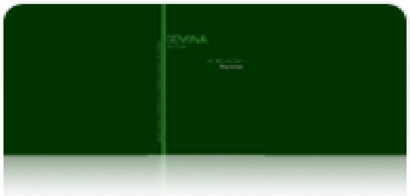

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Thermoregulatory responses of sindhi and guzerat heifers under shade in a tropical environment

Respostas termorregulatórias de novilhas sindi e guzerá sob condições de sombra em um ambiente tropical

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Abstract

This study characterized the thermal environment and assessed the physiological aspects of acclimatization of Sindhi and Guzerat heifers in a tropical environment (Brazil) under shade. Eight Sindhi and eight Guzerat purebred heifers (*Bos indicus*) had their physiological traits measured twice a day (9:00 a.m. and 2:00 p.m.). Environmental data during the experimental period were collected at two-hour intervals between 5:00 a.m. and 5:00 p.m. The temperature-humidity (THI) and the black globe temperature-humidity (BGHI) indices were calculated, and surface temperature (S_t), respiratory rate (R_r), and rectal temperature (R_t) were collected, being used to estimate heat loss by cutaneous (E_c) and respiratory (E_r) evaporation. In the warmer parts of the day (1:00 and 3:00 p.m.), the THI and BGHI reached values of 80.26 and 81.25, respectively. There was no significant difference in rectal temperatures between the breeds, but higher values were observed in the afternoon. Heat transfer by cutaneous evaporation reached 118.71±12.91 $W.m^{-2}$ and 103.43±6.82 $W.m^{-2}$ at 2:00 p.m. for the Sindhi and Guzerat heifers, respectively. Under these conditions (air temperature was between 29 and 30°C), 84% of the total latent heat loss in Sindhi and Guzerat heifers was represented by E_c. It can be concluded that Sindhi and Guzerat heifers can maintain homeothermy with minimal thermoregulatory effort under shade conditions in a tropical environment.

Key words: Heat tolerance. Physiological parameters. Prediction models. Zebu cattle.

Resumo

Objetivou-se com este estudo caracterizar o ambiente térmico e respostas fisiológicas de novilhas Sindi e Guzerá em ambiente tropical. Oito novilhas Sindi e oito Guzerá *(Bos indicus)* foram utilizadas para medições fisiológicas duas vezes ao dia (09:00 e 14:00). Durante o período experimental, os dados ambientais foram coletados em intervalos de duas horas, entre 05:00 e 17:00. O índice de temperatura-

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umidade (ITU) e o de globo negro-umidade (ITGU) foram calculados. Foram aferidas a temperatura de superfície (T_S) , frequência respiratória (F_R) e a temperatura retal (T_R), sendo estimados a perda de calor por evaporação cutânea (E_C) e pelo trato respiratório (Er). Nos horários mais quentes do dia (01:00 e 15:00), o ITU e ITGU atingiram valores de 80,26 e 81,25, respectivamente. Não houve diferença significativa para a temperatura retal entre as raças, contudo, valores mais elevados foram observados no período da tarde. As estimativas para a transferência de calor latente via evaporação cutânea atingiram 118,71 ± 12,91 $W.m^{-2}$ e 103,43 ± 6,82 $W.m^{-2}$ no período da tarde (2:00) para as novilhas Sindi e Guzerá, respectivamente. Em condições de temperatura do ar entre 29 e 30 ° C, 84% da perda de calor latente total em novilhas Sindi e Guzerá foi representada pela Ec. Pode-se concluir que novilhas Sindi e Guzerá criadas em condições de sombra, numa região tropical, conseguem manter a homeotermia com baixo dispêndio de energia para a termorregulação.

Palavras-chave: Bovinos zebuínos. Modelos de predição. Parâmetros fisiológicos. Tolerância ao calor.

