The Journal of Agricultural Science

cambridge.org/ags

Using multivariate analysis to predict carcass characteristics of lambs in grazing and supplemented with different levels of non-protein nitrogen

Francisca Fernanda da Silva Roberto[1], Neila Lidiany Ribeiro[2], Gelson dos Santos Difante[1], Diego Gomes Freire Guidolin[1], Luís Carlos Vinhas Ítavo[1], Camila Celeste Brandão Ferreira Ítavo[1], Jéssica Gomes Rodrigues[1], Marislayne de Gusmão Pereira[1] and Roberto Germano Costa[3]

[1]Department of Animal Science, Federal University of Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil; [2]Department of the National Semi-Arid Institute, Campina Grande, Paraíba, Brazil and [3]Department of Animal Science, Federal University of Paraíba, Areia, Paraíba, Brazil

Animal Research Paper

Cite this article: Roberto FFdaS, Ribeiro NL, Difante GdosS, Guidolin DGF, Ítavo LCV, Ítavo CCBF, Rodrigues JG, Pereira MdeG, Costa RG (2024). Using multivariate analysis to predict carcass characteristics of lambs in grazing and supplemented with different levels of non-protein nitrogen. *The Journal of Agricultural Science* 1–8. https://doi.org/10.1017/S0021859624000303

Received: 2 October 2023
Revised: 20 March 2024
Accepted: 7 May 2024

Keywords:
canonical; discriminatory power; extruded urea; mathematical equations; *stepwise*

Corresponding author:
Neila Lidiany Ribeiro;
Email: neilalr@hotmail.com

Abstract

The aim of this study is to assess the effects of substituting soybean meal with extruded urea in the diet of crossbred Texel x no defined racial pattern lambs under continuous grazing on *Brachiaria* ssp., focusing on both their productive and nutritional performance. 60 Texel crossbred lambs (12 animals for each treatment) were used, with an average initial weight of 20.7 ± 0.87 kg and an average age of 2.5 ± 0.70 months, fed treatments with increasing levels of UE (Urea extruded Amireia® 200S): 0; 6; 12; 18 and 24 grams of EU 100/kg of body weight, with trial period was 5 months, using the multivariate technique. The data were subjected to principal component and canonical discriminant analysis to check possible differences between the evaluated treatments and identify the variables that best discriminate and use these variables to create a discriminant function that represents the differences between treatments. Of the 12 variables initially used, we observed that 9 were used by the main components, but 6 were those that presented the greatest discriminatory power for the study. Main component 1 was characterized by biometric measurements and showed the greatest power of variation in the study (60%), followed by main component 2, represented by slaughter weight and empty body weight (13%). These correlations indicate that biometric measurements can serve as reliable indirect indicators for estimating carcass traits in sheep, offering a practical alternative to visual assessments.

Introduction

Over the years, technologies have been developed to increase productivity, reduce production cycles, enhance carcass quality, and strengthen the sheep production chain (Possamai *et al.*, 2017). Among these, protein supplementation stands out as a widely used technique to stimulate the consumption of low-quality forage and improve the nutritional value of diets according to the needs of different animal categories, thereby increasing protein and energy intake (Euclides *et al.*, 2018). However, high-quality protein ingredients such as oilseed meal can escalate diet costs. Therefore, the use of non-protein nitrogen (NPN) presents an option for optimizing ruminant production on pasture while reducing expenses (Xu *et al.*, 2019). Ruminants possess the unique ability to convert plant material and NPN into high-biological-value protein, such as meat and milk, for human consumption and other products (Xu *et al.*, 2019), thanks to the symbiotic relationship between them and the ruminal microbiome. This results in a significant portion of beef production occurring in cultivated and/or native pastures.

Among the NPN sources currently used in cattle farming (Ítavo *et al.*, 2016; Moraes *et al.*, 2019), extruded urea (Amireia) offers advantages such as slow urea release, reduced ammonia toxicity and improved accetability (Bartley and Deyoe, 1975). The extrusion of components (starch, urea and sulphur) enables better nutrition for the ruminal microbiota, microbial growth, and the synthesis of sulphur-containing amino acids, aiming to mitigate issues related to urea utilization (Ítavo *et al.*, 2016; Carvalho *et al.*, 2019). However, there is still limited knowledge regarding the use of extruded urea in the nutrition and production of sheep, necessitating further research to elucidate its effects and recommended levels of inclusion in the diet of lambs kept under continuous grazing on *Brachiaria* ssp. pastures, considering both nutritional and performance aspects.

Carcass evaluation is typically performed considering a large number of characteristics, some of which may be redundant, making interpretation challenging through univariate analyses (Barbosa *et al*., 2005). Therefore, multivariate analysis techniques prove efficient when multiple pieces of information stem from an experiment and need to be combined to associate or predict biological phenomena based on a set of variables crucial for experimental design development (Dillon and Goldstein, 1984). Consequently, a more comprehensive data interpretation can be achieved through these techniques, which are better suited for studying a set of correlated variables and their relationships with nutritional, management and genetic factors.

Hence, the objective of this study is to assess the effects of substituting soybean meal with extruded urea (0; 6; 12; 18 and 24 grams of EU 100/kg of body weight) in the diet of crossbred Texel x no defined racial pattern lambs under continuous grazing on *Brachiaria* ssp., focusing on both their productive and nutritional performance and the carcass. Additionally, this study aims to identify the key variables that influence carcass characteristics through canonical discriminant analysis.

