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Evaluation of environmental parameters in a microregion in southern Amazonas State, Brazil, and their relationship with heat stress in dairy cattle

Avaliação de parâmetros ambientais em uma microrregião no sul do estado do Amazonas e suas relações com estresse térmico de bovinos leiteiros

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Abstract
Environmental thermal comfort provides higher efficiency in the exploitation of dairy farming, as the responses of animals to the environment are decisive in the activity's success. This study aimed to evaluate heat stress in dairy cows in the municipality of Humaitá, located in the south of the Amazonas State (AM), Brazil. Air temperature (TA) and relative humidity (RH) data were used to calculate the temperature humidity index (THI) in the dry (August 2020) and rainy seasons (January 2021). The August data were collected at the automatic weather station belonging to the National Institute of Meteorology. The January data were collected by a Hobo® U23-001 thermo-hygrometer installed at Fazenda Nossa Senhora Aparecida. The hourly and monthly means of the data were calculated and, subsequently, boxplots were plotted. TA and RH were 0.65 °C and 0.64% below the provisional climatological normal (PCN), respectively, for August, while January presented 0.77 °C and 3.61% above the PCN, respectively. THI values ranged from 56.25 (comfortable) to 84.68 (emergency) in August and 74.15 (comfortable) to 84.07 (emergency) in January. The maximum THI was observed in August, as well as the largest range. The results allow inferring that heat stress in dairy cows in the municipality of Humaitá-AM presents a state of alert even for cross-breed animals. Thus, the use of shading in pastures is suggested to minimize the effect of heat stress on the productive performance of the animals.
Keywords: Cattle farming; animal stress; dairy production.

Resumo
O conforto térmico ambiental proporciona uma maior eficiência na exploração da pecuária leiteira, pois as respostas do animal ao ambiente são determinantes no sucesso da atividade. O objetivo deste trabalho foi avaliar o estresse térmico em vacas leiteiras no município de Humaitá, localizado no sul do estado do Amazonas (AM), Brasil. Foram utilizados dados de temperatura do ar (TA) e umidade relativa do ar (UR) para cálculo do Índice de Temperatura e Umidade (ITU) na estação seca (agosto de 2020) e na estação chuvosa (janeiro de 2021). Para o mês de agosto os dados foram coletados na estação meteorológica automática pertencente ao Instituto Nacional de Meteorologia. Em janeiro os dados foram coletados com o Termo-higrômetro (Hobo®, modelo U23-001) instalado na Fazenda Nossa Senhora Aparecida. As médias horárias e mensais dos dados foram feitas e, posteriormente, plotados gráficos boxplots. Os dados coletados para os meses do estudo apresentaram a TA e UR para o mês de agosto 0,65ºC e 0,64% abaixo da Normal Climatológica Provisória (NCP), respectivamente. Por outro lado, janeiro apresentou 0,77ºC e 3,61% acima da NCP, respectivamente. Os ITUs variaram entre 56,25 (confortável) e 84,68 (emergência), em agosto e de 74,15 (confortável) a 84,07 (emergência) em janeiro. O máximo ITU foi observado em agosto, bem como a maior amplitude. Baseados nos resultados encontrados pode-se aferir que o estresse térmico em vacas leiteiras no município de Humaitá-AM apresenta estado de alerta, mesmo para animais de raças cruzadas. Assim, sugere-se o uso de sombreamento nas pastagens para minimizar o efeito do estresse térmico no desempenho produtivo destes animais.
Palavras-chave: Bovinocultura; Estresse Animal; Produção leiteira.

