



## Article

# Effects of Climatic Conditions and Supplementation with Palm Cake on the Thermoregulation of Crossbred Buffaloes Raised in a Rotational Grazing System and with Natural Shade in Humid Tropical Regions

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**Simple Summary:** The objective of this work was to evaluate the effects of climatic conditions and supplementation based on palm kernel cake, on the thermoregulation of crossbred buffaloes in the eastern Amazon. Over a 12-month period, 24 female buffaloes with an initial age of  $54 \pm 7$  months and an average weight of  $503.1 \pm 23$  kg were divided into four groups with different levels of palm kernel cake supplementation relative to body weight. The animals were kept in *Brachiaria brizantha* pastures with access to water and mineral salt. Supplementation did not influence the physiological variables of thermoregulation. Throughout the year, mean values of rectal temperature, respiratory rate and body surface temperature were higher in the afternoon ( $p > 0.05$ ). Supplementation with palm cake did not result in influences on the thermoregulation of buffaloes in the study region. The respiratory rate showed an association with the annual seasonality of temperatures, with higher averages in the afternoons of the rainy season. The positive correlation between the rectal temperature, respiratory rate, and body surface temperature indicates that buffaloes respond to atmospheric thermal elevations (afternoon period), which is reflected in increasing thermal indices.

**Abstract:** In ruminants, diet composition has a positive correlation with heat production, which can influence thermoregulation, energy expenditure and, consequently, animal performance. The objective of this work was to evaluate the effects of climatic conditions and supplementation based on palm kernel cake, on the thermoregulation of crossbred buffaloes in the eastern Amazon. The research was carried out at Embrapa Amazônia Oriental ( $01^{\circ}26' S$  and  $48^{\circ}24' W$ ), Belém, Pará, and lasted 12 months (representing the entire year). Twenty-four buffaloes, females, with initial age and an average weight of  $54 \pm 7$  months and  $503.1 \pm 23$  kg, respectively, non-pregnant, non-lactating and clinically healthy were used, divided into four treatments based on the supplementation content of the palm cake (%DM) in relation to their body weight (%): 0, 0.25, 0.50 and 1.0. The animals were kept in paddocks with *Brachiaria brizantha* (cv. Marandu), in a rotating system, with water to drink and mineral salt ad libitum. Equipment was installed to record environmental data (temperature and relative humidity, dew point temperature, wet bulb and black globe) and physiological data: rectal temperature (RT); respiratory rate (RR); and body surface temperature (BST), recorded twice a day,

always in the morning (6:00 a.m. to 7:00 a.m.) and afternoon (12:00 p.m. to 1:00 p.m.) shifts, and were used to calculate the Globe Temperature and Humidity Index (GTHI). Supplementation did not influence the physiological variables of thermoregulation ( $p > 0.05$ ). However, there were differences in the GTHI between the shifts, with higher means in the afternoon shift, especially in the less rainy period of the year, where the GTHI reached  $92.06 \pm 2.74$  ( $p < 0.05$ ). In all periods of the year, the mean values of RT, RR and BST were higher in the afternoon shift ( $p > 0.05$ ). The respiratory rate (RR) is associated with the annual seasonality of the thermal waters, with higher averages in the afternoons of the rainy season. The positive correlation for rectal temperature, respiratory rate and body surface temperature indicated that buffaloes respond to thermal elevations in the atmosphere (afternoon period) and, consequently, reflect on the GTHI. Supplementation does not influence thermoregulation; the changes observed occurred in response to the region's thermal and rainfall conditions (mainly in the afternoon shift), with higher GTHI values.

**Keywords:** animal bioclimatology; equatorial climate; co-product; heat stress; supplement; ruminants; thermoregulation

## 1. Introduction

Animal thermoregulation is a set of mechanisms that seek to adjust the internal body temperature of animals, in an attempt to maintain it at values compatible with life, when there is fluctuation in the temperature of the environment [1,2]. The use of these mechanisms has a direct influence on the animal's behavior, energy expenditure and performance [3]. Some factors, such as diet, in a challenging climate situation, can also influence or enhance the thermoregulation process, due to the caloric increment [4]. Thermal stress can be caused by numerous factors such as skin lesions, no trees, and intense solar radiation [5,6].

Thermal comfort is defined as a state in which thermal equilibrium is zero. According to specifications of specific interest, the thermal comfort zone can be defined as between 16 and 25 °C, that is, in this ambient temperature range basal metabolism is lower and thus thermoregulation occurs without evapotranspiration [7].

