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# Morphology of coat and skin of small ruminants reared in the Brazilian semi-arid region

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ABSTRACT

The structure of the coat and integument of small ruminants reared in semi-arid regions have valuable characteristics that favor their adaptation to the region. The objective of this study was to evaluate the structural characteristics of the coat and integument and sweating capacity of goats and sheep in the Brazilian semi-arid region, using 20 animals, 10 of each breed, 5 males and 5 females of each species, grouped in a completely randomized design in a 2 x 2 factorial scheme (2 species and 2 genders) with 5 replicates. The animals were already being kept under the influence of high temperatures and levels of direct solar radiation before the day of the collections. At the time of the evaluations, ambient temperature was high, with low relative humidity. The pattern of epidermal thickness and sweat glands per body region was superior in sheep ($P < 0.05$), and the number of hair follicles and sweat rate were similar ($P > 0.05$) between the species. There was no difference ($P > 0.05$) in the evaluated characteristics between the genders, showing that they are not influenced by hormones. The morphology of the coat and skin of these animals showed a superiority of goats compared to sheep.

## 1. Introduction

In northeastern Brazil, a hot environment, characterized by high levels of radiation and ambient temperature, as well as low levels of precipitation (Pantoja et al., 2017; Leite et al., 2021), rearing small ruminants constitutes a large part of the livestock production of the region, which concentrates the largest fraction of sheep herds (66.7%) and goat herds (93.9%) in the country, with totals of 12.63 and 10.04 million head (IBGE, 2019) , representing an important socio-economic activity. The main breeds reared in the northeast are Santa Inês sheep and Moxotó goats, and almost half of the these animals are farmed extensively (Pantoja et al., 2017; Souza et al., 2019).

Ambient temperature and direct solar radiation are the main factors that affect the thermal exchanges of animals (Fonsêca et al., 2019; Façanha et al., 2020). Goats and sheep, as homeotherms, constantly adjust their physiology to maintain the thermal balance between the heat produced by metabolism and the heat obtained from the environment (Maia et al., 2016; Fonsêca et al., 2017; Marques et al., 2021). This regulation is mainly influenced by physical characteristics of the skin surface of the animals, such as hair coat thickness, density, length and diameter (Sejian et al., 2019; Amorim et al., 2019), as well as skin characteristics, which includes dermal thickness, numbers of sweat and sebaceous glands, and hair follicles, determining the general thermal isolation of the animal's body (El-Tarabany et al., 2017; Sejian et al., 2019).

Heat loss in the latent form occurs with the displacement of water inside the animal's body to the epidermis or respiratory tract (Curtis, 1983), where heat is lost in the conversion of water from the body into vapor, through the sweat secreted by the sweat glands and moisture from the respiratory tract (Maia et al., 2016; Aboul Naga et al., 2021). In animals kept at high temperatures, the main forms of latent heat loss are

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**Abbreviation's list**

| | |
|---|---|
| ANOVA | Analysis of variance |
| $T_{EP}$ | Epidermal thickness |
| $T_A$ | Air temperature |
| HF | Hair follicles |
| $R_H$ | Relative humidity |
| SG | Sweat glands |
| BGTHI | Black globe temperature and humidity index |
| CER | Cervical |
| $T_{HC}$ | Hair coat thickness |
| THO | Thoracic |
| $L_H$ | Hair length |
| GLU | Gluteal |
| $N_H$ | Number of hairs per area unit |
| SR | Sweating rate |
| $W_H$ | Weight of the number of hairs per area unit |
| $ND_H$ | Numerical density of the sample |
| $VD_H$ | Volumetric density of the sample |

skin evaporation are respiratory convection (Gesualdi Júnior et al., 2014; Maia et al., 2016; Silva et al., 2017). Excess heat dissipated through respiratory mechanisms and sweating (Maia et al., 2016; Fonsêca et al., 2017) may result in changes in blood parameters, since there is an increase in the loss of water volume and ionic compounds (El-Tarabany et al., 2017; Sejian et al., 2019).

The coat of the animals also interferes with their thermal exchange. The morphological characteristics of their coat may indicate the condition of acclimatization to the environment in which they live (Marcone et al., 2021; Al-Haidary et al., 2021), as coats with lower density become a favorable characteristic in hot environments, for facilitating the removal of hot air circulating through the hairs (Paim et al., 2013; Maia et al., 2016), and the fleece hinders the evaporation of body water, reducing heat loss through transpiration (Wojtas et al., 2014; Costa et al., 2015).

