



## Growth curve, carcass traits and Kleiber ratio of Dorper crossbred with hairless native Brazilian sheep breeds

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### ABSTRACT

In Brazil, much of the sheep farming is practiced with native breeds or crossbred with specialized breeds. The market is growing and to serve consumers it is necessary to regularly provide quality meat. Rearing these animals with lower production costs can be achieved using feed efficiency and growth information, useful to define the most appropriate crossbreed for both farm structures and breeder's objectives. Thus, the objective of the present work was to evaluate the growth, carcass traits and Kleiber ratio (KR) of, respectively, 44 and 39 animals slaughtered at 120 (120D) and 240 days (240D) of the following crosses: Dorper x Morada Nova females and males (F<sub>DMN</sub>, M<sub>DMN</sub>), Dorper x Santa Inês females and males (F<sub>DSI</sub>, M<sub>DSI</sub>), and Dorper x Rabo Largo females and males (F<sub>DRL</sub>, M<sub>DRL</sub>). The traits evaluated were: the weight of the rib, loin, left half carcass, shoulder, leg, Longissimus Dorsi muscle area (LDM), growth curve and KR. Univariate and multivariate analyses were used, and it was observed, at 120D, that DSI and M<sub>DRL</sub> had higher cut weights. There was the superiority of the M<sub>DSI</sub> in relation to the others for the cuts rib, loin (except with DRL that was similar), half carcass and shoulder at 240D. At 240D all crossbreeds have a value greater than 100 % of the percentage of their asymptotic weight, except the M<sub>DSI</sub>. At 240D the animals tended to lower values of KR compared to 120D. Differences were observed between the crosses considering the variables simultaneously. In the grouping at 120D, an approximation between DSI and M<sub>DRL</sub> was observed. The DMN at 240D, have lower values for carcass traits and growth and superiority for KR and degree of maturity. The M<sub>DRL</sub> with F<sub>DRL</sub> and F<sub>DSI</sub> were characterized as intermediate for growth, carcass, and KR. In PCA1 at 120D, most of the explanation for differentiating crosses are concentrated in meat cuts. At 240D again, the carcasses contributed to differentiate the crosses, however sharing with the parameters of growth. It is concluded that animals should be slaughtered before 240D. If it is used to slaughter 120D, the cattle rancher can choose, when economically feasible, to slaughter animals regardless of sex and crossing, however, the farmers must be attentive only to prioritize the DSI and M<sub>DRL</sub> as an alternative to serving the consumer market that prefers heavier cuts.

### 1. Introduction

The Brazilian sheepmeat market is growing and, according to the latest estimate by the IBGE (2015), the country has a total sheep population of approximately 18.1 million individuals, of which almost 60 % is concentrated in the Northeast region. However, compared to other farming activities in Brazil, sheep farming is less important than other farming activities, being traditionally a subaltern activity and being

often practiced without modern technology and knowledge. The result of this fact directly reflects in the quality of the product derived from this system, in which the majority of sheep meat offered to the consumer is of poor quality and/or come from animals of advanced ages (Malhado et al., 2009).

Therefore, standardization and improvement of carcass quality are important aspects to valorise the product and to attract more and more consumers who, in turn, are increasing their demand regarding the

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regularity in the supply and quality of the meat (Oliveira et al., 2017). In order to improve breeding and to increase productivity in Brazilian sheep production, producers need to use new strategies and improved technologies to raise these animals. Evaluating carcass traits, besides performance traits, is an efficient alternative to verify possible changes in the development and/or yield of commercial cuts (Santos et al., 2015).

In addition, evaluating food efficiency is another important factor, since food management has a high cost in the economic income of the property (Nkrumah et al., 2006). Efficient animals have better feed conversion and remain less time on the farm, thus influencing grass optimization (Basarab et al., 2003). Among the techniques that have been used to identify animals with higher body growth, without increasing the cost of maintenance energy (Archer et al., 1999; Gomes et al., 2012), the most effective is the Kleiber ratio (KR), mainly for its practicality (Kleiber, 1936). Indeed, it is not necessary to measure the individual consumption of the animal to calculate the KR. On the contrary, most feed efficiency assessment indices have the disadvantage of being measured from individual consumption, raising economic costs for the identification of animals with higher feed efficiency (Robinson and Oddy, 2004).

In order to make a reliable selection decision, it is also essential to evaluate the growth curve of the animals (Salem et al., 2013), conveying the idea of precocity, choice of feeding management and identification of suitable slaughter age (Carneiro et al., 2007). As a result, the growth curve has an asymptotic weight (A) that represents the weight of adulthood (McManus et al., 2003; Malhado et al., 2008), and a rate of growth (K), also known as maturity rate (Ratkowsky, 1990). High growth rate animals provide softer and leaner meats when compared to late animals (Moreno et al., 2010; Pilar et al., 2013).

In addition, the slaughter of precocious animals offers advantages such as improved productivity and efficiency of the production system (Gottschall, 2005). In Brazil, sheep production is mainly based on the use of naturalized or locally adapted breeds that have undergone natural or anthropic even if empirical selection since their introduction during the colonization period. These animals have hardiness, reproductive efficiency, longevity and low mortality rate (McManus et al., 2009), as well as lower nutritional requirements (Yilmaz et al., 2013).