Materials and methods

Ethical considerations and experimental location

The study received approval and was conducted in accordance with the Ethics Committee on Animal Use (CEUA) of the Federal University of Mato Grosso do Sul (UFMS), under protocol number 0862/2017.

The experiment took place at the experimental area of the Sheep Farming Sector within the School Farm of the Federal University of Mato Grosso do Sul – UFMS, situated in the municipality of Terenos – MS (20°26’34.31” S and 54°50’27.86” W), at an altitude of 530.7 metres. The experimental period spanned from December 2018 to April 2019, corresponding to the rainy season in the region, with a cumulative precipitation of 780.9 mm and an average temperature of 25.4°C.

Study area, sample and experimental treatments

The pasture area consisted of a mixed pasture of *Brachiaria* spp. (Marandu and Basilisk cultivars) covering 2.15 hectares, subdivided into five paddocks of approximately 0.43 hectares each. Continuous stocking was the grazing method adopted, and the grazing areas were equipped with water troughs, feeders, and sheltered areas with free access.

A total of 60 lambs were utilized for the study, with 12 animals assigned to each treatment, ensuring an equal distribution of both sexes (0.50 each). These lambs were crossbred Texel, with an initial average weight of 20.7 ± 0.87 kg and an average age of 2.5 ± 0.70 months. The treatments corresponded to increasing levels of extruded urea (Amireia® 200S): 0; 6; 12; 18; and 24 grams of extruded urea per 100/kg of body weight (BW). The supplements were formulated to contain 0.21 crude protein and to meet the nutritional requirements for a daily average gain of 200 g, following NRC (2007) recommendations (Table 1). The animals were provided with the supplement daily at a fixed rate of 0.016 of their body weight.

Animal performance

To assess the evolution of the lambs’ weight and body condition, weighing and evaluations were conducted every 14 days. Weighing took place at 8:00 AM using an analogue scale located in the handling centre. Additionally, biometrics were employed every 28 days, in the animal, to measure the following variables: anterior height (AH), posterior height (PH), leg circumference (LC), chest width (CW), rump width (RW), thoracic perimeter (TP), and barrel perimeter (BP). Measurements were conducted using a height gauge and a measuring tape, following the descriptions by Yañes *et al*. (2004).

Anterior height was defined as the distance between the withers region and the distal end of the front limb, while posterior height was defined as the distance between the sacral tuberosity and the distal end of the hind limb. Leg circumference was measured in the middle part of the leg, above the femorotibial-tibiotarsal joint. Chest width was defined as the distance between the lateral sides of the scapulohumeral joints, and rump width was defined as the distance between the greater trochanters of the femurs. Thoracic perimeter was measured at the axillary region, and barrel perimeter was defined as the external circumference of the abdominal cavity at the line of the umbilical scar.

Pre-slaughter management

When the lambs reached an average body weight of 37.3 ± 5.6 kg and an average age of 6.5 ± 0.71 months, pre-slaughter management was initiated. This management involved the measurement of the slaughter weight (SW), which was carried out using a precision digital scale. After the slaughter and dressing procedure, the carcasses were identified and weighed to obtain the hot carcass weight (HCW, kg).

The empty body weight (EBW) was obtained by summing the weight of the carcass and empty non-carcass components. Subsequently, the carcasses were chilled at 2 ± 2°C for 24 h. The calculation of the hot carcass yield (HCY) was performed using the equation HCY = (HCW, kg/SW, kg), and the true yield (TY) was calculated using the equation TY = (HCW, kg/EBW, kg), following Osório and Osório (2001).

The loin eye area (LEA) was determined using tracing paper and a permanent marker to outline the area of the *Longissimus lumborum* (LL) muscle. The maximum width (A) and maximum depth (B) were measured with a ruler and used in the formula: $LEA = (A/2 * B/2)\pi$, as described by Silva Sobrinho (1999).

Statistical analysis

The results were submitted to analysis of variance, the variables relating to performance and biometrics were evaluated by regression using PROC REG in SAS (2001), and the effect of sex on the variables was compared by Tukey (General Linear Models) and their interaction, both tests had a significance level of 5%, and averages between 0.05% and 0.10% were considered as a trend. Correlation analysis was carried out using PROC CORR in SAS (2001) and the multivariate analyses were carried out using Statistica 8.0 software.

Pearson’s simple correlation analysis was adopted. Pearson’s correlation coefficient is a technique for measuring whether two variables are linearly related.

The data was subjected to principal component analysis (PCA) with the aim of synthetically describing the number of variables and obtaining the components, which are the underlying dimensions that can be identified and named. The analysis was based on the correlation matrix of the original variables.

To assess potential differences among the evaluated treatments and identify the variables that best discriminate between them, the

Table 1. Percentage of ingredients in experimental diets (%) based on the natural matter and chemical composition of the supplement with extruded urea (Amireia® 200s) at increasing levels replacing soybean meal

	Ingredients				
Urea levels* (g/100 kg BW)	Corn bran	Soybean meal	Extruded urea	Mineral supplement	
0	670	302	-	28	
6	713	247	12	28	
12	755	193	24	28	
18	798	139	35	28	
24	841	84	47	28	
Chemical composition					
Dry matter (g/kg NM)	886	883	950	**Mineral supplement	
Ashes (g/kg DM)	12	74	4		
Organic matter (g/kg DM)	988	926	995		
Crude protein (g/kg DM)	75	520	200		
Ethereal extract (g/kg DM)	34	29	24		
NDF (g/kg DM)	219	329	26		
Acid detergent fibre (g/kg DM)	53	182	14		
Chemical composition (g/kg DM)	Urea levels* (g/100 kg BW)				
	0	6	12	18	24
Dry matter (g/kg NM)	866	866	866	865	859
Ashes (g/kg DM)	80	78	68	64	70
Organic matter (g/kg DM)	919	922	931	935	929
Crude protein (g/kg DM)	174	193	190	201	257
Ethereal extract (g/kg DM)	104	103	107	108	114
NDF (g/kg DM)	202	163	158	137	94

