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Surface Temperature and Heat Transfer between Body Regions of Africanized Honeybees (*Apis mellifera* L.) in Hives under Sun and Shade Conditions in the Northeastern Semi-arid Region of Brazil

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Abstract: This work was done at the experimental station of the Federal Rural University of the Semi-arid Region (UFERSA) in Mossoró, Brazil. This work aimed to evaluate the surface temperature of the bees and heat transfer between body regions of Africanized honeybees (*Apis mellifera* L.) in hives under sun and shade conditions in the northeastern semi-arid region of Brazil. Twelve colonies of Africanized honeybees housed in Langstroth hives were used. The body surface temperature of the bees was measured using a mini infrared thermometer (Fluke model 62). The climatological data were obtained through a meteorological station. The comparison of means was performed by the Tukey-Kramer test (p < 0.01), and data analysis using the Statistical Analysis System software. The body temperatures of the bees are not homogeneous and fluctuate throughout the day, in accordance with the environmental variations. The temperature of the thorax is generally higher, followed by the head and abdomen. The head and the abdomen are parts of the body for which the excess temperature of the thorax is transferred, with the head being the main one. The bees that were in the shade, managed to keep their body temperatures at relatively normal levels, while the bees that were in the sun, had a considered increase of its surface body temperatures higher than 2 °C, being necessary the activation of mechanisms of heat loss, and consequently there is a deviation of energy that could be used for other activities within the colony.

Key words: Surface temperature, shading, thermal comfort, *Apis mellifera.*

1. Introduction

Several environmental factors may have influence on the colonies, including air temperature, wind speed, relative air humidity and solar radiation, and their consequences have been demonstrated in some studies [1-3]. Environments characterized by high temperatures and intense solar radiation, as is the case of the northeastern semi-arid region, are worrisome, since they promote the overheating within the colonies and may lead the bees to abandon their hives even in the presence of brood and queen [4]. The study of the surface temperature of bees has been used as an important tool to understand the thermal homeostasis of a colony [5, 6]. It is precisely these studies of how bees control their temperatures, which justify productive losses in hot climates and provide a basis for research that proves the importance of providing a comfortable climatological environment for bees. Therefore, this study was carried out to evaluate the surface temperature and heat transfer between body regions of Africanized bees (*Apis mellifera* L.) in hives under sun and shade conditions in the

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northeastern semi-arid region. Understanding how Africanized honeybees control their body temperature and the behavioral and physiological responses developed to maintain thermoregulation levels throughout the day are of fundamental importance [7, 8].

This is even more important when comparing light internal temperatures of hives as in the case of a shady environment or when the internal temperature of the hive is high when exposed directly under solar radiation. It is precisely these studies that allow the evaluation of the causes of loss of productivity of the colonies of honeybees in very hot climates [9]. It is very important to demonstrate the responses of the bees submitted to different thermal environment [10, 11].

2. Materials and Methods

This work was carried out from October 2014 to August 2015 at Technological Center of Beekeeping and Meliponiculture of Rio Grande do Norte (CETAPIS), located at the experimental station of the Federal Rural University of the Semi-arid Region (UFERSA) in Mossoró, Brazil. Three colonies of bees were used at a time, with a spacing of 24 m between them, being placed individually under structures (“latadas”), with wooden pillars and with movable ceiling of asbestos cement tiles (Brasilit) to allow hives to receive the direct action from the rays of the sun or be protected in the shade, depending on the condition of the experiment. Each quarter, these three colonies were replaced by other colonies of the experimental apiary, using the same criteria of choice (standardization of biomass and population), totaling 12 colonies in every experiment. Near the hives (200 m), there were tanks of drinking water for the bees. Twice a week each colony received 250 mL of energy food composed of 60% water and 40% sugar. For the data collection, the coverage of the wood structures was removed, according to the experiment schedule. Data were collected every 15 d. First, data were collected from the three hives under shading conditions. When the data collection was completed, the cover of each structure was removed and after two days of intervals, the analyses of the hives exposed directly to the solar radiation were carried out.

