Predicting the carcass characteristics of Morada Nova lambs using biometric measurements

Roberto Germano Costa1*, Anny Graycy Vasconcelos de Oliveira Lima2, Neila Lidiany Ribeiro1, Ariosvaldo Nunes de Medeiros2, Geovergue Rodrigues de Medeiros3, Severino Gonzaga Neto2, Ronaldo Lopes Oliveira4

1 Universidade Federal da Paraíba, Departamento de Ciência Animal, Bananeiras, PB, Brasil.
2 Universidade Federal da Paraíba, Departamento de Zootecnia, Areia, PB, Brasil.
3 Instituto Nacional do Semiárido, Campina Grande, PB, Brasil.
4 Universidade Federal da Bahia, Escola de Medicina Veterinária e Zootecnia, Departamento de Zootecnia, Salvador, BA, Brasil.

ABSTRACT - The objective of this work was to use biometric measurements to predict carcass characteristics of lambs of the Morada Nova breed. We used 48 lambs with mean initial body weight (BW) of 15.0 ± 0.04 kg and slaughter body weight (SBW) of 26.37 ± 2.43 kg. The animals were weighed weekly and underwent a period of adaptation of 15 days before slaughter. The biometric measurements were obtained the day before slaughter, comprising body length, withers height, rump height, thigh length, breast width, rump width, thigh perimeter, rump perimeter, thorax perimeter, leg length, and body condition score. Additional measurements included slaughter BW and empty BW (EBW). The data recorded at slaughter comprised the weights of the viscera, carcass, and internal fat and offal. The in vivo measurements of body length were present in most of the equations for predicting the SBW, EBW, hot carcass weight (HCW), and cold carcass weight (CCW). The SBW and EBW presented a variation of approximately 9%. The variables that evaluated the carcass, HCW, and CCW demonstrated less data variation than SBW and EBW, which was probably because these measurements were obtained following evisceration and skinning, thus removing factors of more significant variation in vivo. The prediction models found in the present study varied with an R² of 0.49-0.93, indicating high levels of variation. In sum, biometric measurements can be used to predict the carcass characteristics of Morada Nova lambs with different body conditions.

Keywords: biometry, carcass quality, lamb carcass, Morada Nova, prediction models

1. Introduction

Body weight (BW) is directly related to the production and profitability of any livestock. Therefore, it represents the optimum parameter by which management, health, production, and marketing decisions can be made. Biometric measurements (BM), which are linear measurements of the body, have long been used as predictors of specific aspects of body composition of domestic animals, that is, they serve as predictors of body weight as well as specific less visible characteristics (Supriyantono et al., 2012). The biometric measurement area is not expensive to measure and is easy to analyze, but the measurements are not accurate (Fonseca et al., 2016). However, it is necessary to develop a means...
of describing and evaluating BW and carcass conformation characteristics, especially in the animal production sector (Ricardo et al., 2016).

Different methods of determining the carcass quantity and body composition of domestic animals have been studied owing to their nutritional and economic importance (Cantón et al., 1992; Fernandes et al., 2010; De Paula et al., 2013; McGregor, 2017). These methods aim to establish a relationship between BM that can be used to estimate BW and carcass parameters in sheep. Therefore, some studies have developed regression equations that can be used to predict BW from some animal body measurements (Karaca et al., 2009; Yılmaz et al., 2013). The correlation matrix of each BM can be used to predict BW or carcass parameters in sheep (Ojedapo et al., 2007; Hernandez-Espinoza et al., 2012; Shehata, 2013; Bautista-Díaz et al., 2017). The interpretation of several BM for estimating BW is difficult due to the high degree of correlation that can exist between them. Therefore, multiple regression analysis should be undertaken as a technique that exhibits a complex relationship between BW and BM and animal carcass measurements (Ricardo et al., 2016).

A locally adapted hair sheep breed from the Brazilian semi-arid region, the Morada Nova, was initially described in the Morada Nova region of Ceará state in Northeastern Brazil (Facó et al., 2008). It is a small animal with high prolificacy and aptitude for meat and skin production under stressful conditions, including high temperatures and prolonged dry periods. Although these animals are resilient, the preference of farmers for larger breeds, as well as the use of crossbreeding with breeds, specialized in meat production (McManus et al., 2019).

The hypothesis of this work was to evaluate if the BM can estimate the characteristics of the carcass, viscera, and internal fat. Given that the information used to estimate the composition of the carcass of Morada Nova lambs through BM is weak, the objective of this work was to use BM to predict carcass characteristics of the Morada Nova lambs.

2. Material and Methods

The experiment was conducted in the municipality of São João do Cariri, PB, Brazil (7°29’34” S and 36°41’53” W). The study was approved by the institutional animal ethics committee (case number 2305/14).

Forty-eight Morada Nova ram lambs were used with mean initial body weight (BW) of 15.0±0.04 and slaughter BW (SBW) of 26.37±2.43 kg. The animals were weighed weekly and underwent a period of adaptation of 15 days to the diet. They were randomly distributed in semi-open pens equipped with a drinker and feeder, with an unpaved floor.

