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# Indirect methods for predicting the body composition of sheep of different sex classes

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**ABSTRACT.** The aim was to evaluate the correlation and develop regression equations for the body composition of sheep of different sex classes, obtained by the comparative slaughter method, using the composition of the neck region and loin eye area (LEA). Forty-five sheep of three sex classes (15 intact males, 15 castrated males and 15 females) received three feeding levels (*ad libitum* or restrictions of 70 or 80% of *ad libitum* intake). Animals were distributed in a 3×3 factorial arrangement, with 5 repetitions. The LEA showed: positive correlation with empty body weight, fasting body weight, meat, protein, ether extract and water ($p < 0.01$), for all sex classes; with bones for intact males and females ($p < 0.01$); with ash content for intact males and a moderate correlation for castrated males ($p < 0.01$). The neck was correlated with empty body weight, fasting body weight, meat, protein, ether extract, water and energy in all sex classes ($p < 0.01$); and moderate correlation with bone ($r=0.58$) and ash ($r=0.67$) for intact males. Intact males showed higher $R^2$ values in their prediction equations in relation to the other sex classes.

**Keywords:** chemical composition; loin eye area; neck. prediction equations.

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## Introduction

Raising native sheep is one of the main economic activities of the rural population in the Brazilian semiarid region. However, studies related to nutritional requirements of these animals are still limited. In this sense, nutritional studies on sheep native to the Brazilian semiarid region are essential and relevant (Costa et al., 2018). The National Research Council (NRC, 2007) is commonly used to formulate diets and evaluate feeding programs in a variety of conditions. However, nutritional requirements are based on data from wool sheep, under non-tropical temperature and climate conditions (Barcelos et al., 2020). Thus, scholars who carry out their research in the Brazilian semiarid region raise the hypothesis that nutritional requirements of non-descript breed sheep, native to the semiarid region, may be different from requirements established by international systems of nutritional requirements for small ruminants. Some studies were conducted to determine the energy and protein requirements of sheep, which could form a database and provide a general summary of requirements for sheep native to the semiarid region (Costa et al., 2013; Pereira et al., 2014; Pereira et al., 2017; Costa et al., 2018).

The determination of the body chemical composition is essential for an efficient production of sheep meat in semiarid regions, since this is the first step for the determination of nutritional requirements (Sousa et al., 2020), aiming at the production of carcasses with higher proportions of muscle and adequate amounts of fat to ensure the juiciness and flavor of meat, meeting the demands of the consumer market (Díaz-López et al., 2017; Cannas, Tedeschi, Atzori, & Lunesu, 2019).

Body composition analysis can be performed by direct and indirect methods. Although the direct determination of body composition by analysis of all body tissues is highly reliable, its execution is costly, requires manpower and time (Costa et al., 2020). In view of this, indirect methods were developed to estimate the body composition of animals, including the analysis of the composition of cuts and carcass measurements that are correlated with body composition, which is estimated using regression equations (Chay-Canul, Tedeschi, Atzori, & Lunesu, 2019; Morales-Martinez et al., 2020; Escalante-Clemente et al., 2022).

Due to differences in the age of physiological maturity, body composition can be affected by the breed and sex class of the animals (NRC, 2007). In this context, indirect methods for predicting body composition should be evaluated in different breeds and sex classes. However, studies to develop indirect methods for predicting body composition in sheep of different sex classes are scarce (Pereira et al., 2018), mainly in relation to the use of indirect methods for predicting body composition of non-descript breed sheep in the Brazilian semiarid region (Rodrigues et al., 2016).

Thus, the objective was to evaluate the correlation and develop regression equations for the body composition of non-descript breed sheep of different sex classes, obtained by the comparative slaughter method, using the composition of the neck region and the loin eye area.

## Material and methods

### Experiment location

The experiment was carried out at the Universidade Federal do Vale do São Francisco (UNIVASF), Petrolina, state of Pernambuco, Brazil (Latitude 09°23'55” S and Longitude 40°30'03” W, 376 m altitude). The predominant climate in the region is semiarid BSh, with summer rains. The rainy season begins in November and ends in April, with an average annual rainfall of 433 mm, relative humidity of 36.73% and average annual temperatures, maximum and minimum, of 32.0 and 26.95°C, respectively.