Introduction

Physiological parameters can be used to evaluate the adaptability of cattle to a specific environment and this has been done in several studies (MULLER; BOTHA, 1993; BROWN-BRANDL et al., 2006; GAUGHAN et al., 2009; MCMANUS et al., 2011; COSTA et al., 2015). Changes in the thermal energy balance such as an increase in the respiratory rate or variations in body temperature above a narrow permissible range are some of the animal's responses to environmental conditions that are outside their thermal comfort zone.

When air temperature is above of the upper critical, evaporative heat loss is greater in order to maintain thermal equilibrium in animals (MAIA et al., 2005a). Cattle heat loss by evaporation occurs mainly at the epidermis and, accounts for approximately 80% of the total loss under heat stress conditions (MCLEAN, 1963; FINCH, 1985; MAIA et al., 2005a; SILVA et al., 2012).

Some researchers have developed mathematical models that use indirect measures such as respiratory rate and surface temperature to predict latent heat flow in cattle (MAIA et al., 2005b; SILVA; MAIA, 2011; SILVA et al., 2012). These studies showed that heat loss by cutaneous evaporation is determined by surface temperature and, latent heat loss through the respiratory tract is based on the respiratory rate and the relationship between the vapor pressure of inspired and expired air.

Indirect measures to estimate an animal latent heat balance and other physiological indicators of adaptability, are important tools to establish the effect of breed-environment interaction on the thermoregulatory responses of cattle. Furthermore, most studies on *Bos indicus* in tropical environments have investigated Nellore cattle, and little attention has been given to other breeds, such as Sindhi and Guzerat (NAVARINE et al., 2009; MCMANUS et al., 2011; COSTA, 2013). Therefore, the present study aimed to verify the physiological aspects of acclimatization of Sindhi and Guzerat heifers in confinement not exposed to the sun. We suggest that Sindhi and Guzerat heifers when reared in tropical conditions but not exposed to the sun could maintain homeothermy with minimal thermoregulatory effort.

Materials and Methods

The study was conducted from June 18 to August 27, 2009 at the Livestock Experimental Station in Alagoinha, PB, Brazil (6° 57' 00" S, 35° 32' 42" W, 135 m altitude). Sixteen purebred heifers (*Bos indicus*), eight Sindhi and eight Guzerat, with a mean age of 21 ± 4.2 months were used. The Guzerat heifers had a mean body weight of 268.17 ± 22 kg, and the Sindhi heifers had a mean body weight of 211.7 ± 21 kg. The animals were maintained in a housed condition. The experimental diets were formulated to meet the nutritional requirements of growing heifers (NRC, 2001) (Table 1). Feeding was divided into two daily servings, one at 7:00 a.m., which offered 40% of the daily portion, and the other at 3:00 p.m., which offered 60%. Access to water was not restricted.

The heifers were housed in individual pens that were built with an east-west orientation, measured 7.5 m^2 in area, and were provided with feeders and drinkers. The material used in the roof was fiber cement roof, which has a thermal conductivity (*k*) of 0.63 $Wm^{-1}K$ (MONTEITH; UNSWORTH, 2008). The animals were never exposed to direct short-wave radiation.

Table 1. Ingredients and chemical composition of the experimental diet based on dry matter.

Ingredients	(%)	
	Guzerat Diet	Sindhi Diet
Pennisetum purpureum	39.17	30.00
Cassava root	30.00	31.31
Cornmeal	21.76	24.70
Soybean meal	5.87	10.90
Urea	1.65	1.58
Mineral salt	1.55	1.51
Chemical composition	(%)	
Dry matter	49.32	54.35
Crude protein	13.51	15.55
Ether extract	2.49	2.53
Neutral detergent fiber	37.73	32.66
Neutral detergent fiber cp[1]	33.20	27.96
Acid detergent fiber	22.43	19.34
Total Carbohydrates	79.97	78.28
Non-fibrous carbohydrates	42.21	37.99

[1]Corrected for ash and protein.