However, naturalized breeds generally have lower productivity than specialized ones (Issakowicz et al., 2014). Thus, an option to aggregate high production and better adaptation is the crossing of native breeds with other genetically superior breeds (Shrestha and Fahmy, 2007). Currently, the Dorper sheep are being crossed with Brazilian native breeds (Carneiro et al., 2007), due to its good maternal ability, high growth rates, and muscularity, all concurring to generate carcasses of high quality (Schoeman, 2000; Cloete et al., 2007).

Among the Brazilian naturalized sheep breeds, we can mention Santa Inês, Morada Nova, and Rabo Largo, which were selected in the Brazilian Northeast area: a semi-arid, hot region with scarce rainfall (Ribeiro and Gonzales-Garcia, 2016). There are no studies evaluating simultaneously growth, traits of meat cuts and KR in native Brazilian breeds x Dorper breed crosses. Thus, the objective of this study was to provide additional information to assist the breeder in identifying suitable crosses for each production system and the most suitable slaughter age through evaluation of carcass traits, growth curve and KR in Dorper crossbred sheep with naturalized breeds Brazilians slaughtered at 120 (120D) and 240 days old (240D).

## 2. Material e methods

### 2.1. Data

Male and female crossbred animals, obtained by Dorper breeders by crossing with Morada Nova, Santa Inês and Rabo Largo ewes, were evaluated. The experiment was carried out at an experimental station in Jaguaquara (BA, Brazil). The animals were slaughtered at 210D and

**Table 1**  
Description of treatments and number of animals slaughtered at 120 and 240 days.

Treatment	120 days	240 days	Total
F_DMN	7	6	13
M_DMN	8	6	14
F_DRL	9	7	16
M_DRL	6	6	12
F_DSI	7	7	14
M_DSI	7	7	14
Total	44	39	83

F\_DMN: ½ Dorper x ½ Morada Nova female; M\_DMN: ½ Dorper x ½ Morada Nova male; F\_DRL: ½ Dorper x ½ Rabo Largo female; M\_DRL: ½ Dorper x ½ Rabo Largo male; F\_DSI: ½ Dorper x ½ Santa Inês female; M\_DSI: ½ Dorper x ½ Santa Inês male.

240D (Table 1). The animals were maintained in a semi-intensive production system, grazing on pastures with *Panicum maximum* (30 %) and *Brachiaria decumbens* (70 %) during the day, and mineral salt offered *ad libitum*. The animals were gathered into the sheepfold late in the afternoon. Supplementation with a nutrient mix was offered during the winter (June to October).

### 2.2. Carcass traits, growth curve parameters and Kleiber ratio

The animals were slaughtered to assess the carcass traits (Fig. 1) after 16-h fasting from solid food. Subsequently, the carcasses were eviscerated. The neck was removed, and the left half of the carcass was divided into four meat cuts (shoulder, rib, loin, and leg). The weight of right half of the carcass and of each cut were recorded. These cuts, together with the half carcass weight, form the carcass variables evaluated. A further cut was made between the 12th and 13th thoracic vertebrae to expose the cross-section of the *Longissimus dorsi* muscle and the area was measured.

The weight of the animals was assessed at 15-day intervals to estimate the growth curve parameters (A and K), using the non-linear Gompertz model, and the NLIN procedure of the SAS program (SAS, 2018). The Gompertz equation is  $yt = A/(1 + b \exp(-Kt))$ , wherein y is the weight in kg, t is the age in days, A is the asymptotic or adult weight, b is an integration constant, and K is the maturity rate. The maturity degree of the animals slaughtered at 240D was evaluated using the formula  $Ut = Yt/A$ , wherein Ut is the maturity degree (%), Yt is the weight (kg) of the animal at 240 days, and A is the asymptotic weight. The Kleiber ratio (KR) was calculated by dividing the mean average daily gain (ADG) by the metabolic live weight ( $PV^{0.75}$ ), as described by Kleiber (1936). The ADG of the animals was calculated using the formula  $ADG = (FW - IW)/N$ , wherein FW is the final weight, IW is the initial weight, and N is the number of days of the period. The metabolic weight was calculated from the live weight raised to 0.75 (Heady, 1975).

### 2.3. Statistical analysis

In order to verify the hypothesis of equality between the genetic groups for all characteristics evaluated, the analysis of variance (ANOVA) was performed using the Tukey test at 5% significance by the GLM procedure (SAS, 2018). To evaluate the proportion of the weight of the cuts (leg, rib, loin and palette) in relation to ½ carcass, the rule of three was used for each animal, by multiplying the meat cut by 100, and the result was divided by ½ carcass.