The diet was formulated according to recommendations of the NRC (2007) for weight gains of 200 g/day, with forage:concentrate ratio of 50:50, composed of Tifton grass hay (Cynodon ssp), ground corn, soybean meal, and mineral supplement, provided in the form of complete mixing. Feed and water were offered ad libitum twice daily (7:30 and 15:30 h), but with knowledge of the feed weight so as to perform the calculation of the intake of each animal. The intake per percentage of live weight and metabolic weight was also calculated.

The following BM, as described by Cézar and Sousa (2007), were recorded for each animal 24 h before slaughter: body length (BL), withers height (WH), rump height (RH), thigh length (TL), breast width (BRW), rump width (RW), thigh perimeter (THP), rump perimeter (RP), thorax perimeter (TP), leg length (LL), and body condition score (BCS). For all measurements, flexible tape fiberglass (Truper®) and a large caliper of 65 cm (Haglof®) were used. The BM was expressed in cm so that it could be related to the composition of the carcass (Fernandes et al., 2010).

All lambs were slaughtered the same day using standard commercial procedures following Brazilian welfare codes of practice (Brasil, 2000). Lambs were fasted on the farm for 8 h and transported to an accredited slaughterhouse and were then weighed to obtain SBW. At the slaughterhouse, lambs had an 8-h rest period with full access to water but not to feed. Experimental animals were left unconscious.
by electrical stunning and slaughtered by bleeding. After slaughter, the carcasses were chilled at 4 °C in a refrigerated chamber, where they remained for 24 h hanging from hooks by the Achilles tendon with the metatarsal joints spaced 17 cm apart. The animals were subsequently skinned and eviscerated.

The hot carcass weight (HCW) was calculated following slaughter, with the carcass divided by the dorsal median line into two halves and refrigerated for a period of 24 h at 1 °C. Subsequently, the viscera and organs (VISC), comprising blood, liver, heart, kidneys, lungs, empty intestines, gall bladder, tongue, and spleen, were removed and weighed. Internal fat (IF) consisted of pelvic fat (around the kidneys and pelvic region) and omental and mesenteric fat (around the gastrointestinal tract). The gastrointestinal tract was weighed both full and empty to determine the empty body weight (EBW). The kidneys and perirenal fat were removed and were subtracted from the HCW and cold carcass weight (CCW) to calculate the hot carcass yield (HCY; (%) = HCW/SBW × 100 and cold carcass yield (CCY; (%) = CCW/SBW × 100 (Cézar and Sousa, 2007). The waste parts of the carcass (skin, head, feet, tail, internal fat, udder, and blood; OFF) were weighted and recorded. In the left half carcass, a cross-section between the 12th and 13th ribs was performed, exposing the cross-section of the Longissimus dorsi muscle, whose area was dashed through a permanent marker with a 2.0 mm mean tip on a transparent plastic film to determine the loin eye area (LEA).

Mean, range, and variance (SD) and Pearson’s correlations were determined for all measurements as well as regression analyses. Regressions were developed with PROC REG of SAS (Statistical Analysis System, version 9.3). The biometric variables used in the development of the prediction equation were: BL, WH, RH, TL, BRW, RW, THP, RP, TP, LL, and BCS. The equations were selected by considering the model coefficient of determination (R²), the root mean square error (RMSE), and the Cp statistic \(\frac{SSE}{\sigma^2 + 2p - n}\) (Equation 1), in which SSE is the error sum of squares, \(\sigma^2\) is the residual variance, p is the number of parameters in the model (including the intercept), and n is the number of records. According to MacNeil (1983), Cp relates \(R^2\) and residual variance and is a more appropriate equation selection criterion than \(R^2\) alone, allowing the identification of optimal subsets. The goal is to find the best model involving a subset of predictors. Hence, in general, a small value of \(C_p\) means that the model is relatively precise (Mallows, 1973).

3. Results

The IF was the measure that presented the highest coefficient of variation (34%) between the BM and carcass characteristics studied (Table 1). The BCS was the measure with the second-highest coefficient of variation (16%). The variables HCW, CCW, OFF, and RW all presented variation around 11%. The variables HCY and CCY presented a significant correlation (P<0.01) with BM, but obtained low coefficients of variation (4.26 and 4.44, respectively).

The BM showed a direct and high correlation with carcass characteristics: IF, OFF, and LEA (Table 2). However, the viscera did not present a correlation (P>0.05) with any of the variables studied. Correlations above 60% (P<0.05) were found between BM and EBW, SBW, HCW, and OFF.

The SBW and EBW characteristics showed a variation of around 9%, and their prediction equations presented \(R^2\) ranging from 0.50 to 0.80 and 0.47 to 0.77, respectively. Mallow’s Cp for the variable SBW ranged from 6.1 to 6.3 when we added the traits WH, TP, BRW, RW, TL, and BCS (Table 3). The Cp value obtained for EBW presented the same behavior. So, we suggest as the best model the one that presented Cp of 5.61 with \(R^2\) 0.76 and RMSE of 1.11. For the variables HCW and CCW, the \(R^2\) of the equation ranged from 0.49 to 0.80, and the BM included in the models were BL, WH, BRW, RP, and BCS. The \(R^2\) value of the prediction equations of HCY and CCY varied from 0.31 to 0.51 and 0.32 to 0.52, respectively, and the BM included in the models were THP, RP, TP, and BCS (Table 4).

