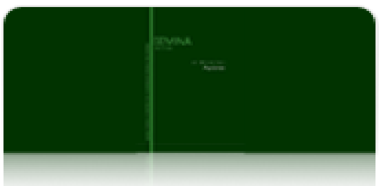

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Coat characteristics and physiological responses of locally adapted ewes in semiarid region of Brazil

Características de pelame e respostas fisiológicas de ovelhas nativas da região Semiárida do Brasil

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Abstract

This study aimed to evaluate the effects of heat stress and characterize the coat characteristics of red and white varieties of Morada Nova sheep raised in the semiarid region of Brazil during the rainy and dry seasons. The following variables were investigated: coat thickness (C_T), inclination angle of the coat (θ_I), hair coat density (H_{DE}), hair length (H_L) and hair diameter (H_D), in conjunction with the physiological responses of rectal temperature (RT) and respiratory rate (RR). The data were tested with an analysis of variance, a Tukey test at a 5% significance level and a correlation analysis. The season of the year (dry and rainy) and the variety (red and white) were used as fixed effects in the analysis of variance. H_L, H_{DE} and H_D were significantly greater in the dry season than in the rainy season ($P < 0.05$), but C_T and θ_I did not differ between seasons ($P > 0.05$). H_L, H_{DE} and H_D were lower and θ_I was greater ($P < 0.05$) for the red variety, but C_T was statistically equal ($P > 0.05$) for the two varieties. It was concluded that the coat characteristics of the Morada Nova ewes favor the adaptation of the sheep to a semiarid environment, including the improved protection of the skin against ultraviolet radiation. In general, the white variety presented characteristics reflecting a higher degree of adaptation to the conditions of the Brazilian semiarid region.
Key words: Conservation of animal genetic resources. Hair coat. Sheep. Tropical environment.

Resumo

O objetivo desse trabalho foi avaliar as características de pelame de ovelhas da variedades vermelha e outra branca da raça Morada Nova, criadas no ambiente semiárido brasileiro, durante as épocas seca e chuvosa. Foram avaliada espessura de pelame (CT), ângulo de inclinação do pelo (I), número de pelos (H_{DE}), comprimento do pelo (H_L) e diâmetro do pelo (H_D), em conjunto com as respostas fisiológicas

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temperature retal (RT) e frequência respiratória (RR). Foram realizados análise de variância e teste de Tukey a 5% de probabilidade. A estação do ano (seca e chuvosa) e variedade (vermelha e branca) foram usadas como fatores fixos. H_L, H_{DE} e H_D foram significativamente maiores na estação seca ($P < 0,05$), mas C_T e θ_I não diferiram. H_L, H_{DE} e H_D foram menor e θ_I foi maior na variedade vermelha, C_T não apresentou diferença em relação a variedade. Conclui-se que as características de pelame das ovelhas Morada Nova favorecem a adaptação a ambiente semiárido, incluindo proteção da pele contra o excesso de raios ultravioleta, com a variedade branca apresentando-se mais favorável à adaptação nas condições da região semiárida brasileira.

Palavras-chave: Ambiente tropical. Conservação de recursos genéticos. Características de pelame. Ovelhas.

Introduction

The knowledge of coat characteristics is essential for understanding the adaptability of animals to hot environments because the skin participates in the process of heat exchange (SILVA, 2008). The maintenance of body temperature within physiological limits is necessary for the maintenance of the health, survival and productivity of sheep (MARAI et al., 2007) because heat stress may affect growth, development, feeding, water intake and reproduction (ZWALD et al., 2003; SILVA, 2008). This effect is particularly marked in animals that are not heat-adapted (CASTANHEIRA et al., 2010; MCMANUS et al., 2011).

The skin and its associated features have always been viewed as characteristics to be considered in the judging of a breed rather than as characteristics to be studied in terms of their effects on production and reproduction in support of adaptability (SILVA, 2008). However, it is known that the coat structure and the air present within the coat increase thermal insulation and promote protection against solar ultraviolet radiation. Moreover, the efficiency of thermolysis is associated with production, weight gain, reproduction and other characteristics not directly related to thermoregulation (TURNER, 1964).

The amount of radiation transmitted through the skin is determined by the combination of the physical structure of the coat and the coat color. Because dark-coated animals absorb more radiation, they are generally more susceptible to heat stress than light-coated animals (MAIA et al., 2003; FAÇANHA-MORAIS et al., 2008; FAÇANHA et al., 2010; CASTANHEIRA et al., 2010; MCMANUS et al., 2011).

Coat characteristics vary according to the season. The characteristics of the coat can be modified over a period of a few days or over several months (SISSON, 1986). Animals with a pigmented epidermis, with short, clear and seated hairs and with low density of hair values are better protected against solar radiation. These characteristics and efficient thermolysis are desirable in animals that live in hot climates such as that of the Brazilian semi-arid region. Such animals are considered to be well adapted to hot climates (FAÇANHA et al., 2010; LEITE et al., 2017).

The physiological responses expressed via the rectal temperature (RT) and respiratory rate (RR) are crucial for the maintenance of homeothermy, especially in animals reared in hot environments such as the Brazilian semiarid region. These responses support the mechanisms of thermal exchange mediated by the coat (FADARE et al., 2012).

The aim of this study was to evaluate the influence of seasonal variation on the physiological responses (rectal temperature and respiratory rate) and the coat characteristics of Morada Nova, a locally adapted breed ewes, of the red and white varieties, raised in the Brazilian semiarid region. The coat characteristics measured included the coat thickness (T_P), the angle of inclination of the hairs

(θ_I), the hair density (H_{DE}), the hair diameter (H_D) and the hair length (H_L).