A graph was developed using the heatmap package (BIBLIO) of the R software (R Development Core Team, 2008), representing the mean Euclidean distances and grouping through complete linkage. An approximately unbiased (AU) test has been calculated through multiscale bootstrap resampling to obtain the confidence set of trees. Clusters

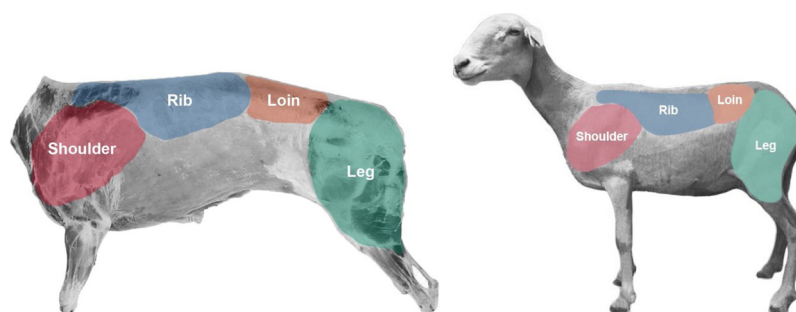


Fig. 1. Illustration of meat cuts.

(edges) with high AU values (i.e., 95 %) were strongly supported by the data. The PAST software was used to test the hypothesis of equality between crosses, considering the traits simultaneously (MANOVA) by the Hotelling's test at 5% significance (Hammer et al., 2001). The diversity among sheep and their relationship with the measured variables were evaluated using the principal component analysis in PAST software (Hammer et al., 2001). The number of main components kept in the results had, as a criterion, the inflection point of the curve of the eigenvalues.

#### 2.4. Animal ethics in the experiment

The project was not submitted for evaluation to the Ethics Committee of State University of Southwest of Bahia (UESB). The experiment was conducted in the Jaguaquara Experimental Station (EBDA), located in the municipality of Jaguaquara (Brazil). The project was not submitted to an animal ethics committee because, at the time of the experiment, UESB and EBDA did not have an animal ethics committee. However, aware of the content of the resolutions of the National Council for the Control of Animal Experimentation – CONCEA, the authors declare that the experiment comply with the ARRIVE guidelines and was carried out in accordance with the U.K. Animals (Scientific Procedures) Act, 1986 and associated guidelines, EU Directive 2010/63/EU for animal experiments. The authors assume full responsibility for the data presented and are available for possible questions, should they be required by competent bodies, as declared in the supplemental document sent to Small Ruminant Research.

### 3. Results

There were significant effects ( $P < 0.05$ ) for the rib, loin, half carcass and shoulder among animals slaughtered at 120D (Table 2). The M\_DSI, F\_DSI and M\_DRL had higher values for the rib in relation to the other evaluated crosses. M\_DMN animals differed ( $P < 0.05$ ) from the others for loin weight, except for F\_DRL, presenting a lower weight when compared to the other crosses. Regarding the half carcass, differences ( $P < 0.05$ ) were found between F\_DSI and M\_DMN (the former having higher values than the latter).

However, both these crosses did not differ from the others. The shoulder value did not differ ( $P > 0.05$ ) between M\_DRL, F\_DSI, M\_DSI and F\_DMN, which presented higher weights than M\_DMN and F\_DRL, except for F\_DMN, which was also similar to the two groups mentioned above. No differences ( $P > 0.05$ ) were found between crosses for leg and KR.

At 240D, there was a difference ( $P < 0.05$ ) between crosses for LDM, rib, loin, half carcass, shoulder, leg and A parameter. Males (DMN, DRL, and DSI) had higher LDM weights compared to females (DMN, DRL, and DSI), and did not differ among themselves ( $P > 0.05$ ). The highest rib cut weight was measured in M\_DSI, which was higher ( $P < 0.05$ ) than the other crosses. Rib cut weight was similar ( $P > 0.05$ ) in the remaining crosses, except for F\_DMN that differed from DRL (both male and female), presenting lower weight.

The loin showed no difference ( $P > 0.05$ ) between the M\_DSI and DRL crosses (both male and female) and was significantly heavier, in relation to the F\_DMN and M\_DMN groups, which did not differ from the F\_DSI. The M\_DSI presented a higher half carcass weight and shoulder, being superior ( $P < 0.05$ ) to all others, followed by F\_DRL, M\_DRL, and F\_DSI, which did not differ ( $P > 0.05$ ) from each other and presented higher values for these traits when compared to DMN (both male and female).

However, regarding the shoulder, there was no significant difference between DMN (both male and female) and F\_DRL. The leg weight was higher for M\_DSI and DRL (both male and female), differing ( $P < 0.05$ ) from DMN (both male and female) and F\_DSI that were similar ( $P > 0.05$ ) to each other.

About parameter A of the growth curve, differences between M\_DSI and DMN (both male and female) were observed, with higher values ( $P < 0.05$ ) for M\_DSI. Regarding the K and DM parameter values, no differences ( $P > 0.05$ ) were observed between the crosses. The KR values were higher and similar ( $P > 0.05$ ) for M\_DMN and F\_DSI crosses, although the latter did not present a difference ( $P > 0.05$ ) between F\_DMN, F\_DRL, and M\_DRL, which were similar ( $P > 0.05$ ).

