

Thermoregulatory responses of goats in hot environments

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Abstract Notwithstanding the solar radiation is recognized as a detrimental factor to the thermal balance and responses of animals on the range in tropical conditions, studies on the amount of thermal radiation absorbed by goats therein associated with data on their production and heat exchange are still lacking. Metabolic heat production and the heat exchange of goats in the sun and in the shade were measured simultaneously, aiming to observe its thermal equilibrium. The results showed that black goats absorb twice as much as the white goats under intense solar radiation (higher than 800 W m^{-2}). This observation leads to a higher surface temperature of black goats, but it must not be seen as a disadvantage, because they increase their sensible heat flow in the coat-air interface, especially the convection heat flow at high wind speeds. In the shade, no difference between the coat colours was observed and both presented a lower absorption of heat and a lower sensible heat flow gain. When solar radiation levels increases from 300 to 1000 W m^{-2} , we observed an increase of the heat losses through latent flow in both respiratory and cutaneous surface. Cutaneous evaporation was responsible for almost 90 % of the latent heat losses, independently of the coat colour. Goats decrease the metabolic heat production under solar radiation levels up to 800 W m^{-2} , and increase in levels higher than this, because there is an increase of the respiratory rate and of the respiratory flow, but the fractions of consumed oxygen and produced carbon dioxide are maintained stable.

The respiratory rate of black goats was higher than the white ones, under 300 W m^{-2} (55 and 45 resp min^{-1}) and 1000 W m^{-2} (120 and 95 resp min^{-1} , respectively). It was concluded that shade or any protection against solar radiation levels above 800 W m^{-2} is critical to guarantee goat's thermal equilibrium. Strategies concerning the grazing period in accordance with the time of the day alone are not appropriate, because the levels of radiation depend on the latitude of the location.

Keywords Coat colour · Heat production · Heat storage · Solar radiation

Introduction

Goats were first introduced in Brazil by European settlers in the XII century, and these animals survived and reproduced, consequently adapted in the new environment. Nowadays, the vast majority of Brazilian goats (93 %) are located in the Northeastern region of Brazil (Oliveira et al. 2007), where undefined breed goats (UDB) constitute the largest group, approximately 95 % of this population (Machado et al. 2000). This group comprises goats with diversity of phenotypic characteristics, like the presence or absence of reduced ears, long hair, horns, wattles and beard, while its coat colours show a diversity of tonality: white, brown, black and roan (Machado et al. 2000). Consequently, there is a great genetic variation between individuals of UDB groups (Oliveira et al. 2007), and according to Machado et al. (2000), these goat populations are more closely related to Continental and West European populations than North African, Balkan or Insular Mediterranean populations.

Brazilian UDB goats provide to traditional populations of the Brazilian Northeast a source of milk and meat, particularly in the semiarid region. This hot environment is characterized

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by intense solar radiation during all year (da Silva et al. 2010) with an average around 844 W m^{-2} (Costa et al. 2014) and water deficit, being the evaporation (near $3000 \text{ mm year}^{-1}$) greater than the rain (between $200\text{--}800 \text{ mm year}^{-1}$). Today these goat populations are totally adapted in the semiarid, but what are the thermoregulatory characteristics responsible by this success? For example, Bedouins in Negev and Sinai Deserts have selected black goats then white ones, although the greater heat gain by these animals is due to the shortwave radiation (Finch et al. 1980).

However, until this moment, there are few data about the thermoregulation of Brazilian UDB goats, like shortwave radiation absorbed by coat surface, heat production, sensible and latent heat flows. As for cattle (Holstein cows), the only report about such matter is that of da Silva et al. (2010), who attempted to quantify the thermal radiation absorbed by dairy cows in pasture in the semiarid region. These information are very useful to help us to answer the following question: does the coat colour influence the thermal equilibrium of UDB goats managed exposed or not to solar radiation? The present investigation aimed to answer this question and to understand the thermoregulation of these animals, and consequently to provide important results to improve breeding and conservation programmes of Brazilian UDB goats.

Materials and methods

The observations were undertaken over a period of 22 days on twelve undefined breed male goats under the environmental conditions of Mossoró, RN, Brazil ($5^{\circ} 11'$ South latitude), during the months of March and September of 2010. Twelve goats with an average of 1.5 years old were observed for eight days in the sun and for 14 days in the shade. Six animals were predominantly white with an average weight of 46.11 kg, while the other six were predominantly black with an average weight of 45.72 kg, and three animals randomly picked out of the two groups were observed per day. The measurements started at 0800 h and ended at about 1700 h. The observations in the shade were made in pens inside the facility (3.0 m height, fiber cement tile), and there was no incidence of direct solar radiation, while observation in the sun the animals were maintained in pens exposed directly to solar radiation.

The meteorological variables were measured at 10-min regular intervals in each sampling day: dry (T_A , $^{\circ}\text{C}$) and wet (T_U , $^{\circ}\text{C}$) bulb temperatures, shortwave solar irradiance (S_t , W m^{-2}), black-globe temperature (T_G , $^{\circ}\text{C}$), partial vapour pressure (e (T_a), kPa) and wind speed (V , m s^{-1}). T_A and T_U were made by a sling psychrometer (Model ventilated psicometer, Antlab, Brazil); T_G was measured with a thermocouple (Model type T, Salcas, Brazil. Accuracy $0.2 \text{ }^{\circ}\text{C}$) inserted into the centre of a hollow 0.15-m-diameter copper sphere, matt black painted (Model black globe, Meteoro,

Brazil), which was placed 50 cm above the ground near the animals; V was measured by a digital thermo-anemometer (Model APM-360, USA).

