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REGULAR ARTICLES

# Tissue composition and allometric growth of carcass of lambs Santa Inês and crossbreed with breed Dorper

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## Abstract

This study aimed to assess the tissue composition and allometric growth of carcasses of Santa Inês and crossbred Dorper x Santa Inês lambs confined for different periods at three body weight classes. Sixty-four lambs from Santa Inês (SI) and crossbred Dorper x Santa Inês (DSI) were slaughtered. The carcasses were refrigerated at 4 °C for 24 h, and half of the right side carcass was divided into five primary cuts, which were then dissected into bone, muscle, and fat. The corrected cold carcass weight (CCWc) was calculated based on the sum of the cuts. There was no effect of the interactions evaluated ($P > 0.05$) among the factors tested. CCWc, muscle (kg), fat (kg), bone (%), M:F, M:B, F:B, and M+F:B were influenced by the lambs' genetic group ($P < 0.05$). An effect of body weight at the beginning of confinement was found only for CCWc, muscle (kg), fat (kg), bone (kg), bone (%), and M:F. The crossbreeding of Santa Inês with breeds Dorper promotes improvements in the qualitative characteristics of the carcass. To obtain better relationships of the quantitative characteristics of the carcass, of sheep introduced in confinements with larger weights, the slaughter weight must be adjusted to that initial weight.

**Keywords** Hair sheep lamb · Breeding · Tissues · Growth · Allometry

## Introduction

Exotic breeds are often introduced and crossed with local breeds aiming to increase productivity while exploring the desirable characteristics of each breed (Dickerson 1970).

Woolless sheep breeds are adapted to the Brazilian edaphoclimatic conditions. However, they have much lower performance levels compared with specialized breeds. Among woolless breeds, Santa Inês (SI) represents the largest herd in Brazil and is the target of several studies involving breeding that aim to produce purebred lambs as well as crossbreds for early slaughter (McManus et al. 2010; McManus et al. 2013). In these crossbreedings, the Dorper breed, originated in South Africa, stands out as a paternal breed for its high growth and development rates and production of carcasses with good conformation (Cloete et al. 2000).

The carcass tissue composition (amounts of fat, muscle, and bone) varies according to age, genetic basis, production system, and diet (Sañudo and Sierra 1993). The terminal breeding of Dorper sheep with native breeds might improve the carcass value of the crossbred offspring (Cloete et al. 2007). Improving precocity, weight gain rate, and dietary efficiency, characteristics are directly related to reductions in feeding costs, carcass weight, and muscle and fat deposition (Purchas et al. 2002).

The quantitative study of the animal growth process involves changes in the animal's shape and composition as a

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result of the differential growth of body parts. Within each tissue, development may be precocious, medium, or late depending on its location in the body, which causes changes in body shape and composition as the animal matures (Owens et al. 1993).

Researches on animal growth curves and development lay important basis for the efficiency of the production system. Information on growth and body composition of tropical breeds is still limited. The present research may extend the understanding on the performance of tropical sheep and their potential as meat-producing animals. The objective of this study was to evaluate the Santa Inês breed in relation to the tissue composition and the allometric growth of the carcass, when crossed with the Dorper breed, under an intensive production system, based on three classes of body weights.

## Materials and methods

This experiment was carried in Castanhal, in the state of Pará, Brazil (1° 17′ 46″ S and 47° 55′ 28″ W). Sixty-four castrated male lambs, split at 32 Santa Inês (SI) and 32 crossbred Dorper x Santa Inês (DSI), with mean initial age of 5 to 7 months were used. The animals were submitted to weighing, vermifugation, identification, and confinement inside a masonry building, housed in individual wooden bays with an area of 1.2 $m^2$ (1.2 × 1.0 m) with a concrete floor covered with shavings and wooden pallets. Feeder and drinking fountain were provided. During this period, the lambs received the same diet, remaining until reaching the stipulated confinement time.