The yield of meat cuts to the half carcass for animals slaughtered at 120D were not different ( $P > 0.05$ ) between crosses (Table 3). In animals slaughtered at 240D, there was a significant effect only for the proportion of rib cut between the crosses. M\_DSI had the highest value for the rib cut weight, however, it differed only from the F\_DMN and F\_DRL, while was similar ( $P > 0.05$ ) to the other crosses.

Regarding animals slaughtered at 120D, it was observed that two groups were strongly supported by the analysis of the heatmap graph (Fig. 2A). One group included the crosses M\_DRL and DSI (both male and female), having as traits, larger carcass size, and consequently larger meat cuts. The other crosses were classified in a second group, having the opposite traits (i.e., smaller size). Two groups were observed in the animals slaughtered at 240D, one composed by the M\_DSI and the other by the remaining crosses (Fig. 2B).

The multivariate analysis (MANOVA) showed differences between the crosses. In animals slaughtered at 120D, there were differences ( $P < 0.05$ ) between M\_DMN with both DRL and DSI (both male and female), as well as F\_DRL differed ( $P < 0.05$ ) from M\_DSI. As for animals slaughtered at 240D, only F\_DMN was different ( $P < 0.05$ ) from DRL and DSI males. When evaluating the main components, a total of three main components were necessary to explain the differences between the animals slaughtered at 120D and 240D. The first 3 components together explained 96.11 % and 96.61 % of the total variance for slaughter at 120D and 240D, respectively (Table 4).

In the 120 D, the meat cuts concentrate 70.41 % explanation total variation between the crosses. Similarly, at 240D the meat cuts explained the 73.53 % of the total variation, sharing the same importance with the growth parameters. It was also observed for this component that the degree of maturity and KR presented a relation in the opposite direction to the parameters of growth and carcass. In the second principal component, the traits of LDM, KR, parameter A, and DM have high values and are inversely related to the rate of maturity. In the third

**Table 2**  
Means and standard deviations of meat cuts (Kg), parameters and Kleiber ratio of crossbred sheep.

	F_DMN	M_DMN	F_DRL	M_DRL	F_DSI	M_DSI
Slaughtered 120 days						
Rib	0.45 ± 0.02 <sup>bc</sup>	0.41 ± 0.08 <sup>c</sup>	0.36 ± 0.02 <sup>c</sup>	0.56 ± 0.07 <sup>ab</sup>	0.64 ± 0.12 <sup>a</sup>	0.55 ± 0.03 <sup>a</sup>
Loin	0.25 ± 0.03 <sup>ab</sup>	0.17 ± 0.05 <sup>c</sup>	0.21 ± 0.05 <sup>bc</sup>	0.28 ± 0.04 <sup>ab</sup>	0.28 ± 0.07 <sup>ab</sup>	0.32 ± 0.06 <sup>a</sup>
½ Carcass	3.36 ± 0.19 <sup>ab</sup>	2.72 ± 0.73 <sup>b</sup>	3.13 ± 0.66 <sup>ab</sup>	3.43 ± 0.20 <sup>ab</sup>	3.91 ± 0.66 <sup>a</sup>	3.86 ± 0.35 <sup>ab</sup>
Shoulder	0.43 ± 0.06 <sup>ab</sup>	0.35 ± 0.03 <sup>b</sup>	0.38 ± 0.06 <sup>b</sup>	0.50 ± 0.07 <sup>a</sup>	0.48 ± 0.04 <sup>a</sup>	0.54 ± 0.03 <sup>a</sup>
Leg	0.96 ± 0.06 <sup>a</sup>	0.77 ± 0.03 <sup>a</sup>	0.79 ± 0.04 <sup>a</sup>	1.08 ± 0.28 <sup>a</sup>	1.18 ± 0.26 <sup>a</sup>	1.16 ± 0.31 <sup>a</sup>
KR	1.47 ± 0.23 <sup>a</sup>	1.64 ± 0.15 <sup>a</sup>	1.60 ± 0.27 <sup>a</sup>	1.37 ± 0.19 <sup>a</sup>	1.61 ± 0.15 <sup>a</sup>	1.43 ± 0.21 <sup>a</sup>
Slaughtered 240 days						
LDM	8.11 ± 1.03 <sup>b</sup>	11.08 ± 1.45 <sup>a</sup>	8.41 ± 0.70 <sup>b</sup>	10.21 ± 0.95 <sup>a</sup>	8.09 ± 1.04 <sup>b</sup>	11.42 ± 1.56 <sup>a</sup>
Rib	0.56 ± 0.11 <sup>c</sup>	0.72 ± 0.09 <sup>bc</sup>	0.78 ± 0.08 <sup>b</sup>	0.87 ± 0.07 <sup>b</sup>	0.73 ± 0.13 <sup>bc</sup>	1.07 ± 0.11 <sup>a</sup>
Loin	0.33 ± 0.05 <sup>cd</sup>	0.30 ± 0.07 <sup>d</sup>	0.41 ± 0.05 <sup>ab</sup>	0.42 ± 0.06 <sup>ab</sup>	0.35 ± 0.04 <sup>bcd</sup>	0.46 ± 0.04 <sup>a</sup>
½ Carcass	4.29 ± 0.49 <sup>c</sup>	4.47 ± 0.68 <sup>c</sup>	5.42 ± 0.23 <sup>b</sup>	5.59 ± 0.39 <sup>b</sup>	5.46 ± 0.54 <sup>b</sup>	6.54 ± 0.64 <sup>a</sup>
Shoulder	0.56 ± 0.10 <sup>c</sup>	0.68 ± 0.10 <sup>c</sup>	0.76 ± 0.02 <sup>bc</sup>	0.82 ± 0.06 <sup>b</sup>	0.77 ± 0.07 <sup>b</sup>	1.01 ± 0.14 <sup>a</sup>
Leg	1.40 ± 0.13 <sup>b</sup>	1.47 ± 0.27 <sup>b</sup>	1.81 ± 0.08 <sup>a</sup>	1.71 ± 0.19 <sup>ab</sup>	1.66 ± 0.21 <sup>b</sup>	2.01 ± 0.29 <sup>a</sup>
A	24.99 ± 4.26 <sup>b</sup>	25.17 ± 7.71 <sup>b</sup>	28.59 ± 4.04 <sup>ab</sup>	30.99 ± 1.80 <sup>ab</sup>	29.45 ± 5.69 <sup>ab</sup>	38.99 ± 7.63 <sup>a</sup>
K	0.01 ± 0.00 <sup>a</sup>	0.01 ± 0.00 <sup>a</sup>	0.01 ± 0.00 <sup>a</sup>	0.02 ± 0.00 <sup>a</sup>	0.01 ± 0.00 <sup>a</sup>	0.02 ± 0.00 <sup>a</sup>
DM	0.25 ± 0.07 <sup>a</sup>	0.27 ± 0.14 <sup>a</sup>	0.33 ± 0.12 <sup>a</sup>	0.41 ± 0.04 <sup>a</sup>	0.35 ± 0.14 <sup>a</sup>	0.36 ± 0.06 <sup>a</sup>
KR	1.38 ± 0.12 <sup>bc</sup>	1.65 ± 0.15 <sup>a</sup>	1.31 ± 0.05 <sup>bc</sup>	1.46 ± 0.08 <sup>bc</sup>	1.60 ± 0.27 <sup>ab</sup>	1.21 ± 0.08 <sup>c</sup>