This fact has already been verified in works with cattle [8,9], goats [10], sheep [11,12] and other species [13,14]. In the Amazon region, where the climate is predominantly equatorial, the largest buffalo herd in Brazil is located [15]. In this area, in addition to the high temperature and humidity, there is a period of more intense rainfall and a dry period during the year [16,17], where animals need to be supplemented to maintain body performance [18,19].

As an ingredient in supplements, palm kernel cake has been widely studied [20–22], as it is a low-cost co-product when compared to traditional ingredients, and has good nutritional value (especially protein and energy); the state of Pará is the largest producer of this material [23,24]. However, the works do not consider buffaloes and thermoregulatory responses, especially in the Amazon region, where most of the animals raised in the country are concentrated and which experience challenging climatic conditions.

Food plays a fundamental role in the thermoregulation of buffaloes, as it is directly related to the ability of these animals to regulate their body temperature. Buffaloes, especially in hot climates, face significant challenges, dissipating excessive heat. The digestion and metabolism of food, along with diet composition, affect internal heat production, which plays a vital role in regulating body temperature in buffaloes.

In buffaloes, thermal stress occurs due to specific factors that provide major disadvantages in relation to cattle, such as a black skin color, black hair, a reduced number of sweat glands/skin area, thick layer of skin epidermis, which makes it vulnerable to solar radiation [25,26].

In view of this, despite the need for animal supplementation in the dry period of the eastern Amazon, as nutritional changes have a direct influence on the thermoregulatory

responses of ruminants, the inclusion of palm cake as a food supplement should be evaluated. Our hypothesis is that climatic conditions and the inclusion of a palm cake-based supplement in the diet may contribute to changes in the thermoregulation mechanisms of Buffaloes. Therefore, the objective of this work was to evaluate the effects of climatic conditions and palm cake-based supplementation of palm oil, on the thermoregulation of crossbred buffaloes in the eastern Amazon.