The diet was provided twice a day (8 a.m. and 5 p.m.) and was composed of 32% elephant grass (*Pennisetum purpureum*) silage, 16.30% soybean meal (*Glycine max* L.), 49.32% corn (*Zea mays* L.), 1.03% calcitic lime, and 1.35% mineral and vitamin supplement. With 2.31 metabolizable energy (Mcal/Kg diet), 12.53% crude protein (CP), 1,92% ether extract (EE), 62% neutral detergent fiber (NDF), and 42.63% acid detergent fiber (ADF), diet formulation was calculated according to the recommendations by the NRC (2007) to achieve gain of 200 g $day^{-1}$. The dry matter, CP, EE, NDF, and ADF were determined according to the methods described by the Association of Official Analysis Chemists (1990). Estimation of metabolizable energy (ME) was assumed that 1 kg total digestible nutrient (TDN) is equivalent to 4.4 Mcal of digestible energy; then, this value was multiplied for 0.82 to arrive at ME intakes (NRC 2007).

After 14 days of adaptation to the diet and experimental conditions, groups were formed by combining genetic groups (GG), body weight at the beginning of confinement (BWB), and time in confinement (TC). The mean BWB was split into classes: light (25 ± 1.57 and 25 ± 2.40 kg), intermediate (28 ± 1.72 and 28 ± 1.40 kg), and heavy (31 ± 1.01 and 31 ± 1.54 kg) for SI and DSI lambs, respectively. The animals were slaughtered in 28-day cycles for four periods in confinement: 0, 28, 56, and 84 days.

The animals were slaughtered according to the industrial routines used in Brazil (Brasil 2000). The whole carcasses were weighed and refrigerated at 4 ± 1 °C for 24 h and then weighed again to obtain the cold carcass weight (CCW). After 24 h of refrigeration, the right-side half-carcass was used to obtain the commercial cuts (neck, shoulder, rib, loin, and leg) according to Lage et al. (2014). All cuts were dissected to obtain the total weight of bone, muscle, and fat (Fisher and de Boer 1994).

The corrected cold carcass weight (CCWc) was calculated based on the sum of the cuts. Carcass bone, muscle, and fat compositions were determined by the sum of the amount of each tissue in the different cuts, which were doubled to extrapolate whole carcass values.

The characteristics of composition, tissue percentage, and respective ratios underwent analysis of variance. When significant difference was found among the effects, the means were compared by Tukey's test at 5% significance. The software R (R Core Team 2016) was used for the ANOVA.

Tissue component growth in relation to the CCWc was studied using the nonlinear allometric function ($y = ax^{\beta}$), as described by Sabbioni et al. (2016). Where $Y$ = total tissue weight; $a$ = is the intercept, "$x$" is the independent variable; $\beta$ = is the allometric coefficient (Stevens 2009; Strauss 1987). The growth was considered isogonic when $\beta = 1$, which indicates that the development rates of $Y$ (tissue) and $X$ (CCWc) were similar in the growth period from 0 to 84 days of confinement. When $\beta \neq 1$, growth was considered heterogonic and could be positive ($\beta > 1$), indicating late development, or negative ($\beta < 1$), indicating early development. Comparisons of the equation parameters between genetic groups were done using the pooled estimates of standard error to determine significant differences (Pilla 1985).

## Results

There was no significant effect of the interactions evaluated ($P > 0.05$) between genetic grouping, body weight class at the beginning of confinement, and time of confinement.

Corrected cold carcass weight (CCWc), muscle (kg), fat (kg), bone (%), ratios muscle/fat (M:F), muscle/bone (M:B), fat/bone (F:B), and (muscle+fat tissue)/bone (M+F:B) (were influenced by the lambs' genetic group ($P < 0.05$), indicate greater mean bone (%) and M:F values in the SI group. DSI groups had higher means of CCWc, muscle (kg), fat (kg), M:B, F:B, and M+F:B (Table 1).

An effect of BWB class was found only for CCWc, muscle (kg), fat (kg), bone (kg), bone (%), and M:F (Table 1). The heavy class (BWB, 31 kg) differed ($P < 0.05$) from the light