\*Means followed by equal letters in the same line do not differ statistically by the Tukey test at 5% significance. LDM: *longissimus dorsi* muscle; A: asymptotic or adult weight; K: maturity rate; DM: degree of maturity in percentage; KR: Kleiber ratio; F\_DMN: ½ Dorper x ½ Morada Nova female; M\_DMN: ½ Dorper x ½ Morada Nova male; F\_DRL: ½ Dorper x Rabo Largo female; M\_DRL: ½ Dorper x ½ Rabo Largo male; ½ F\_DSI: ½ Dorper x ½ Santa Inês female; M\_DSI: ½ Dorper x ½ Santa Inês male.

principal component, LDM and DM had high values.

#### 4. Discussion

The production of native sheep is characterized as an activity of cultural, social and economic importance for semi-arid regions and plays an important role in the development of small rural properties (Costa et al., 2008). Crossbreeding between specialized exotic breeds and local breeds has shown satisfactory results. In a study by Souza et al. (2014), the Santa Inês breed presented a high tolerance to heat and when crossed with Dorper breeds producing crossed animals that were tolerant to high temperatures. Barbosa Neto et al. (2010) suggested Dorper sheep as a paternal breed for terminal crosses in order to improve productive efficiency in tropical environments.

The superiority of the crosses increased the productivity in extensive breeding systems, exploiting the advantages of complementarity and heterosis (Paim et al., 2011). From the zootechnical point of view, crossbreeding between Dorper breed and native breeds have been more indicated for commercialization, especially between Dorper and Santa Inês, due to the greater adult weight and higher maturity rate (Carneiro et al., 2007), similar to that observed in our study.

Sexual dimorphism was observed at 120 days for the rib, shoulder (DRL) and loin (DMN) weights. This can be justified by the

physiological nature of the sexes, in which the different parts of the body tissues develop at different speeds, resulting in different development of body proportions (Lawrie, 2005). Generally, sex influences the weight of the animal, generating larger heavier males compared to females as adults. However, when young, females tend to be higher in carcass yield (fat deposition) and show more precocity than males in gaining weight. It should be noted that the potential of the animals of our study wasn't probably expressed in its entirety at 120 days. That is, the animals were young and were initiating their bony and muscular developments corresponding to the evaluated meat cuts.