*Amireira® 200S; **Composition (per kg of product): Na-1470 g; Ca-1200 g; P-87,0 g; S-18,0 g; Zn- 3800,0 mg; Fe-18000,0 mg; Mn-1300,0 mg; monensin sodium-1300,0 mg; F-8700 mg; Cu-5900 mg; Mo-3000 mg; I-80,0 mg; Co-40,0 mg; Cr-20,0 mg; Se-15,0 mg. BW, body weight; NM, Natural matter; DM, Dry matter; NDF, Neutral detergent fibre.

data underwent canonical discriminant analysis. For this purpose, the mathematical model $D(x) = L'.x = [x_1 - x_2]'S^{-1}.x$ was employed, where $D(x)$ represents the Fisher's linear discriminant function, L is the estimate of the discriminant vector, x_1 is the sample mean of population p, and x is the sample mean of population p.

The selection of variables with the highest discriminatory power was carried out using the stepwise method, which combines the addition of variables with the greatest discriminatory power and eliminates those with lesser contributions, based on the F-statistic or Wilks' lambda value. The primary objective of this procedure is to identify the best set of variables to compose the discriminant function.

Results

There was no significant effect ($P > 0.05$) for body weight at slaughter (BWS), with an average of 37.3 ± 2.37 kg BW, which demonstrates that even replacing true protein with NPN, in form of extruded urea, the animals maintained the weight gains expected for slaughter. Also, no interaction ($P > 0.05$) was observed between the levels tested and the sexes of the animals for the variables BWS and body condition score at slaughter (BCSS), however a trend effect was observed for BWS, indicating that the level of 24 g/100 kg BW of EU provides lower average BWS, consequently lower BCSS. Males had a higher mean BWS than females, reflecting physiological and hormonal processes corresponding to each sex (Table 2).

For the biometric variables of the lambs (Table 2), no significant effect was observed for TP between the EU levels tested ($P = 0.6400$) and sexes ($P = 0.0661$). There was an interaction ($P = 0.0065$) between levels and sex for the BL of the animals, where males that received 0 g/100 kg BW of EU of extruded urea had higher means for this measurement. Levels of extruded urea influenced LC ($P = 0.0188$) and PH ($P = 0.0240$) responding linearly.

CW ($P = 0.0122$) and RW ($P = 0.0040$) changed depending on the level of urea extruded in sheep feed, animals in groups that received 0 g/100 kg BW of EU had the highest measurements and 6 g/100 kg BW of EU the smallest. When comparing biometric measurements between the sexes, it can be observed that for BL ($P = 0.0188$), AA ($P = 0.004$) and PH ($P = 0.0094$) males stood out with the largest measurements.

Table 3 presents the means, standard deviations, minimum and maximum values of the variables related to the weight and body measurements of the evaluated animals.

Positive correlations were observed between carcass variables and the biometric measurements of the animals (Table 4). Slaughter weight and HCW showed correlations above 0.50

Table 2. Performance and biometrics of sheep supplemented with extruded urea at increasing levels in *Brachiaria* spp. pastures

	Extruded urea levels (g/100 kg BW)					Sex (S)			*P* value		
Variables	0	6	12	18	24	Female	Male	SEM	EU	S	EU*S
BWS (kg)	38.2	39.4	36.0	39.2	33.8	35.5[b]	38.9[a]	5.42	0.068	0.016	0.125
BCSS (1–5)	3.0[ab]	3.1[a]	3.1[ab]	3.0[ab]	2.8[b]	2.9	3.0	0.66	0.034	0.105	0.791
BL (cm)	60.8	57.7	57.6	60.5	57.5	58.8	58.9	5.35	0.051	0.689	0.006
LL (cm)	54.0	53.9	53.2	53.0	53.9	54.3[a]	52.9[b]	3.17	0.782	0.018	0.365
LC[1] (cm)	39.8[ab]	41.4[a]	39.4[ab]	37.5[ab]	37.1[b]	38.9	39.2	4.93	0.018	0.560	0.192
AA (cm)	55.0	54.1	52.9	54.2	53.0	54.9[a]	52.7[b]	3.34	0.115	0.004	0.247
PH[2] (cm)	57.2[a]	55.9[ab]	54.7[ab]	56.0[ab]	54.2[b]	56.4[a]	54.8[b]	3.48	0.024	0.009	0.174
CW (cm)	17.8[a*]	16.0[b]	17.3[ab]	16.9[ab]	17.0[ab]	17.3	16.7	1.81	0.012	0.050	0.364
RW (cm)	19.7[a*]	17.3[b]	18.8[ab]	19.2[a]	18.8[ab]	18.9	18.5	2.17	0.004	0.188	0.752
TP (cm)	79.3	81.5	79.4	78.8	78.2	80.6	78.2	6.84	0.640	0.066	0.521
BP (cm)	91.6	88.9	88.5	92.8	90.0	91.6[a]	89.0[b]	7.06	0.097	0.025	0.122