The evaluations began at eight o’clock and ended at sixteen o’clock. The whole observation period throughout the day was divided into three periods: period 1 (evaluations between 8 am and 9 am—lower temperatures); period 2 (evaluations between noon and 1 pm—higher temperatures); period 3 (evaluations between 3 pm and 4 pm—intermediate temperatures). A mini infrared thermometer (Fluke model 62) was used to measure the temperature of the bees, which allowed non-contact temperature measurements and behavioral dysfunctions. In each period, the bees’ thoracic temperatures (body temperature) were evaluated in the three hives when the bees were returning from the field, immediately after their arrival from the field in the survey. In each hive, the thoracic temperature of 10 bees were measured, totalizing 90 bees evaluated in each day of observation under shade conditions and 90 bees evaluated under sun’s radiation. The measurements of the surface temperature were inside the hives and in three body regions of the bees (head, thorax and abdomen).

As a greater time was needed for this evaluation, a beehive was used in each one of these schedules, with two hives being evaluated in period 1, two in period 2 and two in period 3. For the surface temperature measurements, three frames were removed from each hive (a frame from the center of the hive and a frame from each side of the hive), and then the surface temperature of 30 bees of each hive per period was measured, chosen at random or 180 bees evaluated on each day of observation. The environmental variables were obtained from the CETAPIS meterological station, located at the experimental station of UFERSA. The analysis of variance was performed by the least squares method [12], and the Tukey test ($p < 0.01$) for the comparison of averages, using the

Statistical Analysis System software [13].

3. Results

The city of Mossoro in the state of Rio Grande do Norte, Brazil, the place where the present research was done, is a typical semi-arid region of northeast of Brazil, which presents the maximum values for air temperature and solar radiation. Fig. 1 showed the averages of air temperature, relative air humidity, wind speed and solar radiation, according to different hours of the day. The maximum values of air temperature and solar radiation were recorded between noon and 1 pm. There was a statistically significant difference ($p < 0.01$) in the thoracic temperature of forage worker bees in the three periods of observation (Fig. 2). The averages for each period were 38.1, 44 and 40.7 °C, respectively. There was a statistically significant difference ($p < 0.01$) between the averages obtained of the bees' surface temperature in the two environments evaluated and at the different observation times, with the average for shade being 33.6 °C and for the sun 35.7 °C. Body surface temperatures fluctuated throughout the day in accordance with variations in air temperature (Fig. 3). The thoracic temperature was clearly higher (35.7 °C) than the head (34.6 °C) and abdomen (33.6 °C). The