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Introduction

Brazilian dairy cattle have an important role in family farming, with more than 1.3 million rural properties distributed throughout the national territory, some of which are less technified, but with great potential for economic growth.[1] This potential has attracted the attention of many researchers when discussing techniques to increase animal production, considering not only the animal but also the environment in which it lives, through alternatives for better animal performance.[2] The animal-environment interaction cannot be treated as disconnected when a higher efficiency in livestock farming is proposed, as the animal stimuli to the particularities of each region will directly imply the activity success.[3, 4]

For instance, the correct identification of environmental factors that influence the productive life of animals, such as the stress imposed by inter-seasonal climate changes, allows adjustments in management practices and production systems, offering sustainability and economic viability.[3] Thus, knowing the dynamics of climate variables, their interaction with animals, and behavioral, physiological, and productive responses are crucial in adapting the production system to the objectives of the activity.[3] In this sense, the selection of more productive breeds and production systems suitable for each region and climate, respectively, with the concern for animal welfare is fundamental.

Welfare can be defined as "The state of an individual relative to its attempts to adapt to its environment…"[5] Thus, the main tools available to the animal to overcome inadequacies in its environment are changes in the physiological or behavioral character due to heat stress, for instance. According to Roth,[6] extreme adjustments are necessary for the physiology and behavior of an animal that is under stress to adapt to environmental and management adversities. The stress caused by high temperatures directly influences milk production, being one of the most serious problems in dairy herds in tropical regions.[7] A problem of adaptation of temperate climate breeds is observed in these regions, as they are more susceptible to physiological and behavioral problems caused by heat stress, whereas zebu breeds are more adapted to tropical regions and, therefore, more rustic and resistant compared to European breeds. According to Melo,[8] *Bos taurus indicus* animals are more tolerant than *Bos taurus taurus* animals due to their higher transpiration capacity and lower metabolic rate.

According to Batista,[9] this adaptability of animals of zebu origin to the tropical climate is related to the lower production of metabolic heat, associated with a better capacity for thermolysis, as zebu breeds have a large number of sweat glands, which increases the ease of losing heat, making them more tolerant to high temperatures than the taurine breeds. Nascimento[10] states that the ideal comfort zone for dairy breeds represents an ambient temperature variation from 10 to 20 °C, in which body temperature is constant and homeothermy is maintained by thermal exchanges. This reduction in energy intake leads the animals to a period of negative energy balance, partially explaining the significant loss of body weight and reduction in production when cows are subjected to heat stress. Stress causes a series of physiological imbalances that, in turn, cause an increase in the nutritional requirements of net energy for maintenance, reducing the energy available for production processes.[11]

According to Coller,[12] the behavioral and physiological mechanisms presented by animals under heat stress are prostration, search for shading, reduced food intake, increased water intake, increased heart and respiratory rate, sweating, peripheral vasodilation, increased saliva production, and search for the ideal comfort zone. Several indices have been developed to measure and evaluate these effects caused by heat to express the animal comfort relative to the environment. The temperature humidity index (THI), originally developed by Thom.[13], is the most used, as it combines the effects of air temperature (TA) and relative humidity (RH) on cattle performance. Rosanova[14] carried out a study in Araguaína-TO based on the Thom[13] index to determine THI and adopted the same methodology that considers a THI up to 74 as comfortable, from 75 to 78 as an alert to producers, from 79 to 83 as danger, and above 84 as an emergency.[14]

Thus, this study aimed to analyze the temperature and humidity of the air and determine the THI to assess the existence of heat stress in dairy cows in the municipality of Humaitá, located in the south of the Amazonas State (AM), Brazil.

Materials and methods

Study area

The study was conducted in the municipality of Humaitá, located in the south of the Amazonas State, on the banks of the Madeira River, Brazil (Figure 1). It is limited by the municipalities of Tapauá and Canutama to the west, Manicoré to the north, east, and west, and the Rondônia State to the south.[15] The municipality is about 680 km from the city of Manaus (AM) and 200 km from the city of Porto Velho (RO). It has an estimated population of 53,383 inhabitants and an area of 33,111 km^2.[15]