All experimental procedures were approved by the Animal Research Ethics Committee (CEUA) of the Universidade Federal do Vale do São Francisco, with protocol number 0010/040713.

### Animals, experimental design and diet

Forty-five non-descript breed sheep of three sex classes (15 males, 15 castrated males and 15 females), with initial body weight of 18.1±0.4 kg and 5 months of age, were confined for 58 days preceded by 30 days for adaptation of the animals to the facilities, handling and experimental diet. During adaptation, animals were identified, weighed and treated against ecto- and endoparasites. Then, animals were housed in individual covered folds (0.8 × 0.8 m), with a concrete floor, equipped with feeders and drinkers. Animals were randomly assigned to a 3×3 factorial arrangement, of three sex classes and three feeding levels, with 5 repetitions.

The feeding levels aimed to provide different energy balances to the animals, since sheep were also used in a parallel study to determine their energy requirements (Table 1). The three feeding levels were: *ad libitum* (positive energy balance); feed restriction of 70% of the average *ad libitum* intake, R70 (maintenance level) and feed restriction of 80% of the average *ad libitum* intake, R80 (negative energy balance).

Feed restriction was calculated based on feed intake observed in the last week of the adaptation period. The amount of feed given to animals subjected to feed restriction was adjusted to provide 70 or 80% of the average dietary intake (g dry matter kg body weight$^{-1}$) of animals subjected to *ad libitum* intake.

**Table 1.** Dry matter intake (DMI), average daily gain (ADG), fasting body weight (FBW), empty body weight (EBW) and neck of sheep of different sex classes, fed *ad libitum* (AL) or restricted at 70 or 80% of *ad libitum* intake.

| Items | Sex classes | | | Feeding levels | | | | *P* value | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | IM | CM | F | AL | 70% | 80% | SEM | S | F | I |
| DMI, kg dia$^{-1}$ | 0.58 | 0.60 | 0.58 | 1.17 | 0.35 | 0.23 | 0.04 | 0.71 | <0.01 | 0.82 |
| ADG, kg dia$^{-1}$ | 0.05 | 0.05 | 0.06 | 0.19 | 0.01 | -0.05 | 0.02 | 0.66 | <0.01 | 0.65 |
| FBW, kg | 21.3 | 21.2 | 20.7 | 29.2 | 18.7 | 15.5 | 1.19 | 0.75 | <0.01 | 0.57 |
| EBW, kg | 19.1 | 19.2 | 18.5 | 26.6 | 16.3 | 13.9 | 0.59 | 0.76 | <0.01 | 0.51 |
| Neck, kg | 0.50 | 0.38 | 0.49 | 0.69 | 0.38 | 0.29 | 0.02 | 0.94 | <0.01 | 0.72 |

IM = Intact males; CM = Castrated males; F = Females; 70% = Feed restriction of 70% of average intake *ad libitum*; 80% = Feed restriction of 80% of average intake *ad libitum*; SEM = Standard error of the means; S = Sex classes effect; F = Feeding level effect; I = Interaction effect between sex classes and feeding level. Significant at the 5% probability level

The diet was formulated at a forage: concentrate ratio of 40:60, on a dry matter basis, following the recommendations of the NRC (2007). The diet consisted of chopped elephant grass (*Pennisetum purpureum*), concentrate based on ground corn and soybean meal, and mineral core (Ovinofós, Tortuga, São Paulo, Brasil) (Table 2).