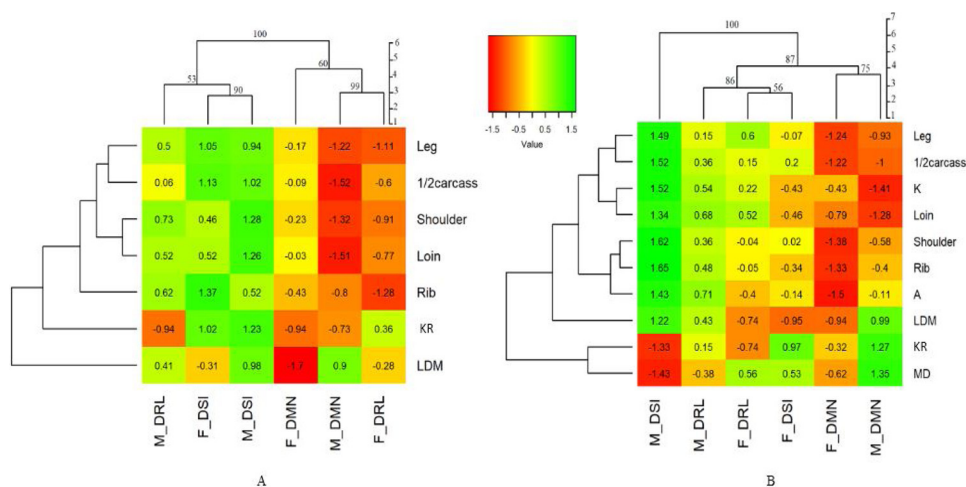
The increase in average values of carcass traits for animals slaughtered at 240D compared to 120D was expected, since the development of these traits increases until reaching the full maturity. Further advancement of the age of the animals leads to a proportional decrease in these traits increment. According to Osório et al. (2012), the speed of muscle growth is similar to that of body weight, and at the maturity age the proportion of muscle in relation to body weight decreases.

The superiority of the M\_DSI crosses in relation to the others for the rib, loin (except with DRL that was similar), half carcass and shoulder at 240D may be due to the fact that Santa Inês is of larger body size and presents larger potential for meat production (Furusho-Garcia et al., 2010). This quality is probably what makes this breed one of the most used in Brazil. Another important fact is that genetic evaluation

**Table 3**  
Percentage of the weight of the meat cuts (%) in relation to the total weight of the ½ carcass of the crossed sheep.

	F_DMN	M_DMN	F_DRL	M_DRL	F_DSI	M_DSI
Slaughtered 120 days						
Rib	15.19 ± 1.62 <sup>a</sup>	14.49 ± 0.97 <sup>a</sup>	14.99 ± 1.53 <sup>a</sup>	14.65 ± 1.61 <sup>a</sup>	15.63 ± 1.62 <sup>a</sup>	15.86 ± 2.27 <sup>a</sup>
Loin	7.98 ± 0.90 <sup>a</sup>	7.17 ± 0.58 <sup>a</sup>	7.55 ± 0.54 <sup>a</sup>	7.55 ± 1.15 <sup>a</sup>	7.33 ± 0.61 <sup>a</sup>	7.39 ± 0.87 <sup>a</sup>
Shoulder	14.31 ± 1.31 <sup>a</sup>	14.84 ± 0.55 <sup>a</sup>	14.68 ± 1.04 <sup>a</sup>	14.06 ± 0.85 <sup>a</sup>	14.49 ± 0.43 <sup>a</sup>	15.06 ± 1.36 <sup>a</sup>
Leg	31.28 ± 0.35 <sup>a</sup>	31.08 ± 0.74 <sup>a</sup>	31.33 ± 0.50 <sup>a</sup>	27.80 ± 9.04 <sup>a</sup>	31.66 ± 0.62 <sup>a</sup>	31.69 ± 1.68 <sup>a</sup>
Total %	68.76	67.58	68.55	64.07	69.12	70.01
Slaughtered 240 days						
Rib	13.45 ± 0.56 <sup>b</sup>	15.17 ± 0.73 <sup>ab</sup>	13.46 ± 0.44 <sup>b</sup>	15.60 ± 1.72 <sup>ab</sup>	14.37 ± 1.16 <sup>ab</sup>	16.41 ± 1.70 <sup>a</sup>
Loin	7.29 ± 0.41 <sup>a</sup>	7.36 ± 0.72 <sup>a</sup>	7.17 ± 0.44 <sup>a</sup>	7.72 ± 1.14 <sup>a</sup>	6.47 ± 0.69 <sup>a</sup>	7.10 ± 0.65 <sup>a</sup>
Shoulder	14.30 ± 1.02 <sup>a</sup>	14.26 ± 0.88 <sup>a</sup>	13.85 ± 0.15 <sup>a</sup>	14.71 ± 1.05 <sup>a</sup>	14.92 ± 0.59 <sup>a</sup>	15.36 ± 0.72 <sup>a</sup>
Leg	32.82 ± 1.00 <sup>a</sup>	30.85 ± 0.60 <sup>a</sup>	32.67 ± 0.16 <sup>a</sup>	30.66 ± 2.45 <sup>a</sup>	32.39 ± 0.55 <sup>a</sup>	30.73 ± 1.38 <sup>a</sup>
Total %	67.85	67.63	67.15	68.68	68.15	69.59

\*Means followed by equal letters in the same line do not differ statistically by the Tukey test at 5% significance. F\_DMN: ½ Dorper x ½ Morada Nova female; M\_DMN: ½ Dorper x ½ Morada Nova male; F\_DRL: ½ Dorper x Rabo Largo female; M\_DRL: ½ Dorper x ½ Rabo Largo male; ½ F\_DSI: ½ Dorper x ½ Santa Inês female; M\_DSI: ½ Dorper x ½ Santa Inês male.