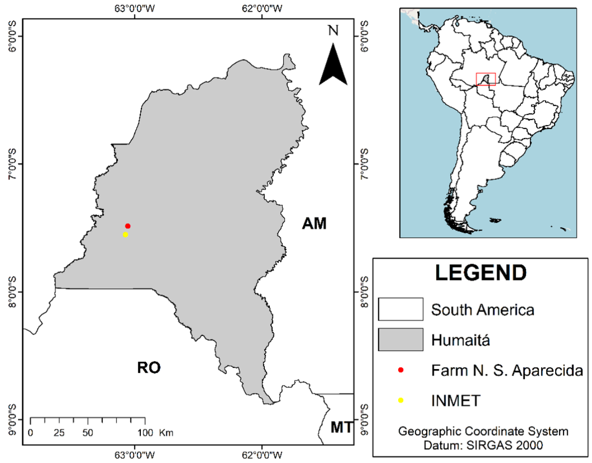

Figure 1. Map of the municipality of Humaitá, located in the microregion of the south of the Amazonas State, and data collection points, represented by the colors red and yellow.

According to Köppen,[16] the climate of Humaitá is B_4WA′a′, that is, a humid climate, with a humidity index that varies between 80 and 100 mm, a moderate water deficit in the austral winter, and annual potential evapotranspiration (ETP) of 1140 mm, in addition to having two distinct seasonal periods, that is, a dry period from June to August and a rainy period from October to April, typical of the Amazon climate.[17]. The total monthly rainfall ranges from 0 to 100 mm in the dry season and reaches close to 326 mm in the rainy season.[18] According to Pedreira Junior,[18] May and September represent the transitions from the rainy and to the dry season and from the dry to the rainy season, respectively.

Data analysis and processing

The air temperature (TA) and relative humidity (RH) data were obtained from the database of the Automatic Weather Station (EMA) belonging to the National Institute of Meteorology – INMET,[19] located at the Federal Institute of Education, Science and Technology of Amazonas – IFAM (7°32′45.36″ S and 63°4′14.20″ W) for August 2020 and using a Hobo® U23-001 thermo-hygrometer installed on the rural property Nossa Senhora Aparecida Farm, located on the road of Alto Crato (7°48′39.99″ S and 63°5′34.67″ W) for January 2021. The Hobo® sensor was previously calibrated with the sensors of the INMET weather station through the comparison method for seven consecutive days. The frequency of data reading was every 15 minutes and, subsequently, the hourly means were obtained in electronic spreadsheets.

Determination and exploratory analysis of the temperature humidity index – THI

The temperature humidity index (THI) was calculated using the model developed by Thom[13] and corroborated by Rosenberg et al.[20] (Equation 1).

$$THI = (0.8 * TA + \left(\frac{RH}{100}\right) * (TA - 14.4) + 46.4)$$

The THI categorization admits four categories, according to Rosenberg et al.[20] (Table 1).

Table 1 – Temperature humidity index (THI) categorization and comfort variation level.

THI	Comfort variables
Up to 74	Comfortable
Between 74.9 and 78	Alert
Between 78.1 and 84	Danger
Higher than or equal to 84.1	Emergency

The dispersion of the monthly hourly mean of THI was presented as boxplots prepared in the free software R version 3.6.1 with the R-Studio interface.[21] The boxplot allows an exploratory analysis of the position, dispersion, symmetry, and outliers of the THI distribution, thus providing a complementary means to describe the data dynamics.

Results and discussion

Air temperature and relative humidity

The air temperature presented a mean of 26.56 °C for August, which is below the provisional climatological normal of air temperature (PCN_{TA} = 27.21 ± 12.26) for the same period, and a mean of 26.7 °C for January, being warmer than the PCN_{TA} = 25.93 ± 12.61 for the same period of study. RH presented a mean of 69.06% for August, being below the provisional climatological normal of relative humidity (PCN_{RH} = 69.7 ± 7.72) for the same period, and a monthly mean of 88.6% for January 2021, being above the PCN_{RH} = 84.99 ± 5.62 for the same period (Figure 2AB).