Materials and Methods

The experiment was conducted in a commercial farm located in a Brazilian semiarid ecosystem at 07° 17' 58'' S, 35°28'43'' W and 117 M.A.S.L. The local annual air temperature ranges between 25 and 35 ºC, the average relative humidity is 70% and the annual rainfall is low (300 to 1000 mm year^{-1}). The rainfall is erratic and is concentrated in a few months of the year, and wet years alternate irregularly with dry years (AESA, 2011). The irregularity of the rainfall in this region is also due to the orographic features of the area. The region's high mountains and plateaus intercept humid air fronts and receive more rain than the surrounding areas, and little rain falls on the leeward side of these elevations (GARIGLIO et al., 2010).

A total of 60 adult non-pregnant Morada Nova ewes, 30 of the red-coated variety and 30 of the white-coated variety, were used in this study. All sheep had previously been wormed and received health examinations. The maintenance of reproductive activity was confirmed by monthly monitoring of the signs of estrus. The sheep were managed under an extensive system that included feeding in native pastures and commercial mineral supplementation. The mineral supplements included sodium chloride (common salt), calcium phosphate, copper sulfate pentahydrate, ventilated sulfur (flowers of sulfur), calcium iodate, ferrous sulfate, zinc sulfate, manganese sulfate, sodium selenite, kaolin, heptahydrate cobalt sulfate, magnesium oxide, and calcium carbonate. Under the local management practices, no protein or energy supplementation was provided.

During the study, a total of 11 samples were collected at intervals of 25 to 35 days from September 2009 to August 2010. The sampling began at 7h00 AM to 10h00 AM. The sheep were randomly assigned to three groups, each containing 20 sheep.

The RT of each sheep was measured after an initial five-minute habituation interval. A digital thermometer was inserted into the rectum of the animal. The thermometer was guided to the roof of the rectal cavity to detect the temperature of the anal mucosa. The thermometer remained at a depth of approximately five centimeters for approximately two minutes, as measured by a timer and buzzer. The temperature was then read (°C). The RR was measured with a clinical stethoscope on an area on the right side of the ewe. The animal's breaths were counted over a measured period of 30 seconds. The result was multiplied by two to calculate the number of breaths per minute (breaths min^{-1}).

A basic meteorological station was used to obtain climatic data on each day of collection. The station included maximum and minimum thermometers, an anemometer positioned at the height of the dorsum of the animals, a black globe positioned in sunlight at the height of the dorsum and a hygrometer. The air temperature (AT), relative humidity (RH) and wind speed (WS) were recorded every three minutes. The radiant thermal load (RTL) and the black globe humidity and temperature index (BGHI) were calculated according to the methodology of Silva (2008) and Buffington et al. (1981), respectively. From January to June 2010, the experiments were performed on days when rain fell. These data were used to represent the rainy season. The data collected from September to December 2009 and in July and August 2010 were obtained on days when no rain fell. These data were used to characterize the dry season. Note that irregular rainfall occurred in the city of Mogeiro (AESA, 2011) during the study period.

The coat thickness (C_T) was measured *in situ* in the croup area with a digital caliper. The caliper was inserted into the coat, perpendicular to the body of the animal, until it touched the skin. The cursor was then moved to touch the outer surface of the coat and obtain the reading. The angle of inclination of the coat (θ_I) was obtained from the following formula (SILVA, 2008):

θ_I = arc sin [C_T (μm) . H_L^{-1} (mm)].

To estimate the hair density (H_{DE}), the number of hairs per cm^2 was calculated. The hair length (H_L) and the hair diameter (H_D) were measured on the hair collected from a known area of the coat with the aid of duckbill pliers. These measurements were performed in the Animal Bioclimatology and Welfare Lab of the Semi-Arid Rural Federal University (UFERSA, Mossoró-RN-Brazil). A Petri dish was placed on a flat, black surface. The hairs collected from each animal were placed individually in the dish to determine the H_{DE}. The H_{DE} was estimated by counting the number of hairs collected in each sample. The sample represented 0.14 cm^2 of skin, the area of the free end of the pliers when opened. Finally, the estimated number was converted to an estimate of the number of hairs per square centimeter of skin based on a conversion factor of 0.14 to 1.

The estimated hair length (H_L) was determined by the same technician who determined the H_{DE} because "hand calibration" is essential to obtain reliable results. A digital caliper was used to perform this measurement. The longest ten hairs from each sample were visually selected, and the arithmetic mean of the H_L of these hairs was then calculated, second methodology described by Udo (1978).

The hairs used for the determination of H_L were used to measure the hair diameter (H_D). The same precautions (i.e., determination by the same technician) were followed to minimize error. A digital micrometer was used to measure the diameter of the ten largest hairs. The arithmetic mean of the H_D of these hairs was obtained, second methodology described by Udo (1978). The statistical evaluation of the coat characteristics was performed with an analysis of variance. The statistical model used in the analysis included the effects of the variety (red and white), the season (dry and wet) and the interaction between them. The random effects of the animal were represented in the model. A symmetric covariance structure was used to include the case of repeated measures on the same animal. A Tukey test at a 5% level of significance was used to compare the means of the coat characteristics. We also performed correlation analyses. All statistical analyses were performed with SAS statistical software, version 8.02 (SAS, 2010). The statistical model used for the analysis was as follows: $Y_{ijk} = \mu + V_i + P_j + VP_k + \varepsilon_{ijk}$, where Y_{ijk} = Value of the ijk-*th* observation of each coat characteristic and physiological parameter evaluated; μ = general average of each coat characteristic or physiological parameter; V_i = effect of the i-*th* variety of Morada Nova ewes; P_j = effect of the j-*th* season of the year; VP_k = effect of the k-*th* interaction between the varieties and the seasons studied; ε_{ijk}= error associated with the observation Y_{ijk}.

Results

The environment was more stressful during the dry period, with a higher air temperature (AT) and radiant thermal load (RTL) and a lower relative humidity (RH). Despite the similarity between seasons in the wind speed (WS) and black globe temperature and humidity index (BGHI), these parameters were relatively high in both seasons. Table 1 shows the means and standard deviations of the climatic variables. The BGHI did not differ (P>0.05) between the dry (84.5) and rainy (82.1) seasons, Table 1.