The direct (S_{dir}) and diffuse (S_{dif}) short wave radiation were measured with a portable pyranometer (Model CMP-22, Kipp and Zonen, Delft, Netherlands) adjusted for the appropriate wavelength range (e.g., $200\text{--}3600 \text{ nm}$). Total short wave solar irradiance was given as

$$S_t = S_{\text{dir}} + S_{\text{dif}} + S_{\text{ref}}$$

with S_{ref} being the reflected short wave radiation,

$$S_{\text{ref}} = \rho_{\text{gs}}(S_{\text{dir}} + S_{\text{dif}})$$

where ρ_{gs} is the reflectance of the ground surface. S_t was classified into five classes as follows: 0 to 300 W m^{-2} (class 1); 300 to 600 W m^{-2} (class 2); 600 to 800 W m^{-2} (class 3); 800 to 1000 W m^{-2} (class 4) and $>1000 \text{ W m}^{-2}$ (class 5). The amount of short wave radiation absorbed by the coat surface (q''_{rc} , W m^{-2}) was calculated according to da Silva et al. (2010) as:

$$q''_{\text{rc}} = [f_s(\alpha_c)(S_{\text{dir}} + S_{\text{dif}})] + 0.5[(\alpha_c)S_{\text{ref}}]$$

where f_s is the shape factor for a horizontal cylinder (analogue of the goat's body),

$$f_s = \frac{2zr[1 - (\cos^2\beta)(\cos^2\omega)]^{0.5} + \pi r^2}{2\pi r(z + 2r)\sin\beta}$$

where z (m) is the height and r (m) is the radius of the horizontal cylinder; α_c are the absorbance values of the hair coat surface, 0.52 and 0.90 for white and black coats, respectively (see da Silva et al. 2003 and Maia et al. 2005); β is the angle of solar elevation and ω is the azimuth angle of the body axis with respect to the sun (degrees).

The metabolic heat production (q''_{m} , W m^{-2}) was obtained by the following equation da Silva and Campos Maia (2013):

$$q''_{\text{m}} = A^{-1}R_R V_T [0, 75Q_{O_2}(O_{2A} - O_{2E}) + 0, 25Q_{CO_2}(CO_{2E} - CO_{2A})]$$

where A is the body surface area ($A = 0.13w^{0.556}$, m^2), and w is the body weight (kg); Q_{O_2} and Q_{CO_2} are the heat coefficients (J L^{-1}) of O_2 and CO_2 , respectively, according to Randall et al. (2011) and Schmidt-Nielsen (2002). An indirect calorimetry

system with a facial mask adjusted on the animal’s muzzle (Fig. 1), was used to measure the O₂ and CO₂ contents of the inhaled (O_{2A} and CO_{2A}) and exhaled air (O_{2E} and CO_{2E}), respectively, by an O₂/CO₂ analyser (Model ML206, ADInstruments, Australia). In other way, the amount of air displaced in each respiratory movement (tidal volume) (V_T , L breath⁻¹), minute-volume (V_R , L s⁻¹) and respiratory rate (R_R , breaths s⁻¹), were measured by a spirometer (Model MI141, ADInstruments, Australia).

The latent heat loss flow from the respiratory system (q''_{er}) was determined, according to da Silva and Campos Maia (2013) as:

$$q''_{er} = A^{-1} \lambda V_T R_R (\Psi_E - \Psi_{Atm})$$

where Ψ_E is the absolute humidity of the expired air (g m⁻³):

$$\Psi_E = \frac{2166.87e(T_E)}{T_E}$$

where T_E is the expired air temperature (K), measured with a thermistor probe (Model MLA415/AL Nasal Temperature Probe, Adinstruments, Australia. Accuracy ±0.15 °C) placed inside the facial mask just in front of the animal’s nostrils, while the H₂O pressures of the atmosphere [$e(T_A)$] and exhaled air [$e(T_E)$] were measured by a CO₂/H₂O analyser (Model Li-7000, LI-COR, USA).

The latent heat flow (q''_{es} , W m²) from surfaces exposed to an air flow, like the animal surface, was determined by the equation da Silva and Campos Maia (2013):

$$q''_{es} = f_c A_c^{-1} (\Psi_S - \Psi_{Atm})$$

where A_c (m²) is the ventilated capsule area, λ (J g⁻¹) is the latent heat of water vaporization and f_c is the air flow through the ventilated capsule (0.045 L s⁻¹). The absolute humidity levels of the animal’s surface and of the atmosphere were Ψ_S and Ψ_{Atm} , respectively (g m⁻³):

$$\Psi_S = \frac{2166.87e(T_{in})}{T_{in}}$$

$$\Psi_{Atm} = \frac{2166.87e(T_A)}{T_A}$$

where $e(T_{in})$ is the partial vapour pressure of the air in the outlet of the ventilated capsule (kPa), measured by a CO₂/H₂O gas analyser (Model Li-7000, Li-Cor, USA) on three body

regions (neck, flank and hindquarters), according to Maia et al. (2005).