According to Martins[17], in Humaitá, the provisional climatological normal for air temperature is PCN_{TA} = 27.21 ± 12.26 for August and PCN_{TA} = 25.93 ± 12.61 for January, whereas the provisional climatological normal for relative humidity is PCN_{RH} = 69.7 ± 7.72 for August and PCN_{RH} = 84.99 ± 5.62 for January. Thus, TA for August 2020 was 0.65 °C below PCN_{TA}, which means a colder month. On the other hand, January was 0.77 °C above PCN_{TA}, thus being warmer for the study period. In terms of RH, August 2020 was 0.64% below PCN_{RH}, which means behavior of lower humidity, while January was 3.61% above PCN_{RH}. Even within the rainy season in the Amazon region, January had a mean RH higher than that observed in August, as expected, but TA showed no significant difference between the two months, as shown in Figure 2 (A and B).

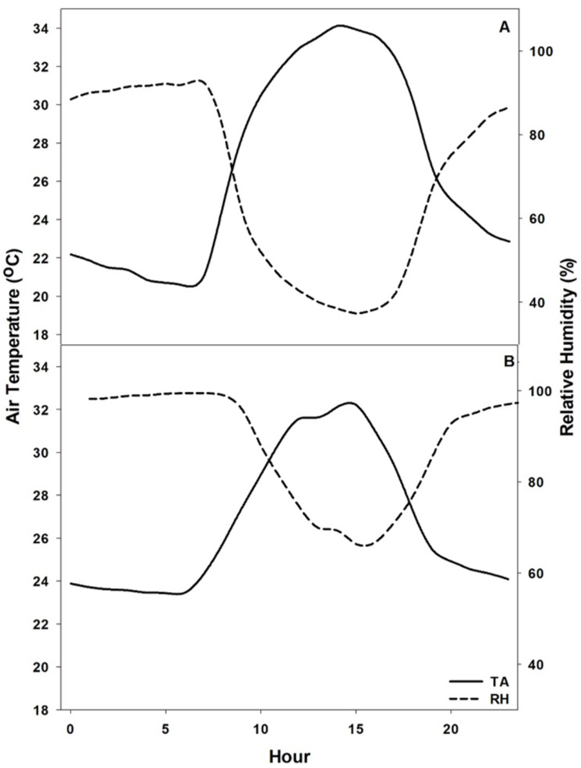

Figure 2. Monthly mean values of air temperature (TA) and relative humidity (RH) in August 2020 (A) and January 2021 (B) in the municipality of Humaitá, located in the Amazonas State, Brazil.

Temperature humidity index (THI)

The THI observed between 00:00 am and 07:00 am had the highest interquartile variations in August 2020. However, 25% of the sample in this time range admits a THI higher than or equal to 74 only at 0:00 am, but this occurs in less than 25% of the observations in the following hours of this interval (Figure 3). THI was lower than or equal to 74 and, consequently, comfortable for the animals in this period.

Figure 4 also shows that the period between 8:00 am and 7:00 pm showed the highest THI variations. However, 50% of the sample in this time range admits a THI lower than 74 only at 8:00 am, but it occurs in more than 75% of the sample higher than 74 in the following hours of this interval, being within an alert to the danger zone. The interval from 7:00 pm to 11:00 pm showed that more than 50% of the sample has a THI lower than or equal to 74, while the interval between 8:00 am and 7:00 pm showed the highest TA of the day and, consequently, a decrease in RH (Figure 2), which indicates a possibility to increase THI in the period from 8:00 am to 8:00 pm, leading to a higher discomfort to the animals. The opposite occurs at night from 00:00 am to 07:00 pm, with a decrease in temperature and an increase in relative humidity, making THI at a comfortable level for the animals.

The time range from 0:00 am to 07:00 am showed no concerns regarding animal thermal comfort, but the rest of the day must be observed with care by producers and measures must be taken to provide a shading area, even if artificial, in the short term, and long-term natural shading to avoid possible losses in milk production as a result of this discomfort.

According to De Miranda,[22] the thermal comfort of zebu cattle varies between 10 and 32 °C, with maximum and minimum critical temperatures of 35 and 0 °C, respectively. However, according to these authors, crossbred animals have a tolerance to intermediate heat between parental breeds, such as European and Indian breeds. Some authors have indicated that the thermal comfort zone is limited by minimum and maximum ambient temperatures of 5 and 31 °C.