Table 1. Mean and standard deviation of climatic variables during the experimental procedure over the dry and rainy seasons of the year in the Brazilian semi-arid region.

Season	AT(°C)	RH (%)	WS (m s^{-1})	BGTHI	CTR (W $m^{2(-1)}$)
Dry	$32.08^a \pm 1.68$	$49.36^b \pm 6{,}41$	1.52 ± 1.07	84.46 ± 6.00	$602.91^a \pm 99.04$
Rainy	$28.38^b \pm 2.05$	$79.01^a \pm 7{,}20$	1.61 ± 0.96	82.14 ± 3.12	$583.65^b \pm 54.32$

AT - air temperature; RH - relative humidity; WS - wind speed; BGHI - Black globe temperature and humidity index; RTL - radiant thermal load; different small letters in columns: significant differences (F test).

The values of Hair Length (H_L), density of hair (H_{DE}) and hair diameter were higher (12.31 mm; 846.82 hairs.$cm^{2(-1)}$, 57.41 mm, respectively) in the dry season than in the rainy season (11.55 mm, 734.29 hairs.$cm^{2(-1)}$; 47.95 mm, respectively). The Coat Thickness (C_T) (5.09 mm and 5.11 mm) and θ_I (44.17° and 47.21°) values did not differ between the periods, as shown in Table 2.

Table 2. Mean and standard deviation of the coat characteristics of red and white Morada Nova sheep in the Brazilian semiarid region during the dry and rainy seasons.

Parameter	Breed	Season		General Average
		Dry	Rainy	
C_T (mm)	MNV	$4.90^b \pm 0.80$	$5.24^a \pm 0.85$	5.07 ± 0.83
	MNB	$5.27^a \pm 0.81$	$4.98^b \pm 1.13$	5.16 ± 0.95
	Average	5.09 ± 0.82	5.11 ± 1.01	5.11 ± 0.89
H_L (mm)	MNV	$11.45^b \pm 1.97$	$10.81^b \pm 1.89$	$11.21^b \pm 1.96$
	MNB	$13.08^a \pm 2.40$	$12.25^a \pm 2.46$	$12.78^a \pm 2.40$
	Average	$12.31^a \pm 2.30$	$11.55^b \pm 2.31$	12.03 ± 2.33
H_{DE} (hair $cm^{2(-1)}$)	MNV	$811.12^{ab} \pm 323.32$	$677.46^c \pm 254.01$	$761.56^a \pm 305.96$
	MNB	$879.20^a \pm 370.49$	$787.24^b \pm 315.68$	$845.60^b \pm 354.34$
	Average	$846.82^a \pm 350.07$	$734.29^b \pm 292.18$	805.47 ± 334.18
H_D (µm)	MNV	$55.38^b \pm 12.20$	$44.63^b \pm 9.41$	$51.40^A \pm 12.38$
	MNB	$59.25^a \pm 14.46$	$51.04^a \pm 9.41$	$56.26^B \pm 13.44$
	Average	$57.41^a \pm 13.56$	$47.95^b \pm 9.93$	53.93 ± 13.16
θ_I (°)	MNV	45.88 ± 10.31	$51.88^a \pm 10.48$	$48.11^a \pm 10.76$
	MNB	42.63 ± 9.19	$42.85^b \pm 10.47$	$42.71^b \pm 9.66$
	Average	44.17 ± 9.86	47.21 ± 11.39	45.29 ± 10.54

RMN - Red Morada Nova sheep; WMN - White Morada Nova sheep; C_T - coat thickness; H_L - hair length; H_{DE} - hair density; H_D - Hair diameter; θ_I - inclination angle of the coat. Lower case and upper case letters in different columns of a given the row represent significant differences (Tukey test, 5% significance).

Despite these results, no significant correlation was found between AT and H_L ($P>0.05$, r = -0.04, Table 3). The hairs were moderately longer, but their higher seating on the epidermis (lower C_T) compensated for this greater length.

Table 3. Pearson correlation coefficients between the coat characteristics and physiological parameters of Morada Nova sheep of different varieties and the environmental parameters of the dry and rainy seasons in the Brazilian semiarid region.

	C_T	H_L	H_{DE}	H_D	θ_I	RT	RR	AT	RH	RTL	BGHI
C_T	1										
H_L	0.08^{*}	1									
H_{DE}	0.06^{ns}	0.02^{ns}	1								
H_D	0.03^{ns}	0.05^{ns}	0.25^{*}	1							
θ_I	0.55^{*}	-0.39^{*}	0.03^{ns}	-0.13^{*}	1						
RT	0.03^{ns}	0.07^{ns}	-0.03^{ns}	0.06^{ns}	-0.21^{*}	1					
RR	0.003^{ns}	-0.04^{ns}	-0.13^{*}	-0.05^{ns}	0.06^{ns}	-0.01^{ns}	1				
AT	0.07^{ns}	-0.04^{ns}	-0.02^{ns}	0.06^{ns}	-0.06^{ns}	0.11^{*}	0.00^{ns}	1			
RH	0.04^{ns}	0.05^{ns}	-0.18^{*}	-0.37^{*}	0.27^{*}	-0.14^{*}	0.06^{ns}	-0.46^{*}	1		
RTL	-0.17^{*}	0.01^{ns}	-0.16^{*}	-0.22^{*}	0.08^{*}	0.13^{*}	0.02^{ns}	-0.18^{*}	0.09^{*}	1	
BGHI	0.09^{ns}	0.02^{ns}	-0.06^{ns}	0.01^{ns}	0.01^{ns}	0.09^{*}	0.02^{ns}	0.98^{*}	-0.3^{*}	-0.17^{*}	1

C_T - coat thickness; H_L - hair length; H_{DE} - hair density; H_D - Hair diameter; θ_I - inclination angle of the coat; RT - rectal temperature; RTL - radiant thermal load; AT - air temperature; RH - relative humidity and BGHI - black globe temperature and humidity index; $^{n.s}$ - no significant difference (P≥0.05); * - significant difference (P<0.05) in Tukey test.

