2.32 and MAE = 1.91). For CFW, from the three selected models (Equations (4–6)), two of
them explained \( p < .01 \) a greater variation \( (r^2_{adj} = 0.71 \) [Equation (5)] to 0.73 [Equation (6)] \) of the depend variable with similar AIC and BIC values. However, compared to Equation (6), the equation (5) had the best goodness of fit due to its lower RMSE value (1.90 versus 2.86), as well as prediction capacity as the cross-validation test evidenced lower RMSPE (1.32 versus 2.33) and MAE (1.09 versus 1.90). Therefore, Equation (5) was selected as the best model to predict CFW, and this included to neck weight and NBW as predictors. Finally, models developed for CBW (Equations (7–9)) explained little \( p < .01 \) of its variation \( (r^2_{adj} = 0.27–0.29) \), being the model of Equation (7) who had a slightly better goodness of fit (similar RMSE but lower AIC and BIC). Despite this, the cross-validation test showed that Equation (9) explained 42% of the variation observed for CBW with similar values for RMSPE and MAE than in Equations (7,8). In consequence, Equation (9) can better predict the CBW than the others. The predictor variables of Equation (9) were neck weight, NFW and NBW. The VIF estimated in the three models selected to predict CMW, CFW, and CBW were within the normal range (<10; Feng-Jenq, 2008), so there were no collinearity problems between predictor variables within each model.

In brief, neck weight and tissue composition are effective predictor variables for constructing prediction models associated with carcass tissue composition of adult Pelibuey ewes, particularly amount of muscle and fat mass. The best equations developed according to each component were: CMW = 0.92 + 14.07 NMW + 7.52 NFW \( (r^2 = 0.63; \) Equation (2)), CFW = −1.30 + 14.57 neck weight − 22.32 NBW \( (r^2 = 0.67; \) Equation (5)), and CBW = 3.02 + 3.25 NW − 0.71 neck weight + 1.37 NBW \( (r^2 = 0.42; \) Equation (9)). The CMW prediction is associated to the neck soft tissue weight, while CFW and CBW to neck bone and soft tissue weight as both dependent variables included total neck weight. Overall, the neck tissue composition predicts with good precision and accuracy the amount of soft tissue in adult Pelibuey ewe carcasses, but not the amount of bone. As the neck cut is of low economic value and weight in relation to the entire carcass, the prediction of carcass muscle and fat mass from neck tissue composition results a suitable and innovative indirect method. It is noteworthy mentioning that it might be easier to have a clearer idea of energy and protein retention levels in Pelibuey ewe carcasses using these prediction models than using the traditional method.

It was noteworthy that, unlike the other models (i.e. CMW and CFW), the equations developed to predict carcass bone mass had low \( r^2 \) values, which was expected since correlation analysis evidenced no relationship between NBW and most of the carcass tissue components. In addition, CBW was the dependent variable with the lowest CV (11.1%), supporting the fact that our Pelibuey ewes have reached the development of their bone structure. Slight variations in CBW are associated to changes in bone mineral concentrations (Barcelos et al. 2021). However, in well-fed ewes,
these changes can be marginal and mainly attributed to physiological status (Chay-Canul et al. 2019b). Therefore, neck tissue composition could not accurately predict CBW due to the low variability presenting bone mass in adult animals.

Remarkably, there are already some multiple regression equations developed to predict carcass tissue composition from biometric measurements in adult Pelibuey sheep, and they have better precision and accuracy than those obtained in this study (Bautista-Díaz et al. 2017). In Bautista-Díaz et al. (2017) study, the equations for CMW, CFW and CBW reached $r^2$ values of 77, 93 and 67%, respectively, versus 63, 67 and 42%, respectively, observed in our study. Others equations developed from fat thickness ultrasound measurements (3rd to 4th and 12th to 13th vertebra) have also showed to predict with high and moderate efficiency to CFW ($r^2 = 0.91$) and CMW ($r^2 = 0.57$) for discard Pelibuey ewes (Chay-Canul et al. 2019a). Similarly, Alfonso et al. (2019) reported the development of a prediction equation for CFW in dairy Churra da Terra Quente ewes using three ultrasound measurements combined with BW as predictors. Although this equation showed excellent accuracy (RPD= 3.8) and $r^2 = 0.94$, its use is not practical due to the number of predictor variables. Based on the above results, both precision and accuracy of our equations could be improved if, in addition to the traits of neck tissue composition, other predictor variables are included, such as zoometric measurements that are easy to measure in the field.

Conclusions
The carcass and neck traits showed a positive relationship, being stronger for the hot and cold carcass weights with the neck traits, which turned out to be adequate predictor variables for the carcass muscle weight and fat. In this sense, the weight of the neck and its content of muscle and fat could be used to predict the composition of the carcass tissue in non-pregnant and non-lactating multiparous Pelibuey ewes. Future research should consider the predictions of these two components of carcass tissue in animals with different physiological states and under different farm management conditions.

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Disclosure statement
The authors declare that they have no conflicts of interest.

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

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ORCID
Ricardo A. García-Herrera [http://orcid.org/0000-0003-2456-4727]
José Herrera-Camacho [http://orcid.org/0000-0002-0207-3313]
Einar Vargas-Bello-Pérez [http://orcid.org/0000-0001-7105-5752]
Alfonso J. Chay-Canul [http://orcid.org/0000-0003-4412-4972]

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

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