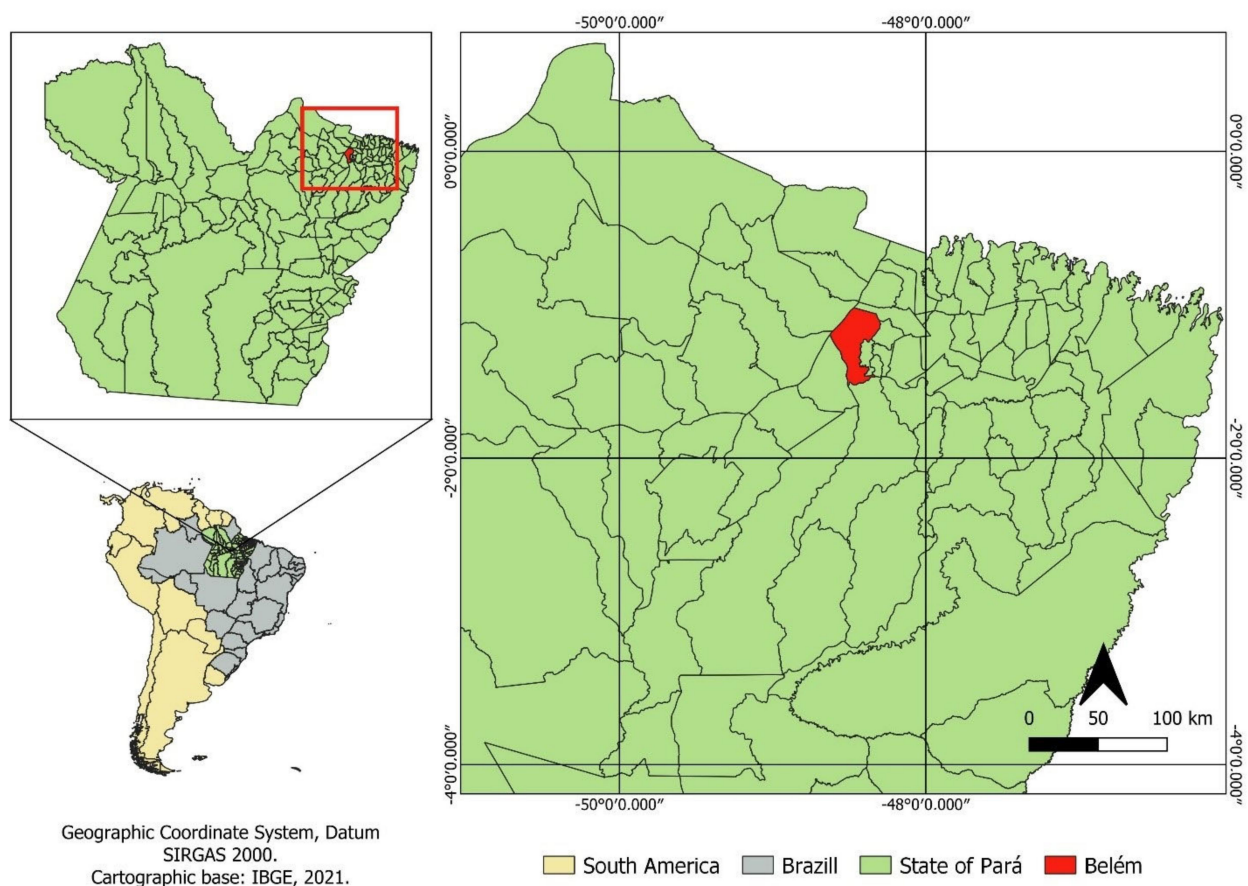
## 2. Materials and Methods

### 2.1. Ethical Aspects

The research was approved by the Ethics Committee for the Use of Animals (CEUA) of the Federal University of Pará—protocol BIO 120-13.

### 2.2. Experimental Area

The experimental test was carried out at Embrapa Amazônia Oriental (01°26' S and 48°24' W) in Belem, Pará, (Figure 1), in the period from July 2013 to June 2014, during the rainy season of the year (January to April), specifically from February to March. The climate is tropical rainy Am, according to the Köppen classification, with an average annual rainfall of 2500 mm, an average temperature of 27 °C, and a relative humidity of 85%, and it has an Af2 climate, according to the Köppen classification adapted by Martorano et al. [27].



**Figure 1.** Location of the study area.

The animals were kept in paddocks with *Brachiaria Brizantha* grass (CV. Marandu) in a rotational system, natural shading, access to water and mineral salt ad libitum. They were distributed in a completely randomized design into four treatments, based on the level of inclusion of palm kernel cake in relation to their body weight: 0.0%, 0.25%, 0.50% and 1%. A total of 0.15% wheat bran was added to all treatments, acting as a palatability agent,

and the supplement was offered in individual troughs, once a day, at 7:00 a.m. The forage supply was homogeneous in all paddocks, being around 9 kg of DM/100 kg of animal live weight throughout the experimental period.

### 2.3. Animals, Diets and Husbandry Conditions

Twenty-four crossbred buffaloes (Murrah  $\times$  Mediterranean—*Bubalus bubalis bubalis*), with an initial age and average weight of  $54 \pm 7$  months and  $503.1 \pm 23$  kg, respectively, which were non-pregnant, non-lactating and clinically healthy were used.

Chemical analyses of the experimental diets were carried out at the Animal Nutrition Laboratory of the Federal University of Pará—UFPA. The content of dry and organic matter, ash and crude protein (Kjeldahl method) was in accordance with the recommendations of the AOAC [28]. Neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose and lignin followed the sequential method, described by Van Soest et al. [29]. The results are presented in Table 1.

**Table 1.** Chemical composition of ingredients and diets.

Diet	Components (% DM)					
	DM	Ash	EE	CP	NDF	ADF
Palm kernel cake	90.47	4.61	11.64	11.12	69.87	48.23
Wheat bran	88.32	5.88	3.48	15.49	44.19	14.27
<i>Brachiaria brizantha</i>	37.4	6.76	2.54	8.19	68.14	40.55
0%	88.32	5.88	3.48	11.69	44.19	14.27
0.25%	89.66	5.09	8.58	12.13	60.24	35.5
0.50%	89.97	4.9	9.75	12.76	63.94	40.39
1%	90.17	4.78	10.57	15.49	66.51	43.78

Dry matter (DM); ether extract (EE); crude protein (CP); neutral detergent fiber (NDF); acid detergent fiber (ADF).

### 2.4. Data Collect

An analysis of the thermal–hydric regime was carried out, using data from climatological normals, as well as meteorological data provided by INMET, corresponding to the experimental period.

Agrometeorological data were obtained from a portable automatic station, programmed to acquire data and store sensor readings in dataloggers every 1 min (Model TGD-300, Instrutherm, São Paulo, Brazil). The station was equipped with sensors for routine measurements of time and climate and a black globe thermometer, installed in each paddock, at the height of the back of the animals, in order to monitor the rotation of the animals in the pastures. The readings of the air temperature (AT, °C), relative air humidity (RH, %), dew point temperature (DPT, °C), wet bulb temperature (WBT, °C) and black globe temperature (BGT, °C) were performed from 6:00 a.m. to 7:00 a.m. and from 12:00 p.m. to 1:00 p.m., when the physiological variables were collected.