The C_T values obtained at different times were similar (P>0.05: 5.09 mm in the dry season and 5.11 mm in the rainy season), but lower values (P<0.05) were found for the red variety in the dry season (4.90 mm) and the white variety in the rainy season (4.98 mm). These lower values indicated a good capacity for thermolysis.

The H_D was higher in the white sheep than in the red sheep in both the dry season (59.25 and 55.38 µm, respectively) and the rainy season (51.04 and 44.63 µm, respectively).

In the dry season, the θ_I of the coat was similar for the red and white varieties (45.88º to 42.63º, respectively). However, the θ_I of the red variety was higher than that of the white variety (P<0.05) during the rainy season (51.88º vs. 42.85º), a characteristic that allows greater penetration of the air and consequently higher convective and evaporative cutaneous thermolysis.

In addition to the differences in coat characteristics, the two varieties showed different physiological responses during different seasons. During the dry season, the red variety required a greater RR to maintain homeothermy. This mechanism was so efficient that these animals always showed a lower RT, even in the warmer months (Table 4).

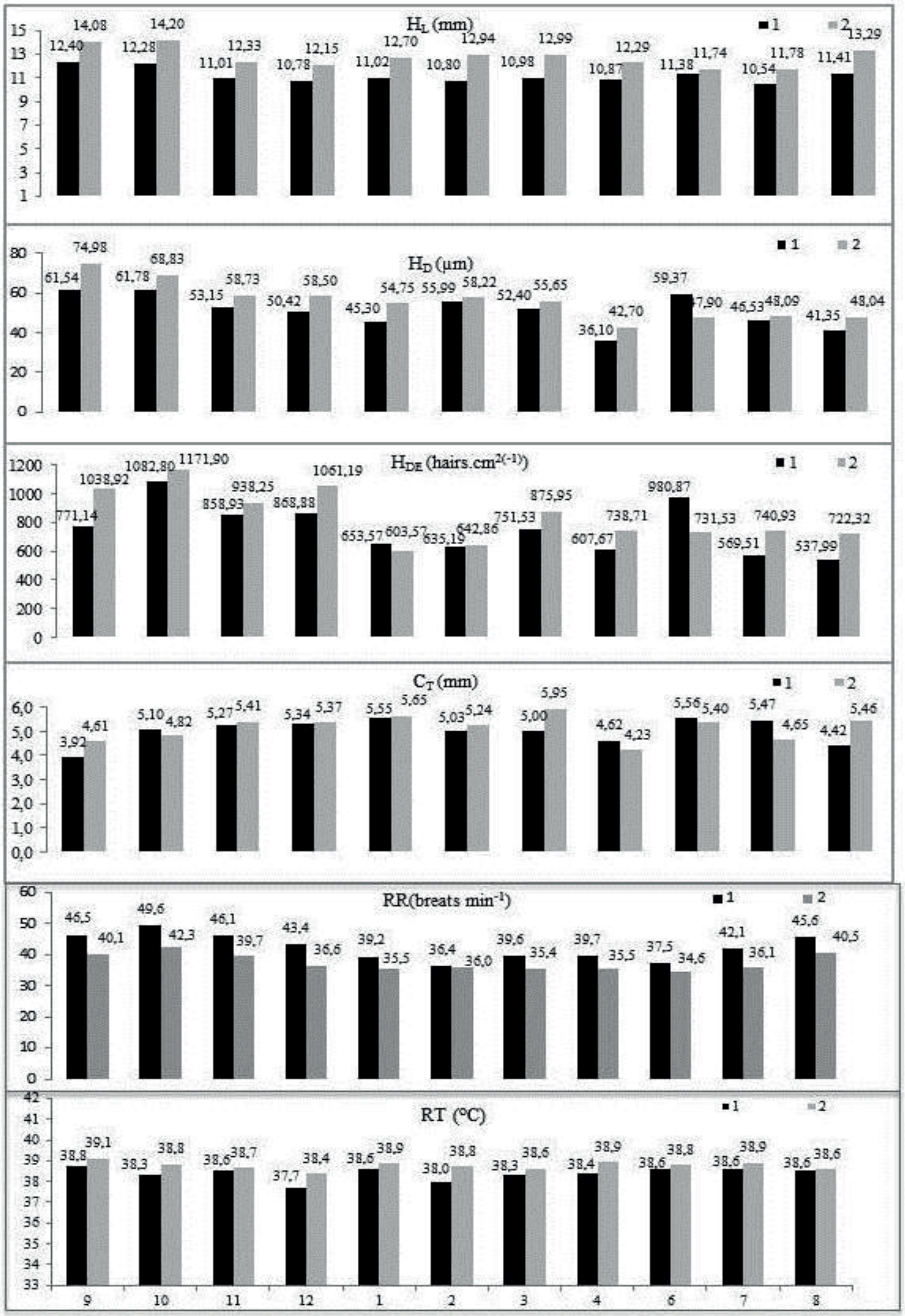
Table 4. Average and standard deviation of physiological parameters of red and white varieties of Morada Nova ewes reared in the Brazilian semi-arid region in the rainy and dry seasons.