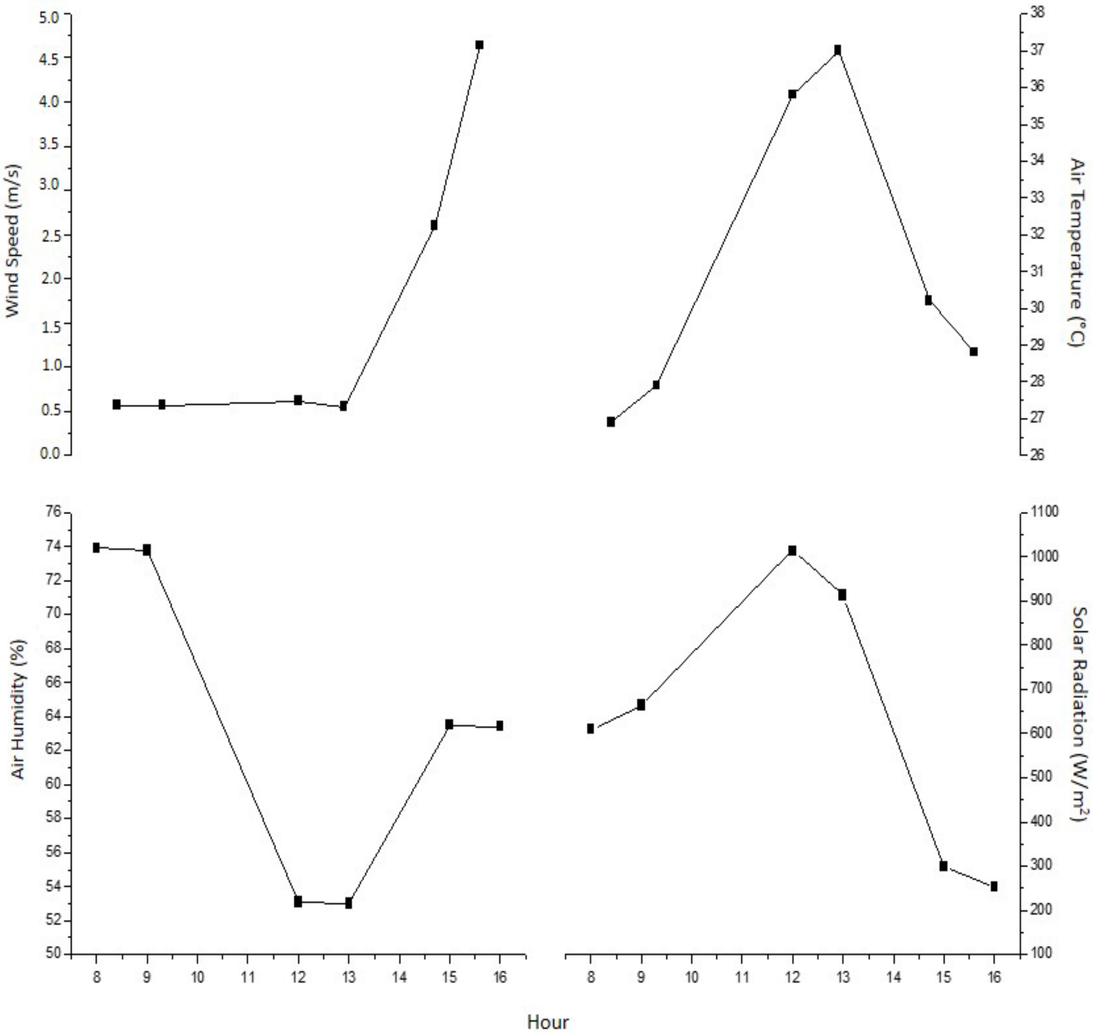

Fig. 1 Mean values of wind speed, air humidity, solar radiation and air temperature observed in Mossoro, RN, Brazil, from October 2014 to August 2015.

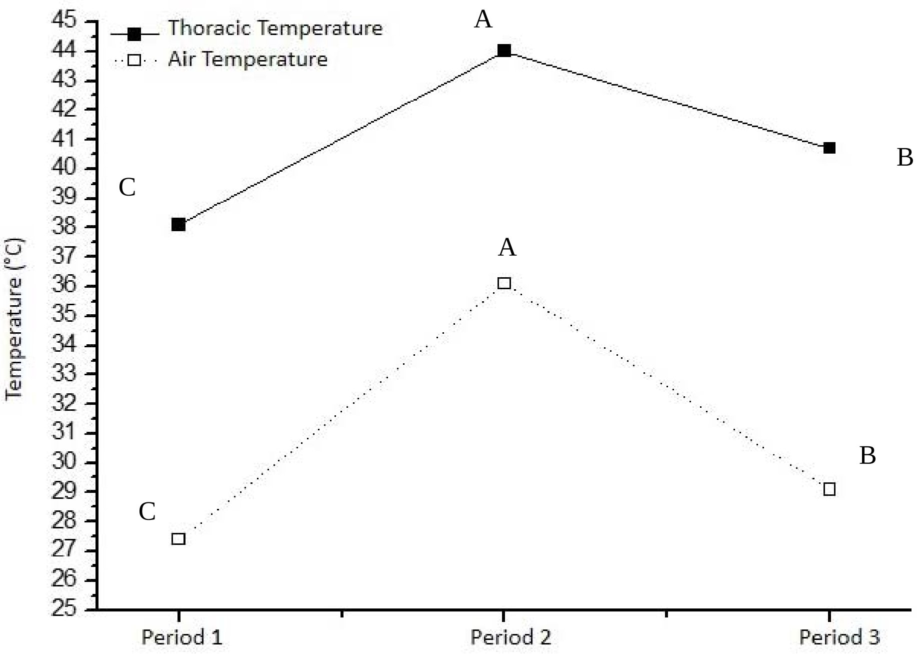

Fig. 2 Mean values of air temperature and thoracic temperature of forage bees at three different periods throughout the day.