**Table 1** Means, standard deviation (SD), and coefficient of variation for corrected cold carcass weight, and tissue composition, percentage, and ratio for Santa Inês and crossbred lambs of different body weights over different times

| Effects | Variables (kg) | | | | | | | | Variables (%) | | | | | | Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CCWc | | Fat | | Muscle | | Bone | | Fat | | Muscle | | Bone | | M:F | | M:B | | F:B | | M+F:O | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| *P* value | 0.0054 | | 0.0088 | | 0.0199 | | 0.4816 | | 0.0427 | | 0.5500 | | 0.0063 | | 0.0216 | | 0.0083 | | 0.0094 | | 0.0007 | |
| SI | 14.91b | 3.66 | 3.24b | 1.54 | 8.21b | 1.88 | 2.92 | 0.40 | 20.38b | 5.71 | 54.9141 | 3.04 | 20.25a | 4.35 | 2.94a | 1.04 | 2.8b | 0.53 | 1.09b | 0.46 | 3.90b | 0.94 |
| DSI | 15.91a | 3.75 | 3.68a | 1.55 | 8.70a | 2.04 | 2.87 | 0.41 | 22.08a | 5.43 | 54.5426 | 3.06 | 18.61b | 3.38 | 2.58b | 0.71 | 3.01a | 0.50 | 1.26a | 0.47 | 4.31a | 0.90 |
| *P* value | < 0.0001 | | < 0.0001 | | < 0.0001 | | < 0.0001 | | 0.0947 | | 0.3458 | | 0.0537 | | 0.1085 | | 0.0800 | | 0.0459 | | 0.0567 | |
| Light | 14.01b | 3.93 | 3.12b | 1.66 | 7.75b | 2.02 | 2.74b | 0.45 | 20.59 | 6.12 | 54.80 | 3.17 | 20.25a | 4.26 | 2.91 | 1.03 | 2.80 | 0.50 | 1.10b | 0.49 | 3.95 | 0.94 |
| Intermediate | 15.00b | 3.06 | 3.23b | 1.41 | 8.22b | 1.66 | 2.82b | 0.27 | 20.65 | 5.69 | 55.23 | 3.28 | 19.47ab | 4.00 | 2.83 | 0.94 | 2.92 | 0.53 | 1.14ab | 0.47 | 4.06 | 0.96 |
| Heavy | 17.22a | 3.47 | 4.03a | 1.49 | 9.41a | 1.90 | 3.14a | 0.37 | 22.49 | 4.95 | 54.14 | 2.64 | 18.57b | 3.56 | 2.55 | 0.71 | 3.01 | 0.53 | 1.28a | 0.44 | 4.29 | 0.92 |
| *P* value | < 0.0001 | | < 0.0001 | | < 0.0001 | | < 0.0001 | | < 0.0001 | | 0.0001 | | < 0.0001 | | < 0.0001 | | < 0.0001 | | < 0.0001 | | < 0.0001 | |
| 0 days | 11.12d | 1.86 | 1.77d | 0.65 | 5.93d | 1.09 | 2.60c | 0.45 | 15.71c | 4.30 | 53.62b | 3.33 | 24.57a | 3.76 | 3.68a | 1.13 | 2.23c | 0.39 | 0.67d | 0.26 | 2.91d | 0.62 |
| 28 days | 14.22c | 2.07 | 2.64b | 0.79 | 8.04c | 0.95 | 2.74bc | 0.34 | 18.29c | 3.30 | 57.40a | 3.25 | 19.43b | 2.16 | 3.20a | 0.59 | 2.95b | 0.29 | 0.96c | 0.25 | 3.92c | 0.48 |
| 56 days | 16.77b | 2.35 | 3.94c | 1.00 | 9.08b | 1.22 | 2.97ab | 0.29 | 23.17b | 3.55 | 54.24b | 2.01 | 18.00bc | 2.63 | 2.41b | 0.48 | 3.07ab | 0.39 | 1.33b | 0.33 | 4.48b | 0.59 |
| 84 days | 19.53a | 1.81 | 5.30a | 0.75 | 10.49a | 1.10 | 3.18a | 0.34 | 27.15a | 2.88 | 53.67b | 1.82 | 16.31c | 1.40 | 2.00b | 0.28 | 3.31a | 0.30 | 1.68a | 0.27 | 5.00a | 0.50 |
| C.V | 9.47 | | 19.27 | | 10.09 | | 10.05 | | 16.00 | | 4.68 | | 12.28 | | 18.94 | | 10.86 | | 21.99 | | 11.57 | |

Genetic group: *SI*, Santa Inês, *DSI*, crossbred; *BWB*, body weight at the beginning of confinement; light (25 kg), intermediate (28 kg), heavy (31 kg). *TC*, time in confinement (0, 28, 56, and 84 days); *CCWc*, corrected cold carcass weight; *M:B*, muscle/bone ratio, *M:F*, muscle/fat ratio, *F:B*, fat/bone ratio, *M + F:B*, (muscle+fatty tissue)/bone ratio