Therefore, the study aims to evaluate the structural characteristics of the coat and integument as well as the sweating capacity of goats and sheep in the Brazilian semi-arid region.

## 2. Materials and methods

The procedures carried out in this study were approved by the Research Ethics Committee (CEP) of the Federal University of Campina Grande, Paraíba, Brazil, CEP Protocol No. 108.2017.

### *2.1. Study site*

The present study was conducted in the sheep farming sector of the Research Center for the Semi-arid Region Development - NUPEÁRIDO, of the Center for Rural Health and Technology, of the Federal University of Campina Grande, Patos, Paraíba, Brazil (07° 05′ 28″ South, 37° 16′ 48″ West, 250 m altitude), characterized by a BSh climate, according to Köppen's classification, with maximum average annual temperature of 32.9 °C and minimum of 20.8 °C and relative humidity of 61%.

### *2.2. Animals, housing and experimental design*

Twenty animals were used in the experiment, 10 Santa Inês sheep (black coat) and 10 Moxotó goats (white coat), 5 males (non-castrated) and 5 females (dry) of both species, with initial average live weight of 26 ± 5 kg, aged 12 ± 3 months. The animals were kept in an extensive system during the months from July to November and were evaluated in November, hot period of the year. During the measurement of the sweat rate, the animals remained fasting and without access to water, as well as in the collection of integument. They were grouped in a completely randomized design, in a 2 x 2 factorial scheme (2 species and 2 genders) with 5 replicates.

### *2.3. Experimental procedures*

The animals had already been kept in an extensive system before the collections, from July to November, which characterized two periods: less hot (July and August) and hot (September and October). For the two periods, the climatological variables (Table 1) were measured during the afternoon, at three different times: 13, 14 and 15h. On the day of sweat rate measurement and integument collection, the environmental variables were measured at the times of collection (14 and 15h).

### *2.4. Data collection*

#### *2.4.1. Environmental variables*

The data of environmental variables, air temperature ($T_A$, °C), relative humidity (RH, %), were stored in an ONSET Comp® HOBO U12-012 datalogger, with one external channel and one internal channel coupled to a black globe positioned at a height similar to that of the animals, in the collection environments. The data were stored daily every hour throughout the experimental period. For these days, the black globe temperature and humidity index - BGTHI (Buffington et al., 1981) were calculated to evaluate the level of thermal stress induced by the environment on the animals.

#### *2.4.2. Hair coat characteristics*

*In vivo* measurements were taken and hair coat samples were collected between the 12th and 13th vertebrae, approximately 10 cm below the spine, always on the right side of each animal to determine hair coat thickness ($T_{HC}$, mm), average hair length ($L_H$, mm), number of hairs per area unit ($N_H$, number of hairs per $cm^{-2}$), weight of the number of hairs per area unit ($W_H$, g), numerical density of the sample ($ND_H$, hairs $cm^{-2}$) and volumetric density ($VD_H$, weight of hairs - $g/cm^{-3}$). First, $T_{HC}$ was measured *in vivo* using a digital caliper, according to the method described by Silva (2000). Then, a hair sample was collected from a known epidermal area (0.06 $cm^2$) in the same site using specially adapted pliers, as described by Lee (1953), and stored in paper envelopes.

$ND_H$ (hairs $cm^{-2}$) was calculated by counting the number of hairs per sample area and then converting the number of hairs counted into the number of hairs per $cm^2$ of surface area. $W_H$ of the hair sample was obtained with a digital scale. $VD_H$ was determined based on the weight of the sample by the sampled area, converted into $cm^3$. The $L_H$ values (mm) of the ten longest hairs within each sample were measured with a digital caliper (PD-200 model, Vonder, Brazil - Accuracy ± 0.01 mm), according to the method described by Udo (1978). This methodology uses the longest hairs, since they have already completed their growth and are effectively at the limit between the surface of the animal and the environment. This eliminates the risk of underestimating this variable, considering hairs recently emerged from the follicles.