The ITU observed between 0:00 am and 7:00 am in January 2021 presented the lowest interquartile variations. However, 50% of the sample in this time range admits a THI lower than or equal to 74 only between 4:00 am and 5:00 am, but it occurs in less than 25% of the observations in the following hours of this interval (Figure 4), thus being between uncomfortable and alert for the animals. The period between 8:00 am and 7:00 pm presented the highest interquartile variations. However, 75% of the sample in this time range has a THI higher than or equal to 75, but it occurs in more than 100% of the observations in this time range between 12:00 pm and 7:00 pm. It is understood that it may be related to an increase in TA and, consequently, a decrease in RH, which increases THI in this period and causes higher discomfort to dairy cattle, even crossbreeds. The opposite occurs at night from 0:00 am to 07:00 am, with a decrease in TA and an increase in RH, which makes THI at a comfortable level for the animals.

January, even within the rainy season in the region, had a THI higher than 75 throughout the days and, therefore, stands out as the most critical period for dairy cattle. These results are corroborated by Rosanova,[14] who found THI values between 75 and 78 in northern Tocantins State, thus requiring immediate solutions of a technical, management, welfare, and animal behavior character to alleviate heat stress.

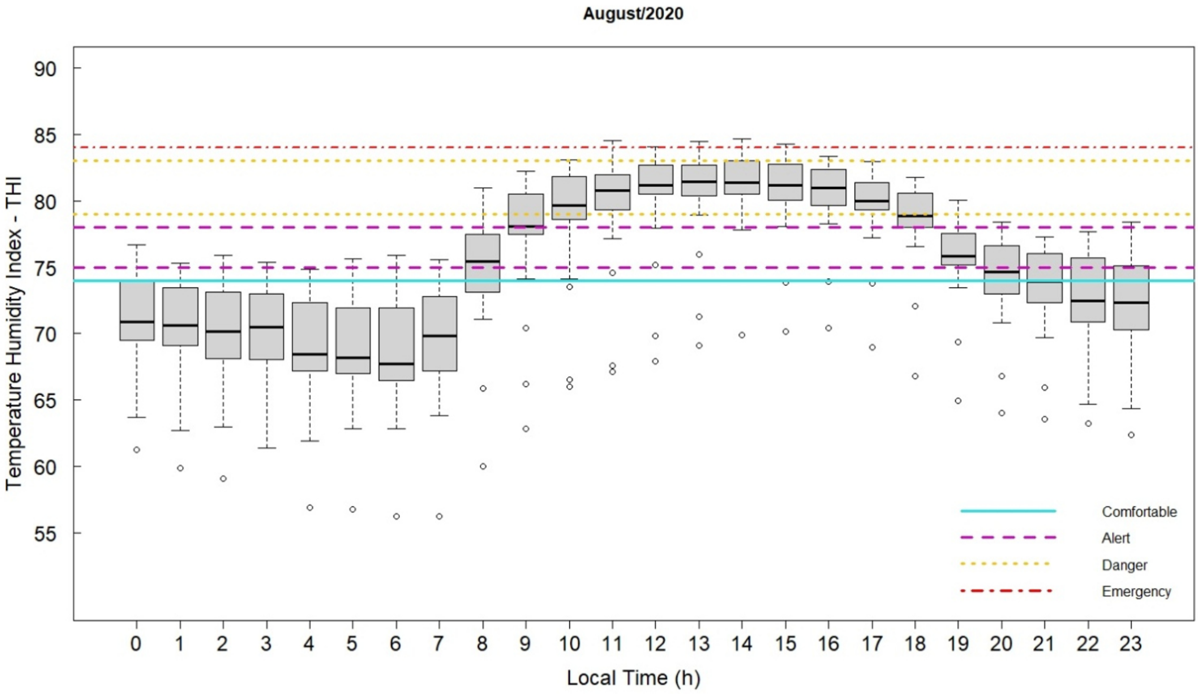

Figure 3. Monthly hourly variability of the temperature humidity index (THI) in Humaitá, Amazonas State, Brazil, in August 2020.