**Table 2.** Proportion of ingredients and chemical composition of experimental diet.

| Items | % DM |
|---|---|
| Elephant grass | 40.0 |
| Ground corn grain | 28.6 |
| Soybean meal | 29.5 |
| Sodium chloride | 0.5 |
| Commercial premix[a] | 1.1 |
| Urea | 0.3 |
| *Chemical composition* | |
| Dry matter, %NM | 63.8 |
| Organic matter, % DM | 92.7 |
| Mineral matter, % DM | 7.3 |
| Crude protein, % DM | 17.9 |
| Ether extract, % DM | 2.9 |
| Neutral detergent fiber, % DM | 37.9 |
| Non-fibre carbohydrates, % DM | 33.9 |
| Digestible energy, Mcal $kg^{-1}$ DM | 2.4 |
| Metabolizable energy, Mcal $kg^{-1}$ DM | 1.9 |

[a]Guaranteed levels provided by the manufacturer (per kg in active elements): 240 g $kg^{-1}$ calcium; 71 g $kg^{-1}$ phosphorus; 28.2 g $kg^{-1}$ potassium; 20 g $kg^{-1}$ sodium; 20 g $kg^{-1}$ Magnesium; 30 mg $kg^{-1}$ cobalt; 400 mg $kg^{-1}$ copper; 250 mg $kg^{-1}$ iron; 1350 mg $kg^{-1}$ manganese; 15 mg $kg^{-1}$ selenium; 1700 mg $kg^{-1}$ zinc; 40 mg $kg^{-1}$ iodine; 10 mg $kg^{-1}$ chromium; 710 mg $kg^{-1}$ fluorine; 135000 IU $kg^{-1}$ Vitamin A; 68000 IU $kg^{-1}$ Vitamin D3; 450 IU $kg^{-1}$ Vitamin E. Means of digestible energy and metabolizable energy at the *ad libitum* level calculated according to National Research Council (NRC, 2001) and National Research Council (NRC, 2016), respectively; NM = Natural matter; DM = Dry matter.

The diet was provided twice a day, at 08:00 and 15:00 and water was provided *ad libitum*. Leftovers were collected and weighed to determine intake and adjust the dry matter intake, allowing 20% leftovers in relation to the total offered for the *ad libitum* treatment. Samples of the diet provided and leftovers were collected and stored at -20°C for further laboratory analysis.

## Dry matter intake and average daily gain

Dry matter intake (DMI) was obtained by the difference between the dry matter offered and the dry matter of leftovers. Animals were weighed at the beginning of the experimental period, every 29 days and at the end of the experimental period, after fasting for 16 hours (with access to water), to obtain the initial body weight, fasting body weight (FBW) and average daily gain (ADG; ADG = total weight gain/feedlot days).

## Slaughter, body composition and ribeye area

Animals were slaughtered at the end of the feedlot, following the Brazilian regulation for the industrial and sanitary inspection of animal products (Decreto nº 9.013, 2017). Animals were previously stunned by cerebral concussion and immediately slaughtered by bleeding by cutting the carotid arteries and jugular veins, with blood collection and weighing. Carcasses were skinned and gutted. The gastrointestinal tract (GIT; rumen, reticulum, omasum, abomasum, small intestine and large intestine) of each animal was removed, washed and weighed. The empty body weight (EBW) was obtained by adding the weights of the carcass, skin, head, blood, tail, internal organs and weight of the clean GIT.

Carcasses were divided lengthwise. In the left half-carcass, the neck cut was obtained, and dissected to obtain bone and meat weights. Still on the left half-carcass, a cross-section was made between the 12nd and 13rd thoracic vertebrae, by demarcating the cross-section of the *Longissimus dorsi* muscle, to measure the ribeye area (LEA), tracing its surface area on a transparent plastic film. Then, the LEA was determined using the AUTOCAD® software. The left half-carcass was dissected, and separated into bones and soft tissues (muscles, fat and tendons).

All non-carcass components, soft tissues and bones of the left half-carcass were ground in an industrial meat grinder (CAF-22, Inox 1/25 CV 300 Kg $h^{-1}$ V17-M, Goiânia, Goiás State, Brasil), for taking homogeneous samples of each body constituent. The skin was cut into small pieces to collect samples for further laboratory analysis.