#### *2.4.3. Skin morphology characteristics and sweat rate*

The integument characteristics determined were: epidermal thickness ($T_{EP}$), number of hair follicles (HF) and number of sweat glands

**Table 1**
Characterization of the thermal environment experienced by the animals before the study collections.

| Period of the year | Environmental variables | | |
|---|---|---|---|
| | $T_A$ (°C) | RH (%) | BGTHI |
| Less hot | 34.56 | 29.51 | 82.77 |
| Hot | 36.67 | 27.23 | 85.75 |

(SG). Skin samples were collected with a skin biopsy punch (diameter of 5 mm) in three regions of the animal's body: cervical (CER), thoracic (THO) and gluteal (GLT) (area μm$^2$ – 8118.63; 9105.70; 7333.51, respectively), in sheared regions. The procedure was performed 10 min after subcutaneous administration of a local anesthetic (2 mL lidocaine hydrochloride, Lidovet – Bravet).

Skin samples were fixed by immersion in 10% formaldehyde for 24 h, and then washed and immersed in 70% alcoholic solution for preservation until processing. Subsequently, the samples were sent for histological analysis and included in paraffin blocks according to the standard histological processing (Heleno et al., 2011). Longitudinal cuts with 5 μm thickness were prepared in microtome and stained with hematoxylin and eosin. The histological slides were digitized in Image-Pro (R) Express Version 6.0 software and Olympus BX-40 microscope, with micrometer scale and digital camera connected to the computer.

Morphometric measurements were performed with the same software, using 4x and 10x objective lenses for counting SG and HF and measuring $T_{EP}$, respectively. Three photomicrographs per skin fragment were scanned and three measurements were performed by photomicrography, totaling 180 measurements (20 animals x 3 photomicrographs x 3 measurements). The mean values for statistical analysis were obtained by the measurements of two fields (Fig. 1) in three histological sections of each sample.

Each animal had three skin fragments from the body regions (CER, THO and GLT), and three photomicrographs of each fragment were digitized, totaling 9 photomicrographs (3 regions x 3 photomicrographs) per animal. In each of these 180 photomicrographs, using the 4x objective lens, the numbers of SG and HF found in the dermis were measured and later converted to the value per cm$^2$ of the sample area, and finally, the 10x objective lens was used to measure the $T_{EP}$.

The sweat rate (SR) of the animals was measured in the afternoon, using the colorimetric method as described by Schleger and Turner (1965). The animals were sheared in the three body regions (CER, THO and GLT), with the aid of scissors and metal razorblade. Filter paper discs with 0.5 cm diameter, previously soaked in 10% cobalt chloride solution were fixed in these regions, naturally dried for 30 min, and then placed in a forced air circulation oven at 75 °C and kept for 15 min, 24 h before being used in the field.

The animals were brought from the field at 12h and kept loose in a shaded environment until the collection started (14h). The average turning time of the discs was calculated as follows: $SR = (22 \times 3600)/(2.06\ t) = 38446.6/t$ (g m$^{-2}$ h$^{-1}$). The result was expressed in grams of sweat per square meter of skin per hour eliminated by the animal (g m$^{-2}$ h$^{-1}$). During the SR test, the animals remained fasting and without access to water.

#### 2.4.4. Statistical analyses

Analysis of variance (ANOVA) was performed using the statistical program SAEG (1993) by the F test, and the means were compared by Tukey test at 5% probability level ($P < 0.05$).

## 3. Results

### 3.1. Environmental variables

The animals were already being kept under the influence of high temperatures and levels of direct solar radiation before the day of collections (Table 1). The average air temperature on the day of collection, between 14 and 15h, it was 35.81 ± °C, remained above the recommended thermal comfort zone for the species. $T_A$ must be between 20 and 30 °C and between 50 and 70% for relative humidity (Eustáquio Filho et al., 2011; Lucena et al., 2013). On the other hand, the RH means remained below that recommended for both species, 27.86 ± %,. The upper critical limit of heat tolerance in sheep/goats is $T_A \geq 36$ °C (Johnson, 1987). There was no significant difference ($P > 0.05$) between the times.

RH was below 30% during the entire pre-experimental period where the animals were being kept and also during the collection period in the afternoon, which is when there is greater thermal discomfort for animals according to Salles et al. (2009), regardless of the time of year.

The average of the BGTHI on the day of collections was 84.4. The BGTHI levels for small ruminates were categorized as follows: <82 - absence of thermal stress; 82 to <84 - moderate thermal stress; 84 to <86 - severe thermal stress; and >86 - extremely severe thermal stress (LPHSI - Livestock, 1990). Although the BGTHI for sheep and goats has not yet been categorized, a base BGTHI limit of 86 was developed for Angus steers under non-shaded conditions (Hahn et al., 2009). Therefore, the climatic data obtained and calculated BGTHI indicate that the sheep were exposed to severe thermal stress.