Environmental variables were collected at two-hour intervals from 5:00 a.m. to 5:00 p.m. every day during the experimental period. Air temperature (T_a), black globe temperature (T_g), and relative humidity (R_H) were recorded. T_a, T_g, and R_H were measured using a mini portable weather station placed inside the confinement pens 1.2 m from the ground. The black globe temperature was measured using a thermometer inserted into a conventional blackened hollow sphere (15 cm diameter) painted with matte black ink. The temperature-humidity index (THI) and the black globe temperature-humidity index (BGHI) calculations were based on the T_a and T_g, variables.

The THI was calculated using the equation in Thom (1959):

$$THI = T_a + (0.36 \times W_{BT}) + 41.5$$

where W_{BT} is the wet bulb temperature. The BGHI was calculated using the equation in Buffington et al. (1981):

$$BGHI = T_g + 0.36\ T_d - 330.08$$

where T_d is the dew point temperature measured in Kelvin.

Physiological traits were recorded twice a day (9:00 a.m. and 2:00 p.m.). The heifers were moved to a contention trunk in a corral beside the confinement area. Rectal temperature (T_r), respiratory rate

(R_r), and surface temperature (T_s) were measured. To obtain T_r, a digital clinical thermometer was introduced into the animal's rectum. The R_r was assessed when the animals were inside their pens, before they were led to the contention trunk, by counting the animals' flank movements for 15 s; this was later multiplied by four to calculate the number of breaths per minute. The T_s was measured using an infrared thermometer (Horiba, mod. IT - 330), that had an adjusted emissivity of 0.98. It was directed perpendicular to the animals' surface at a distance of 20 cm from the following regions: the head, the back, the shin, and the udder. The T_s value was determined according to the equation in Pinheiro et al. (2005):

$$T_s = 0.1 \cdot T_{head} + 0.7 \cdot T_{back} + 0.12 \cdot T_{shin} + 0.08 \cdot T_{udder}$$

Mathematical models developed by Maia et al. (2005b) and Silva et al. (2012) were used in order to estimate latent heat flux through the respiratory tract:

$$E_r = \lambda\,(\Psi_{EXP} - \Psi_{ATM})/r_{VR}\ \mathrm{W \cdot m^{-2}}$$

where E_r is the heat flux through the respiratory tract, λ (2500.7879 - 2.3737t_a [$\mathrm{J.g^{-1}}$]) is the latent heat of water vaporization, Ψ_{EXP} is the absolute humidity ($\mathrm{g.m^{-3}}$) of the expired air, Ψ_{ATM} is the atmospheric absolute humidity, and r_{VR} is the water vapor resistance to heat loss through the respiratory tract. In order to estimate the absolute atmospheric humidity we used the following equation:

$$\Psi_{ATM} = 2166.869\ P_V/(T_a + 273.15)\ \mathrm{g \cdot m^{-3}}$$

where P_V is the vapor pressure of air at a given air temperature (T_a), calculated using the equation:

$$P^*_V\ \{T_a\} = 0.61078 \times 10^{7.5\ Ta/(Ta + 237.5)}\ K_{pa}$$

The absolute humidity of the expired air (Ψ_{EXP}) was calculated according to the following equations developed by Silva et al. (2012) and Maia et al. (2005b):

$$\Psi_{EXP} = 2166.869\ P_{VEXP} / (T_{EXP} + 273.15)\ \mathrm{g \cdot m^{-3}},$$

$$T_{EXP} = 9.47 + 1.18T_a - 0.01278\ T_a^2\ ^{\circ}\mathrm{C},$$

$$P^*_V\ \{T_{EXP}\} = 0.61078 \times 10^{7.5\ T_{EXP}/(T_{EXP} + 237.5)}\ K_{PA}$$

where $P_{V(EXP)}$ is the vapour pressure of the expired air and T_{EXP} is expired air temperature. Finally, the water vapor resistance to heat loss through the respiratory tract (r_{VR}) was given by the following function:

$$r_{VR} = 2583.921 - 48.445\ R_r + 0.3414\ R_r^2 - 2.037\ T_a\ \mathrm{S \cdot m^{-1}}$$