The body surface temperature was measured inside (T_{in} , K) the capsule by means of a thermocouple (Model PT-100 class A, Salcas, Brazil. Accuracy ±0.2) and outside (T_s , K) by an infrared camera (Model B60, Flir, USA) on six body regions (head, neck, flank, rump, wither and belly); consequently, T_S in the outside capsule was considered an average of these regions. The rectal temperature (T_R , °C) was recorded with a similar thermocouple, inserted in the rectum of animal.

The convection heat flow (q''_c , W m⁻²) from the coat surface to the atmosphere was given by Newton’s Law of Cooling, according to Incropera et al. (2008)

$$q''_c = h_C (T_S - T_A)$$

where h_C (W m⁻² K⁻¹) is the convective heat transfer coefficient

$$h_C = k N_U d_C^{-1}$$

where k (W m⁻¹ K⁻¹) is the thermal conductivity of the air; N_U is the Nusselt number, determined according to Chapman (1987); Montheith and Unsworth (1990) and da Silva and Campos Maia (2013), by assuming the body as a horizontal cylinder. The wind speed needed to calculate the Reynolds number was measured with a thermo-anemometer (Model APM-360, Alnor, USA) placed 1 m from the animals.

The heat exchange by long wave radiation between the coat surface and the environment was based on Stefan-Boltzmann’s Law, according to Incropera et al. (2008):

$$q''_r = h_R (T_S - T_{RM})$$

where h_R is the radiation heat transfer coefficient

$$h_R = \epsilon_S \sigma (T_S + T_{RM}) (T_S^2 + T_{RM}^2)$$

(W m⁻² K⁻¹), $\epsilon_S=0.98$ is the emissivity of animal surface, $\sigma=5.67051 \times 10^{-8}$ W m⁻² K⁻⁴ is the Stefan-Boltzmann constant and T_{RM} is the mean radiant temperature (K) of the surroundings, estimated according to da Silva (1999) and da Silva and Campos Maia (2013).

The data were analysed by the least-squares method (Harvey 1960) using the statistical analysis system (SAS Institute 1995). For the multiple comparison of means, the Tukey’s test ($P \leq 0.05$) was used. The statistical model used to describe the variables was the following:

$$Y_{ijklmn} = \mu + C_i + A_{ji} + E_k + (CE)_{ik} + D_{lk} + S_m$$

$$+ (CS)_{im} + (ES)_{km} + (CES)_{ikm} + \epsilon_{ijklm}$$

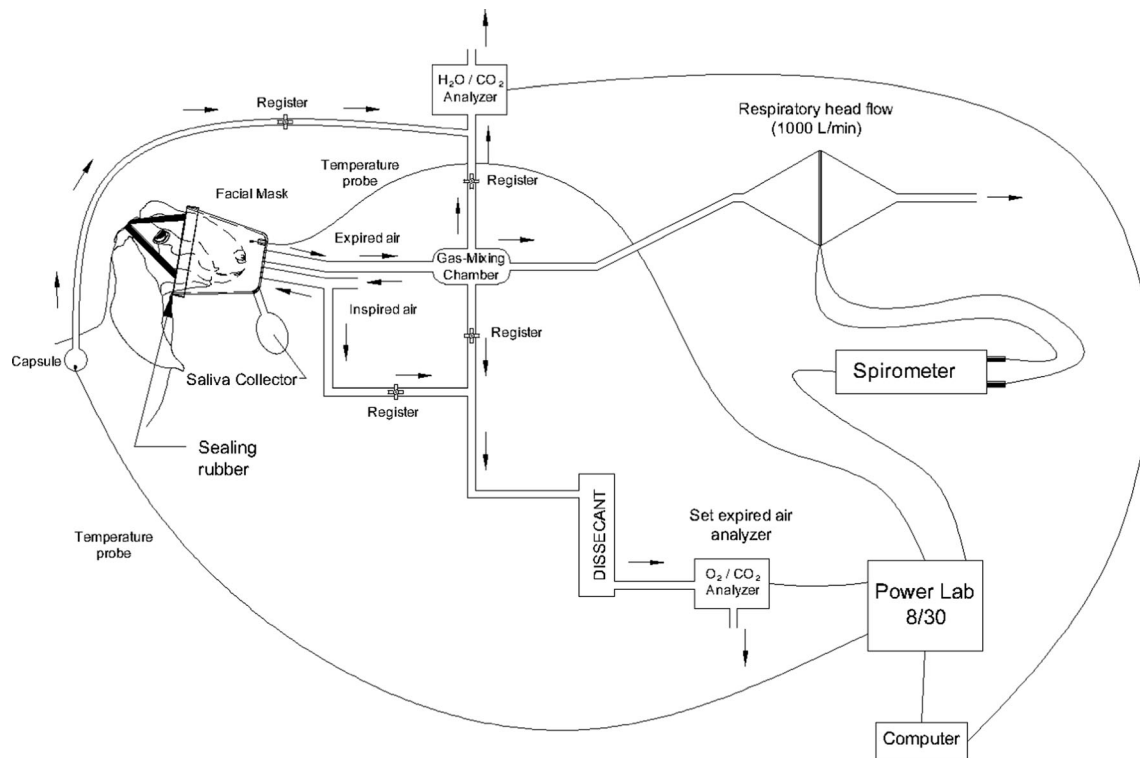


Fig. 1 System of indirect calorimetry using a facial mask for goats

where Y_{ijklmn} is the n th observation of the j th goat of the i th coat colour in the k th environment in the l th hour; C_i is the fixed effect of the i th coat colour (i =black or white); A_{ji} is the random effect of the j th animal within the i th coat colour; E_k is the fixed effect of the k th environment (k =shade or sun); $(CE)_{ik}$ is the interaction between the i th coat colour with the k th environment; D_{lk} is the random effect of the sampling day within the k th environment; S_m is the fixed effect of the m th short-wave solar irradiance class ($m=1, \dots, 5$); $(CS)_{im}$ is the interaction between the i th coat colour with the m th short-wave solar irradiance class; $(ES)_{km}$ is the interaction between the k th environment with the m th short-wave solar irradiance class; $(CES)_{ikm}$ is the interaction between the i th coat colour with the k th environment and with the m th short-wave solar irradiance class. Finally, ε_{ijklmn} is the residual term, including the random error and μ is the overall mean.

Results

The average air temperature and shortwave solar irradiance were 32.8°C and 767.2 W m^{-2} , respectively (Table 1), but they exceeded 36°C and 1000 W m^{-2} around midday. This heat load is responsible for the high average of the mean radiant temperature, 310.7 K . The air temperature was positively correlated with solar radiation ($r=0.43$), but negatively correlated with the air relative

humidity ($r=-0.87$). However, the wind speed increased after midday and showed no correlation with other meteorological variables (Fig. 2).

The analyses of variance showed that the interaction between the place where animals were kept (shade or sun) and the levels of solar radiation and coat colour was the main source of variation for all the variables, except for the latent heat loss (respiratory and cutaneous). In this case, the main source of variation was the interaction between levels of solar radiation and place.

The coat surface of black goats absorbed around 400 W m^{-2} when exposed to solar radiation above 800 W m^{-2} , while the white ones absorbed only 200 W m^{-2} , consequently the coat surface temperatures for black and

Table 1 Average, minimum and maximum values of air temperature (T_A), solar radiation (S_t), mean radiant temperature (T_{RM}), relative humidity (U_R) and wind speed (V) observed in Mossoró, RN, Brazil from March to September, 2010

Variable	N	Average	Minimum	Maximum
T_A ($^\circ\text{C}$)	702	32.96	28.00	37.20
U_R (%)	501	60.83	36.91	86.82
T_{RM}	702	310.74	305.77	315.42
V (m s^{-1})	711	3.18	0	16.20
S_t (W m^{-2})	670	767.23	10.13	1028.00

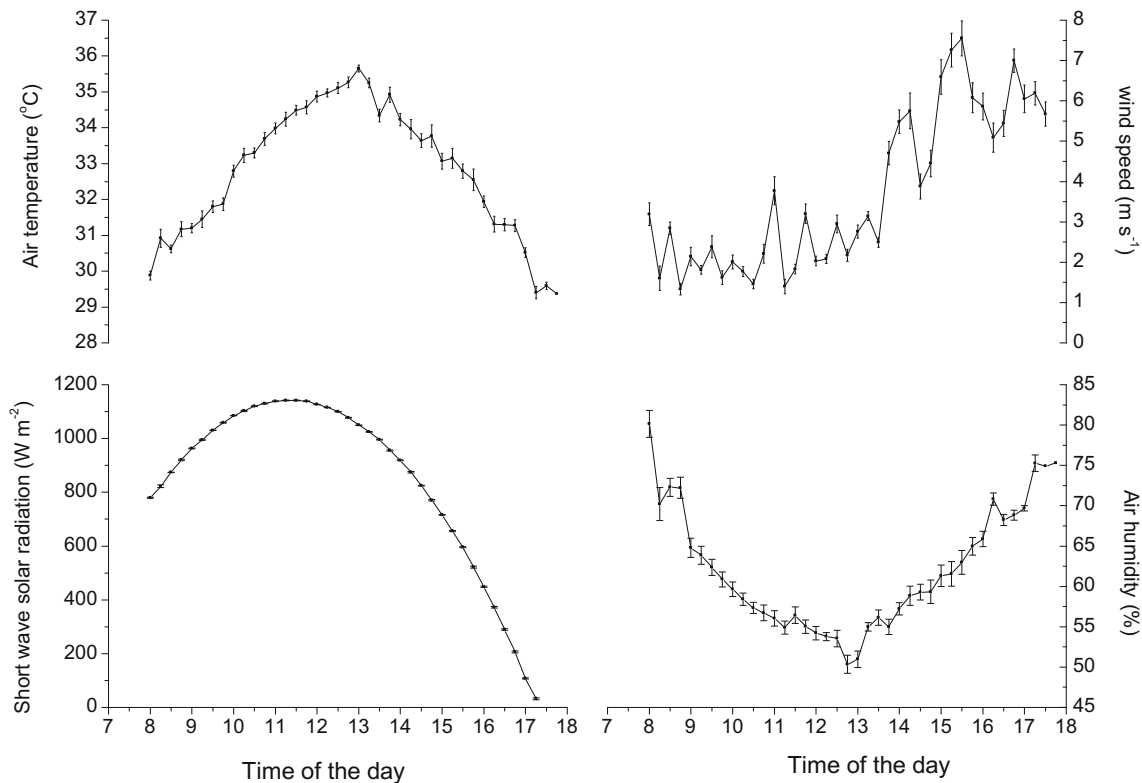


Fig. 2 Average values of air temperature, air relative humidity, solar radiation and wind speed according to the time of the day, during all the observation period from March to September of 2010 in the Brazilian semiarid (Mossoró, RN)