Parameter	Sheep variety	Season		Average
		Dry	Rainy	
RR (breaths min^{-1})	MNV	$45.54^a \pm 8.23$	38.49 ± 7.34	$42.23^a \pm 8.57$
	MNB	$39.27^b \pm 8.57$	35.41 ± 8.68	$37.47^b \pm 8.82$
	Average	$42.26^A \pm 8.96$	$36.89^B \pm 8.20$	39.75 ± 9.02
RT (°C)	MNV	$38.41^b \pm 0.56$	$38.39^b \pm 0.52$	$38.40^b \pm 0.54$
	MNB	$38.76^a \pm 0.56$	$38.79^a \pm 0.52$	$38.77^a \pm 0.54$
	Average	38.59 ± 0.58	38.60 ± 0.56	38.59 ± 0.57

RR - respiratory rate; RT - rectal temperature; MNV - red Morada Nova variety; MNB - white Morada Nova variety; different small letters in columns: significant difference (Tukey test, P<0.05).

Figure 1 displays the behavior of the coat characteristics and physiological responses. H_L and H_D were generally higher in September and October (dry season). The H_{DE} of the white variety was greater than that of the red variety in the dry season. The H_{DE} values of the white and red varieties did not differ in the rainy season except during the months of March, April and June. The monthly disposition of the physiological variables revealed that the animals were under stress in all the months of the study, since they did not present RR greater than 60 mov.min^{-1} nor RT greater than and 40.5 °C.

Figure 1. Monthly variation (September of year one to August of year two) of the hair density (H_{DE}, hairs cm^{-2}), hair diameter (H_D, mm), hair length (H_L, mm), hair coat thickness (C_T, mm), respiratory rate (breaths/min) and rectal temperature (°C) of Morada Nova red (1) and white (2) ewes.



Discussion

The AT during the dry season was 32.1ºC, a value higher than the thermally comfortable temperature. This AT value may indicate a slightly stressful environment for Morada Nova sheep (LEITE et al., 2017; SILVA et al., 2017). If the AT exceeds 29ºC, the most efficient heat loss mechanism is evaporative because thermolysis for convection and radiation is hindered or inhibited (SILVA, 2008) by the low RH (FAÇANHA et al., 2010), as observed in this study (49.36%).

In contrast, the AT during the rainy season (28.4°C) was within the 20°C to 30°C range of thermal comfort for sheep specified by Silva et al. (2017). However, this AT value was higher than the comfort level of 24ºC to 27ºC specified by Fuquay (1981). The high AT, especially in combination with the high RH (79.01%), may have hampered the effectiveness of the sweating and breathing mechanisms of evaporative thermolysis (SILVA, 2008; FAÇANHA et al., 2010; LEITE et al., 2017).

Bezerra et al. (2011) observed BGHI values ranging between 87.5 and 82.2 for the dry and rainy seasons, respectively, in a study also conducted in the Brazilian semiarid region. The values of the present study were similar to those found by Bezerra et al. (2011).

The evaluation of the climatic indices associated with the physiological parameters studied indicated that the animals appeared to show little thermal discomfort. These results show the relatively high adaptability of the sheep to the climatic conditions of the Brazilian semiarid region and are similar to the findings of Rajab et al. (1992), Sleiman and Abi Saab (1995), Quesada et al. (2001), Al-Haidary (2004), McManus et al. (2009), Castanheira et al. (2010) and Leite et al. (2017).

The H_L was considered low overall and was lower in the red-coated ewes (11.21 mm) than in the white-coated ewes (12.78 mm). The high H_L during the hottest period (the dry season) was due to the higher H_L of the white sheep (13.08 mm) in this season. During the rainy season, the H_L decreased in both varieties (10.81 mm in the red ewes and 12.25 mm in the white ewes), favoring heat loss through the coat, as noted by Leite et al. (2017). In the white-coated animals, long hair was essential to protect the skin, decreasing the incidence of skin diseases. However, the long hair did not favor thermolysis by convection, which is not the principal mechanism of thermolysis if the AT is high (MAIA et al., 2003; SILVA, 2008; FAÇANHA et al., 2010; MCMANUS et al., 2011).

Verissimo et al. (2009) observed an H_L of 9.1 mm in the red variety of Santa Ines sheep and a value of 9.4 mm in white- and dark-coated ewes. The values found in this study were similar to those obtained by Leite et al. (2017), who found a mean H_L of 12.3 mm in red Morada Nova ewes.

The H_{DE} of the white color variety of Morada Nova ewes was always greater than that of the red variety, both in the dry season (879.20 hairs $cm^{2(-1)}$ and 811.12 hairs $cm^{2(-1)}$, respectively) and in the rainy season (787.24 hairs $cm^{2(-1)}$ and 677.46 hairs $cm^{2(-1)}$, respectively). The literature presents different opinions about the significance of H_{DE} values. Maia et al. (2003), Bertipaglia et al. (2008), McManus et al. (2011), and Leite et al. (2017) stated that most H_{DE} values favor the occurrence of thermolysis through the coat. Gebremedhin et al. (1997) and Gebremedhin and Wu (2002) stated that lower H_{DE} values favor thermolysis in hot environments by allowing greater air intake and increased cutaneous evaporation. These authors indicated that the influence of the wind is greater if the H_{DE} is less than 1000 hairs $cm^{2(-1)}$.

In the current study, the H_{DE} was always less than 1000 hairs $cm^{2(-1)}$. This characteristic allowed greater evaporation during the periods of the day when the AT was lower than the skin temperature. The H_{DE} was negatively correlated with the RH and the RTL ($P<0.05$; -0.18 and -0.16, respectively, Table 3). These results show that the H_{DE} was lower during the cold (rainy) season, facilitating thermolysis.

Cutaneous evaporative cooling is one of the most important mechanisms of thermal control and is promoted by sweating (BERTIPAGLIA et al., 2008). This mechanism is important for the maintenance of homeothermy in Morada Nova sheep.

High H_{DE} values are also associated with an increased number of sweat glands. The sweat glands are important for evaporative thermolysis through the skin if the surface temperature of the epidermis is greater than the AT (HOFMEYER et al., 1969; SILVA; STARLING, 2003; MARAI et al., 2007).