### 3.2. Hair coat characteristics

The structural characteristics of the coat (Table 2) did not show significant effect ($P > 0.05$) between the genders. However, among the species, the weight and volumetric density of the hair were higher in sheep, and hair length was higher in goats, varying significantly ($P < 0.05$), while the other characteristics did not differ.

Hair coat thickness averaged 4.80 mm among the species, was similar between species and genders. The number of hairs was similar between species and genders and within the standard (Amorim et al., 2019), demonstrating the adaptability of goats and sheep to the Brazilian semi-arid climate, where the animals were exposed to an environment of thermal discomfort, subjected to high values of $T_A$ and BGTHI and low RH (Table 1).

Goats had lighter hair weight, 83.66% lower compared to sheep, and with higher $L_H$ (24.57% higher compared to sheep), therefore thinner and longer, with lower $VD_H$ (46.98% lower compared to sheep).

### 3.3. Skin morphology characteristics and sweat rate

The patterns of epidermal thickness and number of hair follicles per

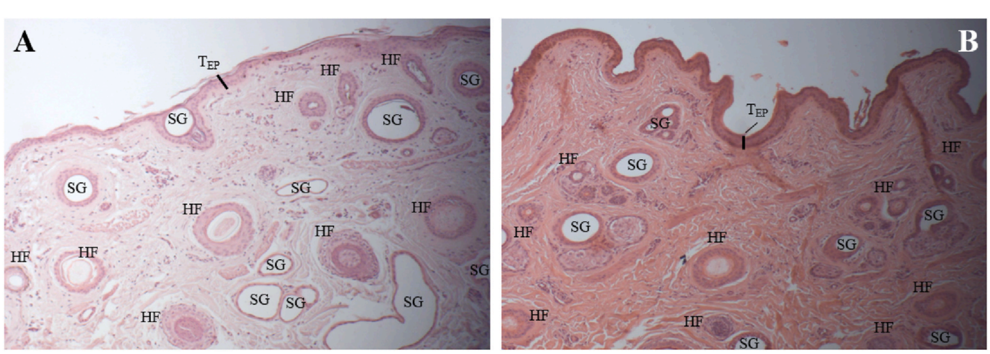


**Fig. 1.** Photomicrographs of the integument (A, sheep and B, goat) highlighting its structures: sweat glands (SG), hair follicles (HF), and epidermal thickness ($T_{EP}$). 10x.

**Table 2**
Means of the structural characteristics of the coat of goats and sheep, in a semi-arid environment.

| Factors | Structural Characteristics of the Coat | | | | | |
|---|---|---|---|---|---|---|
| | $T_{HC}$ (mm) | $N_H$/cm$^2$ | $W_H$ (g) | $L_H$ (mm) | $ND_H$ (hairs/cm$^2$) | $VD_H$ (g/cm$^3$) |
| Species | | | | | | |
| Sheep | 5.30 A | 319.60 A | 0.371 A | 21.45 B | 532.66 A | 0.798 A |
| Goats | 4.30 A | 306.80 A | 0.202 B | 28.44 A | 511.33 A | 0.367 B |
| Gender | | | | | | |
| Male | 4.90 A | 301.30 A | 0.142 A | 25.06 A | 502.16 A | 0.307 A |
| Female | 4.70 A | 325.10 A | 0.096 A | 24.83 A | 541.83 A | 0.139 A |
| CV (%) | 39.94 | 40.15 | 78.71 | 13.22 | 40.15 | 81.72 |

*Means followed by equal letters do not differ by the F test at 5% significance level.

body region of Santa Inês and Moxotó goats are presented in Table 3. The numbers of HF did not differ statically ($P > 0.05$) between the two species. The interaction between the fixed effects (gender vs. body region) for HF and $T_{EP}$ was not statistically significant ($P > 0.05$). $T_{EP}$ differed statistically between the species ($P < 0.05$) (Table 3). The $T_{EP}$ of Santa Inês was higher ($P < 0.05$) than that of Moxotó in all evaluated regions.

The HFs of each body region were counted in a known area (area in μm$^2$: CER -8118.63; THO - 9105.70; GLT - 7333.51) and standardized to 100 μm$^2$. The HF values were similar between the species, which can be attributed to the natural selection of the animals, which went through similar processes of adaptation to the northeastern semi-arid environment, as well as to the sites where they were reared and selected.