The variable SBW and EBW varied by 9%, and their prediction equations showed \(R^2\) ranging from 0.50 to 0.80 and 0.47 to 0.77, respectively. The BM that were most important in formulating the prediction models were BL, WH, BRW, RP, and BCS (Table 4).
Predicting the carcass characteristics of Morada Nova lambs using biometric measurements

Costa et al.

For the IF prediction equations, the $R^2$ ranged from 0.26 to 0.40, and the BM included in the equations were RH, TL, and BCS. The prediction equations of the variable OFF presented $R^2$ of 0.39 to 0.56, and the variables BL, BRW, and BCS were most important in obtaining the prediction equations. The LL and BCS measures were part of the prediction equations of the variable VISC, and the equations showed low $R^2$, which varied from 0.29 to 0.35, although significant ($P<0.01$). The prediction equations of LEA presented similar $R^2$ to those of the prediction equations of the VISC, and the BM included in the prediction equations comprised BCS and BL.

4. Discussion

The Morada Nova breed has good productive potential, especially of lambs, since they reach slaughter weight in more time without a decline in the quality of their meat (Medeiros et al., 2009).

In this study, the BW was not included as an independent measure since it varies considerably among the carcasses of domestic animals (Hernandez-Espinoza et al., 2012; De Paula et al., 2013; Bautista-Díaz et al., 2017). Several studies have demonstrated a direct relationship between BW and BM in goats (Mahieu et al., 2011; Souza et al., 2014) and sheep (Sowande and Sobola, 2008; Bautista-Díaz et al., 2017). Assan et al. (2013) reported a significant relationship between BM, which can be used to estimate BW and carcass parameters due to the practicality low price of the method. Therefore, the best results are obtained when other BM are included in the predictive model. This statement corresponds with the results of this study, which used Morada Nova sheep as an efficient model to estimate the variables SBW and EBW.

In equation 1, including BL, a high correlation with BM was observed with the BRW. Multiple regression analysis has been used to interpret complex relationships between BW and certain BM (Yakubu and Mohammed, 2012). An essential step in the construction of a multiple regression model for predictive purposes is to determine the variables that best contribute to the response variable, with the elimination of non-significant variables ($P>0.05$). Mallow’s $C_p$ parameter substitute was used to

Table 1 - Descriptive analyses of the data measured on live animal (n = 48 lambs)

| Variable                     | µ±SD   | CV (%) | Maximum | Minimum |
|------------------------------|--------|--------|---------|---------|
| Biometric measurements       |        |        |         |         |
| Body length                  | 58.78±2.09 | 3.56   | 63.00   | 54.00   |
| Withers height               | 60.89±3.52 | 5.78   | 66.50   | 51.50   |
| Rump height                  | 62.06±2.73 | 4.40   | 69.00   | 56.30   |
| Thigh length                 | 54.48±2.19 | 4.01   | 60.00   | 51.00   |
| Breast width                 | 18.32±1.29 | 7.07   | 21.00   | 14.70   |
| Rump width                   | 20.31±2.31 | 11.36  | 25.00   | 11.00   |
| Thigh height                 | 40.02±2.46 | 6.15   | 44.00   | 31.00   |
| Rump perimeter               | 74.90±3.93 | 5.24   | 85.00   | 65.00   |
| Thoracic perimeter           | 80.23±4.40 | 5.48   | 91.00   | 71.00   |
| Leg length                   | 31.14±1.29 | 4.13   | 34.00   | 29.00   |
| Body condition score         | 2.47±0.41 | 16.58  | 3.50    | 2.00    |
| Carcass characteristics      |        |        |         |         |
| Slaughter body weight        | 26.37±2.43 | 9.22   | 31.58   | 22.71   |
| Empty body weight            | 21.96±2.07 | 9.45   | 26.04   | 17.49   |
| Hot carcass weight           | 13.33±1.44 | 10.81  | 16.35   | 10.87   |
| Cold carcass weight          | 13.00±1.43 | 11.03  | 16.01   | 10.54   |
| Hot carcass yield            | 50.52±2.15 | 4.26   | 55.22   | 46.66   |
| Cold carcass yield           | 12.99±1.43 | 11.03  | 16.01   | 10.54   |
| Organs and viscera           | 4.08±0.29 | 7.01   | 3.58    | 4.78    |
| Internal fat                 | 1.84±0.63 | 34.36  | 3.43    | 0.92    |
| Off                          | 7.28±0.81 | 11.10  | 9.19    | 5.75    |
| Loin eye area                | 8.89±1.30 | 14.62  | 11.44   | 6.50    |