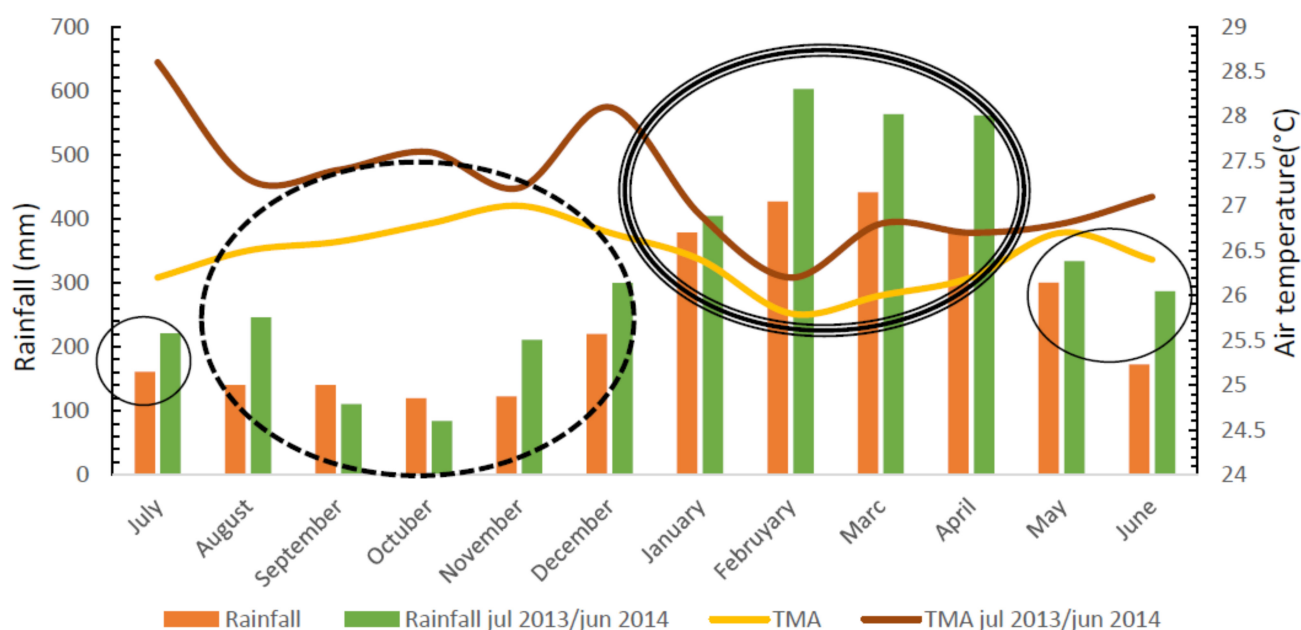
From the values of environmental variables, the Globe Temperature and Humidity Index (GTHI) was calculated, proposed by Buffington et al. [30], through the equation  $GTHI = BGT + 0.36 TPO + 41.5$ . The GTHI value considers the effects of dry bulb temperature, RH, solar radiation and air movement, since the BGT, which composes the formula of this index, indicates the effects of the combination of these meteorological variables [31], in addition to providing an indirect measure of ambient radiant heat. GTHI values are used to assess the thermal comfort situation of animals with the following scale: up to 74, comfort; from 74 to 78, alert; from 79 to 84, dangerous; and above 84, emergency [32].

The physiological variables studied were the rectal temperature (RT, °C), respiratory rate (RR, movements/minute) and body surface temperature (BST, °C) measured every 14 days, in the morning between 6:00 a.m. and 7:00 a.m. and in the afternoon between 12:00 p.m. and 13:00 p.m. To obtain the RT, a veterinary clinical thermometer was used, with a scale of up to 44 °C, with the reading result expressed in degrees centigrade. The RR was obtained by inspecting and counting the thoracoabdominal movements for 1 min



minute. The BST was obtained with the help of an infrared thermometer (Model TD-965—Instrutemp, São Paulo, Brazil) activated at a maximum distance of 1 m from the measurement points on the animal, which were the forehead, left side of the thorax and left flank, having obtained the average of these values. Data for physiological variables were expressed as means and standard deviations.