**Fig. 2.** Heatmap of principal components for animals slaughtered at 120 (A) and 240 (B) days. F\_DMN: Dorper x Morada Nova female; M\_DMN: Dorper x Morada Nova male; F\_DRL: Dorper x Rabo Largo female; M\_DRL: Dorper x Rabo Largo male; F\_DSI: Dorper x Santa Inês female; M\_DSI: Dorper x Santa Inês male. KR: Kleiber ratio; LDM: *longissimus dorsi* muscle; A: asymptotic or adult weight; K: maturity rate; DM: degree of maturity in percentage. Cophenetic correlation coefficient: 0.78 (A) and 0.77 (B).

**Table 4**  
Principal components of traits evaluated in crossbred sheep.

	Slaughtered 120 days			Slaughtered 240 days		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
LDM	-	-	-	0.19	<b>0.52</b>	<b>-0.64</b>
Rib	<b>0.40</b>	-0.03	0.28	<b>0.35</b>	0.22	-0.01
Loin	<b>0.43</b>	-0.10	0.07	<b>0.35</b>	-0.17	0.13
½ carcass	<b>0.44</b>	-0.13	-0.24	<b>0.35</b>	0.04	0.31
Shoulder	<b>0.43</b>	-0.01	0.23	<b>0.35</b>	0.19	0.15
Leg	<b>0.44</b>	-0.09	0.14	<b>0.35</b>	0.00	0.35
Kleiber ratio	0.27	<b>0.40</b>	<b>-0.81</b>	-0.25	<b>0.49</b>	0.21
A	-	-	-	<b>0.32</b>	<b>0.38</b>	-0.03
Maturity rate	-	-	-	<b>0.35</b>	<b>-0.26</b>	-0.03
Maturity degree	-	-	-	-0.25	<b>0.41</b>	<b>0.54</b>
Explained variance (%)	70.41	15.91	9.79	73.53	16.35	6.73

The values in bold represent greater values.  
LDM: *longissimus dorsi* muscle; A: asymptotic or adult weight.

programs have been carried out with Santa Inês, which justifies its greater performance when crossed with the Dorper breed. A fact also observed by Carneiro et al. (2007) and Malhado et al. (2009), studying the same crosses.

At 240D, all crosses had more than 100 % of the percentage of their asymptotic weight, except for M\_DSI. This indicates that animals can be slaughtered before that age. The results obtained for DM at 240D showed that the animals already reached physiological maturity at the time of slaughter, regardless of sex. The animals were possibly in the same DM, in which the increase in the amount of muscle already stabilized, with only the increase of the body fat of the young sheep. In this context, to follow the demands of the consumer market, it is important to create strategies for a better finishing period and/or fat deposition in the carcass, mainly because marbling is the last to be deposited and is a positive factor on softness, palatability, and succulence of the meat (Costa et al., 2002).

In relation to KR, 240D animals presented lower values when compared to 120D ones. The decrease of this index with the advancing of the age is a consequence of the greater requirement of the animal for muscular tissue and fat development. High values of KR index indicate a greater dilution of maintenance requirements, that is, improved body growth obtained without increasing the cost of maintenance (Archer et al., 1999). Therefore, animals in the growth phase have a lower requirement for metabolizable energy for maintenance, thus ensuring greater energy availability for muscle tissue gain, demonstrating that slaughtering at an early age may be advantageous in certain production systems to answer specific consumer markets.

The ratio between meat cuts yield and half carcass both at 120D and

240D, showed that carcasses maintained a similar pattern of weights and proportion of prime cuts, except for the rib that did not follow the same pattern of the other cuts at 240D. According to Issakowicz et al. (2014), the comparison of the of weight and proportion of cuts is important for the commercial evaluation of the carcasses, since the different anatomical regions show a variety of economic values.

The grouping observed for the animals at 120D clearly showed the approximation between the DSI crosses (both male and female) and M\_DRL, indicating that at this age the body development of these animals was similar and with greater potential to increase the deposition of muscle in the carcass, presenting larger weights for the commercial cuts in relation to the other crosses. These cross products can be an alternative when the consumer market chooses heavier cuts.

According to Landim et al. (2017), it can be observed a greater performance of carcass of crossbred animals with great heterotic effect (i.e., they provide improvements in the performance of the animals). These authors reported superiority of 33 % of the crossbred in relation to purebred animals when they performed the crosses between Santa Inês and Rabo Largo breeds and considered these individuals ideal for the production of meat since it was possible to aggregate rusticity and production potential. It is worth mentioning the good performance of the M\_DRL, which can stimulate the use of Rabo Largo breed in crossings and thus increase the interest in this breed that is at risk of extinction.

