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ANIMAL PRODUCTION

Effect of solar radiation on Holstein heifers' physiological variables and grazing behavior

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ABSTRACT. The objective was to assess the physiological and behavioral variables of pasture-raised Holstein heifers on the basis of their coat color. Eight heifers were used, four with black coat, and four with white coat. In the morning and afternoon periods, their physiological variables were measured, namely respiratory rate (RR, mov min. $^{-1}$), rectal temperature (T_R, °C), and coat surface temperature (T_S, °C). The behavior analysis considered the site (sun or shade), position (standing or lying down), and activities (idleness, rumination, grazing, and others). The data of the physiological variables were assessed through analysis of variance, and significance, through Tukey's test at 5%, while behavioral data were assessed using the Chi-squared test (SAS Software). There was a difference for all of the heifers' physiological variables as a function of coat color ($p < 0.0001$) and period ($p < 0.0001$), with black ones showing greater results than white ones as to all physiological variables in the afternoon period ($p < 0.0001$). Grazing behavior is reduced during the hottest hours of the day. We conclude that solar radiation changes the physiological variables and grazing behavior of pasture-raised Holstein heifers.

Keywords: biometeorology; heat load; coat color; surface temperature.

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Introduction

The beginning of a heifer's life has an enormous influence on the success of the entire production process of dairy cattle, as this animal will be a future replacement for the matrices. In order for heifers to have a good growth and performance when maturing, mainly taurine breeds such as Holstein animals, it is necessary that the environment offers good conditions, as extreme temperatures interfere with their thermal comfort, impairing their growth and future performance (Oliveira, Melo Costa, & Chiquitelli Neto, 2019).

The effects of thermal stress are assessed through behavioral and physiological changes, such as surface temperature (Costa, Feitosa, & Montezuma, 2015), which depend on environmental conditions, such as air temperature and wind, as well as on the animal's physiological conditions. Thus, it contributes to the maintenance of body temperature through heat transfer with the environment at pleasant temperatures.

The high levels of solar radiation in tropical areas negatively affect the thermal comfort of cattle, especially European breeds, causing the animals to need shading areas. The presence of tree shade favorably and significantly affects the performance of these animals (Silva, Guilhermino, & Morais, 2010). There are few studies focused on the interference of climatic factors on pasture-raised heifers.

Scientific research in animal production is increasingly modern, and for this reason, non-invasive technologies and equipment are shown to be allies that value animal welfare and comfort, with a highlight on infrared thermography. Using this technique, it becomes possible to identify distinct regions of surface temperature, which makes it an important tool for the recognition of physiological events in animals (Bouzida, Bendada, & Maldague, 2009), useful for thermal stress assessment (Stewart, Webster Jr, Schaefer, Cook, & Scott, 2005).

When the sensible heat transfer mechanisms of homeothermic animals are not sufficient to maintain body temperature, their metabolic heat, together with the heat from the environment, becomes greater than the heat that is dissipated, leading to a thermal imbalance in the animal (Barnabé, Pandorfi, Almeida, Guiselini, & Jacob, 2015). In this way, the body reacts by increasing sweating and respiratory rate in order to eliminate excess heat (Morais et al., 2008), through evaporative heat transfer mechanisms (Silva, 2008; Maia, Silva, & Loureiro, 2005).

Pasture-raised animals are exposed to direct solar radiation, which is the main ambient factor that causes increased thermal stress and discomfort for animals in tropical climates. In this context, the objective of this study was to assess the behavior, and physiological variables, such as surface temperature, rectal temperature and respiratory rate, of pasture-raised Holstein heifers, as a function of their coat color.

Material and methods

This experiment was approved by the Ethics Committee on the Use of Animals [*Comitê de Ética no Uso de Animais*] (CEUA protocol No. 5192051020). It was conducted in July 2018, lasting 12 days, at the Experimental Farm of Iguatemi [*Fazenda Experimental de Iguatemi -FEI]*, of the State University of Maringá [*Universidade Estadual de Maringá – UEM*], Maringá, PR, Brazil. The farm is located at latitude 23° 25' South and longitude 51° 57' West, with an altitude of 540 m. The region has a mesothermal humid subtropical climate with hot summers, average annual rainfall of 1276 mm, and temperature range above 7°C, according to the Paraná Institute of Rural Development [*Instituto de Desenvolvimento Rural do Paraná - IAPAR*].

Eight Holstein heifers aged 10 months and with an average weight of 164.38 kg ± 30.13 kg were used. The animals were selected in accordance with the percentage (more than 75%) of white or black coat color and identified through the natural hair of their coat. The heifers were kept in paddocks with areas of approximately 1300 m² containing drinking fountains, *Cynodon plectostachyus* pasture, native pink trumpet trees (*Handroanthus heptaphyllus*) and shade cloth (polypropylene screens with 80% shading) as sources of shading. The diet supplied to the animals consisted of *Cynodon plectostachyus* pasture, concentrate feed and corn silage (Table 1); the silage and feed were provided daily at nine in the morning and distributed in three troughs.