The research considered the transition period between the periods (more and less rainy) of the year, identified when analyzing the climatic data, mainly in the afternoon, from May to July, where there was a significant decrease in the relative humidity of the air, as well as a significant increase in the air temperature. Thus, the data were organized into three periods of the year: rainier (January to April), transition (May to July) and less rainy (August to December) (Figure 2). The objective of this division was to detect whether the meteorological conditions of these periods influenced the physiological responses of buffaloes.



**Figure 2.** Climatological normal data compared to those observed during the experimental period in the municipality of Belém, Pará. Note: TMA = Average air temperature; TMA Jul 2013/Jul 2014 = average annual temperature.

### 2.5. Statistical Analysis

A completely randomized experimental design was used, in a factorial arrangement of four treatments (0%, 0.5%, 0.25% and 1% of palm kernel cake), three periods of the year (rainier, transition and less rainy) and two shifts (morning and afternoon). Analyses of variance were performed using the Statistical Analysis System software (Version 6.08) [33] to verify the effect of the treatment on the co-product levels, day shift (morning and afternoon), and period of the year (rainier, transition and less rainy), and their interactions with the physiological parameters mentioned above. Means were compared using Tukey's test, at 5% probability. Pearson's linear correlations were performed to verify the magnitude and direction of the proportionality of the physiological variables and observe the independence of the variances of the pairs of observations used.

### 3. Results

The average rainfall during the experimental period was 3921.9 mm, the rainiest period being from January to May (monthly rainfall greater than 330 mm), and the least rainy period corresponding to the period from August to December.

The average annual temperature was 26.4 °C, with maximum monthly averages between 30.9 and 32.8 °C, relative air humidity around 84% and annual insolation of 2586 h. The average temperature observed in the less rainy period was equal to 26.7 °C, being higher than that observed in the wettest period (26 °C).

There was a difference in the GTHI between the shifts, with the afternoon averages being higher throughout the year and especially in the less rainy period, where the GTHI reached  $92.06 \pm 2.74$ , statistically different from the rainiest period ( $88.66 \pm 3.78$ ) and transitional ( $87.65 \pm 3.76$ ) ( $p < 0.05$ ) (Table 2).

**Table 2.** Averages and standard deviation of the Globe Temperature and Humidity Index in the experimental area, in the morning and afternoon shifts, and in the three periods of the year.

Period	Shift	
	Morning	Afternoon
Rainier	$74.11 \pm 1.09$ <sup>Aa</sup>	$88.66 \pm 3.78$ <sup>bA</sup>
Transition	$74.79 \pm 1.27$ <sup>aA</sup>	$87.65 \pm 3.76$ <sup>bA</sup>
Less rainy	$74.46 \pm 1.37$ <sup>aA</sup>	$92.06 \pm 2.74$ <sup>bB</sup>

<sup>A,B</sup> Period averages, within each shift, followed by different capital letters, in the same column of each climate variable and index are different ( $p < 0.05$ ); <sup>a,b</sup> Means of shifts, within each period, followed by different lowercase letters, in the same line are different ( $p < 0.05$ ).

The diets did not influence the rectal temperature ( $p > 0.05$ ), but there was an influence of the environment on this variable ( $p < 0.05$ ). In all periods of the year, the mean RT values in the afternoon shift were higher (rainiest period:  $39.23 \pm 0.86$  °C, transition:  $39.00 \pm 0.93$  °C and less rainy period:  $39.15 \pm 0.66$  °C), compared to those in the morning (mean  $38.67$  °C) (Table 3). In both shifts, there was no difference in RT between periods of the year ( $p > 0.05$ ).

**Table 3.** Means and standard deviations of physiological variables in the morning and afternoon, in the three periods of the year.

Physiological Variable	Period	Shift	
		Morning	Afternoon
Rectal temperature (°C)	Rainier	$38.64 \pm 0.36$ <sup>aA</sup>	$39.23 \pm 0.86$ <sup>bA</sup>
	Transition	$38.62 \pm 0.22$ <sup>aA</sup>	$39.00 \pm 0.93$ <sup>bA</sup>
	Less rainy	$38.77 \pm 0.70$ <sup>aA</sup>	$39.15 \pm 0.66$ <sup>bA</sup>
Respiratory rate (mov./min.)	Rainier	$19.95 \pm 5.94$ <sup>aA</sup>	$49.40 \pm 28.75$ <sup>bA</sup>
	Transition	$19.05 \pm 5.39$ <sup>aA</sup>	$40.16 \pm 22.15$ <sup>bAB</sup>
	Less rainy	$19.94 \pm 7.04$ <sup>aA</sup>	$35.66 \pm 17.08$ <sup>aB</sup>
Body surface temperature (°C)	Rainier	$30.46 \pm 1.34$ <sup>aA</sup>	$34.46 \pm 2.07$ <sup>bA</sup>
	Transition	$29.55 \pm 1.33$ <sup>aA</sup>	$34.30 \pm 1.72$ <sup>bA</sup>
	Less rainy	$29.84 \pm 1.41$ <sup>aA</sup>	$34.82 \pm 1.23$ <sup>bA</sup>