At 240D, the M\_DSI showed an animal with a large profile (greater structure) corroborating the previous results, which highlights its superiority, although with lower KR and DM (despite having surpassed 100 %). Considering that KR is an indirect indicator of feed conversion and an important selection criterion for growth efficiency, M\_DSI crosses tend to be less precocious (low value of KR), which may limit the profitability of the production system because they present higher feed consumption. It is emphasized that feed consumption is an important economic factor, mainly associated with the use of animals with slow growth.

In general, the use of KR in sheep breeding programs serves as an alternative tool to increase feed conversion efficiency and may serve in selection to improve the increment of weight gain and consequently higher growth speed. Tabeli (2012) also confirms the importance of KR in the selection of animals with greater body growth, due to their practicality and to help the selection of individuals with greater growth efficiency, instead of selecting only animals according to size. However, it must be stressed out that it is essential to estimate genetic parameters to verify if genetic gains are possible.

DMN animals tended to cluster, showing that at this age (240D) it is possible to perceive more clearly the genetic differences in phenotypic expression. DMN at 240D, have lower values for carcass traits and growth. However, M\_DMN draws attention to its superiority to KR, as

well as its DM. After standardizing the age of the animals, this relationship is economically feasible, since, in general, animals with earlier maturity are smaller in size, and it is possible to optimize the stocking rate (Menezes et al., 2010).

In addition, under the extensive system, individuals who present greater body growth associated with the lowest energy requirement are more indicated, since the adaptation to the edaphoclimatic and management conditions, limits a good performance and, consequently, the efficiency of meat production (Silveira et al., 2011). In fact Morada Nova breed has been highlighted among the sheep breeds adapted to the climatic conditions of the Brazilian north-eastern semi-arid region, due to its high rusticity, prolificacy and aptitude for meat and leather production (Brasil et al., 2016).

In the extensive production systems of the Northeast of Brazil as well as in other arid regions, this breed represents an important genetic resource for the production of sheep meat (Lacerda et al., 2016), serving as a source of protein for local populations (McManus et al., 2013). The DRL and DSI females showed lower values of LDM and shoulder, with carcass size intermediates between the crosses. Similarly, they showed lower values than crosses regarding GM and A parameter. The group composed by M\_DRL, F\_DRL, and F\_DSI can be characterized by an intermediate value for carcass traits, growth, and efficiency (KR).

The small differences observed in the crosses when slaughtered at 120D, allow the sheep farmers to choose, when economically viable, to slaughter male and/or female animals, regardless of the cross. It is emphasized that probably at that age the genetic effects have not been expressed in their totality yet, that is, the animals are young and are initiating bone muscular development. Meat cuts such as rib and loin may reinforce this hypothesis, since the former is part of the bony structure (rib), while the second (loin) is the upper part of the back, which comprises cuts gastronomically known as "carré" and "selle".

The market's demand for smaller prime cuts, focusing on the ease of preparation, is a reality to be addressed by producers. Thus, DMN may be an option when the consumer market opts for smaller cuts. However, Issakowicz et al. (2014) reported that even at 240D of age, the Morada Nova breed still does not have a satisfactory finishing (fat and conformation). These same authors recommended a later slaughter for this breed. On the other hand, the complementarity of the traits transmitted by Dorper in the crossing with these animals can make them more precocious, allowing their use in production systems more efficiently.

The low yield of DMN crossing for meat cuts probably should be related to the fact that it has already reached the full development of muscle tissue before 240D. In this sense, if the farmer wants to slaughter animals early and has limited infrastructure for the production of animals with larger body sizes, such as the DSI and DRL, the DMN can be a crossing option, in order to optimize the cost-benefit in production.

The differences observed between the groups when the traits were considered simultaneously (MANOVA), corroborate the results obtained by analysis of variance (ANOVA), with the superiority of DSI and DRL animals in relation to DMN. This may be due to the better size of these crosses, which has greater potential to increase muscle deposition in the anatomical or commercial interest regions when compared to DMN. Thus, animals with fast development (i.e., Morada Nova) tend to complete their bony and muscular growth earlier than the ones of high dimensions but tend to present low thoracic depth and shorter body length.

The arrangement of the first major component at both 120D and 240D characterizes animals with the highest body structure (i.e., DSI and DRL, mainly males). The second and the third main components at 120D and 240D, match animals with lower development of meat cuts and greater KR (mainly associated with DMN, which accounts for most of the explanation of these components). It should be noted that the development of LDM is directly related to the increase in weight and age of the animals (Santos et al., 2016).

## 5. Conclusion

The arrays generated in the main components were effective in discriminating crosses. This technique can be used as an additional tool by breeders when selecting, acquiring and/or classifying specific crosses according to body development. This is fundamental in order to meet consumers' preferences seeking commercial cuts of specific size or profile. In general, it is recommended to slaughter the animals before 240D. If the 120D slaughter is used, the farmer can choose, when economically viable, to slaughter animals regardless of sex and crossing, being attentive only to prioritize the DSI and M\_DRL as an alternative to serving the consumer market seeking heavier cuts.

## Declaration of Competing Interest

The authors declare no conflicts of interest.

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