Table 1. Nutritional composition of the diet ingredients, with pasture, feed and silage being provided to Holstein heifers, and the means for dry matter (DM), mineral matter (MN), organic matter (OM), crude protein (CP), neutral detergent fiber (NDF) and ethereal extract (EE).

Diet ingredients	Composition (%)					
	DM	MN	OM	CP	NDF	EE
Cynodon plectostachyus pasture	20.65	09.12	90.88	17.68	53.77	3.50
Concentrate feed	89.48	10.63	89.37	26.25	15.84	2.94
Corn silage	30.33	04.30	95.70	08.07	50.38	3.00

Environmental variables

The air temperature (T_{AIR}, °C) and relative humidity (RH, %) meteorological variables were measured using a digital thermo-hygrometer (Incoterm®, 7666), air velocity (V_{AIR}, m s^{-1}) was measured using a digital thermo-anemometer (Incoterm®, TAN 100), black globe temperature (T_G, °C) was measured using two black globes, one positioned in the sun, and the other, in the shade, at the same height as the trunk of the animals, corresponding to the geometric center of the heifers.

The black globe was used to approximate the solar radiation felt by the animal, measured at one-hour intervals (from 8:00 to 18:00). From the Black Globe Temperature (T_G, °C), it was possible to calculate the Mean Radiant Temperature (MRT, K) and the Radiant Thermal Load Index (RTL, W m^{-2}), developed by Esmay (1979), obtained through the following equation:

$$MRT = 100 \left[2.5\sqrt{V}(T_G - T_{AIR}) + \left(\frac{T_G}{100}\right)^4 \right]^{1/4}, \mathrm{K}$$

where: V is air velocity (m s^{-1}), T_G is black globe temperature (K), and T_{AIR} is air temperature (K).

$$RTL = \sigma\, MRT^4 , \mathrm{W\ m^{-2}}$$

where: RTL is Radiant Thermal Load (W m^{-2}), σ is the Steffan-Boltzmann constant (5.67 x 10^{-8} W m^{-2} K^{-4}), and MRT is mean radiant temperature (K).

Physiological variables

The physiological variables were measured as well, namely respiratory rate (RR, mov min.$^{-1}$), rectal temperature (T_R, °C), and coat surface temperature (T_S, °C). Respiratory rate and rectal temperature were measured in two periods, in the morning (8:00) and in the afternoon (15:00).

Respiratory rate was measured by visually counting the number of respiratory movements (mov min.$^{-1}$) observed in the flanks of the heifers over one minute, using a manual counter. Rectal temperature was measured with the aid of a digital clinical thermometer (Incoderm®, G-TECH) inserted into the animal’s rectum, until the device stabilized, for about 1 minute.

Surface temperature (T_S) was measured by capturing thermographic images using an infrared camera (Fluke®, Ti110), with the animal always positioned on its right side, in order for its largest surface area to be recorded, so it was possible to measure the average surface temperature to represent the animal’s whole body (Figure 1); in this way, the animal’s trunk was delimited, except for the limbs and head (Silva, 2008). The images were analyzed using the software (Fluke®, Smart View 4.3) at one-hour intervals, from 08:00 to 17:00, for a period of 10 hours.

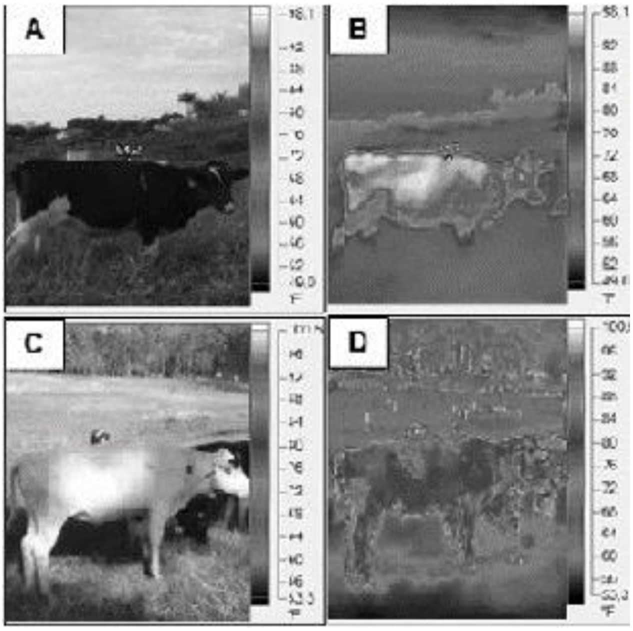

Figure 1. Capture of infrared thermographic images, with the animals in the right lateral position for surface temperature detection (T_S, °C). Black Holstein heifer (A), with the respective thermographic image (B); and white Holstein heifer (C), with the respective thermographic image (D). Source: Authors.

Behavioral variables

The identifications of the heifers for behavioral assessment were based on the individual characteristics of each animal, such as a specific shape in a certain area of the body of each heifer and coat color. The heifers were placed in the paddocks two weeks before the beginning of the experiment, for the animals to adapt to coexistence in groups, and so that the main behaviors could be observed for data collection. The details of each behavior are described in the ethogram (Table 2), which was adapted in accordance with methodology described by (Altmann, 1974; Broom & Fraser, 2010).