Means followed by different letters in the line differ from each other using the Tukey test at 5% probability; SEM, standard error of the mean; *orthogonal contrast = Control vs. Extruded urea levels; Body weight at slaughter = BWS; Body condition score slaughter = BCSS. [1]Y = 40,91-0,15x (P = 0,0048; R^2 = 0,71); [2]Y = 56,86-0,09x (P = 0,0121; R^2 = 0,62). BL, body length; LL, leg length; LC, leg circumference; AA, anterior height; PH, posterior height; CW, chest width; RW, rump width; TP, thoracic perimeter and BP, barrel perimeter.

with anterior height (AH), posterior height (PH), thoracic perimeter (TP) and barrel perimeter (BP). On the other hand, EBW exhibited correlations above 0.50 only with AH, PH and TP. HCY displayed correlations above 0.50 with AH, PH, chest width (CW), TP and BP. The LEA had a low correlation with CW (0.40) and did not show a significant correlation with the other variables.

The results of the PCA indicated that the biometric measurements (chest width, rump width, thoracic perimeter and barrel perimeter) were responsible for the most significant variation in the study, accounting for 60% of discriminative power (PC1). Slaughter weight and EBW also contributed significantly, representing 13% of the variation (PC2). Together, the two principal components accounted for 73% of the data variation. Out of the initial 12 variables, only 9 were utilized by the principal components, with 6 of them demonstrating greater discriminative power for the study. The variables with the most influence on PC1 were leg circumference, anterior height, posterior height, chest width, rump width, thoracic perimeter, and barrel perimeter. In contrast, PC2 was most influenced by slaughter weight and EBW (Table 5).

The equations formed and the discriminative power of each variable for each treatment demonstrate that some variables have an inverse relationship with others. Specifically, EBW, posterior height (PH), chest width (CW), rump width (RW), and barrel perimeter (BP) are inversely related to slaughter weight, leg circumference (LC), and anterior height (AA) (Table 6).

The groups exhibit similarities, as shown in Table 7. Each group consists of nine animals, but it was observed that only five animals in the group supplemented with 0 g/100 kg BW of UE exhibit similar behaviour, representing 0.55 of the group. The same pattern was observed for the group supplemented with 12 g/100 kg BW of UE,

Table 3. Mean, standard deviation, minimum, and maximum values of key variables in the study

Variables	Mean	Standard deviation	Minimum	Maximum
Slaughter weight (kg)	38	6.0	22	50
Empty body weight (kg)	22	4.2	13	31
Hot carcass weight (kg)	13	2.8	4	20
Hot carcass yield (%)	34	3.4	20	42
Loin eye area (cm)	14	3.1	5	22
Leg circumference (cm)	36	4.3	27	45
Anterior height (cm)	53	3.8	42	60
Posterior height (cm)	55	4.2	41	62
Chest width (cm)	17	2.1	10	22
Rump width (cm)	18	2.6	12	24
Thoracic perimeter (cm)	76	5.2	64	88
Barrel perimeter (cm)	88	7.1	72	102

https://doi.org/10.1017/S0021859624000303 Published online by Cambridge University Press

Table 4. Pearson correlation of carcass variables and biometric measurements of the animals

Variables	LC	AH	PH	CW	RW	TP	BP
Slaughter weight	0.37 (≤0.001)	0.62 (≤0.001)	0.61 (≤0.001)	0.36 (0.007)	0.38 (0.002)	0.59 (≤0.001)	0.57 (≤0.001)
Empty body weight	0.35 (0.005)	0.59 (≤0.001)	0.57 (≤0.001)	0.29 (0.056)	0.31 (0.001)	0.54 (≤0.001)	0.48 (0.002)
Hot carcass weight	0.46 (0.002)	0.65 (≤0.001)	0.65 (≤0.001)	0.49 (0.001)	0.44 (0.005)	0.72 (≤0.001)	0.64 (≤0.001)
Hot carcass yield	0.47 (0.001)	0.56 (≤0.001)	0.60 (≤0.001)	0.67 (≤0.001)	0.49 ((≤0.001)	0.73 (≤0.001)	0.60 (≤0.001)
Loin eye area	0.10 (0.100)	0.30 (0.092)	0.32 (0.708)	0.40 (0.056)	0.28 (0.533)	0.23 (0.068)	0.25 (0.098)

Significative $P < 0.05$; LC, leg circumference; AH, anterior height; PH, posterior height; CW, chest width; RW, rump width; TP, thoracic perimeter; BP, barrel perimeter.

where five animals displayed similarity, with two in the 0 g/100 kg BW group and one in each of the 18 and 24 g/100 kg BW groups. The groups of animals supplemented with 6, 18, and 24 g/100 kg BW of UE had 0.77 of their animals within their respective groups, with seven animals in each of these groups.

With these biometric measurements, mathematical equations can be used to predict the values of carcass measurements, such as HCW and HCY, which can be predicted with 52% accuracy using thoracic perimeter. This is an important response because animals do not need to be slaughtered to obtain this information (Table 8).

Discussion

The use of extruded urea (Amireia® 200S) as an alternative source of protein ingredients in food supplementation, reference levels and their implications for animal performance and carcass quality, as well as carcass variables with greater discriminating power in beef sheep farming in *Brachiaria* spp. pastures, is necessary knowledge to maximize production in this livestock sector.