Means in the same column followed by different letters differ ($P < 0.05$) according to Tukey's test

Significance level $*P < 0.05$ and $**P < 0.01$

*CV* coefficient of variation

(BWB, 25 kg) and intermediate (BWB, 28 kg) classes, with higher mean values of CCWc, fat (kg), muscle (kg), bone (kg), and F:B. The intermediate class obtained higher mean CCWc and muscle (kg) values than the light class, but they did not differ from each other, nor did fat (kg), bone (kg), bone (%), or F:B. The M:F ratio did not differ among the light, intermediate, and heavy classes.

The lambs confined for 84 days had higher ($P < 0.01$) values of the parameters assessed (Table 1), except for muscle (%) and M:F. No difference ($P > 0.05$) was found between TC of 56 and 84 days for bone (kg), muscle (%), M:F, or M:B.

For the genetic groups (SI and DSI), the allometric coefficients of fat, muscle, and bone did not differ ($P > 0.05$) for the different weight classes (light, 25 kg; intermediate, 28 kg). However, for Santa Inês and crossbreed lambs, within the heavy class, there were differences ($P < 0.05$) in growth velocity for bone and fat; there was no difference for the muscle (Fig. 1). In relation to the heavy class, a higher value ($B = 2.1521$) was registered for SI animals, indicating a later maturation rate, with DSI being earlier than Santa Inês group ($P < 0.05$).

The allometry ($\beta$) coefficients for bone indicated that the growth of the bone was precocious ($\beta < 1$), as the tissue growth rate (impetus) was greater than the total weight of the corrected cold carcass. Muscle tissue has isogonic growth ($\beta = 1$), which shows muscle growth occurs at the same rate as CCWc over the timeframe considered. Fat growth is late ($\beta > 1$), i.e., fat growth impetus is lower than that of CCWc and, consequently, an increase in carcass weight raises the fat growth rate.

The light (Fig. 1a) and intermediate (Fig. 1b) classes indicated that adipose tissue exceeded bone growth at 14.52 and 14.54 kg of cold carcass corrected for the light and intermediate classes, respectively. For the heavy class, the adipose tissue of the SI animals exceeded the growth of bone tissue (Fig. 1c) only after 15.8 kg of CCWc. However, the adipose tissue of the DSI animals overcame the bone growth even before the 12.5 kg of CCWc, which corresponds to the initial value of CCWc for this heavy class.

## Discussion

The superiority of qualitative characteristics in the carcasses of crossbreed (DSI) lambs compared with Santa Inês (SI) ones was evidenced by the higher averages obtained for CCWc, muscle (kg), fat (kg), bone (%), M:G, M:B, F:B, and M+