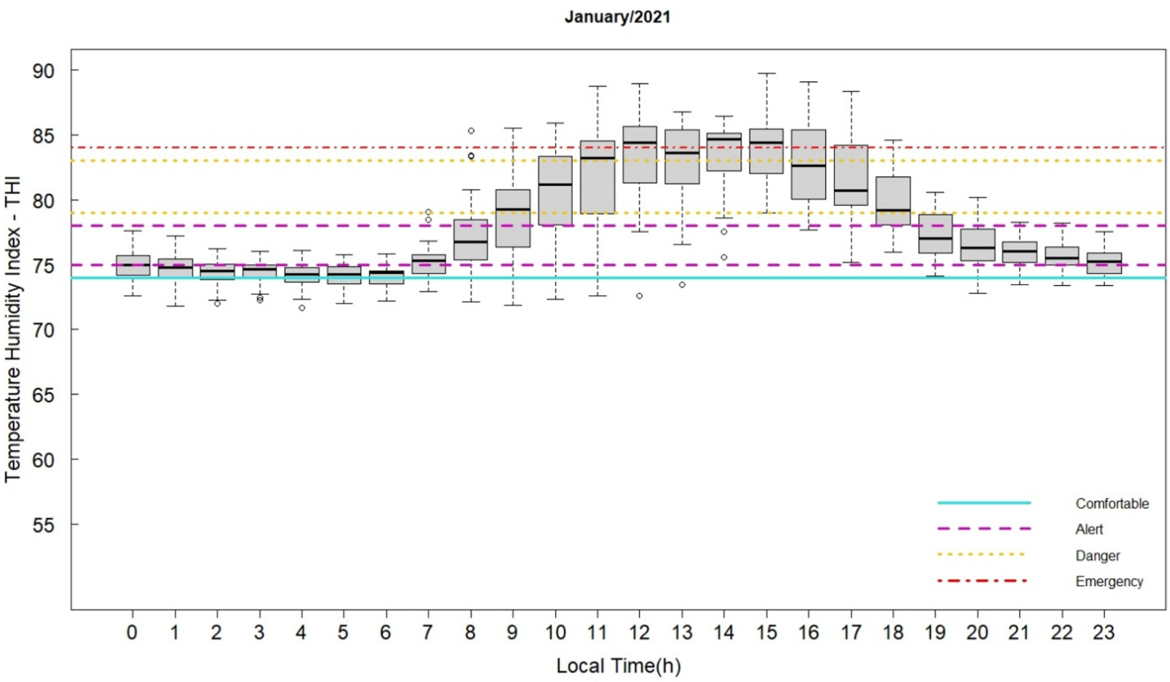

Figure 4. Monthly hourly variability of the temperature humidity index (THI) in Humaitá, Amazonas State, Brazil, in January 2021.

THI had a higher variation for August 2020, with values ranging from 56.25 and 84.68 throughout the day and a monthly mean of 74.36, with a large difference from January 2021, as the variation for this period was between 74.15 and 84.07, with a monthly mean of 78.21. Therefore, August was more comfortable for dairy cattle than January. The existence of THI above 74 was a common factor in the experimental areas, regardless of the period or season. Moreover, the combined effect of TA and RH on the animals in these areas can result in production losses, with restrictions on the exploitation of dairy farming if measures are not taken by technicians and producers. The study areas had high mean THI values, with a mean of 74.36 for August 2020 and 78.21 for January 2021 (Table 2), classifying them as a favorable environment in August 2020 and stressful in January 2021. THI is increased in January because is a rainy month with a higher relative humidity.

According to Rosanova,[14] saturated humid air inhibits water evaporation through the skin and respiratory tract under high humidity conditions, and the environment becomes more stressful for the animal. Also, according to the authors, this situation makes it difficult to work with specialized breeds, normally adapted to temperate climate regions, which are more sensitive to these conditions of heat stress despite being more productive.