The epidermis was thicker in Santa Inês, a result that may be associated with greater hair weight and volumetric density (Table 2), which require a greater structure of support and functionality, as well as higher concentration of sweat glands, which may result in a greater sweating in these animals, assuming that they would lose more heat in the latent form than goats (Silva et al., 2010; Amorim et al., 2019). $T_{EP}$ is of genetic nature and can vary according to species, breed and age of animals, tending to be thinner in younger animals (Jacinto et al., 2004; Tolentino et al., 2014; Pantoja et al., 2017).

The patterns of the number of sweat glands and sweat rate per body region of Santa Inês sheep and Moxotó goats are presented in Table 4. SR did not differ statistically ($P < 0.05$) between the species. The interaction between the fixed effects (gender vs. body region) for SG and SR was not statistically significant ($P > 0.05$). The number of SG differed statistically between the species ($P < 0.05$) (Table 4). The number of SG per area was higher in Santa Inês sheep ($P < 0.05$) than in Moxotó goats in all evaluated regions. The similarity in SG and SR values between the genders demonstrates that these variables are independent of the sexual hormones and behavior.

**Table 3**
Means for number of hair follicles/area (μm$^2$) and epidermal thickness (μm), in the different parts of the body (cervical - 8118.63 μm$^2$; thoracic - 9105.70 μm$^2$; gluteal – 7333.51 μm$^2$), and by gender, in the integument of goats and sheep reared in a semi-arid environment.

| Body region | Hair follicle (x100μm$^2$) | | | Epidermal thickness (μm) | | |
|---|---|---|---|---|---|---|
| | CER | THO | GLT | CER | THO | GLT |
| Species | | | | | | |
| Sheep | 0.207 Aa | 0.155 Aa | 0.347 Aa | 2.272 Aa | 2.089 Aa | 2.200 Aa |
| Goats | 0.275 Aa | 0.158 Aa | 0.209 Aa | 1.828 Ba | 1.758 Ba | 1.845 Ba |
| p-value | 0.6934 | 0.2274 | 0.1289 | 0.0008 | 0.4063 | 0.5711 |
| Gender | | | | | | |
| Male | 0.224 Aa | 0.152 Aa | 0.198 Aa | 2.010 Aa | 1.922 Aa | 1.931 Aa |
| Female | 0.257 Aa | 0.161 Aa | 0.358 Aa | 2.089 Aa | 1.925 Aa | 2.115 Aa |
| p-value | 0.1894 | 0.3022 | 0.4861 | 0.5979 | 0.9005 | 0.7848 |

Means followed by the same lowercase (rows) and uppercase (column) letters do not differ by the F test at 5% significance level.

**Table 4**
Means for number of sweat glands/area (μm$^2$) and sweat rate (g m$^{-2}$ h$^{-1}$), in different parts of the body (cervical - 8118.63 μm$^2$; thoracic - 9105.70 μm$^2$; gluteal - 7333.51 μm$^2$), and by gender, in the integument of goats and sheep reared in semi-arid environment.

| Body region | Sweat glands (x100μm$^2$) | | | Sweat rate (g m$^{-2}$ h$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Cervical | Thoracic | Gluteal | Cervical | Thoracic | Gluteal |
| Species | | | | | | |
| Sheep | 0.334 Aa | 0.346 Aa | 0.382 Aa | 562.07 Aa | 583.80 Aa | 890.25 Aa |
| Goats | 0.230 Ba | 0.134 Ba | 0.152 Ba | 623.85 Aa | 604.71 Aa | 667.76 Aa |
| p-value | 0.0001 | 0.8512 | 0.9185 | 0.6812 | 0.3784 | 0.2811 |
| Gender | | | | | | |
| Male | 0.274 Aa | 0.261 Aa | 0.249 Aa | 471.49 Aa | 643.05 Aa | 701.30 Aa |
| Female | 0.291 Aa | 0.219 Aa | 0.286 Aa | 714.43Aa | 545.45 Aa | 856.71 Aa |
| p-value | 0.3122 | 0.0582 | 0.3403 | 0.3098 | 0.5427 | 0.4467 |

Means followed by equal lowercase (rows) and uppercase (column) letters do not differ by the F test at 5% significance level.