$µ±SD =$ mean ± standard deviation; $CV -$ coefficient of variation.
| Variable | WH  | RH  | TL  | BRW | RW  | TP  | THP | LL  | BCS | SBW | EBW | HCW | CCW | HCY | CCY | VISC | IF  | OFF  | LEA |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|------|-----|
| BL       | 0.29| 0.42| 0.40| 0.44| 0.42| 0.42| 0.42| 0.70| 0.68| 0.66| 0.33| 0.62| 0.40|     |      |      |     |      |
| WH       | -   | 0.88| 0.56| 0.67| 0.61| 0.47| 0.37| 0.44| 0.61| 0.64| 0.41| 0.40| 0.41| 0.36| 0.38| 0.31|     |      |     |
| RH       | -   | -   | 0.73| 0.64| 0.57| 0.50| 0.38| 0.50| 0.70| 0.62| 0.46| 0.44| 0.46| 0.50| 0.50| 0.30|     |      |     |
| TL       | -   | -   | -   | 0.35|     | 0.45| 0.41| 0.76| 0.32| 0.50| 0.50| 0.55|     |     |     |     | 0.35| 0.36|     |
| BBW      | -   | -   | -   | -   | 0.75| 0.45|     |     |     |     |     |     |     |     |     |     |     |     |     |
| RW       | -   | -   | -   | -   | -   | 0.58|     |     |     |     |     |     |     |     |     |     |     |     |     |
| TP       | -   | -   | -   | -   | -   | -   |     |     |     |     |     |     |     |     |     |     |     |     |     |
| RP       | -   | -   | -   | -   | -   | -   | -   |     |     |     |     |     |     |     |     |     |     |     |     |
| THP      | -   | -   | -   | -   | -   | -   | -   | -   |     |     |     |     |     |     |     |     |     |     |     |
| LL       | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.51| 0.52| 0.51|     |     |     |     |     |     |     |
| BCS      | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.47| 0.43| 0.55| 0.47| 0.46| 0.47|     |     |     |     |
| SBW      | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.92| 0.81|     |     |     |     |     | 0.39| 0.69| 0.47|     |
| EBW      | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.92| 0.32| 0.29| 0.31|     |     |     |     |     |     |
| HCW      | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.92| 0.55| 0.58|     |     |     |     |     |     |     |
| CCW      | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.56| 0.59|     |     |     |     |     |     |     |     |
| HCY      | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.99|     |     |     |     |     |     |     |     |
| CCY      | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.56|     |     |     |     |     |     |     |
| VISC     | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.58|     |     |     |     |     |     |
| IF       | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.44|     |     |     |     |     |
| OFF      | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 0.80|     |     |     |     |

BL - body length; WH - withers height; RH - rump height; TL - thigh length; BRW - breast width; RW - rump width; TP - thigh perimeter; RP - rump perimeter; THP - thoracic perimeter; LL - leg length; BCS - body condition score; SBW - slaughter body weight; EBW - empty body weight; HCW - hot carcass weight; CCW - cold carcass weight; HCY - hot carcass yield; CCY - cold carcass yield; IF - internal fat; OFF - waste parts of the carcass; VISC - viscera and organs; LEA - loin eye area.
### Table 3 - Regression equations to predict some *in vivo* traits of Morada Nova lambs

| No. equation | Equation | Cp   | $R^2$ | RMSE | P-value |
|--------------|----------|------|-------|------|---------|
| **Slaughter body weight (SBW)** | | | | | |
| 1 | $SBW = -21.79(\pm 7.24)+0.82(\pm 0.12)BL$ | 61.35 | 0.50 | 1.75 | <0.0001 |
| 2 | $SBW = -30.66(\pm 6.50)+0.68(\pm 0.11)BL+0.28(\pm 0.06)WH$ | 32.78 | 0.57 | 1.76 | <0.0001 |
| 3 | $SBW = -40.56(\pm 5.98)+0.55(\pm 0.10)BL+0.32(\pm 0.06)WH+0.19(\pm 0.04)TP$ | 12.83 | 0.75 | 1.26 | <0.0001 |
| 4 | $SBW = -38.68(\pm 5.80)+0.48(\pm 0.10)BL+0.22(\pm 0.07)WH+0.43(\pm 0.20)BRW+0.19(\pm 0.04)TP$ | 9.59 | 0.78 | 1.20 | <0.0001 |
| 5 | $SBW = -39.10(\pm 5.53)+0.43(\pm 0.10)BL+0.26(\pm 0.07)WH+0.76(\pm 0.24)BRW−0.27(\pm 0.12)RW+0.20(\pm 0.04)TP$ | 6.33 | 0.80 | 1.15 | <0.0001 |
| **Empty body weight (EBW)** | | | | | |
| 1 | $EBW = −18.01(\pm 6.35)+0.68(\pm 0.11)BL$ | 40.83 | 0.50 | 1.53 | <0.0001 |
| 2 | $EBW = -26.37(\pm 5.51)+0.55(\pm 0.09)BL+0.26(\pm 0.06)WH$ | 14.45 | 0.65 | 1.26 | <0.0001 |
| 3 | $EBW = -32.33(\pm 5.58)+0.47(\pm 0.09)BL+0.28(\pm 0.05)WH+0.11(\pm 0.04)TP$ | 8.11 | 0.70 | 1.17 | <0.0001 |
| 4 | $EBW = -31.09(\pm 5.56)+0.42(\pm 0.09)BL+0.22(\pm 0.07)WH+0.28(\pm 0.19)BRW+0.12(\pm 0.04)TP$ | 7.73 | 0.72 | 1.16 | <0.0001 |
| 5 | $EBW = -31.42(\pm 5.42)+0.38(\pm 0.09)BL+0.25(\pm 0.07)WH+0.54(\pm 0.23)BRW−0.21(\pm 0.11)RW+0.12(\pm 0.04)TP$ | 6.38 | 0.74 | 1.13 | <0.0001 |
| 6 | $EBW = −28.99(\pm 5.49)+0.36(\pm 0.09)BL+0.25(\pm 0.06)WH+0.55(\pm 0.22)BRW−0.25(\pm 0.11)RW+0.10(\pm 0.04)TP+0.79(\pm 0.47)BCS$ | 5.61 | 0.76 | 1.11 | <0.0001 |
| 7 | $EBW = 27.30(\pm 5.46)+0.38(\pm 0.09)BL+0.33(\pm 0.08)WH−0.21(\pm 0.11)TL+0.58(\pm 0.22)BRW−0.31(\pm 0.12)RW+0.13(\pm 0.04)TP+0.86(\pm 0.46)BCS$ | 4.97 | 0.77 | 1.08 | <0.0001 |