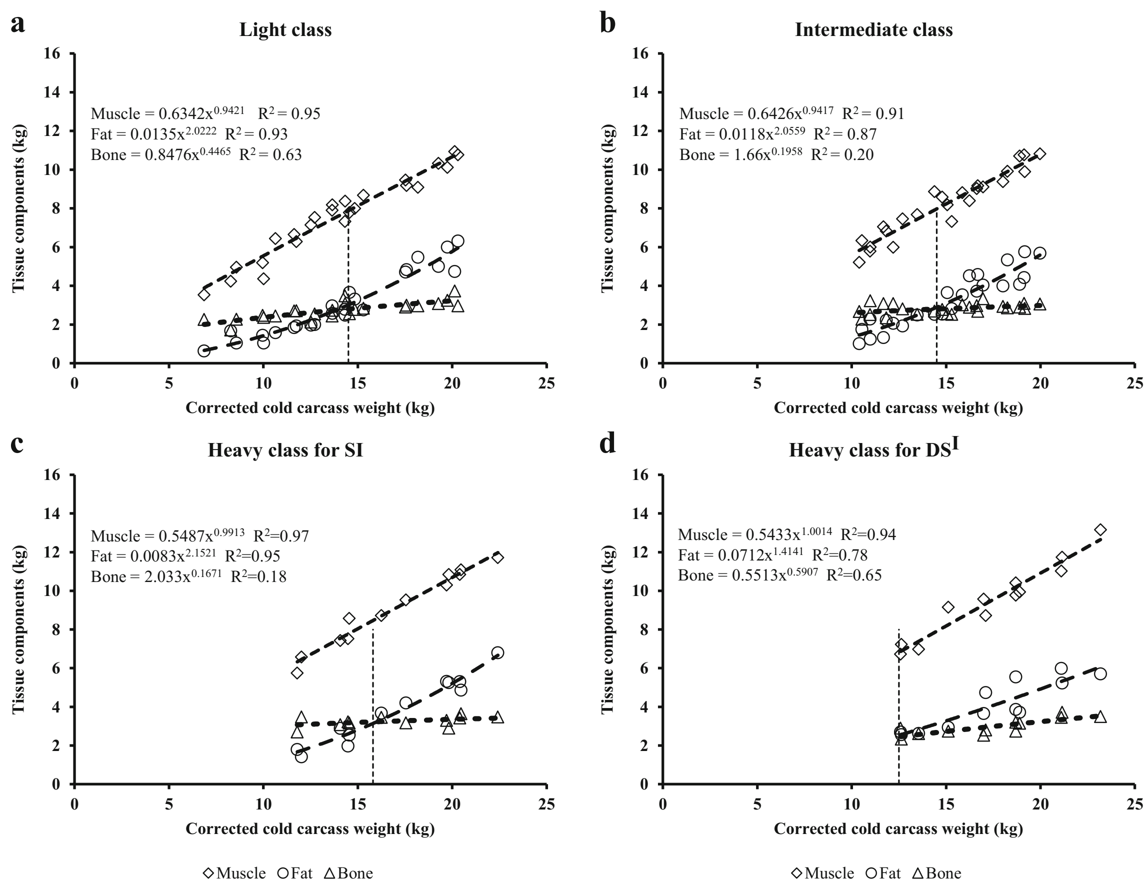


**Fig. 1** Allometric ratio among tissue components and corrected cold carcass weight of the genetic groups (SI and DSI) for different body weights at the beginning of confinement (BWB) (light 25 kg, intermediate 28 kg, and heavy 31 kg). Weights were observed for muscle, fat, and bone and estimated by Huxley's exponential model for muscle, fat, and bone for the **a** light, **b** intermediate, and **c** heavy SI and **d** heavy DSI classes

F:O, as well as the lower proportion of bone in the carcass (bone %).

DSI lambs reached a higher fat percentage than SI ones, which shows crossbreeding the two GGs leads to greater fat deposition on the carcass of animals in confinement. Moreover, the higher M:F percentage among SI lambs indicated a greater potential for muscle deposition and lower fat deposition in the carcass. The lower bone percentage in the carcass increased the value of the edible portion. The DSI animals achieved a higher mean value (4.31 in relation to CCWc) for the edible portion, differing from SI lambs.

Such result may be attributed to the heterosis and complementarity of the breeds, showing that the crossbred animals are more efficient in producing the edible portion of the carcass. That shows the efficacy of using terminal crossbreeding aiming to produce lambs that stand out regarding characteristics associated with growth rate and carcass composition (Freking and Leymaster 2004).

The greater CCWc for the animals in the body weight at the beginning of confinement 31 kg (heavy) class can be explained by the greater weight at slaughter (Table 1) and presented greater amount of carcass muscle and fat compared with the animals in the body weight at the beginning of confinement 25 kg (light) or body weight at the beginning of confinement 28 kg (intermediate) classes. The heavier carcass weight was due to the larger body structure of the heavy class compared with the others at the beginning of confinement.

The increase in time in confinement led to a higher M+F:B ratio mainly because of the increase in F:B ratio, indicating the increase in the proportion of carcass fat. However, since the mean values of M:F, which is a determining factor for carcass's fat content, did not differ between 56 and 84 days (Table 1), it is understood that the confinement of SI and DSI lambs, regardless of the BWB, may be shortened to 56 days. The lower percentage of muscle (muscle %) at 84 days compared at 56 days may be explained by the greater rate of fatty tissue deposition, which gradually increases after the rate of muscle tissue deposition drops, that shows lighter animals are more efficient in converting feed into meat (Schoonmaker et al. 2002).

The M:F ratio showed that fat increased with longer TC, i.e., at 84 days, a greater amount of fat (5.30 vs 3.94 kg) was found for a given amount of muscle (10.48 vs 9.08 kg) compared with TC of 56 days.