In order to estimate the heat loss by cutaneous evaporation, the exponential model developed by Silva and Maia (2011) as a function of the animal's surface temperature (T_S) was used:

$$E_c = 31.5 + 3.67e^{(Ts - 27.9)/2.1915}\ \mathrm{W \cdot m^{-2}}$$

Data were analyzed by the least square methods (HARVEY, 1960). The General Linear Model (GLM) procedure was used to test the effects of breed (Sindhi or Guzerat) and time of the day (9:00 a.m. or 2:00 p.m.) on the physiological traits. The following mathematical model was used in the analysis of variance for T_s, R_r, T_r, E_c, and E_r:

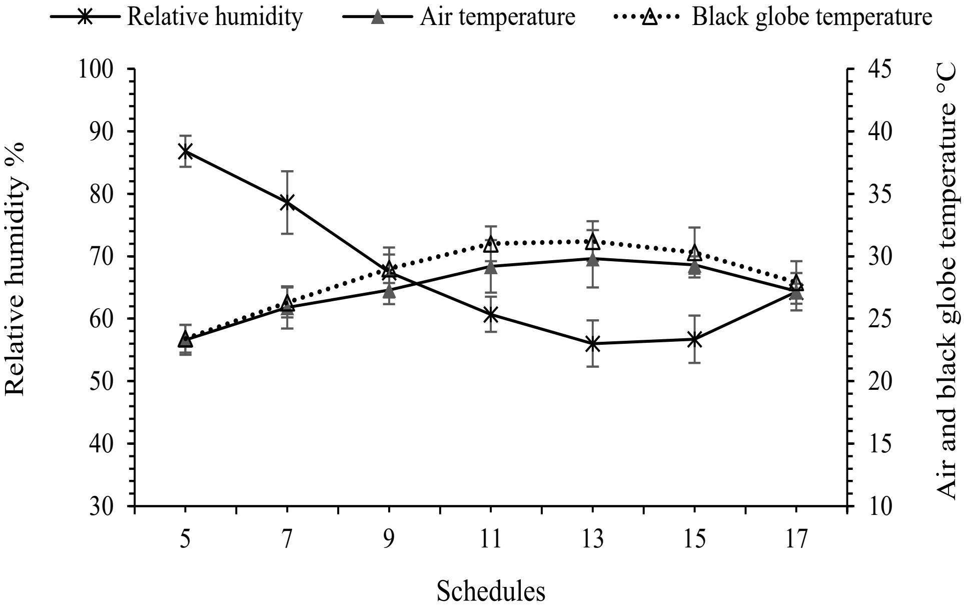
$$y_{ijk} = \mu + B_i + T_j + I_{ij} + e_{ijk}$$

where y_{ijk} = the kth observation on the jth time of day of the ith breed; B_i= the fixed effect of the ith breed (I = Sindhi or Guzerat); T_j = the effect of the jth time of the day (j= 9:00 a.m. or 2:00 p.m.); I_{ij} represents the interaction effects between the ith breed and the jth time of the day; and μ and ε_{ijk} = the overall mean and the error term, respectively. The statistical package used for all analyses was SAS version 9.3 (SAS Inst. Inc., Cary, NC, USA).

Results and Discussion

Air temperature varied during the day ($P < 0.05$), and ranged from 23.30 ± 1.5 to 29.80 ± 2.1 between 5:00 a.m. and 5:00 p.m. The temperatures were highest between 11:00 a.m. and 3:00 p.m. (Figure 1). According to Brown-Brandl et al. (2006), the thermoneutral zone (TNZ) generally ranges between 10 and 30°C for most adult cattle breeds. Gaughan et al. (2009) reported that the heat tolerant *Bos indicus* must have an upper end for TNZ that is greater than that for typical *Bos taurus* cattle. Baêta and Souza (2010) reported 34°C as being the upper end of the thermoneutral zone for Zebu cattle.

Figure 1. Environmental data (mean ± SEM) measured during the experimental period at each two hours.