## Laboratory analysis

Samples were oven-dried at 105°C for 72h to determine the fatty dry matter (FDM). Subsequently, samples were subjected to successive washes with petroleum ether, obtaining the pre-defatted dry matter (PDDM) (Kock & Preston, 1979). Then, samples were ground in a ball mill (TE350, Tecnal, Piracicaba, São Paulo State, Brasil), for determinations of crude protein (CP), ether extract (EE) and ash according to the Association of Official Analytical Chemists (AOAC, 2016).

The physical and chemical compositions obtained in the left half-carcass were extrapolated to the whole carcass using the meat-to-bone ratio over the cold carcass weight of each animal. Body energy was determined from protein and fat contents and their respective caloric equivalents, using the equation recommended by the Agricultural Research Council (ARC, 1980):

$$\text{Energy content (Mcal)} = 5.6405 \times \text{protein (kg)} + 9.3929 \times \text{fat (kg)} \quad (1)$$

Retained levels of fat, protein and energy were estimated according to the ARC model (1980):

$$Y = a + b \times \log EBW + e \quad (2)$$

where Y = logarithm of total protein (kg), fat (kg) or energy (Mcal) content retained in the empty body weight, a = intercept, b = slope and e = random error.

### Statistical analysis

Data were analyzed using the Statistical Analysis System 9.1 (SAS Institut, Cary, NC, USA). The PROC CORR procedure was used to assess the correlation of the LEA and the physical and chemical composition of the neck with the physical and chemical composition of the empty body for each sex class. The PROC GLM procedure was used to propose linear regression equations to predict body composition using the LEA and neck composition for each sex class. $p \leqslant 0.05$ was used to determine the significance of correlations and coefficients of regression equations. The following statistical model was used:

$$Y = \mu + \alpha + \beta + \alpha\beta + e \quad (3)$$

where μ = mean, α = effect of feeding level, β = effect of sex class, αβ = interaction of feeding level with sex class and e = random error.

## Results and discussion

Loin eye area was positively correlated with EBW, FBW, meat, CP, EE and water ($p < 0.01$), for all sex classes (Table 3). Strong positive correlation ($p < 0.01$) was found between LEA and bones for intact males (r=0.75) and females (r=0.73) ($p < 0.01$) (Table 3). LEA showed a strong positive correlation ($p < 0.01$) with ash content for intact males (r=0.86) and a moderate correlation (r=0.60) for castrated males (Table 3). LEA had no correlation with bones (P=0.19) for castrated males (Table 3). Loin eye area showed no correlation with ash content (P=0.17) for females (Table 3).

Except for the equations for intact males, $R^2$ values of the equations for predicting meat and bone values and body composition from the LEA were low (Table 4). Loin eye area in $cm^2$ varied more between feeding levels in intact males (from 4.8 ± 0.8 to 10.2 ± 0.8) than in castrated males (from 4.7 ± 0.8 to 8.6 ± 0.8) and females (from 5.7 ± 0.8 to 7.8 ± 0.8), for 80% restriction and *ad libitum* levels, respectively.

The higher coefficients of determination observed between LEA and the variables meat, bone, CP, EE, ash and water for males in relation to other sex classes can probably be explained by the difference in muscle deposition between sex classes, since intact males have a higher muscle mass content compared to females and castrated males, due to the anabolic effect of testosterone (Needham, Lambrechts, & Hoffman, 2017), which stimulates muscle and skeletal growth and is present at higher levels in intact males (Nazari-Zonouz et al., 2018).

**Table 3.** Correlation coefficients between loin eye area (LEA) and empty body weight (EBW), fasting body weight (FBW) and proximate composition of empty body (in kg) of sheep of different sex classes, fed *ad libitum* (AL) or restricted at 70 or 80% of *ad libitum* intake.