**BL** - body length; **WH** - withers height; **TP** - thigh perimeter; **BRW** - breast width; **RW** - rump width; **BCS** - body condition score; **TL** - thigh length. **Cp** - means that the model is relatively precise; **$R^2$** - coefficient of determination; **RMSE** - root mean square error.
Table 4 - Regression equations to predict the carcass characteristics of Morada Nova lambs

| No. equation | Equation                                                                 | Cp  | R²   | RMSE | P-value     |
|--------------|---------------------------------------------------------------------------|-----|------|------|-------------|
| Hot carcass weight (HCW) |                                                                          |     |      |      |             |
| 1            | \( HCW = -9.67(\pm 3.48) + 0.37(\pm 0.06) \times RH \)                   | 51.74 | 0.49 | 1.04 | <0.0001     |
| 2            | \( HCW = -21.52(\pm 3.92) + 0.30(\pm 0.07) \times BL + 0.27(\pm 0.05) \times RH \) | 23.86 | 0.65 | 0.87 | <0.0001     |
| 3            | \( HCW = -19.44(\pm 3.53) + 0.26(\pm 0.06) \times BL + 0.24(\pm 0.05) \times RH + 1.07(\pm 0.30) \times BCS \) | 10.83 | 0.74 | 0.77 | <0.0001     |
| 4            | \( HCW = -17.98(\pm 3.42) + 0.22(\pm 0.06) \times BL + 0.18(\pm 0.05) \times RH + 0.26(\pm 0.11) \times BWR + 1.06(\pm 0.28) \times BCS \) | 7.23 | 0.76 | 0.73 | <0.0001     |
| 5            | \( HCW = -19.88(\pm 3.51) + 0.21(\pm 0.06) \times BL + 0.15(\pm 0.05) \times RH + 0.30(\pm 0.11) \times BWR + 0.06(\pm 0.03) \times RP + 0.87(0.30) \times BCS \) | 6.12 | 0.78 | 0.72 | <0.0001     |
| 6            | \( HCW = -20.25(\pm 3.37) + 0.24(\pm 0.06) \times BL + 0.14(\pm 0.07) \times WH - 0.01(\pm 0.09) \times RH + 0.22(\pm 0.11) \times BWR + 0.07(\pm 0.03) \times RP + 0.91(\pm 0.29) \times BCS \) | 4.03 | 0.80 | 0.69 | <0.0001     |
| 7            | \( HCW = -20.31(\pm 3.31) + 0.23(\pm 0.06) \times BL + 0.14(\pm 0.04) \times WH + 0.22(\pm 0.11) \times BWR + 0.07(\pm 0.03) \times RP + 0.91(\pm 0.28) \times BCS \) | 2.06 | 0.80 | 0.68 | <0.0001     |
| Cold carcass weight (CCW) |                                                                          |     |      |      |             |
| 1            | \( CCW = -9.92(\pm 3.45) + 0.37(\pm 0.06) \times BL \)                   | 51.61 | 0.50 | 1.03 | <0.0001     |
| 2            | \( CCW = -21.66(\pm 3.90) + 0.30(\pm 0.07) \times BL + 0.27(\pm 0.05) \times RH \) | 23.85 | 0.65 | 0.86 | <0.0001     |
| 3            | \( CCW = -19.57(\pm 3.49) + 0.25(\pm 0.06) \times BL + 0.24(\pm 0.05) \times RH + 1.07(\pm 0.29) \times BCS \) | 10.51 | 0.74 | 0.76 | <0.0001     |
| 4            | \( CCW = -18.11(\pm 3.39) + 0.22(\pm 0.06) \times BL + 0.18(\pm 0.05) \times RH + 0.26(\pm 0.11) \times BWR + 1.07(0.28) \times BCS \) | 6.78 | 0.77 | 0.73 | <0.0001     |
| 5            | \( CCW = -19.97(\pm 3.47) + 0.21(\pm 0.06) \times BL + 0.14(\pm 0.05) \times RH + 0.30(\pm 0.11) \times BWR + 0.06(\pm 0.03) \times RP + 0.88(\pm 0.29) \times BCS \) | 5.74 | 0.78 | 0.71 | <0.0001     |
| 6            | \( CCW = -20.33(\pm 3.34) + 0.23(\pm 0.06) \times BL + 0.14(\pm 0.04) \times WH - 0.01(\pm 0.09) \times RH + 0.23(\pm 0.11) \times BWR + 0.07(\pm 0.03) \times RP + 0.92(\pm 0.28) \times BCS \) | 3.81 | 0.80 | 0.68 | <0.0001     |
| Hot carcass yield (HCY) |                                                                          |     |      |      |             |
| 1            | \( HCY = 31.11(\pm 4.35) + 0.48(\pm 0.11) \times THP \)                   | 8.67 | 0.31 | 1.82 | <0.0001     |
| 2            | \( HCY = 31.68(\pm 4.21) + 0.38(\pm 0.12) \times THP + 1.41(\pm 0.70) \times BCS \) | 6.33 | 0.37 | 1.75 | <0.0001     |
| 3            | \( HCY = 42.87(\pm 5.87) + 0.38(\pm 0.11) \times THP - 0.16(\pm 0.06) \times TP + 2.16(\pm 0.72) \times BCS \) | 1.97 | 0.45 | 1.65 | <0.0001     |
| 4            | \( HCY = 39.26(\pm 5.88) + 0.36(\pm 0.11) \times THP + 0.21(0.10) \times RP - 0.29(\pm 0.08) \times TP + 1.95(\pm 0.70) \times BCS \) | -0.16 | 0.51 | 1.58 | <0.0001     |
| Cold carcass yield (CCY) |                                                                          |     |      |      |             |
| 1            | \( CCY = 29.15(\pm 4.37) + 0.50(\pm 0.11) \times THP \)                   | 8.94 | 0.32 | 1.82 | <0.0001     |
| 2            | \( CCY = 29.75(\pm 4.22) + 0.39(\pm 0.11) \times THP + 1.50(\pm 0.70) \times BCS \) | 6.05 | 0.38 | 1.75 | <0.0001     |
| 3            | \( CCY = 40.61(\pm 5.90) + 0.39(\pm 0.11) \times THP - 0.15(\pm 0.06) \times TP + 2.23(\pm 0.72) \times BCS \) | 2.10 | 0.46 | 1.66 | <0.0001     |
| 4            | \( CCY = 36.93(\pm 5.89) + 0.37(\pm 0.11) \times THP + 0.21(0.10) \times RP - 0.28(\pm 0.08) \times TP + 2.01(\pm 0.70) \times BCS \) | -0.15 | 0.52 | 1.59 | <0.0001     |
### Table 4 (Continued)