In the TNZ, an animal can maintain homeostasis through normal physiological and metabolic processes, which require minimal expenditure of energy (BERNABUCCI et al., 2010). In our study, the air temperature was maintained within a suitable range for both breeds. In regions with low latitudes, such as the tropics, there is little variation in the average annual temperature, and T_a does not seem to cause significant changes in the physiology and metabolism of adult Zebu cattle.

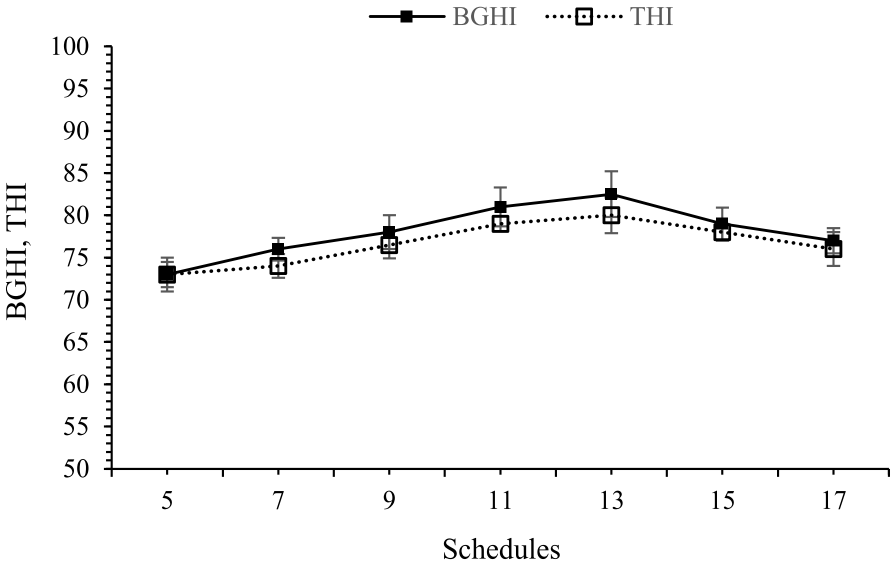
High values for R_h were observed early in the day when the air temperature was lowest. The opposite was observed when the air temperature was highest (Figure 1). The R_h daily variation range was 56±2.20 to 86.8±2.16%. The variation in T_g (range: 23.30±1.5 to 31.20±0.6) was similar to T_a (Figure 1). In shade conditions, T_g is not affected by short-wave radiation and its values are therefore close to the air temperature.

Even in shade conditions, indirect long-wave radiation emitted from the roof can be significant for housed cattle, and the use of materials with a high thermal capacity becomes relevant. Roof materials should therefore have appropriate thermophysical properties. In our study, cement fiber roof was used as a roofing material. This material has an emissivity (ε) of 0.97 and a thermal conductivity (*k*) of 0.67 $W.m^{-2}$ (CHAPMAN, 1987; MONTEITH; UNSWORTH, 2008).

Values of between 72.23 and 80.26 were observed during the experimental period for the temperature-humidity index (THI) and 72.00 and 81.5 for the BGHI (Figure 2). Previous studies with dairy cattle, mainly using the THI and BGHI indices, have reported consistent results with regard to the classification of the ideal environment for raising cattle in temperate climates (BUFFINGTON et al., 1981). According to the National Weather

Service (USA) classification, the limits of the THI and BGHI for dairy cattle are as follows: up to 74 represents a comfortable situation, 74-78 triggers an alert state, 79-84 represents a dangerous situation, and over 84 is an emergency.

Figure 2. Temperature-humidity index (THI), black globe temperature-humidity index (BGHI); (mean ± SEM) calculated during the experimental period.



Despite its obvious limitations, the THI has been frequently used in the classification of environments for cattle raised in tropical regions, using the argument that it is correlated with the productive performance of the animal; however, such arguments are valid only when they are related to temperate regions, where the index was developed (BOHMANOVA et al., 2007; SILVA et al., 2007; ZIMBELMAN et al., 2009; SILVA et al., 2014). In the case of genotypes that are more adapted to tropical conditions, the values set for the climatic environmental classification of Holstein cattle less adapted to these conditions may be overestimated for other genotypes, such as Sindhi and Guzerat cattle.