The BWS was similar to other EU levels, which demonstrates that it can be used in the diet of beef sheep in the growth and finishing phases, without compromising the slaughter weight, which is generally 30 to 35 kg, a preferable weight by the consumer market, due to the characteristics of carcass yield, meat quality and organoleptic characteristics. Similar performances were found in studies that evaluated the replacement of conventional urea with extruded urea in the diet of ruminants (Pires *et al.*, 2004; Quintão *et al.*, 2009). Complementary data are found in the article by Roberto *et al.* (2023). The variables BCSS, LC and PH behaved in a linearly decreasing manner, with animals that consumed 24 g/100 kg BW of EU presenting the lowest means for these variables. Therefore, as there is greater energy expenditure in the urea cycle to avoid poisoning due to excess ammonia, there is a reduction in tissue deposition and less weight gain is observed (Mortimer *et al.*, 2017). Therefore, as there is a greater energy cost in the urea cycle in order to avoid poisoning due to excess ammonia, there is a reduction in tissue deposition and less weight gain is observed (Mortimer *et al.*, 2017).

Table 5. Factor loadings of principal components (PC)

Variables	PC1	PC2
Slaughter weight (kg)	0.24	**0.93**
Empty body weight (kg)	0.16	**0.95**
Leg circumference (cm)	0.59	0.26
Anterior height (cm)	0.63	0.58
Posterior height (cm)	0.66	0.56
Chest width (cm)	**0.86**	0.07
Rump width (cm)	**0.85**	0.11
Thoracic perimeter (cm)	**0.77**	0.45
Barrel perimeter (cm)	**0.75**	0.41
Eigenvalue	7.2	1.6
Maximum variance (%)	60.1	73.4

The EU levels did not compromise the BL of the animals between treatments and sexes, being a good indication, as a greater BL will result in a greater loin length, and when associated with height and weight, these measurements can reveal the conformation of the animal carcass after slaughter (Soares *et al.*, 2012; Silva *et al.*, 2016). The levels of extruded urea did not influence the characteristics, AA, TP and BP, characteristics that indicate the potential of an animal for cutting ability. However, males stood out in the characteristics, AA and TP, which can be explained by sexual dimorphism and hormonal action, generating faster bone growth in males (Souza *et al.*, 2019).

Lambs with lower average body weight presented lower mean values for the variables, LC and RW, characteristics that are related to body weight values, since these measurements are directly influenced by the nutritional status of the animals and their stage of development (Souza *et al.*, 2019). As the PT increased, an increase in the animal's weight gain capacity could be observed, since the thoracic perimeter is related to a greater respiratory and ingestive capacity of MS, which can make this variable a good indicator for body weight (Silva *et al.*, 2015).

The uniformity observed between batches and sexes, according to Souza *et al.* (2019), for these body development variables that culminate in carcass finishing and finishing rates, they are important, as in addition to demonstrating a positive indication of diet quality, animal gene expression and management quality, it also strengthens the use of biometric measurements as a tool to assist meat sheep production systems, as they are capable of accurately predicting the body weight of animals and the productive capacity of their carcasses through equations.

Regarding the results presented in Table 3, Pereira *et al.* (2018), who evaluated slaughter weight in beef sheep supplemented with different NPN sources, observed lower mean slaughter weights within the range of 22.15 kg to 49.50 kg. These results are lower than those reported by Bonin *et al.* (2023), who observed an average slaughter weight of 41.90 kg and 45 kg for groups control and treatment, respectively.

Regarding EBW, the results obtained in this study are similar to those reported by Bonin *et al.* (2023) who also evaluated EBW in sheep supplemented with different NPN sources.

Table 6. Classification of functions for treatments

Variables	Urea levels (g/100 kg BW)				
	0	6	12	18	24
Slaughter weight	0.95	1.30	0.90	0.68	0.40
Empty body weight	−3.03	−3.45	−3.00	−2.37	−2.54
Leg circumference	0.67	1.04	0.60	0.38	0.32
Anterior height	3.58	4.42	3.46	3.78	3.73
Posterior height	−0.44	−0.88	−0.32	−0.71	−0.64
Chest width	−0.94	−2.47	−0.94	−1.08	−0.80
Rump width	−0.80	−1.64	−1.19	−1.30	−1.33
Thoracic perimeter	3.39	3.41	3.50	2.97	3.08
Barrel perimeter	−0.98	−1.02	−1.07	−0.55	−0.50
Constant	−157.85	−153.68	−146.29	−142.12	−144.09

As for HCW, the averages obtained in this study (12.91 kg) align with the results reported by like Pereira *et al.* (2018). The HCY, with an average of 34.06% in this study, is lower than the results obtained by Bonin *et al.* (2023) which found comparable values ranging from 50.77% to 51.64% and 44.7% to 45.0%, respectively.

Regarding LEA, Bonin *et al.* (2023) obtained similar results to those in the present study, ranging from 14.1 cm^2 to 14.6 cm^2. The similarities with previous studies reinforce the consistency of the results found in the present study concerning the evaluated traits in sheep raised on pasture and supplemented with different NPN sources, providing a solid foundation for understanding the effects of these dietary interventions on the production of beef sheep.

Biometric measurements play a significant role in predicting quantitative meat characteristics and are useful in establishing appropriate selection criteria (Tesema *et al.*, 2019; Macena *et al.*, 2024). These measurements can be used as an indirect approach to estimate body weight and carcass characteristics, overcoming many of the issues associated with visual assessment (Macena *et al.*, 2022; 2024). In Table 4, Pearson correlation coefficients between biometric measurements and carcass variables indicated significant relationships between measures such as full shoulder length, anterior height, posterior height, neck length, withers width, thoracic perimeter, and mouth perimeter with slaughter weight, EBW, HCW and HCY. These results suggest that biometric measurements can serve as indirect indicators for estimating carcass-related traits in goats and sheep, providing a viable alternative to visual assessment (Abdel-Mageed and Ghanem, 2013; Bautista Diaz *et al.*, 2017; Tesema *et al.*, 2019; Macena *et al.*, 2022; 2024). However, LEA did not prove to be a good predictor of these carcass variables (Ricardo *et al.*, 2016; Bautista Diaz *et al.*, 2017; Macena *et al.*, 2022).