| | EBW | FBW | Meat | Bone | CP | EE | Ash | Water |
|---|---|---|---|---|---|---|---|---|
| | | | | Intact males | | | | |
| LEA | 0.90 | 0.88 | 0.89 | 0.75 | 0.89 | 0.83 | 0.86 | 0.90 |
| *P* value | * | * | * | * | * | * | * | * |
| | | | | Castrated males | | | | |
| LEA | 0.72 | 0.73 | 0.84 | 0.38 | 0.78 | 0.72 | 0.60 | 0.68 |
| *P* value | * | * | * | 0.19 | * | * | * | * |
| | | | | Females | | | | |
| LEA | 0.61 | 0.57 | 0.70 | 0.73 | 0.70 | 0.52 | 0.37 | 0.63 |
| *P* value | * | * | * | * | * | * | 0.17 | * |

Meat = muscle + fat + sinews; CP = Crude protein; EE = Ether extract; * - Significant correlation at the 5% probability level

**Table 4.** Linear regression equations to estimate the proximate composition (in kg) in empty body (y) as a function of the loin eye area (LEA, in cm$^2$) of the carcass, (x), of sheep of different sex classes, fed *ad libitum* (AL) or restricted at 70 or 80 % of *ad libitum* intake.

| | Parameters | | | | | | $R^2$ | *P* value | |
|---|---|---|---|---|---|---|---|---|---|
| Sex classes | Y | | Intercept | | Slope | X | | Intercept | Slope |
| Intact males | Meat, kg | = | -1.00 | + | 1.01 | LEA | 0.79 | 0.39 | * |
| Castrated males | Meat, kg | = | -0.02 | + | 0.97 | LEA | 0.71 | 0.99 | * |
| Females | Meat, kg | = | -0.17 | + | 0.97 | LEA | 0.50 | 0.93 | * |
| General | Meat, kg | = | -0.27 | + | 0.96 | LEA | 0.68 | 0.71 | * |
| Intact males | Bone, kg | = | 1.39 | + | 0.13 | LEA | 0.58 | * | * |
| Castrated males | Bone, kg | = | 1.68 | + | 0.16 | LEA | 0.15 | * | 0.19 |
| Females | Bone, kg | = | 1.25 | + | 0.16 | LEA | 0.53 | * | * |
| General | Bone, kg | = | 1.55 | + | 0.13 | LEA | 0.21 | * | * |
| Intact males | Water, kg | = | 0.57 | + | 1.22 | LEA | 0.83 | * | * |
| Castrated males | Water, kg | = | 6.50 | + | 0.98 | LEA | 0.47 | * | * |
| Females | Water, kg | = | 6.11 | + | 0.91 | LEA | 0.40 | * | * |
| General | Water, kg | = | 5.37 | + | 1.04 | LEA | 0.59 | * | * |
| Intact males | CP, kg | = | 0.59 | + | 0.34 | LEA | 0.80 | 0.12 | * |
| Castrated males | CP, kg | = | 1.02 | + | 0.32 | LEA | 0.62 | 0.06 | * |
| Females | CP, kg | = | 1.12 | + | 0.28 | LEA | 0.49 | 0.05 | * |
| General | CP, kg | = | 0.94 | + | 0.31 | LEA | 0.65 | * | * |
| Intact males | EE, kg | = | -2.00 | + | 0.63 | LEA | 0.69 | * | * |
| Castrated males | EE, kg | = | -0.97 | + | 0.54 | LEA | 0.52 | 0.36 | * |
| Females | EE, kg | = | -1.36 | + | 0.59 | LEA | 0.27 | 0.47 | * |
| General | EE, kg | = | -1.37 | + | 0.58 | LEA | 0.49 | * | * |
| Intact males | Ash, kg | = | 0.39 | + | 0.07 | LEA | 0.75 | * | * |
| Castrated males | Ash, kg | = | 0.51 | + | 0.07 | LEA | 0.36 | * | * |
| Females | Ash, kg | = | 0.72 | + | 0.02 | LEA | 0.14 | * | 0.17 |
| General | Ash, kg | = | 0.52 | + | 0.06 | LEA | 0.43 | * | * |

Meat = muscle + fat + sinews; CP = Crude protein; EE = Ether extract; $R^2$ = coefficient of determination; * - Significant at the 5% probability level.