There was no significant difference (P > 0.05) in surface temperature between Sindhi and Guzerat cattle (Table 2; Table 3). However, for both breeds, the surface temperature was higher at 2:00 p.m. than in the morning (9:00 a.m.). The amount of energy from the environment that is absorbed at the animal's surface, together with the heat that is transferred from the inner core to the periphery by circulatory convection, which determines the animal's surface temperature. Hair color, epidermis and hair conformation influence surface temperature (SILVA et al., 2003; BROWN-BRANDL et al., 2006). Cattle with shorter and wider hair, and a light-colored coat are more adapted to hot environments than those with long-haired, darker coats (GAUGHAN et al., 2009; JIAN et al., 2013). These characteristics are common to both breeds that we studied, except for coat color (Sindhi cattle have red hair).

With respect to hair coat color, we expected a higher surface temperature on Sindhi cattle, which have red hair, than on Guzerat cattle, which have white-gray hair, due to the greater heat absorbance (α) of red hair α = 0.777, compared to 0.54 for white hair (SILVA; MAIA, 2012). Silva et al. (2003) reported that Nellore cattle, which have a mixture of white and dark hair, similar to Guzerat, had a higher reflectance (ρ) than cattle with white hair, and that gray coats reflect better than red coats at the 300-600 nm wave lengths. This spectrum comprises of short-wave radiation. However, we maintained the animals in shade conditions and so did not observe any differences in surface temperature between the breeds.

Table 2. Means square of surface temperature (St), respiratory rate (Rr), heat loss by cutaneous evaporation (Ec) and heat loss by respiratory evaporation (Er) of Sindhi and Guzerat heifers.

Source	d.f	S_t	R_r	R_t	E_c	E_r
Breed	1	1.3021ns	689.4525**	1.7981ns	1,854.9799ns	1.5689ns
Time of the day	1	137.2647**	31.5584ns	4.8870**	63,063.9033**	1.3241ns
Residual	80	12.5144	46.2063	1.6800	2,999.6522	1.6647

ns = statistically non-significant; ** P < 0.01.

Table 3. Physiological traits (mean ± SEM) of Sindhi and Guzerat heifers.

Response variable	Time of the day		P - *value*		
Surface temperature, °C	9:00 a.m. (*n* = 92)	2:00 p.m. (*n* = 88)	Breed	Time of the day	Breed vs time of the day
Sindhi	31.63±0.2b	34.15±0.25a	0.3600	0.0001	0.8817
Guzerat	31.85±0.2b	34.45±0.30a			
Respiratory rate, min^{-1}					
Sindhi	33.63±1.2B	34.40±1.54B	0.0002	0.4110	0.7557
Guzerat	38.90±1.3A	40.60±1.72A			
Rectal temperature, °C					
Sindhi	38.50±0.2a	38.90±0.05b	0.0821	0.0042	0.9902
Guzerat	38.80±0.2a	39.28±0.04b			