The M:F ratio is very important and must be assessed in studies involving ratios among tissues. The higher fat content may result in better meat quality since the fatty tissue carries substances that impart flavor to the meat product (Brewer 2012). Lower amounts of fat reduce the acceptability of lamb meat and carcasses with 2 mm of subcutaneous fat thickness, or less have been classified in a sensory test as inferior regarding flavor and satisfaction (Sañudo et al. 2000).

For the light and intermediate classes (Fig. 1a and b), the intersection of the allometric curves of bone and adipose tissues occurs approximately at 14.5 kg of CCWc weight, indicating the moment at which the muscle:fat ratio would decrease. This way, considering the CCWc yields of 44.13%, 46.18%, and 46.06% for SI lambs in the light, intermediate, and heavy classes, respectively, and 46.52%, 47.23%, and 51.01% for DSI animals in the light, intermediate, and heavy classes, respectively, the recommended body weights at slaughter would be 31 kg for DSI lambs confined at 25 kg or 28 kg, 33 kg for SI animals confined at 25 kg, and 32 kg for SI lambs confined at 28 kg that leads to carcasses with the greatest M:F ratio. The confinement of DSI lambs at 31 kg may be inappropriate and, consequently, costly since the intersection of the growth curves of bone and fat occur at a point below 12.5 kg CCWc (Fig. 1d), indicating that the high carcass weights will be caused by larger fat deposits.

For SI animals, confinement at 31 kg results in animals with better fat content levels as the growth of fatty tissue surpasses that of bone at 15.80 kg CCWc since the allometric growth of fat in this genetic group occurs later than in DSI lambs. If a CCWc yield of 46.06% is adopted, the animals should be slaughtered at 34 kg body weight.

The behavior of tissues in relation to CCWc over the experimental period matches the physiological pattern of bone and fat growth and development described by Berg and Butterfield (1968) and the statement by Owens et al. (1993), who declare bone tissue has a faster growth rate than muscle and fat. The same behavior was noticed by Furusho Garcia et al. (2009) when assessing the allometric growth of body tissues of pure Santa Inês lambs and crossbred Santa Inês with Texel, Ile de France, and Bergamácia as a function of cold carcass weight. However, those authors observed precocious muscle growth only for the pure animals and those crossbred with Bergamácia.

The intermediate class had a different pattern than that obtained for the other classes, with precocious muscle growth irrespective of the genetic group. Wood et al. (1980) showed that both carcass weight and breed had similar effects on the percentage of lean meat. It shows that confining castrated SI and DSI lambs at 28 kg for finishing is viable since this phase would feature higher muscle growth rate than in light class animals (25 kg).

Although fatty tissue shows late growth in both cases, and based on the higher allometric coefficient among SI lambs ($\beta = 2.1521$) compared with DSI ones ($\beta = 1.4141$), distinct finishing patterns are found for both genetic groups within the heavy class, with SI exhibiting a lower fat deposition rate (Fig. 1c). The alternative of confining animals with initial body weight of 31 kg would be useful for systems that slaughter heavier animals. However, it must be seen with caution since the cost of maintaining those animals increases in face of the decrease in muscle growth while fat deposition grows increasingly more.

The crossbreeding of Santa Inês and Doper promotes improvements in the qualitative characteristics of the carcass and increases the weight of cold carcass, in addition to guaranteeing greater amounts and percentage of muscle in the carcass and better relation muscle + fat:bone.

The input body weight in the system is determinant on the carcass quality. Confined SI lambs with greater initial weight present greater potential for muscle and fat production in the carcass at shorter confinement times, which certainly occurred in previous stages for crossbred lambs of the same initial weight. To obtain better relationships of the quantitative characteristics of the carcass, of sheep introduced in confinements with larger weights, the slaughter weight must be adjusted to that initial weight.

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## Compliance with ethical standards

**Ethical approval** This study was conducted in strict conformity with the Brazilian legislation on experimentation involving the use of animals adopted by the National Council of Experimental Control (CONCEA) and was approved by the Ethics Committee In Animal Use (CEUA) of the Federal University of Pará, located in Belém-PA, Brazil, under approval no. 97/2015, of 01/12/2015.

**Conflict of interest** The authors declare that they have no conflict of interest.

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