Higher $R^2$ values of the equations for predicting meat and bone values and body composition from the LEA for intact males may be related to the greater variation in the LEA value, providing a better fit of the regression equation. According to Issakowicz et al. (2018), the greater muscle deposition in the carcass of intact males is evidenced by the larger loin of these animals, once the *Longissimus lumborum* muscle has a high positive correlation with body development and can also be used to estimate the muscle amount in the region.

Ripoll, Joy, and Sanz, (2010) obtained higher $R^2$ values for the prediction equations of lean, fat-free (0.95) and bone (0.88) tissues in the carcass of sheep from ultrasound measurements taken between the 12nd and 13rd thoracic vertebrae (depth and width of the *Longissimus* muscle and subcutaneous fat). These higher $R^2$ values presented by these authors can be attributed to the greater amounts of parameters measured and used as independent variables in the estimate, thus promoting a better fit of the equations.

The neck showed a strong positive correlation ($p < 0.01$) with EBW (r=0.86), FBW (r=0.85), meat (r=0.89), CP (r=0. 74), EE (r=0.88) and Energy (r=0.90) and a moderate correlation ($p < 0.01$) with bone (r=0.58) and ash (r=0.67) for intact males (Table 5). Differing from the results obtained in this study, Gastelum-Delgado et al. (2022) in a study predicting the tissue composition of the carcass from the composition of the neck and shoulder in male Blackbelly lambs, reported that total weights of muscle, bone and fat in the carcass are positively correlated with the components of the shoulder, but not with the tissue composition of the neck.

The use of tissue and chemical composition of the neck seems to be a viable alternative for estimating the body composition of non-descript breed sheep native to the Brazilian semiarid region, mainly because the neck represents a cut of low commercial value (Rivera-Alegria et al., 2022) and obtaining it for predictive analysis result in lower losses compared to the use of the section from the 9th to 11st ribs. In this sense, for castrated males, the neck presented a strong positive correlation ($p < 0.01$) with EBW (r=0.88), meat (r=0.90), bone (r=0.83), CP (r=0.86), EE (r=0.90), ash (r=0.82), water (r=0.86) and energy (r=0.87) (Table 5). Regarding females, there was a strong positive correlation ($p < 0.01$) between the neck and FBW (r=0.87), meat (r=0.89), CP (r=0.90) and water (r=0.87) (Table 5). A very strong correlation was detected between neck and water content (r=0.91) for intact males, neck and FBW (r=0.92) for castrated males and between neck and EBW (r=0.91), EE (r=0.94) and energy (r=0.95) for females (Table 5).

There was no correlation between the neck and the variables bone (P=0.13) and ash (P=0.06) for females (Table 5). Rivera-Alegria et al. (2022) on the prediction of carcass traits using neck traits found that, with the exception of bone weight, all neck traits can be considered predictive variables for muscle and fat in the carcass of Pelibuey ewes.

**Table 5.** Correlation coefficients between empty body weight (EBW) and fasting body weight (FBW) with neck weight and between the proximate composition of the empty body and the proximate composition of the neck of sheep of different sex classes, fed *ad libitum* (AL) or restricted at 70 or 80% of *ad libitum* intake.

| | EBW | FBW | Meat | Bone | CP | EE | Ash | Water | Energy Mcal kg$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Intact males | | | | |
| Neck | 0.86 | 0.85 | 0.89 | 0.58 | 0.74 | 0.88 | 0.67 | 0.91 | 0.90 |
| *P* value | * | * | * | * | * | * | * | * | * |
| | | | | | Castrated males | | | | |
| Neck | 0.88 | 0.92 | 0.90 | 0.83 | 0.86 | 0.90 | 0.82 | 0.86 | 0.87 |
| *P* value | * | * | | * | * | * | * | * | * |
| | | | | | Females | | | | |
| Neck | 0.91 | 0.87 | 0.89 | 0.41 | 0.90 | 0.94 | 0.49 | 0.87 | 0.95 |
| *P* value | * | * | * | 0.13 | * | * | 0.06 | * | * |

Meat = muscle + fat + sinews; CP = Crude protein; EE = Ether extract. * - Significant at the 5% probability level.