The numbers of SG in sheep were similar in all regions analyzed, maintaining a pattern in quantity per area. The same behavior was not found in goats, which had lower numbers of SG in the THO and GLT regions when compared to CER (Table 4). Among the genders, the number of SG did not differ. Regarding the excreted volume of sweat, sheep excreted an average SR of 679.70 g m$^{-2}$ h$^{-1}$ and goats excreted 632.10 g m$^{-2}$ h$^{-1}$. When comparing by gender, on average, males excreted 605.28 g m$^{-2}$ h$^{-1}$ and females excreted 705.53 g m$^{-2}$ h$^{-1}$, similar values, reinforcing that these variables are independent of hormonal influence.

By analyzing the variation in the number of SG and in the SR excreted by the species in the evaluated regions, it can be affirmed that sweat excretion is not homogeneous throughout the body and that the number of SG does not influence the excreted volume of sweat, but rather its functionality (Medeiros et al., 2015). Factors such as location, number of SG and their functional status interfere in the skin evaporation of the animals (Silva and Starling, 2003; Silva, 2008).

The mean of SG in Santa Inês (0.402 SG/100 μm$^2$) was higher than in Moxotó (0.158 SG/100 μm$^2$), an increase of 154.43%. However, the means of SR for the two species were similar, that is, the SG of Moxotó had much more functionality than those of Santa Inês. At temperatures above 30 °C, 80% of heat loss by goats occurs in the form of skin evaporation (Maia et al., 2005). In the present study, the recorded $T_A$ values were above the thermal comfort zone (TCZ) recommended for both species, being on average 35.80 °C, which may have influenced the functionality of SG.

## 4. Discussion

The exposure of animals to high temperatures can trigger a series of metabolic dysfunctions, since sensible exchanges stop being the main pathway and make way for evaporation exchanges (Silva et al., 2017; El-Tarabany et al., 2017), as increased water losses by the respiratory tract (water vapor) and skin surface (sweat) occur through stimuli such as elevated $T_A$ (Costa et al., 2015; Sejian et al., 2019). Goats and sheep, in addition to excreting water, also eliminate important mineral salts for the proper functioning of bodily functions (Müller, 1978).

Low RH combined with air velocity for short periods may favor heat exchange by evaporation (respiratory or cutaneous), relieving stress in animals (Sousa Júnior et al., 2008; Façanha et al., 2020). However, if these combinations occurred for long periods, especially in arid and semi-arid environments, both skin evaporation and respiratory evaporation would cause undesirable side effects, such as dryness of mucous membranes, leading to a burning sensation (Collier and Gebremedhin, 2015), especially at warmer times of the day, in the afternoon.

The animals were kept in an extensive system, grazing in uncovered soil and under little natural shading, which increased thermal radiation, so the animals faced a much more pronounced situation of thermal discomfort.

Hair coat thickness functions as a protective layer against the direct solar radiation in animals; however, depending on their characteristics, the opposite may occur, resulting in greater heat absorption of radiation, especially in animals with dark coat, such as Santa Inês sheep, hindering the exchange of heat through convection and conduction (Aboul Naga et al., 2021). A less thick coat can facilitate heat exchanges, especially evaporative ones, where excess heat can be easily eliminated by skin evaporation. Short and thick hairs, growing from under a pigmented epidermis, tolerate more effectively the conditions of the tropical environment (Maia et al., 2005; Ligeiro et al., 2006; Costa et al., 2015).

Higher hair density may contribute to a greater number of sweat glands in the epidermis. The means of numerical density of hairs were similar between the species, while the volumetric density of sheep was higher, which can be justified by the higher values of hair coat thickness and hair weight.

Hairs protect the animals from direct solar radiation and the intense thermal load to which they are subjected. In the studies, the characteristics of goats indicate greater adaptation to the Brazilian semi-arid environment. The lower value of $VD_H$ contributes to greater loss of thermal energy, which becomes advantageous in hot environments, as it promotes a greater movement of air through the hairs, removing the layer of air trapped inside the coat (Bianchini et al., 2006; Ligeiro et al., 2006).

As $ND_H$ increases, air penetration in $T_{HC}$ decreases, so that the air and moisture trapped in this layer warm the animals, instead of cooling them, thus reducing the heat mass transferred to the environment (McArthur, 1991; Maia et al., 2003). In addition, the efficiency of evaporative cooling depends on the amount of water molecules reaching the skin surface, that is, smaller spaces between hairs function as a barrier, preventing evaporative heat loss, besides avoiding the contact of water with the skin, in the case of rains, depending on the precipitated volume, and $T_A$ at the time it occurs can actually harm rather than contributing (Maia et al., 2015).