Behavioral observations were carried out from 08:00 to 17:00, totaling 9 hours of monitoring per day. The methodology used was spatial analysis, with the space being individually chosen by the animals, using the ad libitum sampling route method, with all individuals visible (Martin & Bateson, 2007). The activity patterns of the animals were recorded individually every 20 minutes, and their behaviors were considered as free choice. Field observations were carried out by two observers per day, who were previously trained and equipped with clipboards and pencils in order to build the ethogram, as proposed by Broom and Fraser (2010).

The behavior groups were separated in accordance with Johnson and Combs (1991) into three main categories, with the behaviors being related to the animals’ place of permanence (sun or shade), position (standing or lying down) and activities (grazing, rumination, idleness, others). Behavioral observations referring to drinking water, walking, socializing and body care were grouped and called “others” for statistical analysis, as they do not directly influence the behavior of the heifers in relation to solar radiation. The whole behavior analysis was based on the research ethogram developed by the authors (Table 2).

Table 2. Ethogram of behaviors and description of the behaviors of pasture-raised Holstein heifers.

Unit	Behavior	Behavior description
Site	In the sun	When in a place with no cover (natural or artificial)
	In the shade	When in a place with cover (natural or artificial)
Position	Standing	Act in which the animal is standing still.
	Lying down	Act in which the animal is lying on the floor.
Activity	Grazing	Act in which the animal is eating grass.
	Ruminating	Act in which the animal is ruminating.
	Idleness	Act in which the animal is still.
	Others	Any other activity the animal is doing.

Source: Authors.

Statistical analysis

The heifers' physiological data were assessed by means of analysis of variance, using the PROC GLM procedure of the Statistical Analysis System (SAS, version 9.0), and for non-parametric data, a PROC REG regression analysis was run. The experimental design used was a 2x2 factorial scheme (with two periods: morning and afternoon, and two coat colors: white and black). Analysis of variance was conducted through the following statistical model:

$$Yij = \mu + C\alpha i + H\beta j + \alpha\beta ij + eij$$

where: Y = observation of physiological variables (surface temperature, rectal temperature, and respiratory rate of the Holstein heifers); μ = parametric mean; Cαi = color (white or black); Hβj = period (morning or afternoon); αβij = interaction between color (αi) and period (β); eij = random error.

The data obtained in the behavioral analysis were assessed through the chi-squared statistical test using the "Statistical Analysis System" program (SAS, version 9.2), with a confidence interval (CI) of 95%.

Results and discussion

The means of the meteorological variables were obtained, air temperature (T_{AIR}, °C), relative air humidity (RH, %) and Mean Radiant Temperature (MRT, °C). The thermal comfort index of the Radiant Thermal Load (RTL, W m^{-2}), as a function of the morning and afternoon periods, was obtained as well, and so were the means of the environmental variables during the experimental period (Table 3).

Table 3. Mean of the Air Temperature (°C), Relative Air Humidity (%) and Mean Radiant Temperature (°C) environmental variables, and Radiant Thermal Load (W m^{-2}).

Environmental variables	Periods of the day (h)		
	morning	afternoon	Mean
Air temperature (°C)	19.50	29.21	24.36
Relative air humidity (%)	56.80	39.40	48.10
Air velocity (m s^{-1})	0.3	2.5	1.4
Mean radiant temperature (K)	309.9	328.3	319.1
Radiant Thermal Load (W m^{-2})	526.4	659.3	592.8

The mean T_{AIR} observed during the afternoon of 29.21°C was higher than the upper critical temperature for dairy cattle (UCT 26°C) suggested by Baêta and Souza (2010). During the experiment, RH did not exceed 71%. While V_{AIR} stood between 0.3 and 2.5 m s^{-1}. Environments that do not have up to 70% relative air humidity and that have wind speeds between 1.9 and 2.5 m s^{-1} facilitate heat loss by sweating (Takahashi, Biller, & Takahashi, 2009). The V_{AIR} values observed in this experiment were favorable, as they contributed to heat exchange by convection, mitigating the sensation of heat imposed by high temperatures.

The means of the black globe temperature in the sun and in the shade are shown in (Figure 2). The lowest black globe temperature recorded in the shade was 18°C at 08:00, and the highest temperature was 28°C at 13:00, while the black globe installed in the sun showed temperatures between 24 and 36°C, at 08:00 and 13:00, respectively.

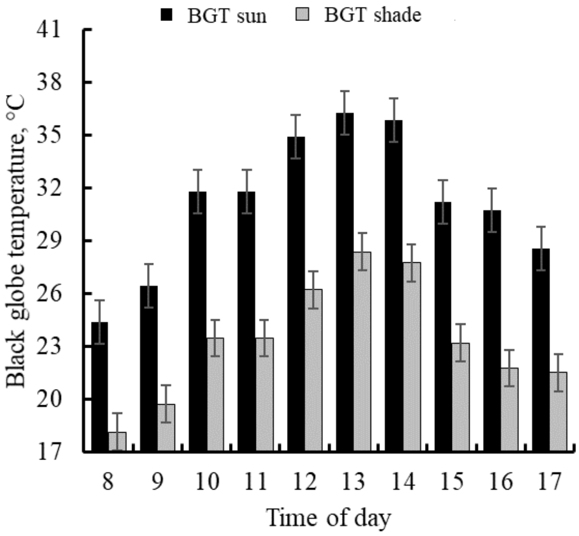

Figure 2. Mean of black globe temperature (BGT, °C) in the sun and in the shade, by time of day. Source: Authors.