| No. equation | Equation                                                                 | Cp  | R²   | RMSE | P-value  |
|--------------|---------------------------------------------------------------------------|-----|------|------|----------|
| **Internal fat (IF)** |                                                                          |     |      |      |          |
| 1            | IF = −5.48(±1.84)+0.12(±0.03)RH                                            | 5.04| 0.26 | 0.55 | <0.0001  |
| 2            | IF = −5.39(±1.74)+0.10(±0.03)RH+0.51(±0.20)BCS                            | 0.60| 0.36 | 0.36 | <0.0001  |
| 3            | IF = −3.76(±1.94)+0.15(±0.04)RH−0.09(±0.05)TL+0.56(±0.19)BCS              | −0.17| 0.40 | 0.40 | <0.0001  |
| **Waste parts of the carcass (OFF)** |                                                                   |     |      |      |          |
| 1            | OFF = −6.81(±2.66)+0.24(±0.05)BL                                              | 13.21| 0.39 | 0.64 | <0.0001  |
| 2            | OFF = −7.34(±2.42)+0.17(±0.05)BL+0.24(±0.07)BRW                            | 4.31| 0.50 | 0.50 | <0.0001  |
| 3            | OFF = −6.78(±2.33)+0.15(±0.05)BL+0.22(±0.07)BRW+0.48(0.21)BCS             | 1.54| 0.56 | 0.56 | <0.0001  |
| **Viscera and organs (VISC)** |                                                                 |     |      |      |          |
| 1            | VISC = 4.69656(±0.99)+1.69746(±0.40)LL                                        | 7.00| 0.29 | 1.11 | <0.0001  |
| 2            | VISC = 1.60340(±1.77)+1.27396(±0.44)LL+0.14265(±0.07)BCS                   | 3.91| 0.35 | 1.07 | <0.0001  |
| **Loin eye area (LEA)** |                                                                 |     |      |      |          |
| 1            | LEA = 4.70(±1.00)+1.70(±0.40)BCS                                              | 7.06| 0.29 | 1.11 | <0.0001  |
| 2            | LEA = 4.04(±4.48)+0.16(±0.06)BL+1.45(±0.41)BCS                             | 4.91| 0.35 | 1.07 | <0.0001  |

**RH** - rump height; **BL** - body length; **BCS** - body condition score; **BRW** - breast width; **RP** - rump perimeter; **WH** - withers height; **THP** - thoracic perimeter; **TP** - thigh perimeter; **TL** - thigh length; **LL** - leg length; **RMSE** - root mean square error.

**Cp** - means that the model is relatively precise; **R²** - coefficient of determination; **RMSE** - root mean square error.
assess the fit of a regression model that has been estimated using ordinary least squares. It is applied in the context of model selection, in which some predictor variables are available for predicting some outcome (Hocking, 1976).

The BCS variable, when included in the models, improves the accuracy of the prediction mode. Bonilha et al. (2011) and Tedeschi et al. (2013) also noted that fat deposits are among the body components demonstrating the most significant variation among carcass characteristics. This diversity in body fat deposits is due to several factors, such as breed, sex, age, weight, and maturity (Bautista-Díaz et al., 2017).