Period 1: between 8 am and 9 am; period 2: between noon and 1 pm; period 3: evaluations between 3 pm and 4 pm.

Different letters indicate significant difference between periods (Tukey-Kramer, $p < 0.01$).

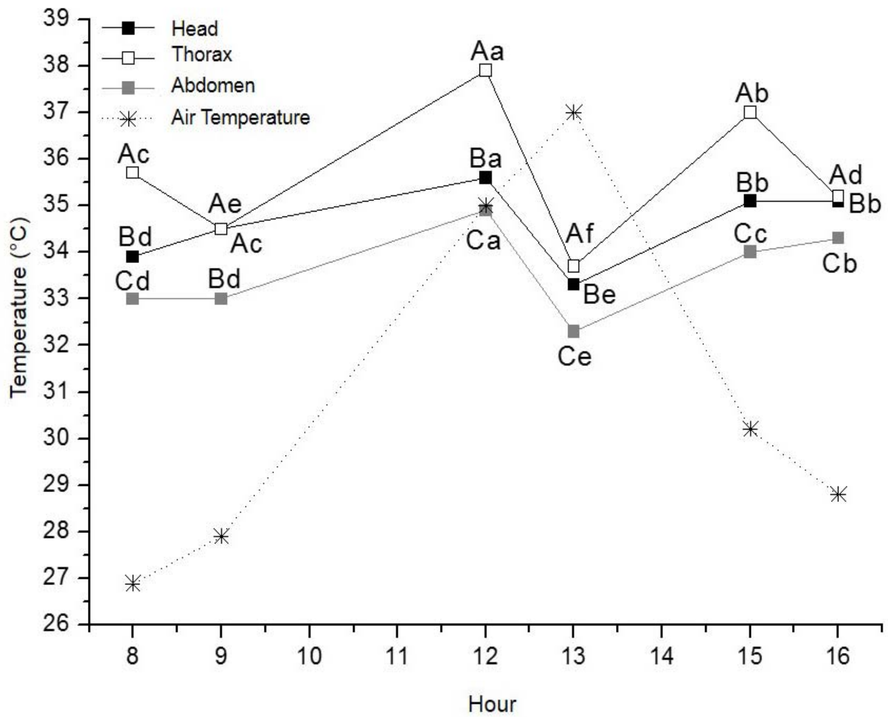

Fig. 3 Mean values of the surface temperature of Africanized bees in three body regions and air temperature according to the time of day.

Different uppercase letters indicate significant difference between body regions at the same time (Tukey-Kramer, $p < 0.01$).

Different lowercase letters indicate significant difference between times within the same body region (Tukey-Kramer, $p < 0.01$).

behavior of the surface temperature of the bees in the different body regions according to the two environments was shown in Fig. 4, and Table 1 showed how the heat transfer occurred between the body regions in the two environments and in the frames of the center and side of the hive.