In this study, a mean difference of 8 to 10°C was found for the black globe in the shade compared to the black globe in the sun; thus, mainly for the hottest periods of the day, from 11:00 to 15:00, the presence of shading in the pasture is essential for the RTL to decrease and for the animals to have places of shelter when the period is uncomfortable.

Collier, Eley, and Sharma (1981) observed a batch of cows under the effect of shading and another without shading, and found a reduction of 8.7°C in the black globe temperature in the shade of. When the animals remained in the sun, their body temperature was similar to the ambient temperature, a fact that compromises the pathways for heat loss by convection, conduction and radiation, favoring the activation of heat exchange through latent forms (Maia, Da Silva, & Loureiro, 2005; Baêta & Souza, 2010).

Similar black globe temperature reduction values in the sun and in the shade were also found by Roman-Ponce, Thatcher, Buffington, Wilcox, and Vanhorn (1997), using the same shading area as in the previous experiment. Berman (2005) reports that the difference between T_{AIR} and MRT is given by black globe temperature. This measure is dependent on the intensity of solar radiation, wind speed, characteristic of the shading provided to the animals, average temperature in the place, and shading area.

According to Baêta and Souza (2010), the main components responsible for the heat exchange transfer process occur through the skin, via a sensible form. It can be seen in (Figure 3C) that the animals spent more time lying down from 11:00 to 15:00, because in this period there was a higher incidence of solar radiation, which caused greater thermal discomfort and made the animals stay lying down, because in this position there was greater heat exchange by conduction between the animals and the ground (Maia et al., 2005).

For Martello, Savastano Jr, Pinheiro, Silva, and Roma Jr (2004a), black globe temperature between 31.6 and 34.7°C cannot be characterized as a situation of thermal stress. In this experiment, we found a black globe temperature variation in the shade from 17 to 28°C; based on this information, we can state that, in the sun, the lowest temperature was 24°C, and the highest, 37°C, and providing shading promoted conditions of thermal comfort for the heifers. Schütz, Rogers, Neil, and Tucker (2009), in an experiment in New Zealand, provided 16 m^2 of shade for each experimental animal; the shades provided 99% blocking against solar radiation. The authors found a 3°C reduction in black globe temperature for the shaded environment compared to the unshaded one.

Some studies show that the greater the shaded area available for the animals, the greater the black globe temperature reduction (Martello, Savastano Jr, Pinheiro, Silva, and Roma Jr 2004a; Roman-Ponce, Thatcher, Buffington, Wilcox, and Vanhorn, 1997). This experiment did not analyze the shade space provided per animal, but rather the difference in temperatures of the black globe installed in the sun compared to the black globe installed in the shade; reductions in the temperature of the globe of up to 10°C were observed, but the shaded area offered to the animals was large, and we observed a big difference in black globe temperature reduction in the shade. Titto, Titto, Titto, and Mourão (2011) compared black globe temperature in an unshaded environment with a shaded environment, offering a shading of 7.5 m^2 per animal, and obtained reduction results of up to 6.4°C for the shaded environment.

MRT represents thermal comfort conditions for animals, as it considers all sources of radiation around them, thus being able to quantify the environmental effects that directly interfere with their productive performance (Takahashi et al., 2009; Silva, 2000). From this index, it is possible to calculate the RTL, which is proportionally related to the mean radiant temperature, that is, the higher the MRT, the higher the RTL (Table 3). The radiant thermal load is strongly linked to the thermal exchanges by radiation between animal and environment; according to Silva (2008), in tropical environments, desirable RTL values should be the lowest possible, but the values obtained in this experiment were relatively high, indicating that the animals were exposed to a high incidence of radiation (Table 3), mainly because these values were measured in the sun, which represents the animal's solar radiation.

Physiological variables

The surface temperature (T_S, °C), rectal temperature (T_R, °C) and respiratory rate (RR, mov min.$^{-1}$) physiological variables of the pasture-raised Holstein heifers were recorded during the morning and afternoon periods (Table 4).

Table 4. Mean of the surface temperature, respiratory rate and rectal temperature physiological variables of the pasture-raised Holstein heifers.

Physiological variables	Animal	Period		Mean	EPM	P value
		08:00	15:00			
Surface temperature (˚C)	White	30.38b	34.76aB	32.57	0.238	< 0.0001
	Black	31.46b	36.28aA	33.87	0.353	< 0.0001
	Mean	30.92	35.52			
	EPM	0.345	0.249			
	P value	0.1649	0.0078			
Respiratory rate (mov min.$^{-1}$)	White	57.5b	61.08aB	59.29	0.664	0.0184
	Black	58.33b	66.83aA	62.58	0.583	< 0.0001
	Mean	57.92	63.96			
	EPM	0.633	0.616			
	P value	0.5620	< 0.0001			
Rectal temperature (˚C)	White	38.73A	38.73B	38.73	0.063	0.9636
	Black	38.53bB	39.00aA	38.77	0.027	< 0.0001
	Mean	38.63	38.87			
	EPM	0.003	0.056			
	P value	0.027	0.0386			

[A, B]Means followed by lowercase letters, in the same line, differ from each other ($p < 0.05$) by Tukey's test. [a, b]Means followed by uppercase letters, in the same column, differ from each other ($p < 0.05$) by Tukey's test. Source: Authors.

