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Predicting the carcass characteristics of Morada Nova lambs using biometric measurements

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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 R^2 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; Yilmaz 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 (R^2), the root mean square error (RMSE), and the Cp statistic $\left(\frac{SSE}{\hat{\sigma}^2} + 2p - n\right)$ (Equation 1), in which SSE is the error sum of squares, σ^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).

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 perimeter	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.

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 Cp parameter substitute was used to

Table 2 - Significant Pearson's correlation coefficients ($P<0.05$) among animal, biometric measurements, and carcass characteristics

Variable	WH	RH	TL	BRW	RW	TP	RP	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	0.31	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		0.54	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
BRW	-	-	-	-	0.75	0.45					0.54	0.62	0.66	0.35	0.33	0.35		0.46	0.58	
RW	-	-	-	-	-	0.58						0.36	0.47	0.44	0.42	0.43		0.43	0.35	
TP	-	-	-	-	-	-				0.43	0.30	0.44	0.53	0.57	0.55	0.57		0.43	0.39	0.30
RP	-	-	-	-	-	-	-	0.77	0.43	0.44	0.50	0.44	0.49					0.37	0.39	
THP	-	-	-	-	-	-	-	-	0.39	0.43	0.45	0.34	0.35						0.30	
LL	-	-	-	-	-	-	-	-	-		0.51	0.52	0.51						0.41	
BCS	-	-	-	-	-	-	-	-	-	-	0.47	0.43	0.55	0.47	0.46	0.47		0.44	0.44	0.53
SBW	-	-	-	-	-	-	-	-	-	-	-	0.92	0.81					0.39	0.69	0.47
EBW	-	-	-	-	-	-	-	-	-	-	-	-	0.92	0.32	0.29	0.31		0.34	0.76	0.57
HCW	-	-	-	-	-	-	-	-	-	-	-	-	-	0.99	0.55	0.58		0.55	0.65	0.49
CCW	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.56	0.59		0.55	0.42	0.49
HCY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.99		0.56	0.76	
CCY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		0.58	0.42	
VISC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		0.44	
IF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.80	
OFF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