Fernandes et al. (2008) found lower correlations between neck fat values and body fat (0.59) and between neck protein and body protein (0.41) in ¾ Boer x ¼ Saanen goats. This difference can be related to differences in the amplitude of the values of variables used for the correlations. In the study by Fernandes et al. (2008), animals were given with the same level of energy in the diet, varying the slaughter weights from 20 to 35 kg, in which the percentages of CP and EE in the neck varied, respectively, from 16.9 to 17.2% and from 12.4 to 14.6%, and the percentages of CP and EE in the empty body varied, respectively, from 17.4 to 17.2% and from 11.6 to 15.1%. In the present study, animals received different levels of energy in the diet through different feeding levels, which resulted in different slaughter weights, and the ranges of variation of parameters used in the correlation were greater, ranging from 6.9 to 18.8% and from 16.6 to 15.6% for EE and CP in the empty body in the 80% feed restriction and *ad libitum* treatments, respectively. Thus, it can be inferred that energy intake levels together with body weight at slaughter affect body composition to a greater extent than just body weight at slaughter.

The EBW and FBW prediction equations as a function of neck weight showed significant slope values for all sex classes and obtained $R^2$ values above 0.70 (Table 6), which means the existence of collinearity between the variables. The prediction equation of EBW for females and FBW for male castrated sheep as a function of neck weight showed $R^2$ values above 0.80 (Table 6), evidencing high collinearity between these characteristics. Deriving the correlation coefficient between neck weight and FBW (0.54) presented by Gomes et al. (2013) for goats, a lower $R^2$ value (0.29) was obtained than the values reported in the present study.

**Table 6.** Linear regression equations to estimate empty body weight (EBW) and fasting body weight (FBW) (y) from the neck weight (x) of sheep of different sex classes, fed *ad libitum* (AL) or restricted at 70 or 80 % of *ad libitum* intake.

| | | | Parameters | | | | | *P* value | |
|---|---|---|---|---|---|---|---|---|---|
| Sex classes | Y | | Intercept | | Slope | X | $R^2$ | Intercept | Slope |
| Intact males | EBW, kg | = | 3.07 | + | 36.50 | kg | 0.73 | 0.30 | * |
| Castrated males | EBW, kg | = | 8.64 | + | 23.64 | kg | 0.78 | * | * |
| Females | EBW, kg | = | 6.95 | + | 27.10 | kg | 0.82 | * | * |
| General | EBW, kg | = | 6.71 | + | 27.92 | kg | 0.75 | * | * |
| Intact males | FBW, kg | = | 4.91 | + | 37.41 | kg | 0.73 | 0.12 | * |
| Castrated males | FBW, kg | = | 9.40 | + | 26.60 | kg | 0.84 | * | * |
| Females | FBW, kg | = | 8.81 | + | 27.92 | kg | 0.75 | * | * |
| General | FBW, kg | = | 8.09 | + | 29.79 | kg | 0.75 | * | * |

$R^2$ = coefficient of determination; * - Significant at the 5% probability level.

With the exception of regression equations to estimate the bone and ash values in the females' empty body, the regressions to estimate the tissue and chemical composition in the empty body from their respective values in the neck were significant (Table 7). Furthermore, in the predictions of CP, EE and water in the empty body for all sex classes, moderate $R^2$ values were obtained for the equations (Table 7).

The good relationships between the tissue composition of the carcass and the neck of non-descript breed sheep native to the Brazilian semiarid region suggest that the neck can be used to predict the tissue composition of the carcass, as also observed by Rivera-Alegria et al. (2022). On the other hand, Argüello, Capote, Ginés, and López (2001) and Gomes et al. (2022) reported that neck tissue composition was not a good parameter for predicting carcass tissue composition in kids. This difference can be ascribed to the different species and slaughter weights between the studies, in addition to the age of the animals, which were younger and, probably, had not yet stabilized their growth curves. So far, there is no record of the relationship between the neck and carcass tissue composition of sheep native to the Brazilian semiarid region.