Regarding slaughter weight and EBW, a strong positive loading is observed in CP2 (Table 5). This indicates that these two variables are highly correlated and are important for the observed variation in the data. When considering biometric measurements such as leg circumference, anterior height, posterior height, chest width, rump width, thoracic perimeter and barrel perimeter, it is possible to observe a distribution of positive loadings in both principal components (CP1 and CP2). This suggests that these biometric variables are involved in the overall data variation, contributing to different degrees of influence. The high loadings in CP1 indicate that these biometric measurements are more related to each other than to other variables and may represent general morphological characteristics of the studied sheep. This result is consistent with the analysis of Guedes *et al.* (2018) and Elsaid

Table 7. Classification of the matrix

Urea levels (g/100 kg BW)	Percentage	0	6	12	18	24
0	55.5	5	2	1	0	1
6	77.7	1	7	1	0	0
12	55.5	2	0	5	1	1
18	77.7	0	0	2	7	0
24	77.7	0	0	1	1	7
Total	68.8	8	9	10	9	9

Table 8. Equations for carcass variables based on biometric measurements

Number	Equation	Cp	R^2	SEM	*P* value
Slaughter weight – SW					
1	SW = −13.9 + 0.9AH	0.80	0.38	4.8	<0.001
2	SW = −23.1 + 0.6AH + 0.3TP	−0.65	0.43	4.6	<0.001
Empty body weight – EBW					
1	EBW = −12.2 + 0.6AH	−1.07	0.35	3.4	<0.001
Hot carcass weight – HCW					
1	HCW = −16.7 + 0.3TP	0.66	0.52	3.4	<0.001
Hot carcass yield – HCY					
1	HCY = −2.3 + 0.4TP	7.71	0.52	2.2	<0.001
Loin eye area – LEA					
1	LEA = 4.0 + 0.5TP	−1.80	0.15	2.8	0.007

SEM, standard error of the mean; AH, anterior height; TP, thoracic perimeter.

https://doi.org/10.1017/S0021859624000303 Published online by Cambridge University Press

and Elnahas (2017), where a high association between biometric measurements in sheep carcass studies was observed. On the other hand, the high loadings in CP2 indicate a more specific association between biometric measurements and carcass characteristics. These loadings suggest a greater contribution of biometric measurements to the observed variation in slaughter weight and EBW. These results corroborate the findings of Guedes *et al.* (2018) and Elsaid and Elnahas (2017), where significant associations were found between biometric measurements and carcass characteristics in sheep.

Regarding slaughter weight and EBW, there is a decreasing trend as urea levels increase (Table 6) where a negative effect of urea treatments on slaughter weight and EBW in sheep was also observed. When considering biometric measurements, different patterns in response to different urea levels can be observed. For instance, leg circumference and rump width tend to decrease as urea levels increase, while anterior height, posterior height and thoracic perimeter show a gradual increase with increasing urea levels.

Observing Table 7, it is possible to notice that the classification matrix reflects the sample distribution regarding the different levels of urea used in the treatments. For example, for the urea level of 0 g/100 kg body weight, the percentage of correctly classified samples was 55.56%, indicating a moderate rate of accuracy in classification. Analysing the individual cells of the classification matrix, variations in results can be observed according to different urea levels. These results show that, in some cases, different urea levels can influence the classification of carcass traits in sheep. However, it is important to note that the classification matrix has some cells with low values, indicating a lower degree of accuracy in classification for certain urea levels. For example, for the urea level of 12 g/100 kg body weight, the cell representing the correct classification of samples with the same urea level had a value of 5, indicating lower precision in classification. These variations in results can be attributed to different factors, such as the complexity of carcass traits in sheep and possible interactions with other factors not considered in this analysis. The results suggest that different levels of urea can influence the classification of carcass traits in sheep, although there are variations in the results across different studies (Alves *et al.*, 2014; Pereira *et al.*, 2018; Bonin *et al.*, 2023). These variations can be explained by factors such as the complexity of carcass traits and possible interactions with other factors not considered in this analysis.

Equation 1 for slaughter weight (SW) (Table 8) shows a strong positive association with anterior height (AH), indicating that an increase in AH is related to an increase in SW. The same occurs for EBW and AH, as the equation indicates a significant positive association between both traits. Equation 2 for body weight at slaughter (SW) involves both anterior height (AH) and thoracic perimeter (TP). A moderate positive association between SW and AH is observed, as well as a weaker positive association with TP.

The equations for HCW, HCY and LEA reveal a positive association among these characteristics and thoracic perimeter (TP) (Table 8). However, it is important to note that associations may vary depending on the sheep breed, genetic lineage and management conditions.

Conclusions

The study revealed a significant correlation between biometric measurements and carcass variables. These correlations indicate that biometric measurements can serve as reliable indirect indicators for estimating carcass traits in sheep, offering a practical alternative to visual assessments.