The H_{DE} values observed in this study were lower than those found by Leite et al. (2017) for red Morada Nova ewes (987.1 hairs $cm^{2(-1)}$) and greater than those observed by McManus et al. (2011) for Santa Inês sheep (314.2 hairs $cm^{2(-1)}$ for the white variety and 307.6 hairs $cm^{2(-1)}$ for the brown variety). The intermediate values of H_{DE} favored both convective sensitive thermolysis at colder times and cutaneous evaporative thermolysis in the warmer periods, demonstrating the high adaptability of the Morada Nova ewes of both varieties in warm environments.

The C_T values found in this study are similar to reported in the literature. Verissimo et al. (2009) found values of 4.7 mm and 4.5 mm in white- and dark-coated Santa Ines sheep, respectively, whereas McManus et al. (2011) observed C_T values of 5.5 mm and 4.7 mm in white and brown Santa Ines sheep, respectively. Leite et al. (2017) found a C_T of 4.7 mm in red Morada Nova sheep.

The low C_T favored thermolysis. The presence of a thin layer of hair is beneficial for thermolysis because it tends to prevent the movement of hot air. This result is consistent with the findings of Yeates (1954) and Hoffmann (2010) that a fine coat is associated with relatively low heat stress and that a thick coat can decrease the survival of sheep in environments with a high annual temperature. Animals with higher C_T and H_{DE} values have great difficulty eliminating latent heat through cutaneous evaporation (MCMANUS et al. 2011).

The low C_T was especially important for the maintenance of homeothermy in the red variety in the dry season because the red coat color produces a higher absorbance and a lower reflectance of solar radiation, resulting in increased surface body temperature (FINCH et al., 1980; BERTIPAGLIA et al., 2008; VERISSIMO et al., 2009; MCMANUS et al., 2011).

The C_T was negatively correlated with the RTL (-0.13; Table 3). This result indicates that the C_T value favored thermolysis during the months with a high RTL (the dry season). The non-significance of the correlation between the C_T and the AT shows that in the conditions of the Brazilian semiarid region, a higher C_T will provide protection against solar radiation and does not affect thermolysis.

The higher H_D in the white-colored ewes favored thermolysis through the coat under warm conditions by increasing the contact between the surface and the air (YEATES, 1954; HALL et al., 1996; MCMANUS et al., 2011; LEITE et al., 2017). The negative correlations between the H_D and RH and RTL (-0.37 and -0.22, respectively, Table 3) confirm this information.

The coat traits of the white variety promoted efficient thermolysis and furnished protection against ultraviolet radiation, but skin lesions were also observed. More skin diseases would be observed if the white variety had the same characteristics as the red variety. These diseases would represent threats to the white-coated animals in environments with high heat stress. These results confirm the principle that in the Brazilian semi-arid region, the protection of the skin against solar ultraviolet radiation is more important than cutaneous thermolysis (SILVA, 2008; MCMANUS et al., 2009). To minimize the damaging effects of ultraviolet radiation, the ideal coat characteristics are a high H_{DE} and a low θ_I to minimize the transmission of short-wave radiation through the coat (MARAI et al., 2007), as shown in this study.

The characteristics of the coat and epidermis are part of the adaptation of an animal to the environment.

Animals living in tropical environments should have protection against intense solar radiation. They are capable of removing excessive body heat from the skin surface. At the same time, they must be protected from external heat (SILVA, 2008).

The Morada Nova ewes exhibited these characteristics, which favored heat loss by evaporation in colder periods and cutaneous convection during periods of heat stress. Except for the C_T, which was greater during the dry period and was associated with skin protection, all the coat traits were characteristic of adaptability to the Brazilian semi-arid region, as described by Hall et al. (1996), Silva (2008), Façanha et al. (2010), McManus et al. (2011) and Leite et al. (2017).

The findings of this study show that during the dry period, certain coat characteristics (H_{DE}, H_D and θ_I) favored thermolysis in the white variety, whereas others (C_T, H_L and θ_I) favored thermolysis in the red variety. During the rainy season, the coat characteristics that favored the white variety were C_T, H_{DE} and H_D, whereas those that favored the red variety were H_L and θ_I. Due to the high level of ultraviolet radiation, the white variety showed certain characteristics that were less favorable for thermolysis but more favorable for promoting greater skin protection. These results indicated that the white variety enjoyed a slight advantage due to the thermolysis characteristics of the coat. However, according to the comparisons found in the literature, both varieties show good adaptive characteristics.

The monthly values of the physiological parameters showed that the ewes were under low heat stress during all months of the study because the RR was not greater than 60 breaths min^{-1} and the RT was not greater than 40.5°C. These findings are consistent with the criteria presented by Silanikove (2000).

It appears from the higher value observed for the RR in the red-coated variety that these sheep used respiratory thermolysis to a greater extent than the white-coated variety during the dry season. The white-coated sheep also needed to increase the RR but to a lesser degree. It is suggested that these animals used evaporative thermolysis extensively to maintain homeothermy because processes that are sensitive to thermolysis are less effective at a high AT even at a low RH (FAÇANHA et al., 2010). Thus, we could demonstrate that a different physiological response occurred in different seasons, as also observed by Cézar et al. (2004), McManus et al. (2009) and Castanheira et al. (2010).

The monthly observations showed that the H_{DE} decreased significantly in both varieties at the beginning of the rainy season (January). This finding may suggest that changes occurred during the transition from the dry season to the rainy season. Silva (2008) and Nixon et al. (2002) stated that sheep in temperate regions change their coat twice a year, during September and March.

The monthly observations showed higher C_T values during the rainy season, with the exception of April. The low C_T value in the red sheep was especially important for the maintenance of homeothermy because the dark coat has a higher absorbance and lower reflectance of solar radiation, resulting in increased heating (FINCH et al., 1980; BERTIPAGLIA et al., 2008; VERISSIMO et al., 2009; MCMANUS et al., 2011).