The prediction equations of LEA presented $R^2$ similar to that of the prediction equations of VISC. Considering the characteristics of the fat deposits of the Morada Nova breed, crossbreeding of this breed with terminal sire breeds can improve performance characteristics in lambs (Issakowicz et al., 2018).

The measurements in the live animal did not result in substantial increases in $R^2$ but led to reducing the lack of fit ($C_p \sim p$) and reduced residual variance (Cardoso et al., 2020). Hernandez-Espinoza et al. (2012) reported that carcass yield is associated with withers height. However, these results differ from those of the present study, which demonstrates that in the case of carcass yield, WH is only correlated when associated with other BM. The yields presented a low correlation with BM because their values come from the ratio between the values of HCW and CCW.

5. Conclusions

Biometric measurements can be used to estimate the carcass characteristics of Morada Nova lambs efficiently. The prediction models found in this study indicate their high levels of accuracy.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: R.G. Costa, A.G.V.O. Lima and A.N. Medeiros. Data curation: A.G.V.O. Lima, N.L. Ribeiro and G.R. Medeiros. Formal analysis: A.G.V.O. Lima. Investigation: A.G.V.O. Lima and N.L. Ribeiro. Methodology: A.G.V.O. Lima and N.L. Ribeiro. Resources: R.G. Costa, S. Gonzaga Neto and R.L. Oliveira. Supervision: R.G. Costa, A.N. Medeiros, G.R. Medeiros, S. Gonzaga Neto and R.L. Oliveira. Writing-original draft: R.G. Costa, A.G.V.O. Lima and N.L. Ribeiro. Writing-review & editing: N.L. Ribeiro.

References

Assan, N. 2013. Bioprediction of body weight and carcass parameters from morphometric measurements in livestock and poultry. Scientific Journal of Review 2:140-150.

Bautista-Díaz, E.; Salazar-Cuytun, R.; Chay-Canul, A. J.; García Herrera, R. A.; Piñeiro-Vázquez, A. T.; Magaña Monforte, J. G.; Tedeschi, L. O.; Cruz-Hernández, A. and Gómez-Vázquez, A. 2017. Determination of carcass traits in Pelibuey ewes using biometric measurements. Small Ruminant Research 147:115-119. https://doi.org/10.1016/j.smallrumres.2016.12.037

Bonilha, S. F. M.; Tedeschi, L. O.; Packer, I. U.; Razook, A. G.; Nardon, R. F.; Figueiredo, L. A. and Alleoni, G. F. 2011. Chemical composition of the whole body and carcass of Bos indicus and tropically adapted Bos taurus breeds. Journal of Animal Science 89:2859-2866. https://doi.org/10.2527/jas.2010-3649

Brasil. 2000. Ministério da Agricultura, Pecuária e Abastecimento. Instrução Normativa nº 3, de 17 de janeiro de 2000. Regulamento técnico de métodos de insensibilização para o abate humanitário de animais de açougue. Diário Oficial da União, Brasília, 24 de janeiro de 2000, Seção 1. p14-16.

Cantón, J. G. C.; Velázquez, A. M. and Castellanos, A. R. 1992. Body composition of purebred crossbred Blackbelly sheep. Small Ruminant Research 7:61-66. https://doi.org/10.1016/0921-4488(92)90068-F

Cardoso, L. L.; Tarouco, J. U.; MacNeil, M. D.; Lobato, J. F. P.; Dambrós, M. C.; Freitas, A. K.; Devincenzi, T.; Feijó, F. D. and Cardoso, F. F. 2020. Sample size and prediction of weight and yield of individual cuts from Bradford steer pistol hindquarters. Scientia Agricola 77:e20180224. https://doi.org/10.1590/1678-992x-2018-0224
Cézar, M. F. and Sousa, W. H. 2007. Carcaças ovinas e caprinas: obtenção-avaliação-classificação. Agropecuária Tropical, Uberaba.

De Paula, N. F.; Tedeschi, L. O.; Paulino, M. F.; Fernandes, H. J. and Fonseca, M. A. 2013. Predicting carcass and body fat composition using biometric measurements of grazing beef cattle. Journal of Animal Science 91:3341-3351. https://doi.org/10.2527/jas.2012-5233

Facó, O.; Paiva, S. R.; Alves, L. R. N.; Lôbo, R. N. B.; Villela, L. C. V. 2008. Raça Morada Nova: Origem, características e perspectivas. Embrapa Caprinos, Sobral. (Série Documentos no. 75).

Fernandes, H. J.; Tedeschi, L. O.; Paulino, M. F. and Paiva, L. M. 2010. Determination of carcass and body fat compositions of grazing crossbred bulls using body measurements. Journal of Animal Science 88:1442-1453. https://doi.org/10.2527/jas.2009-1919

Fonseca, M. A.; Tedeschi, L. O.; Valadares Filho, S. C.; De Paula, N. F.; Silva, L. D. and Sathler, D. F. T. 2016. Evaluation of equations to estimate body composition in beef cattle using live, linear, and standing-rib cut measurements. Animal Production Science 57:378-390. https://doi.org/10.1071/AN15312

Hernandez-Espinosa, D. P.; Olva-Hernández, J.; Pascual-Córdova, A. and Hinojosa-Guáller, J. A. 2012. Descripción de medidas corporales y composición de la canal en corderos Pelibuey: Estudio preliminar. Revista Cientifica 22:24-31.