**Table 7.** Linear regression equations to estimate the proximate composition of the empty body (y) as a function of the proximate composition of the neck (x) of sheep of different sex classes, fed *ad libitum* (AL) or restricted at 70 or 80 % of *ad libitum* intake.

| Sex classes | Parameters | | | | | $R^2$ | *P* value | |
|---|---|---|---|---|---|---|---|---|
| | Y | Intercept | | Slope | X | | Intercept | Slope |
| Intact males | Meat, kg = | 0.05 | + | 20.13 | Meat, kg | 0.78 | 0.96 | * |
| Castrated males | Meat, kg = | 2.17 | + | 12.11 | Meat, kg | 0.70 | * | * |
| Females | Meat, kg = | 1.69 | + | 14.44 | Meat, kg | 0.78 | * | * |
| General | Meat, kg = | 1.50 | + | 14.98 | Meat, kg | 0.72 | * | * |
| Intact males | Bone, kg = | 0.95 | + | 12.65 | Bone, kg | 0.33 | * | * |
| Castrated males | Bone, kg = | 0.65 | + | 19.14 | Bone, kg | 0.69 | 0.55 | * |
| Females | Bone, kg = | 1.75 | + | 5.34 | Bone, kg | 0.16 | * | 0.13 |
| General | Bone, kg = | 2.41 | + | 14.02 | Bone, kg | 0.44 | * | * |
| Intact males | Water, kg = | 2.13 | + | 35.19 | Water, kg | 0.84 | 0.13 | * |
| Castrated males | Water, kg = | 6.63 | + | 21.68 | Water, kg | 0.75 | * | * |
| Females | Water, kg = | 6.42 | + | 20.32 | Water, kg | 0.75 | * | * |
| General | Water, kg = | 5.40 | + | 24.65 | Water, kg | 0.74 | * | * |
| Intact males | CP, kg = | 0.96 | + | 31.30 | CP, kg | 0.51 | 0.11 | * |
| Castrated males | CP, kg = | 1.47 | + | 19.22 | CP, kg | 0.74 | * | * |
| Females | CP, kg = | 1.43 | + | 22.64 | CP, kg | 0.81 | * | * |
| General | CP, kg = | 1.49 | + | 22.68 | CP, kg | 0.61 | * | * |
| Intact males | EE, kg = | -0.08 | + | 42.11 | EE, kg | 0.77 | 0.87 | * |
| Castrated males | EE, kg = | 0.35 | + | 32.99 | EE, kg | 0.80 | 0.36 | * |
| Females | EE, kg = | -0.50 | + | 46.90 | EE, kg | 0.89 | 0.17 | * |
| General | EE, kg = | -0.04 | + | 40.30 | EE, kg | 0.80 | 0.86 | * |
| Intact males | Ash, kg = | 0.53 | + | 21.70 | Ash, kg | 0.45 | * | * |
| Castrated males | Ash, kg = | 0.61 | + | 15.90 | Ash, kg | 0.67 | * | * |
| Females | Ash, kg = | 0.75 | + | 6.64 | Ash, kg | 0.24 | * | 0.06 |
| General | Ash, kg = | 0.63 | + | 14.55 | Ash, kg | 0.47 | * | * |

Meat = muscle + fat + sinews; CP = Crude protein; EE = Ether extract; $R^2$ = coefficient of determination; * - Significant at the 5% probability level.

Fernandes et al. (2008) reported a higher $R^2$ value (0.90) for the equation for predicting the percentage of EE in the empty body in goats, based on the EE content found in the neck and non-carcass components. This difference may be related to the inclusion of the EE value of the non-carcass components in the prediction, as the chemical composition of the neck is more closely related to the composition of the carcass, since this commercial cut is a part thereof. In addition, native sheep deposit a greater proportion of visceral fat and a lower proportion of fat in the carcass (Souza et al., 2020), which may have contributed to this result.

## Conclusion

The AOL and the chemical composition of the neck were correlated with the tissue and chemical composition of the empty body and proved to be efficient in their predictions in non-descript breed sheep of different sex classes.

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