<sup>A,B</sup> Period averages, within each shift, followed by different capital letters, in the same column of each physiological variable, are different ( $p < 0.05$ ). <sup>a,b</sup> Shift averages, within each period, followed by different lowercase letters, on the same line are different ( $p < 0.05$ ).

Supplementation also did not influence respiratory rate values ( $p > 0.05$ ). However, in all periods of the year, there was a difference between shifts ( $p < 0.05$ ). The RR of the afternoon shift (wettest period:  $49.40 \pm 28.75$  mov./min., transition:  $40.16 \pm 22.15$  mov./min. and less rainy:  $35.66 \pm 17.08$  mov./min.) was always higher ( $p < 0.05$ ). The effect of the periods of the year on the RR values of the afternoon shift, where the highest RR means occurred in the wettest period of the year ( $p < 0.05$ ).

The body surface temperature values were not influenced, which were also not influenced by the period of the year ( $p > 0.05$ ). The BST was influenced by the shifts, with the highest values also observed in the afternoon (rainiest period:  $34.46 \pm 2.07$  °C, transition:  $34.30 \pm 1.72$  °C and least rainy:  $34.82 \pm 1.23$  °C) ( $p < 0.05$ ).

The RT showed a positive correlation with air temperature (0.628) and GTHI (0.597), and a negative correlation with relative air humidity (−0.569) (Table 4). RR also showed a positive correlation with air temperature (0.748) and GTHI (0.689), and a negative correlation with relative air humidity (−0.637). In BST, the correlation was positive with air temperature (0.939) and GTHI (0.933), and negative with relative humidity (−0.873).

**Table 4.** Correlation between climatic variables, thermal comfort and physiological indices of crossbreeds (Murrah x Mediterranean) buffaloes.

Index	RT (°C)	RR (mov./min.)	BST (°C)
Air temperature	0.628 **	0.748 **	0.939 **
Relative humidity	−0.569 **	−0.637 **	−0.873 **
Globe Temperature and Humidity Index	0.597 **	0.689 **	0.933 **

RT—Rectal temperature; BST—Body surface temperature; RR—Respiratory rate (movements per minute).  
\*\*—significance at 1%.

#### 4. Discussion

Precipitation data during the experimental period remained within the local average, and are also in line with those found by Pachêco [34]. In this study, palm oil cake did not influence the thermoregulation of buffaloes in the Amazon. The thermal comfort of the animals depends, to a high degree, on the levels of relative humidity in the air in association with the air temperature [6,17], and the GTHI represents this association well.

The GTHI differences between the shifts (all periods of the year), with higher averages in the afternoon shift, indicate an emergency situation for the animals, suggesting thermal stress, especially in the less rainy period of the year, where the GTHI had the highest average. Similar GTHI values were found by Silva et al. [35], with averages in the afternoon shift of  $83.9 \pm 2.2$ ,  $87.6 \pm 3.1$  and  $88.8 \pm 2.6$ , in the rainiest, transition and less rainy periods of the year, respectively, when evaluating the thermal comfort of buffaloes in a silvopastoral system, also in the eastern Amazon. The results were also close to those recorded by Santos et al. [36] in the Brazilian semi-arid region ( $85.5$ —afternoon shift). Apart from certain GTHI or THI, thermoregulatory mechanisms to deal with thermal stress are not sufficient to maintain thermal stability [37].

The absence of significance in the thermoregulatory responses of the animals probably occurred because the animals had presented moderate thermal stress [38]. However, the animals suffered opposite effects, where in the afternoon, with high values of GTHI and air temperature, the efficiency of heat loss by conduction, convection and radiation decreased, due to the increase in the temperature gradient between the animal's skin and the environment. In this situation, the animal can, to a certain extent, maintain body temperature through peripheral vasodilation, increasing peripheral blood flow and surface temperature [39]. However, if the ambient temperature continues to rise, the animal starts to depend on the loss of heat by evaporation, through respiration (increase in RR), to maintain homeothermia [40].