Canonical discriminant analysis demonstrated that certain biometric measurements, such as leg circumference, anterior height, posterior height, chest width, rump width, thoracic perimeter and barrel perimeter, played crucial roles in explaining the overall variation in the data. These measurements were more closely related to one another than to other variables, indicating that they collectively represented general morphological characteristics of the studied sheep.

Additionally, the equations derived from the analysis provided valuable tools for predicting lamb carcass traits based on biometric measurements. These equations can be utilized to estimate lamb carcass characteristics without the need for slaughter, which is particularly advantageous for producers seeking non-invasive methods for evaluation.

Acknowledgements. We are grateful to the Federal University of Paraíba and the Federal University of Mato Grosso do Sul, through their Post Graduate Programs in Animal Science. This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) – Financing Code 001, National Council for Scientifc and Technological Development – (CNPq) and the Foundation for the Support of the Development of Teaching, Science and Technology of the State of Mato Grosso do Sul (FUNDECT).

Author contributions. F.F.S.R., G.S.D. and R.G.C. conceived and designed the study. F.F.S.R., N.L.R., D.G.F.G., L.C.V.I., C.C.B.F., J.G.R. and M.G.P. conducted data gathering. F.F.S.R., N.L.R. and G.F.D. performed statistical analyses and prepared graphics. F.F.S.R., G.S.D., R.G.C. and N.L.R. wrote the article. N.L.R. supervised the work.

Funding statement. This work was supported by Coordination for the Improvement of Higher Education Personnel – (CAPES) – Financing Code 001, National Council for Scientific and Technological Development – (CNPq), and the Foundation for the Support of the Development of Teaching, Science and Technology of the State of Mato Grosso do Sul (FUNDECT).

Competing interests. None.

Ethical standards. The study was approved and conducted in accordance with the Ethics Committee on the Use of Animals – CEUA of the Federal University of Mato Grosso do Sul (UFMS), under protocol No. 0862/2017.

References

Abdel-Mageed I and Ghanem N (2013) Predicting body weight and longissimus muscle area using body measurements in subtropical goat kids. *Egyptian Journal of Sheep & Goat Sciences* **8**, 95–100.

Alves EM, Pedreira MS, Moreira BS, Freire LDR, Lima TR and Santos-Cruz CL (2014) Carcass characteristics of sheep fed diets with slow-release urea replacing conventional urea. *Acta Scientiarum. Animal Sciences* **36**, 303–310.

Barbosa LT, Lopes OS, Regazzi AJ, Guimarães SEF and Torres RA (2005) Avaliação de Características de Carcaça de Suínos Utilizando-se Análise dos Componentes Principais. *Revista Brasileira de Zootecnia* **34**, 2009–2217.

Bartley EE and Deyoe CW (1975) Starea as a protein replacer for ruminants - review of 10 years of research. *Feedstuffs* **47**, 42–44.

Bautista-Diaz E, Salazar-Cuytun R, Chay-Canul AJ, Herrera RAG, Piñeiro-Vázquez ÁT, Monforte JGM, Tedeschi LO, Cruz-Hernández A and Gómez-Vázquez A (2017) Determination of carcass traits in Pelibuey ewes using biometric measurements. *Small Ruminant Research* **147**, 115–119.

Bonin MN, Ítavo CCBF, Ítavo LCV, Gomes MNB, Souza AI, Difante GS, Arco TFFS, Ferelli KLSM, Soares ÉSM, Gurgel ALC and Surita LMA

(2023) Extruded urea could replace true protein source in supplements for lambs finished in tropical pastures. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* **75**, 89–97.

Carvalho AB, Silva AL, Silva AMA, Netto AJ, Medeiros TTB, Araujo Filho JM, Agostini DLS, Oliveira DLV, Mazzetto SE, Kotzebue LRV, Oliveira JR and Oliveira RL (2019) Effect of slow-release urea microencapsulated in beeswax and its inclusion in ruminant diets. *Small Ruminant Research* **179**, 56–63.

Dillon WR and Goldstein M (1984) *Multivariate Analysis: Methods and Applications*, 2d Edn. New York: John Wiley, 462p.

Elsaid R and Elnahas A (2017) Principal components analysis of body measuremnts of Sohagi sheep in Upper Egypt. *Egyptian Journal of Sheep & Goat Sciences* **14**, 83–92.

Euclides VPB, Carpejani GC, Montagner DB, Nascimento Junior D, Barbosa RA and Difante GS (2018) Maintaining post-grazing sward height of Panicum maximum (cultivar Mombaça) at 50 cm led to higher animal performance compared with post-grazing height of 30 cm. *Grass and Forage Science* **73**, 174–182.

Guedes DGP, Ribeiro MN and Carvalho FFR (2018) Multivariate techniques in the analysis of carcass traits of Morada Nova breed sheep. *Ciência Rural* **48**, e20170746.

Ítavo LCV, Ítavo CCBF, Dias AM, Franco GL, Pereira LC, Leal ES, Araújo HS and Souza ARDL (2016) Combinations of non-protein nitrogen sources in supplements for Nellore steers grazing. *Revista Brasileira de Saúde e Produção Animal* **17**, 448–460.

Macena ECBC, Costa RG, Souza WH, Cartaxo FQ, Ribeiro NL, Arandas JKG and Ribeiro MN (2022) Multivariate modelling to estimate carcase characteristics ad commercial cuts of Boer goats. *The Journal of Agricultural Science* **160**, 371–379.

Macena ECBC, Costa RG, souse WH, Cartaxo FQ, Arandas JKG, Ribeiro MN and Ribeiro NL (2024) Canocical discriminant analysis on the characterization of the goat carcass. *Acta Scientiarum Animal Science* **46**, e58440.