white goats were 41.1 and 38.2 °C, respectively (Fig. 3). However, when the goats were protected against the direct solar radiation, they absorbed almost eight times less, just 58 W m⁻² and 26 W m⁻² for black and white animal, and the coat surface temperature were 36.3 °C and 36.0 °C, respectively. In terms of sensible heat flow, when the level of short wave solar radiation was higher than 800 W m⁻² the animals exposed to the sun gained about 320 W m⁻² (black) and 180 W m⁻² (white). However, when they were under the shade or shelter the gain was equal to 60 W m⁻² (black) and 30 W m⁻² (white).

When the solar irradiance increased from 300 to 1000 W m⁻², and animals were exposed to sun, the cutaneous evaporation raised from 52 to 131 W m⁻², independently of the coat pigmentation (Fig. 4). The same occurred for the respiratory evaporation, but in this case, the heat losses varied from 7.8 to 13.9 W m⁻². Consequently, the cutaneous evaporative heat loss represents almost 90 % of the latent heat loss of UDB goats under all the levels of solar irradiance.

The contrary occurred to the metabolic heat production that decreased almost 70 to 60 W m⁻² until solar irradiance reached 800 W m⁻², but after this solar radiation level, the metabolic heat production increased to 66 W m⁻² for the black animals, while the white goats maintained at 60 W m⁻². When goats were under

shelter or shade (Fig. 5), the metabolic heat production increased from 54 to 65 W m⁻². Animals exposed to the sun had higher rectal temperatures in the schedules of highest radiation levels (Fig. 5) than when managed in the shade. This result suggests that UDB goats exposed to high solar radiation levels (above 800 W m⁻²) were not able to sustain the body temperature, mainly the black animals. In these conditions, the rectal temperature was 39.4 and 39 °C to black and white animals, respectively. Now in the same conditions of solar irradiance but the animals protected from the sun, the rectal temperature was 38.8 and 38.7 °C, respectively.

Under the sun black and white animals increased the respiratory rate from 55 to 120 breaths min⁻¹ and 45 to 95 breaths min⁻¹, respectively (Fig. 6), when the solar radiation rose from 300 to 1000 W m⁻². But in the shade, those animals had a slight increase from 37 to 49 breaths min⁻¹. The same was observed to the respiratory air flow, goats in the sun increased from 0.26 to 0.48 L s⁻¹ and 0.22 to 0.38 L s⁻¹, respectively, while those under shade increased from 0.18 to 0.23 L s⁻¹ and 0.20, to 0.24 L s⁻¹, respectively. As expected, the respiratory rate and the respiratory flow are positively, linearly correlated ($r=0.776$), according to Fig. 7.

The fractions of consumed oxygen ($\Delta O_2=O_{2A}-O_{2E}$) and produced carbon dioxide ($\Delta CO_2=CO_{2E}-CO_{2A}$) were