Goats of the Sannen and Pardo Alpina breeds had longer hairs compared to other breeds and, thus, obtained better protection against solar radiation (Aiura et al., 2010). In addition to the coat, skin pigmentation also contributes to a greater resistance to the ultraviolet rays, since the skin becomes a protective barrier to solar radiation, as is the case of animals of the Santa Inês and Moxotó breeds, which have pigmented skin.

Coat characteristics are important in the adjustment of body heat and directly influence heat exchange between the animal and the environment, being indicators of the degree of adaptability of the animals. The similarity in the coat structure characteristics between the genders demonstrates that these variables are independent of sexual hormones and behavior and that these characteristics of adaptation to the hot climate are passed on to descendants.

Sweat production depends both on the number of sweat glands and on their functionality. Glandular activity occurs through stimuli, such as high temperatures, causing an increase in blood supply to the epidermis, offering additional amounts of stimuli for their action (Alvarez et al., 1970; Dellmann and Brown, 1982). Goats and sheep have apocrine SG, which in addition to excreting water, also excretes mineral salts, important for the proper functioning of the animal's body, which can generate metabolic depletion in animals when using this resource for their homeostasis (Müller, 1978).

When correlating SR with the structural characteristics of the coat and integument of the animals in the present study, it was possible to note that sheep have thicker epidermis (Table 3), and it is assumed that there is a greater number of glands per skin area, while goats have a thinner epidermis, lighter hairs and lower $VD_H$, hence higher density of SG per area, which can facilitate the loss of sensible and latent heat, demonstrating the different morphological mechanisms of adaptability used by goats and sheep to adapt to the hot climate of the Brazilian semi-arid region.

The level of wind penetration in the hair coat depends on the spacing between hairs and on $T_{HC}$ (Tregear, 1965). In the hot period of the year, the hair tends to be shorter and with a larger diameter, which thus allows air circulation, cooling the skin. That is what occurred with the studied animals, which were subjected to a thermally stressful environment (Table 1), and modified the structural characteristics of their coat to favor evaporative thermal exchanges (sweating) (Table 4).

SR is a physiological mechanism used for the maintenance of homeostasis. For skin evaporation to occur, some factors must be taken into consideration, such as wind speed, relative humidity, ambient temperature and coat, because these factors have a direct influence on the surface temperature and sweating of the animal. Sweating becomes effective as $T_A$ is increased, along with the reduction of RH, which occurred during the experimental period, and under these conditions there is a greater supply of blood flow to the peripheral region of the skin, which stimulates the activity of SG, increasing sweat production (Ligeiro et al., 2006).

The condition of any semi-arid tropical region can be described as a dry and extremely hot, with marked fluctuations in water and food resources (Leroy et al., 2018). Animals kept in an extensive system in these regions suffer even more from the effects of exposure to high $T_A$ and low RH, because in addition to being in a thermally stressful environment, they are also under direct exposure to solar radiation, which directly influences the loss of sensible and latent heat. In northeastern Brazil, especially in the semi-arid region of the country, during the hottest period, approximately 65% of total shortwave radiation is due to direct sun exposure. In this situation, evaporative losses are the only efficient means of heat exchange (Silva et al., 2010).

As expected, the structures of the coat and integument of small ruminants reared in semi-arid regions have valuable characteristics that favor their adaptation to the region (Amorim et al., 2019), and although they showed similar values of SR, it is possible to verify, even in a speculative way, that Moxotó has better adaptability than Santa Inês.

## 5. Conclusions

The present study provides some evidence about phenotypic acclimation of goats and sheep reared in a semi-arid environment. The morphological characteristics of the skin surface and coat of these animals showed superiority of goats as compared to sheep. However, further investigations addressing this aspect, as well as what environmental factors (e.g., daytime, air temperature, solar radiation) provide the stimulus for the changes, are important to elucidate the environmental factors that influence these changes in the species.

## Authors' contributions

NMHM: Conceptualization, Methodology, Data analysis, Formal Analysis, Writing. DAF; BBS; ANLC; JVF: Writing-Review & Editing. TCS: Writing-Review & Editing. DAF; OBS; KCD: Writing-Review & Editing. NMHM; MRS; LFB: Methodology, Writing-Review & Editing. AA: Conceptualization, Project Supervision, Writing Review & Editing.

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## Declaration of competing interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

## Data availability

No data was used for the research described in the article.

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