The elevation of rectal temperature in a hot environment indicates that the heat release mechanisms have become insufficient to maintain homeothermia [41,42]. This result can be attributed to the higher incidence of solar radiation in the afternoon. Cattle and buffaloes, in similar climatic conditions, presented similar results [43], where the RT of buffaloes increased from  $38.0$  °C to  $39.3$  °C, in the morning and afternoon, respectively, reaffirming that this variable physiology is influenced by the rise in ambient temperature. Higher rectal temperatures in the afternoon were also observed by Magalhães et al. [43] and Silva et al. [44], who found the RT ( $39.26$  and  $39.11$  °C) of cattle and buffaloes in the afternoon higher than those in the morning ( $38.05$  and  $38.11$  °C), respectively. The variation in rectal temperature in crossbred buffaloes was observed by Shenhe et al. [45] during the seasons of the year, and they also found the influence of environmental temperature: ( $39.24$  °C) in summer; ( $38.34$  °C) in spring and ( $38.13$  °C) in winter. This increase can be

attributed to the inability to dissipate excess body heat generated during the thermal load of the warmer months [46,47].

Even in the morning (milder temperatures), the values are above the normal variation range for buffaloes, from 37.4 to 37.9 °C [47]. The effects of ambient temperature on the rectal temperature of buffaloes are an indication of thermal stress in animals [48,49]. An increase of close to 1 °C in rectal temperature is enough to reduce productive performance in most domestic animal species [1]. In both shifts, there was no difference in RT ( $p > 0.05$ ) between the periods of the year, demonstrating that in all periods of the year in the Amazon region, the animals are susceptible to thermal stress in the afternoon shift.

In all periods of the year, the RR of the afternoon shift was higher. This was probably due to the fact that it was the hottest period of the day, and due to the onset of respiratory evaporative thermolysis mechanisms in order to maintain homeothermia. In evaluating the mean RR data, in the morning shift, the observed values are within the normal variation range for buffaloes, from 18 to 30 (movements/minute) [46]. In the same region (eastern Amazon), Silva et al. [44] observed higher values in buffalo heifers in the morning shift ( $28.3 \pm 1.1$  to  $29.8 \pm 1.1$ —movements/minute), but still within the normal variation range for buffaloes.

On the other hand, the values observed in the afternoon (all periods of the year), surpassed those indicated for situations of thermoneutrality of the buffalo species, which was already expected, since the combination of climatic elements caused a greater degree of discomfort to the animals, because they raised the respiratory rate in order to maintain the body temperature. In situations of thermal stress, this physiological variable presents high values, even before there is an increase in rectal temperature values [49,50]. In an attempt to maintain body temperature, the buffaloes increased their respiratory rate from 22 to 48 movements per min, when the temperature ranged from 28.3 to 34.7 °C [51].

In the afternoon shift, the highest RR values occurred in the wettest period of the year. This result may have occurred due to the difficulty these animals have in dissipating heat by evaporation, as the RH is quite high during this period. In buffaloes, heat loss through exhaled air is more important than perspiration, as they have low efficiency in heat loss through the skin [52,53].

The information obtained from BST has been widely used, as in addition to helping in the diagnosis of pathologies, it can indicate the physiological state and well-being of the animals [54]. The effect of the day shift on BST occurred as the highest GTHI and AT values were found in the afternoon. Because of this, there was an increase in blood flow from the central core to the body periphery, in an attempt to eliminate heat, which contributed to the elevation of BST [35,55]. BST is directly related to the environmental conditions of RH, air temperature, incidence of wind, and physiological conditions, such as vascularization and evaporation by sweat [50,56]. At mild air temperatures, this variable contributes to maintaining body temperature through heat exchange with the environment [57].

The correlation data suggest that increasing air temperature increases RT, RR and BST, that the increase in RH implies a reduction in RT, RR and BST, and the increase in GTHI reflects the elevation of RT, RR and BST data. The positive correlation between air temperature and GTHI, and the negative one with relative humidity, indicates that the animals reacted to increases in air temperature and GTHI with an increase in RT. The conditions of climate, environment and diet influence the metabolism and physiology of the animals, which may be reflected in the increase in rectal temperature as a response to the situation [58].