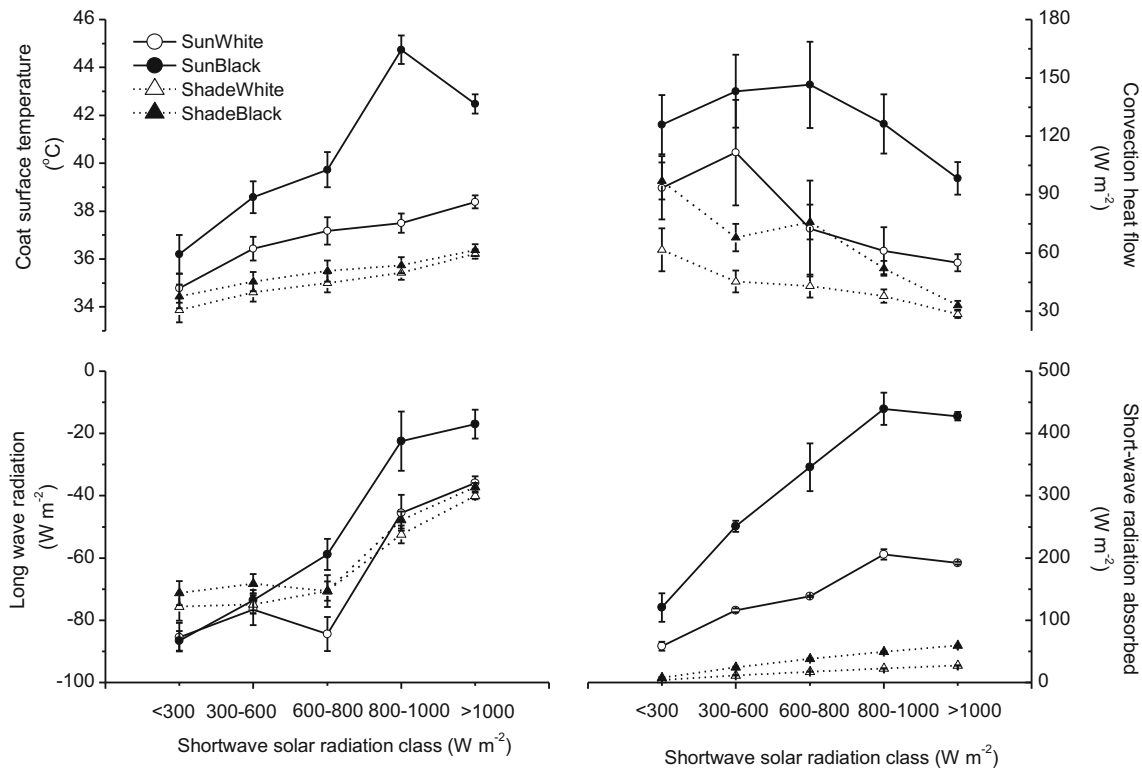


Fig. 3 Least squares means of coat surface temperature, heat exchange by long wave radiation, heat flow by convection and short wave radiation absorbed by the animals' body as a function of the shortwave solar

radiation levels and environment (sun and shade) of black and white UDB goats in the Brazilian semiarid (Mossoró, RN)

calculated and plotted as a function of the respiratory rate (Fig. 7). When respiratory rate rises from 25 to 200 breaths min⁻¹, it was possible to verify a decrease from 3.17 to 0.37 % in ΔO₂ and from 3.28 to 0.33 % in ΔCO₂; however, this was not linear, it was inverse.

Discussion

Most of the data collected (almost 75 %) was between 08:00 and 15:00 hour. This period was characterized by high levels of short wave radiation above 800 W m⁻². Thus, this

Fig. 4 Least squares means of the latent heat loss in the respiratory system and in the cutaneous surface as a function of the short wave radiation levels of black and white UDB goats under sunny and shade conditions in the Brazilian semiarid (Mossoró, RN)

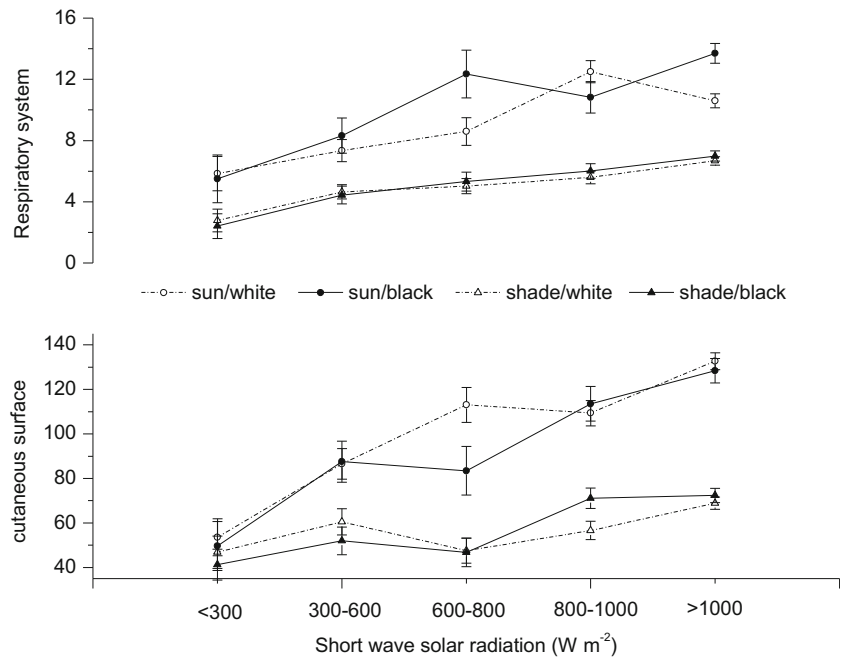
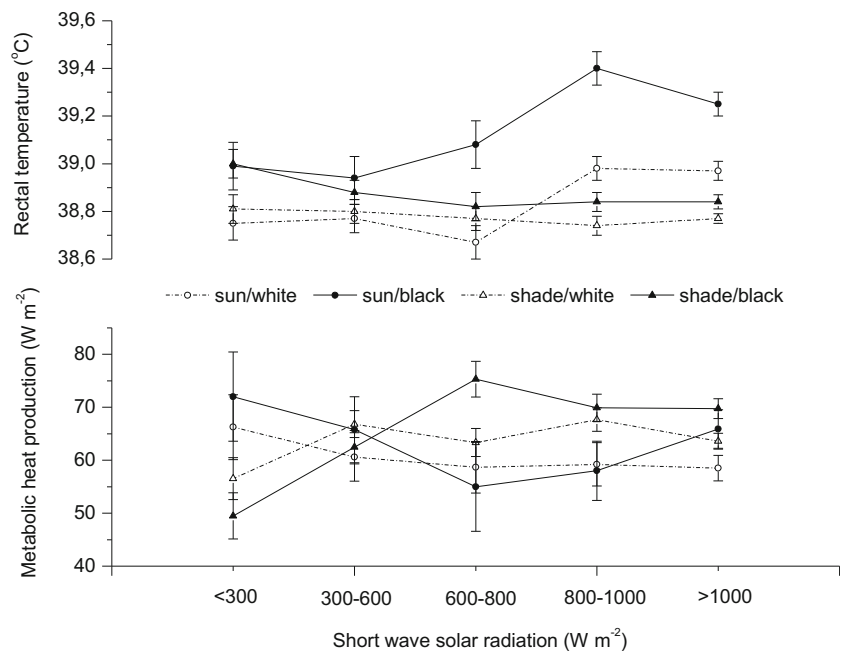