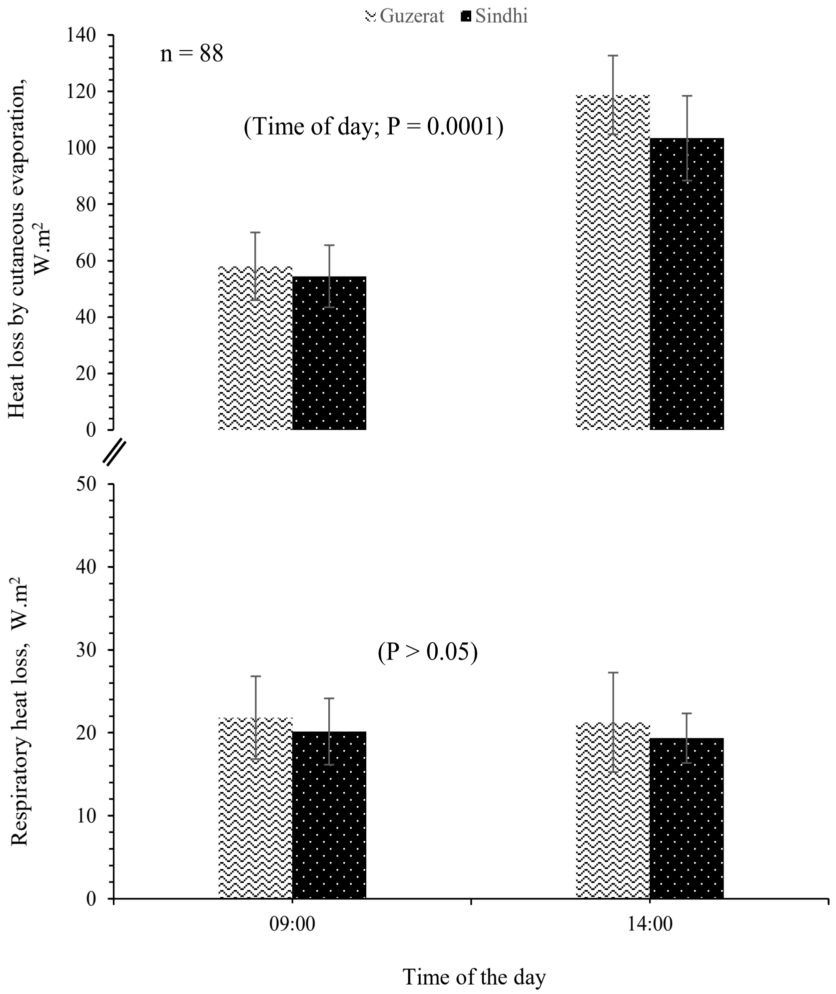
Means with different letter (lower case in the same line and capital letter in the same column) differ statistically by f test (P < 0.05).

Furtado et al. (2012) obtained similar results in a study on Sindhi and Guzerat calves in confinement. They also did not observe any surface temperature differences between breeds. In study with Nellore cattle, Costa (2013) reported an increase in surface temperature when these animals were transferred of the shade condition to the exposition to the sun. According to Martello et al. (2004), values between 31.6°C and 34.7°C are considered normal for cattle bred in regions with hot climates. Overall, our results showed that even during the hottest time of the day (2:00 p.m.) the surface temperature was higher than the air temperature, although the difference was smaller, which favored the loss of heat by sensible processes. As air temperatures approach surface temperatures, evaporation becomes the major route for heat exchange with the environment.

Predictions for heat transfer by cutaneous evaporation were similar (P > 0.05) for both breeds. When the time-of-day effect was considered, we observed that cutaneous evaporation increased in the afternoon (2:00 p.m.), and at this point, ranges of 118.71±12.91 and 103±6.82 were observed in Guzerat and Sindhi heifers, respectively (Figure 3). Under tropical condition, at a temperature of 30°C, Maia et al. (2005a) recorded a range of 250 to 300 W.m^2 for heat loss by cutaneous evaporation in Holstein cows. These results suggested that in a similar environment, the energetic costs of thermoregulation are higher for Holstein cows than for Guzerat and Sindhi heifers.

The respiratory rate was higher in Guzerat cattle ($P < 0.05$; Table 3). However, there was no significant effect of time of the day, and during the warmest period (2:00 p.m.) the animals did not increase their respiratory rates ($P > 0.05$). According to Hahn et al. (1997), 60 respiratory movements do not represent a stressful situation for cattle bred in tropical environments. Pereira et al. (2008) reported that cattle under heat stress that are suited to hot climates increase their respiratory frequency to 80 movements per minute at 34°C. The increased respiratory rate in Guzerat heifers can be attributed to their temperament, since these animals were more reactive than Sindhi at the time of data collection. Gaughan et al. (2000) stated that respiratory frequency is a good indicator of an animal's thermal condition; however, other factors need to be taken into account when interpreting the results.