The surface temperature of black-coated animals was higher (33.87°C) than that of white-coated animals (32.57°C); the highest temperature in black ones is due to their higher absorption of solar radiation, and it is possible to correlate that the higher the RTL (Table 3), the higher the surface temperature of the heifers (Table 4). A study carried out by Façanha, Silva, Maia, Guilhermino, and Vasconcelos (2010) found that this temperature difference for black coat is higher than for white coat in the same individual. However, this temperature difference observed in this study occurred in animals from different groups of black and white color.

No difference ($p > 0.05$) was observed in the surface temperature of white and black heifers in the morning, which is related to the environmental data shown in Table 3. The lowest temperatures were recorded in this period, which was not able to promote greater discomfort for black heifers. As the T_{AIR} increases, black heifers feel more uncomfortable than white ones ($p < 0.05$) in the afternoon (Table 3).

Analyzing the periods for each coat, we can see that the surface temperature in the afternoon was higher for both groups ($p < 0.0001$) because of the MRT. Black-coated animals absorb most of the shortwave radiation that is transformed into energy and raises the surface temperature, raising the respiratory rate as well, while the white color reflects much of the incident radiation (Façanha et al., 2010).

White-coated animals would be the most suitable combination in environments with high solar radiation, as they have lower surface temperature. On the other hand, these animals, due to the absence of melanin, suffer from skin lesions caused by solar radiation, leading to discomfort. To alleviate the stress caused by the high absorption of radiation in black-coated animals and skin lesions in white ones, the use of properly applied shading minimizes their exposure to solar radiation and provides better thermal comfort conditions.

To verify surface temperature along the times of the day, Figure 3 shows the surface temperature of the animals from 08:00 to 18:00; there was an increase in this variable above 34°C between 14:00 and 15:00, for both the white and black coats. In this figure, surface temperature has a strong relationship with the times of the day, which can be observed by the coefficients of determination for surface temperature, which was 0.71°C for white animals ($p < 0.0001$), and 0.51°C for black ones ($p=0.0009$).

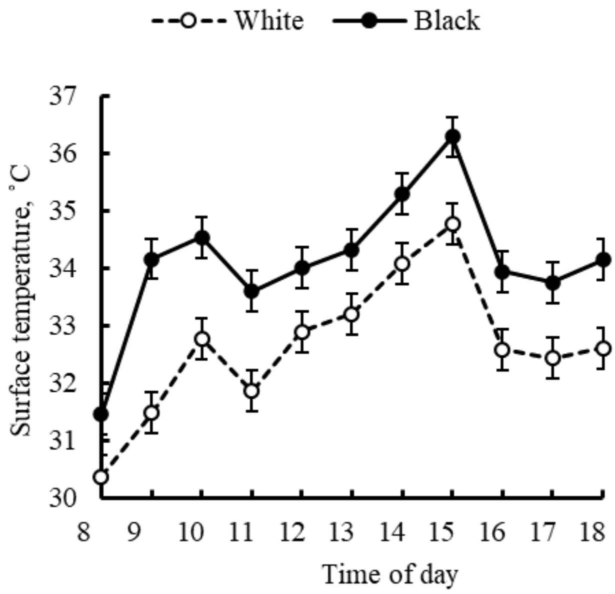

Figure 3. Surface temperature of pasture-raised Holstein heifers by time of day. Source: Authors.

The mean respiratory rate (RR) in black-coated animals, 62.58 mov min.$^{-1}$, was higher than that of white-coated ones, 59.29 mov min.$^{-1}$ (Table 4). However, only in the afternoon this mean was greater ($p < 0.0001$) for black animals. The respiratory rate considered normal for cattle is 23 mov min.$^{-1}$, which indicates absence of heat stress. Respiratory movements were classified in accordance with the level of stress in the cattle as follows: stress under control, 46 to 65 mov min.$^{-1}$; onset of thermal stress, 70 to 75 mov min.$^{-1}$; pronounced stress, 90 mov min.$^{-1}$; severe stress with large losses, 100 to 120 mov min.$^{-1}$; mortal stress, because of which the animals cannot eat or drink water, above 120 mov min.$^{-1}$ (Brettas, Nascimento, Guimarães, & Souza, 2017).

In this study, the respiratory rate range was close to the range of stress under control (46 to 65 mov min.$^{-1}$) in the morning and afternoon periods for both coat types. The high amount of solar radiation causes changes in the physiological mechanisms of the animals, as a way of adapting to the environment, one of which is the increase in the respiratory rate (RR) (Santos et al., 2005).