Conclusions

The two varieties of Morada Nova ewes showed coat characteristics that produced good adaptability to the Brazilian semi-arid environment.

The coat characteristics of the white-coated Morada Nova ewes primarily provided protection against ultraviolet radiation, whereas the coat characteristics of the red variety primarily favored the mechanisms of thermolysis associated with the skin.

The red variety of Morada Nova sheep was found to show a higher respiratory rate and consequently a better ability to maintain homeothermy through respiratory thermolysis, thus achieving lower body temperatures.

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References

AGÊNCIA EXECUTIVA DE GESTÃO DAS ÁGUAS DO ESTADO DA PARAÍBA - AESA. Monitoramento pluviométrico mensal do Estado da Paraíba. João Pessoa: AESA, 2011. Disponível em: <http://site2.aesa.pb.gov.br/aesa/monitoramentoPluviometria.do?metodo=listarMesesChuvasMensais>. Acesso em: 28 set. 2011.

AL-HAIDARY, A. A. Physiological responses of Naimey sheep to heat stress challenge under semi-arid environments. *International Journal of Agriculture & Biology,* Faisalabad, v. 6, n. 2, p. 307-309, 2004.

BERTIPAGLIA, E. C. A.; SILVA, R. G.; CARDOSO, V.; FRIES, L. A. Effects of hair coat traits and sweating rate on reproductive performance of Braford cows. *Revista Brasileira de Zootecnia,* Viçosa, MG, v. 37, n. 9, p. 1573-1583, 2008.

BEZERRA, W. M. A. X.; SOUZA, B. B.; SOUSA, W. H.; CUNHA, M. G. G.; BENÍCIO, T. M. A. Comportamento fisiológico de diferentes grupos genéticos de ovinos criados no semiárido paraibano. *Revista Caatinga,* Mossoró, v. 24, n. 1, p. 130-136, 2011.

BUFFINGTON, D. E.; AROCHO, c. A.; CANTON, G. H.; PITT, D. Black globe humidity index (BGHI) as a comfort equation for dairy cows. *Transactions of the ASAE,* st Joseph, v. 24, n. 3, p. 711-714, 1981.

CASTANHEIRA, M.; PAIVA, S. R.; LOUVANDINI, H.; LANDIM, A.; FIORVANTI, M. C. S.; DALLAGO, B. S.; CORREA, P. S.; McMANUS, C. Use of heat tolerance traits in discriminating between groups of sheep in central Brazil. *Tropical Animal Health and Production*, Amsterdam, v. 42, n. 8, p. 1821-1828, 2010.

CÉZAR, M. F.; SOUZA, B. B.; SOUZA, W. H.; PIMENTA-FILHO, E. C.; TAVARES, G. P.; MEDEIROS, G. X. Avaliação de parâmetros fisiológicos de ovinos Dorper, Santa Inês e seus mestiços perante condições climáticas do trópico semi-árido nordestino. *Ciência e Agrotecnologia,* Lavras, v. 28, n. 3, p. 614-620, 2004.

FAÇANHA, D. A. E.; SILVA, R. G.; MAIA, A. S. C.; GUILHERMINO, M. M.; VASCONCELOS, A. M. Anual variation of morphologic traits and hair coat surface temperature of Holstein cows in semi-arid environment. *Revista Brasileira de Zootecnia,* Viçosa, MG, v. 39, n. 4, p. 837-844, 2010.

FAÇANHA-MORAIS, D. A. E.; MAIA, A. S. C.; SILVA, R. G.; VASCONCELOS, A. M.; LIMA, P. O.; GUILHERMINO, M. M. Variação anual de hormônios tireoideanos e características termorreguladoras de vacas leiteiras em ambiente quente. *Revista Brasileira de Zootecnia,* Viçosa, MG, v. 37, n. 3, p. 538-545, 2008.

FADARE, A. O.; PETERS, S. O.; YAKUBU, A.; SONIBARE, A. O.; ADELEKE, M. A.; OZOJE, M. O.; IMUMORIN, I. G. Physiological and haematological indices suggest superior heat tolerance of white-coloured West African Dwarf sheep in the hot humid tropics. *Tropical Animal Health and Production*, Amsterdam, v. 45, n. 1, p. 157-165, 2012.

FINCH, V. A.; DMI'EL, R.; BOXMAN, R.; SHKOLNIK, A.; TAYLOR, R. Why black goats in hot deserts? Effects of coat color on heat exchanges of wild and domestic goats. *Physiological Zoology,* Chicago, v. 53, n. 1, p. 19-25, 1980.

FUQUAY, J. W. Heat stress as it affects animal production. *Journal of Animal Science,* Champaing, v. 52, n. 1, p. 164-174, 1981.

GARIGLIO, M. A.; SAMPAIO, E. V. S. B.; CESTARO, L. A.; KAGEYAMA. P. Y. *Uso sustentável e conservação dos recursos florestais da Caatinga*. Brasília: Serviço Florestal Brasileiro, 2010. 368 p.

GEBREMEDHIN, K. G.; NI, H.; HILLMAN, P. E. Temperature profile and heat flux through irradiated fur layer. *Proceedings of the 5th Livestock of Environment Symposium*, Minessota, v. 40, n. 5, p. 226-233, 1997.

GEBREMEDHIN, K. G.; WU, B. Simulation of sensible and latent heat losses from wet-skin surface and fur layer. *Journal of Thermal Biology*, Germany, v. 27, n. 4, p. 291-297, 2002.

HALL, S. J. G.; RUSSEL, A. F. J.; REDDEN, H. Coat fibres of Nigerian sheep and goats: a preliminary characterization. *Small Ruminant Research*, Amsterdam, v. 22, n. 1, p. 169-175, 1996.

HOFFMANN, I. Climate change and the characterization, breeding and conservation of animal genetic resources. *Animal Genetics*, Malden, v. 41, n. 1, p. 32-46, 2010.