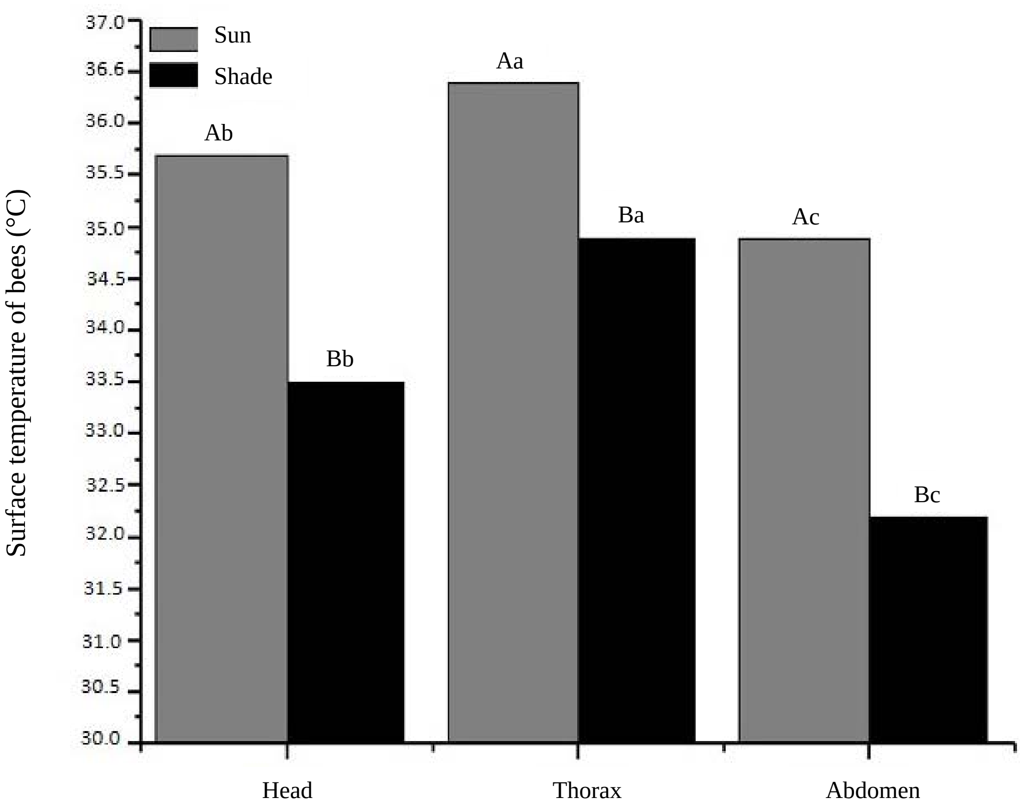

Fig. 4 Mean surface temperature values of Africanized honeybees in three body regions in both environments, sun and shade.

Different uppercase letters indicate significant difference between the environments in the same body region (Tukey-Kramer, $p < 0.01$).
Different lowercase letters indicate significant difference between body regions within each environment (Tukey-Kramer, $p < 0.01$).

Table 1 Surface temperature of Africanized honeybees (head, thorax and abdomen) collected from the center and side of hives, according to the environment (sun and shade) in different air temperature ranges and solar radiation.

Period	T_A (°C)	RS (W/m^2)	Shade						Sun					
			Central (°C)			Side (°C)			Central (°C)			Side (°C)		
			Head	Thorax	Abdomen	Head	Thorax	Abdomen	Head	Thorax	Abdomen	Head	Thorax	Abdomen
1	26.9	610.1	33.2	35.1	32.2	33.2	34.1	32.2	34.7	36.9	33.8	34.7	36.9	33.8
	27.9	663.6	33.2	35.1	32.2	33.2	34.1	32.2	35.7	34.1	33.8	35.8	34.3	33.8
2	35.8	1014.0	33.2	36.8	32.2	34.0	35.0	33.4	37.7	39.9	36.8	37.7	39.9	37.5
	37.0	913.6	35.2	34.0	32.1	34.0	36.9	33.4	32.0	32.0	32.0	32.0	32.0	32.0
3	30.2	299.9	34.1	35.7	32.9	33.4	35.0	31.4	36.6	38.7	35.9	36.6	38.7	35.9
	28.8	253.5	33.0	33.9	31.8	32.0	34.0	31.4	37.8	36.0	37.0	37.8	36.6	37.0

Period 1: between 8 am and 9 am; period 2: between noon and 1 pm; period 3: evaluations between 3 pm and 4 pm.
T_A: air temperature ranges; RS: solar radiation.