Fig. 5 Least squares means of the metabolic heat production and the rectal temperature as a function of the short wave radiation levels of black and white UDB goats under sunny and shade conditions in the Brazilian semiarid (Mossoró, RN)



meteorological variable was more important than air temperature and relative humidity and influenced the thermal equilibrium of UDB goats managed in the Brazilian semiarid region. This high level of solar radiation led to the high amount of solar radiation absorbed by the coat surface. Goats exposed to solar radiation, mainly the black ones, had a higher gradient of temperature between the coat surface and the environment ($\Delta = T_s - T_A$). Therefore they lost more heat by convection than the white ones (Fig. 3). However, the contrary occurred to the long wave radiation flow: due to the negative temperature

gradient between the coat surface and the mean radiant temperatures ($\Delta = T_s - T_{RM}$) the animals gained heat. Obviously, the sensible heat balance of the animals was negative; in other words, the animals gain heat by short and long wave, but lost just a part of it by convection (Fig. 3). Otherwise the amount of water vapour in the atmosphere was not a limiting factor to the evaporative heat loss because of the high and negative correlation between air temperature and humidity (Fig. 2). Wind speed had a lower contribution to the thermal balance of goats during the hottest hours of the day, because its

Fig. 6 Least square means of the respiratory rate and the respiratory volume of black and white UDB goats under sunny and shade conditions as a function of the short wave solar radiation levels in the Brazilian semiarid (Mossoró, RN)

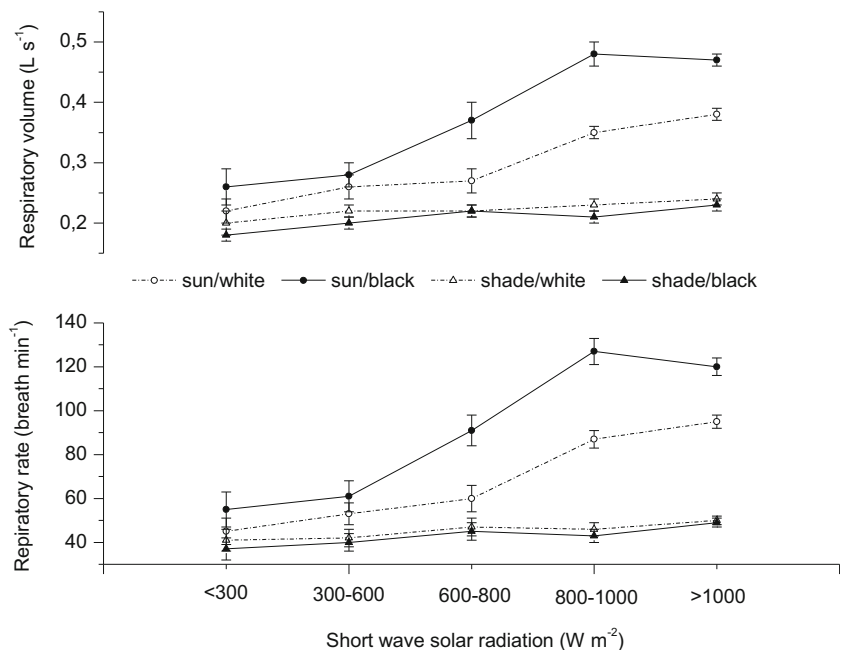
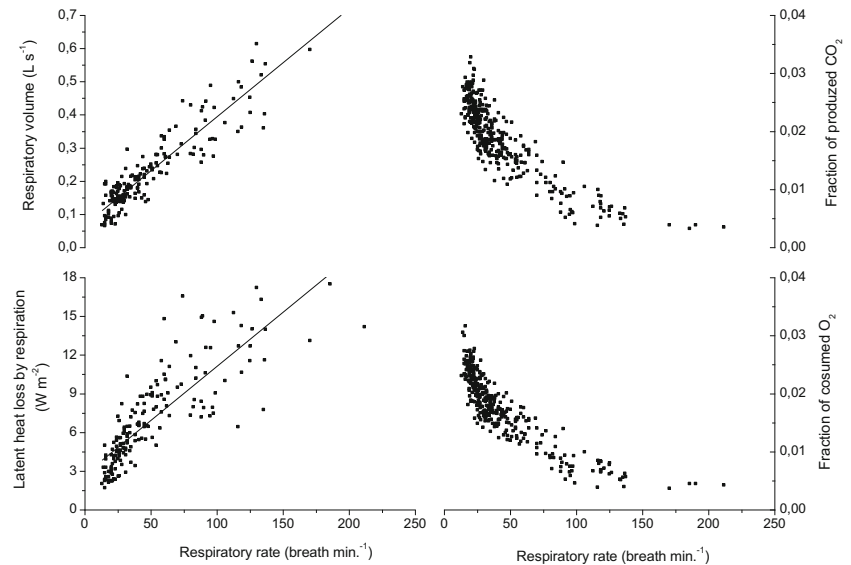


Fig. 7 Fractions of consumed oxygen (O_2) and produced carbon dioxide (CO_2), respiratory air flow and latent heat loss by respiration as a function of the respiratory rate of UDB goats in the Brazilian semiarid (Mossoró, RN)



velocity was low ($<2.0 \text{ ms}^{-1}$). The heat loss by convection was important after 15:00 hour, when its displacement was high ($>5.0 \text{ ms}^{-1}$).