HOFMEYER, H. S.; GUIDRY, A. J.; WALTZ, F. A. Effects of temperature and wool lengh on surface and respiratory evaporative losses of sheep. *Journal of Applied Physiology*, Washington, v. 26, n. 1, p. 517-523, 1969.

LEITE, J. H. G. M.; FAÇANHA, D. A. E.; COSTA, W. P.; CHAVES, D. F.; GUILHERMINO, M. M.; SILVA, W. S. T.; BERMEJO, L. A. Thermoregulatory responses related to coat traits of Brazilian native ewes: an adaptive approach. *Journal of Applied Animal Research*, Abingdon, v. 45, n. 1, p. 1-7, 2017.

MAIA, A. S. C.; SILVA, R. G.; BERTIPAGLIA, E. C. A. Haircoat traits in Holstein cows in tropical environments: a genetic and adaptative study. *Revista Brasileira de Zootecnia,* Viçosa, MG, v. 32, n. 4, p. 843-853, 2003.

MARAI, I. F. M.; EL-DARAWANY, A. A.; FADIEL, A.; ABDEL-HAFEZ, M. A. M. Physiological traits as affected by heat stress in sheep - a review. *Small Ruminant Research*, Amsterdam, v. 71, n. 3, p. 1-12, 2007.

McMANUS, C.; LOUVANDINI, H.; GUGEL, R.; SASAKI, L. C. B.; BIANCHINI, E.; BERNAL, F. E. M.; PAIVA, S. R.; PAIM, T. P. Skin and coat traits in sheep in Brazil and their relation with heat tolerance. *Tropical Animal Health and Production*, Amsterdam, v. 43, n. 1, p. 121-126, 2011.

McMANUS, C.; PALUDO, G. R.; LOUVANDINI, H.; GUGEL, R.; SASAKI, L. C. B.; PAIVA, S. R. Heat tolerance in Brazilian sheep: physiological and blood parameters. *Tropical Animal Health and Production*, Amsterdam, v. 41, n. 1, p. 95-101, 2009.

NIXON, A. J.; FORD, C. A.; WILDERMOTH, J. E.; CRAVEN, A. J.; ASHBY, M. G.; PEARSON, A. J. Regulation of prolactin receptor expression in ovine skin in relation to circulating prolactin and wool follicle growth status. *Journal of Endocrinology*, Melbourne, v. 172, n. 3, p. 605-614, 2002.

QUESADA, M.; McMANUS, C.; COUTO, F. A. D. A. Tolerância ao calor de duas raças de ovinos deslanados no Distrito Federal. *Revista Brasileira de Zootecnia*, Viçosa, MG, v. 30, n. 3, p. 1021-1026, 2001.

RAJAB, M. H.; CARTWRIGHT, T. C.; DAHM, P. F.; FIGUEIREDO, E. A. Performance of three tropical hair sheep breed. *Journal of Animal Science*, Champaing, v. 70, n. 11, p. 3351-3359, 1992.

SILANIKOVE, N. Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science*, New York, v. 67, n. 1-2, p. 1-18, 2000.

SILVA, R. G. *Biofísica ambiental*: os animais e seu ambiente. São Paulo: FUNEP, 2008. 386 p.

SILVA, R. G.; STARLING, J. M. C. Evaporação cutânea e respiratória em ovinos sob altas temperaturas ambientes. *Revista Brasileira de Zootecnia,* Viçosa, MG, v. 32, n. 6, p. 1956-1961, 2003. Suplemento 2.

SILVA, W. E.; LEITE, J. H. G. M.; SOUSA, J. E. R.; COSTA, W. P.; SILVA, W. S. T.; GUILHERMINO, M. M.; ASENSIO, L. A. B.; FAÇANHA, D. A. E. Daily rhythmicity of the thermoregulatory responses of locally adapted Brazilian sheep in a semiarid environment. *International Journal of Biometeorology*, Ohio, v. 61, n. 7, p. 1-11, 2017.

SISSON, S. *Anatomy of the domestic animals*. Rio de Janeiro: Guanabara Koogan, 1986. 678 p.

SLEIMAN, F. T.; ABI SAAB, S. Influence of environment on respiration, heart rate and body temperature of filial crosses compared to local Awassi sheep. *Small Ruminant Research*, Amsterdam, v. 16, n. 1, p. 49-53, 1995.

STATISTICAL ANALYSES SYSTEM - SAS. Procedures guide statistical procedures. Ver. 9.4. 4th ed. Cary: SAS Institute, 2013. 556 p.

TURNER, H. G. Coat characters of cattle in relation to adaptation. *Proceedings of the Australian Society of Animal Production*, New South Wales, v. 5, n. 2, p. 181-187, 1964.

UDO, H. M. *Hair coat characteristics in Friesian heifers in the Netherlands and Kenya.* Wagneingen: Meded. Landbouwhogeschool Wagneingen, 1978. 135 p.

VERISSIMO, C. J.; TITTO, C. G.; KATIKI, L. M.; BUENO, M. S.; CUNHA, E. A.; MOURÃO, G. B.; OTSUK, I. P.; PEREIRA, A. M. F.; NOGUEIRA FILHO, J. C. M.; TITTO, E. A. L. Tolerância ao calor em ovelhas Santa Inês de pelagem clara e escura. *Revista Brasileira de Saúde e Produção Animal*, Salvador, v. 10, n. 1, p. 159-167, 2009.

YEATES, N. T. M. Environmental control of coat changes in cattle. *Nature*, London, v. 174, n. 1, p. 609-610, 1954.

ZWALD, N. R.; WEIGEL, K. A.; FIKSE, W. F.; REKAYA, R. Identification of factors that cause genotype by environmental interaction between herds of Holstein cattle in seventeen countries. *Journal of Dairy Science*, Hinsdale, v. 86, n. 3, p. 1009-1018, 2003.