Hocking, R. R. 1976. The analysis and selection of variables in linear regression. Biometrics 32:1-49. https://doi.org/10.2307/2529336

Issakovicz, J.; Issakovicz, A. C. K. S.; Bueno, M. S.; Costa, R. L. D.; Geraldo, A. T.; Abdalla, A. L.; McManus, C. and Louvandini, H. 2018. Crossbreeding locally adapted hair sheep to improve productivity and meat quality. Scientia Agricola 75:288-295. https://doi.org/10.1590/1678-992x-2016-0505

Karaca, O.; Altn, T.; Cemal, İ.; Özdemir, S. and Yılmaz, M. 2009. Body measurements and udder characteristics in Karya sheep. p.355-361. In: Proceedings of the 6th National Animal Science Congress, Erzurum (Atatürk University Faculty of Agriculture).

MacNeil, M. D. 1983. Choice of a prediction equation and the use of the selected equation in subsequent experimentation. Journal of Animal Science 57:1328-1336. https://doi.org/10.2527/jas1983.5731328x

Mahieu, M.; Navès, M. and Arquet, R. 2011. Predicting the body mass of goats from body measurements. Livestock Research for Rural Development 23.

Mallows, C. L. 1973. Some comments on Cp. Technometrics 15:661-675.

McGregor, B. A. 2017. Relationships between live weight, body condition, dimensional and ultrasound scanning measurements, and carcass attributes in adult Angora goats. Small Ruminant Research 147:8-17. https://doi.org/10.1016/j.smallrumres.2016.11.014

McManus, C.; Olivardo, F.; Shiotsuki, L.; Rolo, J. L. J. P. and Peripolli, V. 2019. Pedigree analysis of Brazilian Mora Nova hair sheep. Small Ruminant Research 170:37-42. https://doi.org/10.1016/j.smallrumres.2018.11.012

Medeiros, G. R.; Carvalho, F. F.; Batista, A. M. V.; Dutra Júnior, W. M.; Santos, G. R. A. and Andrade, D. K. B. 2009. Efeito dos níveis de concentrado sobre as características de carcaça de ovinos Morada Nova em confinamento. Revista Brasileira de Zootecnia 38:718-727. https://doi.org/10.1590/S1516-35982009000400019

NRC - National Research Council. 2007. Nutrient requirements of small ruminants. 7th ed. National Academic Press, Washington, DC.

Ojedapo, L. O.; Adeleji, T.A.; Olayeni, T. B.; Adeleji, O. S.; Abdullah, A. R. and Ojebiyi, 0. O. 2007. Influence of age and sex on body weight and some body linear measurements of extensively reared wad goats in derived savannah zone of Nigeria. Journal of Animal and Veterinary Advances 6:114-117.

Ricardo, H. A.; Roça, R. O.; Lambe, N. R.; Seno, L. O.; Fusikawa, I. H. S. and Fernandes, A. R. M. 2016. Prediction of weight and percentage of salable meat from Brazilian market lambs by subjective conformation and fatness scores. Revista Brasileira de Zootecnia 45:639-644. https://doi.org/10.1590/S1516-35982016000400010

Shehata, M. F. 2013. Prediction of live body weight and carcass traits by some live body measurements in Barki lambs. Egyptian Journal of Animal Production 50:69-75.

Souza, D. S.; Silva, H. P.; Carvalho, J. M. P.; Melo, W. O.; Monteiro, B. M. and Oliveira, D. R. 2014. Desenvolvimento corporal e relação entre biometria e peso de cordeiros lactantes da raça Santa Inês criados na Amazônia. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 66:1787-1794. https://doi.org/10.1590/1678-7364

Supriyantono, A.; Tomiyama, M. and Suzuki, K. 2012. Estimation of (co)variance components and genetic parameter of withers height, chest girth, and body length of Bali cattle using an animal model. International Journal of Molecular Zoology 2:45-50.

Sowande, O. S. and Sobola, O. S. 2008. Body measurements of West African dwarf sheep as parameters for estimation of live weight. Tropical Animal Health and Production 40:433-439. https://doi.org/10.1007/s11250-007-9116-z

Tedeschi, L. O.; Fox, D. G. and Kononoff, P. J. 2013. A dynamic model to predict fat and protein fluxes associated with body reserve changes in cattle. Journal of Dairy Science 96:2448-2463. https://doi.org/10.3168/jds.2012-6070

R. Bras. Zootec., 49:e20190179, 2020
Yakubu, A. and Mohammed, G. L. 2012. Application of path analysis methodology in assessing the relationship between body weight and biometric traits of red Sokoto goats in Northern Nigeria. Biotechnology in Animal Husbandry 28:107-117. https://doi.org/10.2298/BAH1201107Y

Yilmaz, O.; Cemal, I. and Karaca, O. 2013. Estimation of mature live weight using some body measurements in Karya sheep. Tropical Animal Health and Production 45:397-403. https://doi.org/10.1007/s11250-012-0229-7