Within the same coat group, respiratory rate was always higher in the afternoon. The increase in respiratory rate in a short period is characterized as a mechanism of latent heat loss (Perissinotto, Cruz, Pereira, & Moura, 2007). For Takahashi et al. (2009), the increase in surface temperature and respiratory rate is the main symptom of heat stress in dairy cattle (Maia et al., 2005).

The reduction in air RH and the increase in T_{AIR} (Table 3) may have caused an increase in the respiratory rate of the heifers in both groups (white coat and black coat). The gradual increase in the temperature of the environment makes it difficult to dissipate heat in the sensible way that occurs through radiation, conduction and convection, and causes changes in the temperature of the animal; for this to happen, there is a need for the activation of mechanisms such as increased respiratory rate, with this factor being the means for heat loss in an insensible way, which consists of water evaporation through the respiratory tract (Santos et al., 2005; Souza & Batista, 2012).

In similar studies with crossbred Holstein and Gir calves, there was greater stress in animals raised in the field, as they use physiological mechanisms in greater quantity; with increased respiratory rate, there is a greater energy expenditure and loss of zootechnical performance (Araújo et al., 2016).

Rectal temperature ranged from 38.53 to 39.00°C (Table 4), with the animals remaining within the limits of normal variation suggested by (Dukes, 2017). These values show that the thermolysis processes were efficient in heat loss (Araújo et al., 2016); however, there was a difference ($p < 0.05$) between white- and black-coated animals in the morning and in the afternoon (Table 4). Despite this difference, rectal temperature stayed within the normal range, which can be explained by the physiological mechanism of increase in respiratory rate (Table 4), as the animals use this increase in respiratory rate as a natural mechanism for body cooling.

Behavioral variables

The behavioral analysis of the heifers in relation to site (A and B), position (C and D) and activity (E and F) are shown in Figure 4. When it comes to the behavior of looking for shaded places or in the sun among heifers with greater amount of white and black hair, they remained the same amount of time in the sun and in the shade, regardless of the assessed periods.