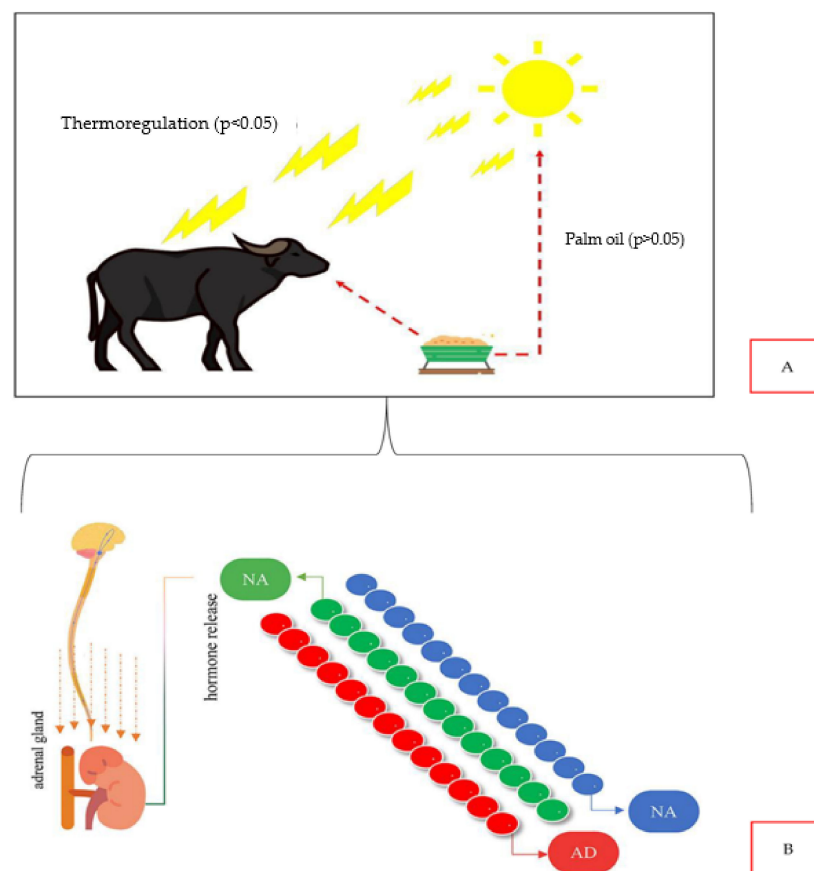
The correlation verified for RR reinforces the idea of regulatory changes depending on the environment. The clearest physiological effects of heat stress in animals include pronounced changes in their heart rate and respiratory rate [59].

The dynamics for BST demonstrate that under conditions with high ambient temperatures and high GTHI, the animal tries to dissipate excess heat and increases blood flow from the central nucleus to the body surface and, consequently, increases the rate of heat flow, which results in high reductions in temperature [60]. When AT increases, UR



decreases; thus, a negative correlation of UR with BST occurs. Similar results were obtained by Silva et al. [35], demonstrating that this variable is an excellent indicator of heat stress in buffaloes.

Furthermore, the fact that supplementation with palm kernel cake did not influence the thermoregulation of buffaloes in the eastern Amazon is an extremely important result (Figure 3). As mentioned, the regions influenced by the Amazonian climate, generally, have six months of the year with high rainfall intensity [17,61–64] as well as the availability of food in the pasture. However, the other six months are of low rainfall (dry period), where forage availability and quality is reduced. During this period, there is a need for supplementation, so that the animals do not decrease their performance or even lose weight. With the information obtained in this work, we can indicate the co-product (palm kernel cake), abundant in the region, as a food strategy in dry periods. These are data that could directly influence the buffalo production chain in the Amazon region.



**Figure 3.** (A) Experiment result infographic (the authors). (B) Graphic representation of the stress stimulus in buffaloes that triggers the release of catecholamines by the sympathetic nervous system, namely adrenaline (AD) and noradrenaline (NAD), as well as cortisol (CT) by the adrenal gland Adapted from [6].

## 5. Conclusions

In conclusion, the study reveals that environmental factors, such as the time of day (morning vs. afternoon), air temperature, Global Temperature and Humidity Index (GTHI), and relative humidity, exert a more pronounced influence on physiological parameters including the rectal temperature (RT), respiratory rate (RR), and body surface temperature (BST), compared to dietary supplementation or the specific period of the year. Notably, afternoon shifts consistently exhibit higher RT and BST values, indicating the critical role of time and environmental conditions in shaping these responses. While dietary supplementation with palm oil cake did not significantly impact thermoregulatory responses in

buffalo within the eastern Amazon's climatic conditions, it presents a potential avenue to enhance productivity. Nevertheless, the study underscores the substantial impact of weather conditions on animal well-being. Further research is recommended to optimize the utilization of these co-products in supplementation in buffalo in the Amazon region.

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