3.1 Hives in the Shade

In period 1 (between 8 am and 9 am), in the three body regions, the temperatures were well regulated independent of the environmental variables, both in the central region of the beehive and on the sides. In period 2, when the air temperature rises to 35.8 °C and the solar radiation reaches its maximum levels of 900-1,014.0 W/m^2, the temperature of the head and the abdomen increase around 1 °C (only in the side of the hive), while the thoracic temperature increases by 1.7 °C in the center and side of the hive approximately 1 °C. In the central region of the hive, the mechanism of heat dissipation through body regions was identified when the thoracic temperature drops by almost 3 °C and concomitantly there is a 2 °C increase in head temperature. On the side of the bee hive the thoracic temperature reached 36.9 °C, but there was no heat transfer to the two regions. In period 3, as air temperature and solar radiation begin to decrease, the surface temperatures of the bees in the body regions also decrease.

3.2 Hives in the Sun

In period 1, heat dissipation could already be identified when occurred transferring of temperature between regions of the body of the bee. This was observed when the temperature of the thorax decreases by almost 3 °C, while the temperature of the head increases by at least 1 °C and the abdomen remains without changes. In period 2, when the air temperature is high (35.8 °C) and the radiation reaches critical levels (more than 1,000 W/m^2), there is a drastic increase in surface temperature in the three body regions. When the air temperature reached 37 °C, the surface temperatures of the bees were homogeneous and low (32 °C). When the air temperature drops to 28.8 °C and the radiation is below 300 W/m^2, the heat transfer behavior of the thoracic region to the head and abdomen is again observed.

4. Discussion

There is no way to control environmental factors that increase the thoracic temperatures of bees when they are foraging. However, it is possible to control the microclimate inside the hive, so that the overheating caused externally is at least mitigated when the bees return from the field in their flights. The surface temperature was highly influenced by environmental conditions. The bees that were in the shade were able to maintain their body temperatures at relatively normal levels, and this means that less effort will be required for their individual temperature control; on the other hand, the bees that were directly in the sun had a considered increase in their temperatures, requiring the activation of heat dissipation mechanisms on a much higher scale. Carvalho [7] also found different body temperatures for the three regions of the bee’s body. In studies on the body temperature of *A. mellifera* bees that forage water, Kovac et al. [6] found that at temperatures between 3 °C and 30 °C, the thoracic temperature was regulated independently of air temperature; however, from 30 °C, the thoracic temperature increased almost linearly with the air temperature. They also observed a more precise control of the bees in the frames of the center of the hive. In the present study, this more precise control in the central region of the hive was not observed in the hives exposed to the sun, showing that the temperature increases in the hives exposed directly to solar radiation, which causes a thermal derangement within the hive, which causes the care of the broods a secondary activity of the bees. High surface temperatures found in hives in the sun stimulated bees to reduce forage activity early in the morning and this implies that the efforts to keep the temperature controlled were much more intense in hives that were exposed directly under solar radiation.

Roberts and Harrison [14] argue that the higher the ambient temperature, the greater the heat transfer process from the thorax to the other regions of bees’ body. And Heinrich [15, 16] found in his work that the head was also used as a heat sink for the excess heat of the thorax. The sudden drop in surface temperature between noon and 1 pm is caused by the use of water to wet the body surface, which would eventually make it homogeneous and very low. Other researchers have also observed this behavior in *A. mellifera* bees. Kovac et al. [17] observed that at room temperature above 34 °C, several bees showed efforts to cool their body through regurgitated droplets of water in their mouthparts to prevent overheating of the body. Carvalho [7] studied the surface temperature of the Africanized bees in the semi-arid region, and observed that bees regurgitated water in their own body to reduce body temperature, as was also the case in the present study.

5. Conclusions

The bees that were in the shade managed to keep their body temperatures at relatively normal levels, while the bees that were submitted directly in the sun had a considered increase of their surface temperatures, being necessary to spend time and energy to control their corporal temperatures. This behavior interferes in the forage activity of the bees and in the productivity of the colony. Therefore, the results of this experiment show that it is a great advantage for the beekeeper to develop shading strategies for their colonies of bees, which will minimize the efforts of the bees to try to control their surface and body temperatures, thus avoiding productive losses.

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