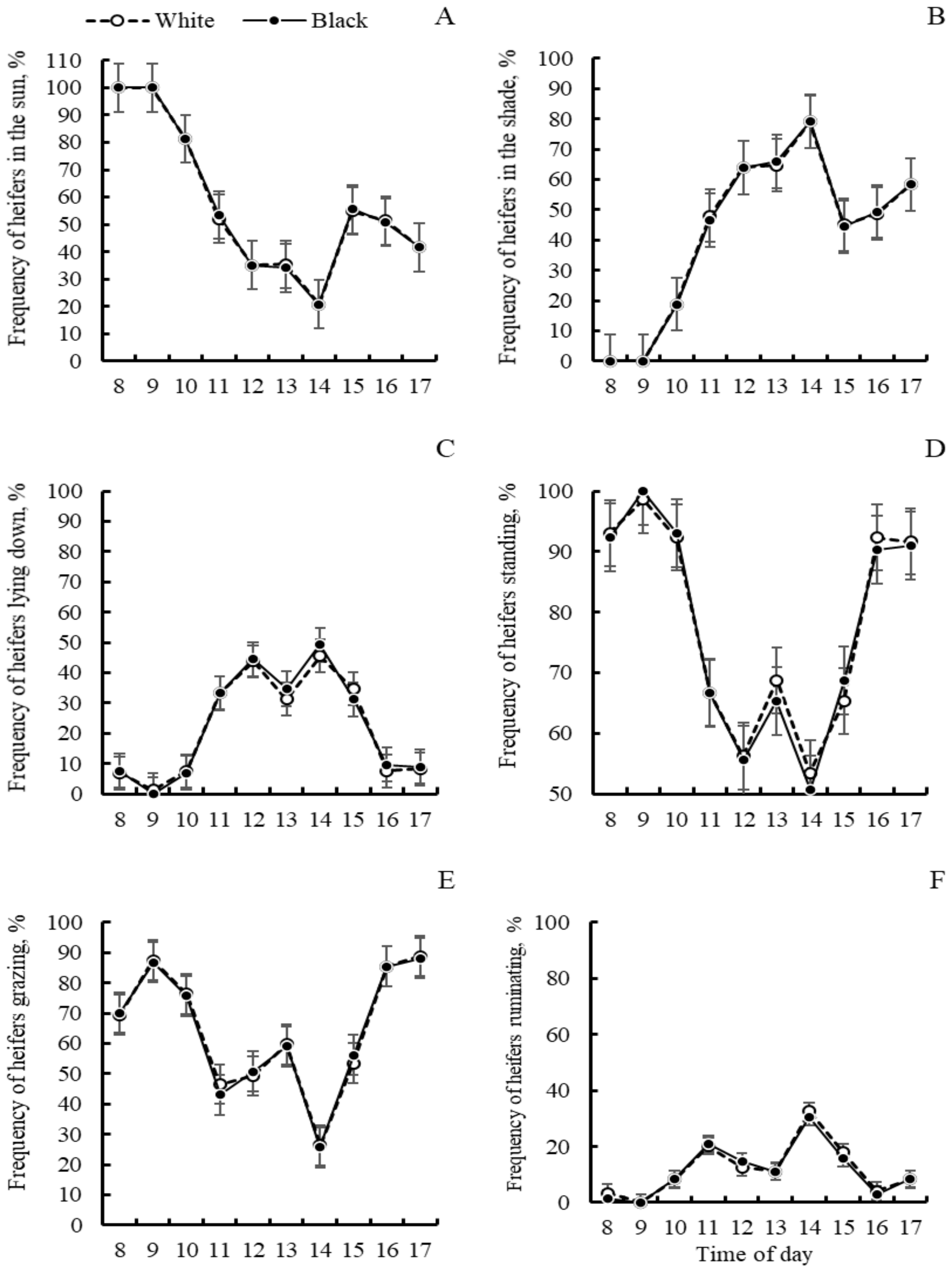

Figure 4. Frequency of behavior of white and black heifers by site (A and B), position (C and D) and activities (D and E), as a function of time of day. Source: Authors.

At 08:00, 09:00 and 10:00, the heifers stayed in the sun; in these periods, the solar radiation index was not able to cause thermal discomfort in the animals, and the RTL at 10:00 was 526.36 W m^2. This is due to the fact that, during these periods, the heifers already had a feeding routine, as shown in (Figure 4E), where the animals were grazing. It is noted that the demand for shade gradually increased in the periods from 10:00 to 14:00 (Figure 4B); this piece of data can be explained on the grounds that, during these periods, the temperature of the black globe installed in the sun remained between 32 and 36°C, while the temperature for the black globe installed in the shade ranged from 23 to 27°C, and therefore, due to the high incidence of solar radiation, the heifers in the sun would be in greater thermal discomfort.

Similar results were found by Schütz et al. (2009), who found that radiation increased, since the objective of shade is to protect animals from excessive gain of solar radiation, preventing heat stress. In this way, the greater permanence of white and black heifers in the same period of time in the sun and in the shade can be explained by the fact that bovines are gregarious animals, and the dominant animal, white in this experiment, has a great influence on the activity that the group is performing. Possibly, if the black heifers felt thermal discomfort due to their darker coat, they would seek shade moments before the white ones. Also, being young animals that have not developed their entire thermoregulatory system (Broom & Fraser, 2010), it is assumed that heifers do not suffer so much because their coat is lighter or darker.

Hillman, Gebremedhin, Parkhurst, Fuquay, and Willard (2001) observed that dark-coated heifers that were kept in the sun absorbed more solar radiation than light ones did. We assume that when heifers mature, this difference in coat changes their behavior, and animals with black coat feel more uncomfortable in the sun than animals with white coat, so animals with dark coat seek shade earlier than those with light coat. It was also observed that, from 16:00, the heifers began to position themselves in the sun, a moment that can be explained by the fact that the incidence of solar radiation is lower in this period, and consequently, the RTL will also be lower, which led the heifers to explore an area outside the shading.

The preference of cattle is for shaded areas, and the radiant heat load spreads among the animals and provides a mass of cold air. In crossbred cattle (Holstein and Gyr), when the Temperature and Humidity Index (THI) reached values of 97, the animals were under severe heat stress, and it was found that their body surface temperature went from 29.05°C, under a situation of comfort, to 47.72°C, after the stress (Ferreira et al., 2006). Hillman et al. (2001), when exposing Holstein cows with black coat to the sun, observed an increase of 0.7°C in the surface temperature of 4.8°C in relation to white cows.

The shading should be a mandatory part of paddocks, so that it can reduce the radiant thermal load from direct solar radiation. To obtain optimal productivity and comfort for dairy cows, providing shade is essential when the ambient temperature exceeds 30°C. In conditions of direct exposure to solar radiation, the heat gain suffered by the animal is generally three to four times greater than for animals subjected to shading, which leads to an increase in respiratory rate in order to maximize evaporation losses, since sensible losses are no longer sufficient to remove body heat from animals, and observed an increase in surface temperature in periods of higher solar radiation (from 12:00 to 14:00), which was on average 7.0°C higher than in animals in the shade, and a higher respiratory rate (Silva & Maia, 2013).

One of the ways to determine whether an animal is in a situation of comfort and well-being is by analyzing its health, production, reproduction and behavior. A behavioral assessment must take into account the level of aggressiveness among the animals, length of rumination, time spent standing, length of idleness, search for cooler places, which have been analyzed by several authors (Kendall et al., 2006; Leme, Pires, Verneque, Alvin, and Arueira, 2005; Schütz et al., 2009). These behaviors can be indicative of the level of stress in which the animals are and can be changed by several factors, such as an environmental stimulus. In this experiment, the behavior of the heifers in conditions of sun exposure and access to shade was assessed in order to characterize whether the predominance of black or white coat leads to different behaviors, depending on the effects of solar radiation.

Behavioral change is the first biological response to a stressor agent, because when animals have their homeostasis threatened, a stimulus occurs in the central nervous system, and the organism reacts with responses in an attempt to defend itself (Dukes, 2017). One of the main stressors in pasture production systems is radiant thermal load, expressed by local solar radiation. Animals tend to eliminate the action of RTL through movement and displacement with changes in position.