The physical properties of coat colour change the amount of heat absorbed by the animal's body surface (da Silva et al. 2003) and consequently its surface temperature (Fig. 3). Black goats exposed to sun presented the surface temperature almost $3 \text{ }^\circ\text{C}$ higher than the white ones, but in the shade, black and white animals showed similar T_s . Therefore, it is expected that black animals are more susceptible to heat stress when exposed to the sun. However, the higher surface temperature of black coat goats must not be seen as a disadvantage of black UDB goats managed exposed to high radiation incidence, because the results described by Gebremedhin et al. (1983), Gebremedhin et al. (1997) and Jiang et al. (2005) showed that the absorption of solar radiation occur largely near the outer coat layer in the black coat, while in white coats, this absorption occur much deeper into the hair coat. Therefore, the temperature profile through the black coat layer is different from a white one, and a peak of temperature close to the interface between the coat and the air helps the animal to lose more heat by convection at the fur-air interface, mainly under strong wind conditions (Gebremedhin et al. 1997).

Independently of this convective cooling, the heat gain by black coat animals was much greater in comparison with white coat animals, mostly in still air conditions (Fig. 3). Thus, we could have expected that black UDB goats lost more latent heat than the white ones. But the results showed that the evaporative cooling was independent of the coat colour (Fig. 4), and it is influenced by solar irradiance mainly when animals were exposed to the sun. The increase in the sweating rate and in the respiratory flow (Fig. 6) was an attempt of the

UDB goats to increase the latent heat loss and to maintain their thermal equilibrium avoiding the heat storage. If we observe the rectal temperature (Fig. 5), it is not clear to observe if the latent heat loss was enough to keep the thermal balance in sunny conditions, especially for the black animals. Thus, the animals decreased the metabolic heat production.

Figure 5 showed that UDB goats decreased its metabolic heat production until 800 W m^{-2} of radiation. Under values higher than this, the metabolic heat production increased, but it was expected to decrease continuously. Figure 7 showed that an increase in the respiratory rate causes a linear increase of the respiratory flow and an exponential decrease in the consumption of O_2 and in the production of CO_2 . Therefore, an increase of the respiratory rate until $120 \text{ breaths min}^{-1}$ causes a decrease in the metabolic heat production, while respiratory rate higher than this causes an increase of it. When the animal breathes more than $120 \text{ breaths min}^{-1}$, the ΔO_2 and ΔCO_2 becomes stable, while the respiratory flow continues to increase.

A previous study by Finch et al. (1980) attempted to understand the reasons by which the Bedouins have selected black goats for the desert environment. They pointed out cultural aspects and the notion that dark animals have a higher protection to ultraviolet damages and are better adapted to the winter season. In the same report, the authors observed that while black animals exposed to the sun presented higher heat storage than white goats, in the shade, this difference disappeared. Similar results were found here. However, their data showed greater heat loss by evaporative in black goats than white ones, while in our results, the heat loss by evaporative flow did not differ for coat colour. These different results might explain for two reasons: we used a different

methodology to measure the evaporative heat loss. Finch et al. (1980) used a weighing-machine for 30 min; and the harsh environment, because the authors made the measurements at midday in the summer season of Negev Desert, with a range of temperature between 35 °C and 46 °C. If we consider the rectal temperature as an indication of heat storage, apparently, the black animals presented higher heat storage in comparison with the white ones, mainly when they were exposed to radiation levels higher than 800 W m⁻².

The results showed that UDB goats were able to maintain their thermal balance in the shade, but when exposed to the sun, the results depend on the solar radiation level. Apparently, these results indicate some advantage of the white animals; nevertheless, this does not necessarily mean that black coat UDB goats are less adapted to the semiarid environment.

The present study is probably the first to quantify and to correlate the levels of solar radiation with thermal equilibrium in UDB goats. In addition, our results suggest that UDB goats are able to deal with the harsh semi-arid environment and its solar radiation conditions using physiological changes, like higher respiratory rate, sweating rate and respiratory flow; reduction in the consumption of oxygen and in the production of carbon dioxide, metabolic heat production and a small increase in the rectal temperature.

Finally, we believe that these findings could be helpful to UDB goat producers with herd management strategies aiming the production of goat milk and meat. First, it is clear that shade must be provided for the animals to guarantee a best animals' performance. But when UDB goats are managed in the field artificial or natural shade must be provided to protect the animals from solar radiation, especially above 600 Wm⁻².

Conclusion

The Brazilian UDB black or white goats need protection against solar radiation to maintain the thermal equilibrium. When they are managed without this protection, their physiological responses are altered, mainly in black goats, when solar irradiance is higher than 800 W m⁻².

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