Table 2 – Mean values of the monthly temperature humidity index (THI) for August 2020 and January 2021 in Humaitá-AM, Brazil.

Measure of dispersion	Agosto	Janeiro
THI MEAN	74.94	78.21
THI STANDARD DEVIATION	5.79	3.79
VARIANCE	33.52	14.38

THI values were lower in August, classified between 56.25 and 84.68. The climate stress is attenuated most of the day, but with THI higher than 79 in the afternoon. It occurs because August is in the dry season of the region (Amazon summer). High temperatures and low relative humidity are recorded at this time of the year. The circulation of the lower troposphere stands out during the dry period, moving to the north of the equatorial trough, providing a displacement of the descending branch of the Hadley cell over the Amazon, which inhibits the formation of clouds and, consequently, rainfall in this region.[18] However, the flow at low levels of the atmosphere, originating from the Atlantic Ocean, favors the transport of moisture in the central and southern region of the Amazon during this period, which guarantees necessary conditions for local convection in the afternoon and explains the disparity relative to other periods of the day.[23]

Nutritional stress also occurs during this period due to the dry season and the lack of pastures and feed, implying low productivity and profitability of the sector throughout the year.[14] Therefore, this condition demands urgent solutions of a technical and management nature for animal welfare, such as zootechnical facilities adapted to the region and more adequate to the behavioral needs of the animals.[24] The THI values obtained in January presented a lower range, varying from 74.15 to 84.07 during the day, but with values above 80 THI after 10:00 am. This period is inserted in the rainy season of the region, in which the South American monsoon systems, the South Atlantic Convergence Zone (SACZ), which extends from the Amazon to the Southeast of Brazil and the Bolivia High, are responsible together for an increase in rainfall.[25]

Bolivian High meteorological system (BH) is an anticyclone at high levels of the troposphere. It results from the convergence of warmer air and humidity at low levels together with the divergence of air that cools at high levels of the atmosphere and varies intra-seasonally and interannual.[26] Therefore, this increase in rainfall and, consequently, an increase in relative humidity, which was above the PCN_{RH} for this period, raised THI for the levels between alert and danger.

Mirelle[27] observed THI means varying from 73.74 to 77.82 in Babalhe, Ceará State, Brazil, for July and November, respectively, with relative stability in most months of the year. THI from January to April was, on average, in the range of 76, being classified as a stressful environment, as found in this study. Similar results were found by Franciele in the municipality of Diamante D'Oeste, Paraná State, Brazil, where the THI means of the full sun treatment reached 80, which indicates a heat stress condition for the animals, even being in a colder region than the study present study, as the thermal condition for THI ranged from 72 to 88.

Conclusion

Thermal stress in dairy cows in the municipality of Humaitá, located in southern Amazonas State presents a state of alert even for cross-breed animals due to the lack of protection from solar radiation in the pastures. Thus, there is a need for the management and use of technologies to mitigate these climate effects on animals. In this context, the use of artificial or natural shading in pastures is suggested to minimize the effect of heat stress on the productive performance of the animals.

Conflict of interests

The authors declare no conflict of interest.

Author contributions

Conceptualization: L. A. S. Rohleder and C. A. S. Querino; *Data curation:* L. A. S. Rohleder and C. A. S. Querino; *Research:* L. A. S. Rohleder and C. A. S. Querino; *Writing (Original Draft):* L. A. S. Rohleder and C. A. S. Querino; *Writing (Review and Editing):* L. A. S. Rohleder and C. A. S. Querino; *Formal analysis:* P. V. Alves, L. A. S. Rohleder and M. A. B. Vaz; *Software:* P. V. Alves, L. A. S. Rohleder and M. A. B.

Vaz; *Resources:* A. L. P. Junior, J. K. A. S. Querino and L. A. S. Rohleder; *Supervision:* C. A. S. Querino.

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