In general, analyzing the data from (Figures 4C and 4D), it is possible to see that the white and black heifers spent the same amount of time in the lying and standing positions. The heifers try to stay in the lying position when they are in a shaded place, which may explain this behavior, and in the shade, the temperature of the ground is usually lower, so the animal is able to exchange heat by conduction; now, when we analyze for how long the heifers remained standing, this length is predominant when they were exposed to the sun.

According to Ferreira (2005), when standing, animals expose a greater surface of contact with the air, which increases the body area subject to convective thermal exchanges, and when lying down, they increase their area of contact with the ground, increasing, in this case, exchanges by conduction. Among behavior patterns, lying down is of great importance for animals, as it provides them with periods of rest. The heifers started to seek this position from 11:00 to 14:00; in addition to remaining lying down, they sought shade to perform the behavior of rumination or idleness, because in these periods higher temperatures were recorded for the black globe installed in the sun.

Krohn and Munksgaard (1993), observed that it is of great importance that dairy cows have periods to rest; cows seek to lie down around 8:00 to 14:00, when in conditions of heat stress, as they remain standing longer. These results are similar to those found in the current experiment. Results that contradict the current study have been found by Kendall et al. (2006); Leme et al. (2005), who observed that the animals spent more time in the standing position when they were in the shade. However, our findings are in agreement with Oliveira et al. (2019); Blackshaw and Blackshaw (1994); Mitlohner et al. (2002); Titto et al. (2011), who noticed that animals in the shade spent more time lying down than standing.

The activities performed by the heifers – grazing (4E), ruminating (4F) – during the experimental period, both in the sun and in the shade, are shown in (Figure 5E). The activities that had the highest frequencies of occurrence were: grazing (30 to 90%), ruminating (0 to 30%) and idleness (0 to 20%).

Idleness is defined as the period in which the animals are still, without performing any other type of activity, as described in Figure 1. In the summer, animals tend to decrease this feeding activity, and thus end up increasing their idleness activity in order to reduce heat production (Baccari Júnior, 2001). It is noted that idleness and ruminating activities (Figure 4B) among white and black heifers increased from 11:00 to 15:00, thus decreasing as of 16:00. It was also observed that the respective activities had the highest occurrence in the late morning to early afternoon, when the heifers would be found lying down in the shade.

Rumination and idleness activities were more frequent in the respective periods (11:00 to 15:00) because the temperature recorded for the black globe in the shade was lower than the temperature recorded for the black globe installed in the sun. Both black and white heifers prefer to perform these activities in the cooler periods, as this way they can reduce their internal heat production, and because this is a hotter period of the day, the animals seek to reduce heat gain in order to alleviate the thermal discomfort caused by solar radiation.

The grazing activity appears at all times of the day, but with different frequencies; it can be observed that the increase in this activity happened in the periods from 08:00 to 10:00 and from 16:00 to 17:00, as shown in Figure 4A. What can explain this behavior of the group is that the animals seek to do this activity in the cooler periods of the day, as the act of eating generates internal heat production.

Grazing behavior can be changed in conditions of ambient temperature and high relative humidity; food consumption starts to occur in periods of lower thermal stress. Grazing reduction in the hottest periods of the day is a behavioral change for the heifers to be able to reduce heat gain through digestion and muscle activity (Martello, Savastano Jr, Silva, & Titto, 2004b).

Another factor that may have influenced grazing increase in the morning is that, from 08:00 to 10:00, the animals had a feeding routine at the trough, and what may have influenced the grazing increase observed between 16:00 and 17:00 was the animals being fed in the morning, so they resumed grazing later in the day, which is a cooler period and when there was shade all around the paddock, allowing the animals to better explore the area.

The activities of drinking water, body care, socialization and walking were not influenced by ambient temperature or by the availability of shade inside the paddock (Figure 4E); thus, such behaviors do not present frequency for analysis in isolation. These activities were not performed from 13:00 to 17:00, but increased between 10:00 and 13:00. They are also not influenced by the group, so the percentage is not high during the periods of the day.

Among the physiological thermoregulation processes of cattle in hot environments, latent heat transfer mechanisms are the main heat loss pathways, namely evaporation on the skin and respiratory surface, with the latter being determined by sweat and increased respiratory rate, as well as pressure and saturation of expired air (Maia et al., 2005; Silva & Maia, 2013). Ambient temperature, as well as relative humidity, solar radiation and wind speed, represent the main meteorological influences on these physiological variables: respiratory rate, surface temperature and rectal temperature (Lee, Roussel, & Beatty, 1974).

Conclusion

The black-coated heifers' are more sensitive to the absorption of solar radiation, but the white ones also feel thermal discomfort. Therefore, to alleviate this discomfort, there is an increase in respiratory rate. The higher the RTL, the higher the surface temperature of the coat of both heifers' colors (white and black). The grazing behavior predominated from 8:00 to 10:00 and from 15:00 to 17:00, when the lowest ambient temperatures. From 11:00 to 15:00, the ambient temperatures were higher due to the greatest incidence of solar radiation, the grazing activity was reduced and coincided with the period of the heifers remaining lying down.

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