Figure 3. Respiratory heat loss and heat loss by cutaneous evaporation (mean ± SEM) estimated in Sindhi and Guzerat heifers.



Regarding latent heat transfer, the amount of energy lost through the respiratory process did not differ between breeds ($P > 0.05$), or between time of the day (Figure 3). The efficiency of this process depends on the vapor pressure in the atmosphere. The air volume that is expired by an animal (tidal volume) is negatively correlated with the number of breaths per minute, i.e., as the respiratory frequency increases, the amount of vapor contained in the expired air decreases (STEVENS, 1981; MAIA et al., 2005b). As consequence, the amount of heat transfer by respiration is reduced; increase in respiratory activity cause an additional production of internal heat, reducing the efficiency of this heat transfer mechanism. In addition, high respiratory rate can lead to serious physiological damage in animals, such as decreased partial pressure of CO_2 in the arterial blood (MAIA et al., 2005b).

According our results, when the air temperature increased, respiratory rate and latent heat transfer by the respiratory tract remained constant. At 9:00 (T_a of 27.30±0.90) the heat of respiratory tract accounted 26 % of the total latent heat loss and at 2:00 p.m. (T_a of 29.80±1.20) this proportion decreased for 16 % of the total latent heat loss. In a situation of heat stress, evaporative heat loss via respiration rate can be greater for European breeds and this occurrence probably reflects the grater engagement of heat loss mechanism for the less adapted breed (HENSEN, 2004).

There was no difference in rectal temperature between breeds ($P > 0.05$), and the animals' homeothermy was maintained in both assessment periods during the day (morning and afternoon), although there was a increase ($P < 0.05$) in the afternoon (Table 3). However, the observed values were within the normal range for the species, which according to Baêta and Souza (2010) is 38.5°C to 39.5°C. It was reported that *Bos indicus* cattle has a low metabolism when compared with European cattle. Animals with low metabolism has a greater capacity to heat storage. In addition, heavier individuals store more energy and require proportionally lower heat production rate (SILVA, 2000). Our results showed a slight tendency in higher rectal temperature for Guzerat heifers.

In a study of a Sindhi heifers herd in the Brazilian semiarid region, Souza et al. (2007) reported a significant increase in rectal temperature in the afternoon; however, this increase did not represent a state of hyperthermia. Comparing the degrees of adaptation of five different cattle breeds under heat stress conditions, such an air temperature of 34°C in climate chambers, Pereira et al. (2008) reported hyperthermia (body core temperature of 41.2°C) in Holstein and Limousin breeds.

Even under environmental conditions in which animals can maintain homeothermy, minor variations in body temperature are observed and, the magnitude of these changes can correspond to the thermoregulatory adjustments that animals expend to maintain thermal equilibrium. However, an adaptive mechanism in species bred in arid regions is thermal storage. In this process, the heat received from the environment is stored, leading to a significant increase in the animal's body temperature (SILVA, 1999; BROSH et al., 1998). This excess heat is eliminated at night by sensible mechanisms, due to the high thermal gradient that exists at this time. In terms of energetic costs, this mechanism present more economy for the animal, because the excessive physiological changes to maintain homeotermy require high use of net energy. No studies reported clearly this mechanism at some *Bos indicus* breeds; however, their process of genetic adaptation suggests that these animals has a thermoregulatory mechanism more efficiently than *Bos taurus*.

According to the physiological traits measured in this study, Sindhi and Guzerat heifers maintained homeothermy with minimal thermoregulatory effort. Thus, the use of shade in a confinement or grazing system in tropical environments, even for breeds more adapted as Zebu cattle, can represent a less energy expenditure for the thermoregulation and consequently better performance for these animals.

Conclusions

The fiber cement roof can be used in shade structures for cattle bred in tropical conditions. Sindhi and Guzerat heifers can maintain homeothermy with minimal thermoregulatory effort under shade conditions in a tropical environment.

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