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(±7.24)+0.82(±0.12)BL	61.35	0.50	1.75	<0.0001
2	SBW = −30.66(±6.50)+0.68(±0.11)BL+0.28(±0.06)WH	32.78	0.57	1.76	<0.0001
3	SBW = −40.56(±5.98)+0.55(±0.10)BL+0.32(±0.06)WH+0.19(±0.04)TP	12.83	0.75	1.26	<0.0001
4	SBW = −38.68(±5.80)+0.48(±0.10)BL+0.22(±0.07)WH+0.43(±0.20)BRW+0.19(±0.04)TP	9.59	0.78	1.20	<0.0001
5	SBW = −39.10(±5.53)+0.43(±0.10)BL+0.26(±0.07)WH+0.76(±0.24)BRW−0.27(±0.12)RW+0.20±(0.04)TP	6.33	0.80	1.15	<0.0001
	Empty body weight (EBW)				
1	EBW = −18.01(±6.35)+0.68(±0.11)BL	40.83	0.50	1.53	<0.0001
2	EBW = −26.37(±5.51)+0.55(±0.09)BL+0.26(±0.06)WH	14.45	0.65	1.26	<0.0001
3	EBW = −32.33(±5.58)+0.47(±0.09)BL+0.28(±0.05)WH+0.11(±0.04)TP	8.11	0.70	1.17	<0.0001
4	EBW = −31.09(±5.56)+0.42(±0.09)BL+0.22(±0.07)WH+0.28(±0.19)BRW+0.12(±0.04)TP	7.73	0.72	1.16	<0.0001
5	EBW = −31.42(±5.42)+0.38(±0.09)BL+0.25(±0.07)WH+0.54(±0.23)BRW−0.21(±0.11)RW+0.12(±0.04)TP	6.38	0.74	1.13	<0.0001
6	EBW = −28.99(±5.49)+0.36(±0.09)BL+0.25(±0.06)WH+0.55(±0.22)BRW−0.25(±0.11)RW+0.10(±0.04)TP+0.79(±0.47)BCS	5.61	0.76	1.11	<0.0001
7	EBW = 27.30(±5.46)+0.38(±0.09)BL+0.33(±0.08)WH−0.19(±0.11)TL+0.58(±0.22)BRW−0.31(±0.12)RW+0.13(±0.04)TP+0.86(±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	R^2	RMSE	P-value
	Hot carcass weight (HCW)				
1	HCW = −9.67(±3.48)+0.37(±0.06)RH	51.74	0.49	1.04	<0.0001
2	HCW = −21.52(±3.92)+0.30(±0.07)BL+0.27(±0.05)RH	23.86	0.65	0.87	<0.0001
3	HCW = −19.44(±3.53)+0.26(±0.06)BL+0.24(0.05)RH+1.07(±0.30)BCS	10.83	0.74	0.77	<0.0001
4	HCW = −17.98(±3.42)+0.22(±0.06)BL+0.18(±0.05)RH+0.26(±0.11)BRW+1.06(±0.28)BCS	7.23	0.76	0.73	<0.0001
5	HCW = −19.88(±3.51)+0.21(±0.06)BL+0.15(±0.05)RH+0.30(±0.11)BRW+0.06(±0.03)RP+0.87(0.30)BCS	6.12	0.78	0.72	<0.0001
6	HCW = −20.25(±3.37)+0.24(±0.06)BL+0.14(±0.07)WH−0.01(±0.09)RH+0.22(±0.11)BRW+0.07(±0.03)RP+0.91(±0.29)BCS	4.03	0.80	0.69	<0.0001
7	HCW = −20.31(±3.31)+0.23(±0.06)BL+0.14(±0.04)WH+0.22(±0.11)BRW+0.07(±0.03)RP+0.91(±0.28)BCS	2.06	0.80	0.68	<0.0001
	Cold carcass weight (CCW)				
1	CCW = −9.92(±3.45)+0.37(±0.06)BL	51.61	0.50	1.03	<0.0001
2	CCW = −21.66(±3.90)+0.30(±0.07)BL+0.27(±0.05)RH	23.85	0.65	0.86	<0.0001
3	CCW = −19.57(±3.49)+0.25(±0.06)BL+0.24(±0.05)RH+1.07(±0.29)BCS	10.51	0.74	0.76	<0.0001
4	CCW = −18.11(±3.38)+0.22(±0.06)BL+0.18(±0.05)RH+0.26(±0.11)BRW+1.07(0.28)BCS	6.78	0.77	0.73	<0.0001
5	CCW = −19.97(±3.47)+0.21(±0.06)BL+0.14(±0.05)RH+0.30(±0.11)BRW+0.06(±0.03)RP+0.88(±0.29)BCS	5.74	0.78	0.71	<0.0001
6	CCW = −20.33(±3.34)+0.23(±0.06)BL+0.14(±0.07)WH−0.01(±0.09)RH+0.23(±0.11)BRW+0.07(±0.03)RP+0.92(±0.28)BCS	3.81	0.80	0.68	<0.0001
	Hot carcass yield (HCY)				
1	HCY = 31.11(±4.35)+0.48(±0.11)THP	8.67	0.31	1.82	<0.0001
2	HCY = 31.68(±4.21)+0.38(±0.12)THP+1.41(±0.70)BCS	6.33	0.37	1.75	<0.0001
3	HCY = 42.87(±5.87)+0.38(±0.11)THP−0.16(±0.06)TP+2.16(±0.72)BCS	1.97	0.45	1.65	<0.0001
4	HCY = 39.26(±5.88)+0.36(±0.11)THP+0.21(0.10)RP−0.29(±0.08)TP+1.95(±0.70)BCS	−0.16	0.51	1.58	<0.0001
	Cold carcass yield (CCY)				
1	CCY = 29.15(±4.37)+0.50(±0.11)THP	8.94	0.32	1.82	<0.0001
2	CCY = 29.75(±4.22)+0.39(±0.11)THP+1.50(±0.70)BCS	6.05	0.38	1.75	<0.0001
3	CCY = 40.61(±5.90)+0.39(±0.11)THP−0.15(±0.06)TP+2.23(±0.72)BCS	2.10	0.46	1.66	<0.0001
4	CCY = 36.93(±5.89)+0.37(±0.11)THP+0.21(0.10)RP−0.28(±0.08)TP+2.01(±0.70)BCS	−0.15	0.52	1.59	<0.0001

Continues...

Table 4 (Continued)

No. equation	Equation	Cp	R^2	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(±0.08)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; R^2 - 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 (Cp~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.

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