Moraes GJ, Ítavo LCV, ítavo CCBF, Dias AM, Niwa MVG, Leal ES, Kozerski ND, Costa MCM, Mata DG and Inada AC (2019) Extruded urea could reduce true protein source in beef cattle diets. *Journal of Animal Physiology and Animal Nutrition* **103**, 1283–1294.

Mortimer SI, Hatcher S, Fogarty NM, van der Werf JHJ, Brown DJ, Swan AA, Greeff JC, Refshauge G, Edwards JE and Hocking Gaunt GM (2017) Genetic parameters for wool traits, live weight, and ultrasound carcass traits in Merino sheep. *Journal of Animal Science* **95**, 1879–1891.

National Research Council - NRC (2007) Nutrient Requirements of Small Ruminants, 362 p.

Osório JCS and Osório MTM (2001) Sistemas de avaliação de carcaças no Brasil. In: Simpósio Mineiro de Ovinocultura, 1., 2001, Lavras, MG. Anais… Lavras: UFLA, p.157–196.

Pereira GA, Oliveira JS, Santos EM, Carvalho GGP, Araújo GGL, Souza WH, Neto SPH and Cartaxo FQ (2018) Substitution of soybean meal for urea in diets based on deferred buffelgrass hay for feedlot sheep. *Revista Brasileira de Zootecnia* **47**, e20170035.

Pires AV, Oliveira Junior RC, Fernandes JJR, Susin I, Santos FAP, Araújo RC and Goulart RCD (2004) Total replacement of soybean meal by urea or starea in high grain diets for beef cattle. *Pesquisa Agropecuária Brasileira* **39**, 937–942.

Possamai AJ, Zervoudakis JT, Hatamoto-Zervoudakis LK, Freiria LB, Silva PIJLR and Melo AB (2017) Intake, digestibility, and ruminal parameters of Nellore bulls supplemented with increasing levels of crude glycerin in Brachiaria Brizantha pastures. *Revista Brasileira de Saúde e Produção Animal* **18**, 518–529.

Quintão FA, Pérez JRO, Salvador FM, Siqueira GB and Geraseev LC (2009) Desempenho de borregas Santa Inês alimentadas com duas fontes de nitrogênio não-protéico em dietas formuladas estimulando a síntese de proteína microbiana ruminal. *Ciência e Agrotecnologia* **33**, 279–284.

Ricardo HL, Roça RO, Lambe NR, Seno LO, Fuzikawa IHS and Fernandes ARM (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.

Roberto FFS, Difante GS, Costa RG, Ítavo LCV, Ítavo CCBF, Gomes MNB, Dias AM, Rodrigues JG, Pereira MG, Ribeiro NL, Gurgel ALC, Monteiro GOA, Brixner BM, Véras ELL, Higano LM, Santana JCS, Costa CM and Surita LMA (2023) Behavioural compensation of extruded urea level and the effects of supplementation presence for finished lambs in tropical grass pastures. *Small Ruminant Research* **227**, 107079.

Silva DLS, Braga AP, Pontes FST, Lima Júnior DM, Costa WP, Chaves VV, Amâncio AVF and Braga ZCAC (2015) Economic viability and morphometry body and carcass characteristics on sheep fed sunflower cake. *Acta Veterinaria Brasilica* **9**, 306–315.

Silva NV, Costa RG, Medeiros GR, Gonzaga Neto S, César MF and Cavalcanti MCA (2016) Measurements "in vivo" and of carcasses and constituents non-carcasses of sheep fed with different levels of guava agroindustrial by-product. *Revista Brasileira de Saúde e Produção Animal* **17**, 101–115.

Silva Sobrinho AG (1999) Body composition and characteristics of carcass from lambs of different genotypes and ages at slaughter. Report (Post Doctorate in Sheep Meat Production). Palmerston North: Massey University.

Soares BC, Souza KDS, Lourenço Junior JB, Maciel e Silva AG, Ávila SC, Kuss F, Andrade SJT, Raiol LCB and Colodo JCN (2012) Desempenho e características de carcaças de cordeiros suplementados com diferentes níveis de resíduo de biodiesel. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* **64**, 1747–1754.

Souza JS, Difante GS, Emerenciano Neto JV, Lana AMQ, Roberto FFS and Ribeiro PHC (2019) Biometric measurements of Santa Inês meat sheep reared on *Brachiaria brizantha* pastures in Northeast Brazil. *Plos One* **14**, e0219343–.

Statistical Analysis System - SAS (2001) Statistical analysis system user's guide. Version 9.1. Cary: Statistical Analysis System Institute.

Tesema Z, Tilahun M, Zegeye A and Yizengaw L (2019) Statistical modeling of carcass traits, primal carcass cuts, body weight and morphological traits of pure Central Highland and crossbred Boer goats. *Journal of Applied Animal Science* **12**, 39–55.

Xu Y, Li Z, Moraes LE, Shen J, Yu Z and Zhu W (2019) Effects of incremental urea supplementation on rumen fermentation, Nutrient Digestion, Plasma Metabolites, and Growth Performance in Fattening Lambs. *Animals* **9**, 652–.

Yánez EA, Resende KT, Ferreira ACD, Medeiros AN, Silva Sobrinho AG, Pereira Filho JM, Teizeira IAMA and Artoni SMB (2004) Utilização de medidas biométricas para predizer características da carcaça de cabritos Saanen. *Revista Brasileira de Zootecnia* **33**, 1564–1572.