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Thermal exchange and physiological variables of remmants of the Nordestino horse breed before and after exercise

Trocas térmicas e variáveis fisiológicas do remanescentes da raça Nordestino antes e após o exercício

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ABSTRACT: The aim of this study was to analyse the physiological parameters and heat exchange of horses remnants of the Nordestino Horse breed used in brazilian cattle-catching, morning (before) and afternoon (after) exercise. The 20 castrated males with teeth classified as "full mouth" were evaluated. The horses were assessed for their phenotype and morphometric measurements were taken to identify whether the animals were remnants of the Nordestino horse breed. The place where you encourage you to perform the exercise was evaluated in terms of air temperature, relative humidity and black globe temperature, to calculate the thermal comfort index (TCI) and the humidity temperature index (HTI). At air temperature (P<0.0001), relative humidity (P<0.001), black globe temperature (P=0.0260), thermal comfort index (P=0.0010) and humidity temperature index (P=0.0035) there was a significant difference morning (before) and afternoon (after) the exercise. According to the TCI value, it can be seen that the thermoregulatory system was activated before and after exercise. From the thermal gradient (surface temperature-air temperature), the animal dissipated more heat after exercise than stored. These animals proved to be resistant and adapted to the semi-arid climate, reinforcing the adaptive qualities of the local genetic resource.

Keywords: oxygen consumption; heat stress; comfort index.

RESUMO: Objetivou-se com este estudo analisar os parâmetros fisiológicos e a troca de calor de remanescentes equinos da raça Nordestino utilizados na pecuária brasileira, nos exercícios matutinos (antes) e vespertinos (após). Foram avaliados 20 machos castrados com dentição classificada como "boca cheia". Os equinos foram avaliados quanto ao fenótipo e medidas morfométricas foram realizadas para identificar se os animais eram remanescentes da raça Nordestino. O local onde se realizava o exercício foi avaliado quanto à temperatura do ar, umidade relativa e temperatura de globo negro, para cálculo do índice de conforto térmico (ITC) e do índice de temperatura e umidade (ITH). Nas temperaturas do ar (P<0,0001), umidade relativa (P<0,001), temperatura de globo negro (P=0,0260), índice de conforto térmico (P=0,0010) e índice de temperatura e umidade (P=0,0035) houve diferença significativa nos períodos matutino (antes) e vespertino (após) do exercício. De acordo com o valor do ICT, pode-se observar que o sistema termorregulador foi ativado antes e depois do exercício. A partir do gradiente térmico (temperatura da superfície-temperatura do ar), o animal dissipou mais calor após o exercício do que o armazenado. Esses animais demonstraram ser resistentes e adaptados ao clima semiárido, reforçando as qualidades adaptativas do recurso genético local.

Palavras-chave: consumo de oxigênio; estresse por calor; índice de conforto.

INTRODUCTION

Brazilian cattle-catching traditional sporting competition in northeastern Brazil, which takes place in the Caatinga ecosystem, where cowboys enter the bush riding their horses (Andrade; Lins; Marques, 2020). It is a sport takes place under the conditions of semi-arid (Brazilian Northeastern Sertão in the Caatinga biome) that require many horses, that is, when the animals enter the bush after cattle, there is an energy expenditure that leads to changes in physiological patterns.

The regulation of body temperature in homeotherms is ensured by thermolysis and thermogenesis mechanisms (Giannetto *et al*., 2020). Thermoregulatory adjustments can be induced not only by changes in environmental temperature, but also by a variety of physiological situations, including age, fasting, food intake, and stress conditions (Arfuso *et al*., 2022). Therefore, the assessment of body temperature represents a valuable tool for monitoring the physiological state, well-being and stress responses in animals. In fact, under stressful conditions, the animal's reaction focuses mainly on the activation of the sympathetic system and the hypothalamic-pituitary-adrenal axis through the release of effector hormones, such as catecholamines and the production of glucocorticoids, respectively. One of the results of the activation of the sympathetic system is the known stress-induced hyperthermia, which consists of an

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increase in core body temperature with, consequently, changes in the temperature of the epidermis (Arfuso *et al*., 2022).

Physical exercise represents a physiological stress factor for the animal, and requires cardiovascular, respiratory, metabolic responses, and musculoskeletal adaptations in athletes in order to restore homeostasis (Bazzano *et al.*, 2016; Arfuso *et al*., 2020). Environmental temperature, relative humidity, solar radiation and other climatological variables influence heart rate, respiratory rate and surface temperature (Arfuso *et al*., 2022). In addition to these, other factors present in the events, such as the stimuli wich are present on the ambient: the sounds and noises caused by people, the visual and olfactory perception of horses in the competition environment, transportation, the presence of horses outside their social group, and the pressure applied by cowboys, can become negative stimuli and increase cortisol levels in animals (Schmidek, 2018).

Therefore, it is essential to monitor physiological parameters during exercise, as this can guide the intensity and type of effort appropriate to the athletic capacity of each animal (Andrade; Lins; Marques, 2020) and can also promote a better understanding of the adaptation mechanisms, as well as the resulting performances of the animals in this sport. Horses used in sports are more tolerant to thermal stress, especially when exposed to environments with high temperatures and high relative humidity (Noordhuizen; Noordhuizen, 2017). Physical exercise culminates in the production of heat, with around 20% of the chemical energy from the oxidation of nutrients being transformed into mechanical energy, responsible for movement, and the remaining (around 80%) being converted into thermal energy. Under conditions of physical exertion, there is an accumulation of thermal energy, which increases body temperature, which, can lead to a situation of animal thermal discomfort (Carvalho; Mara, 2010).

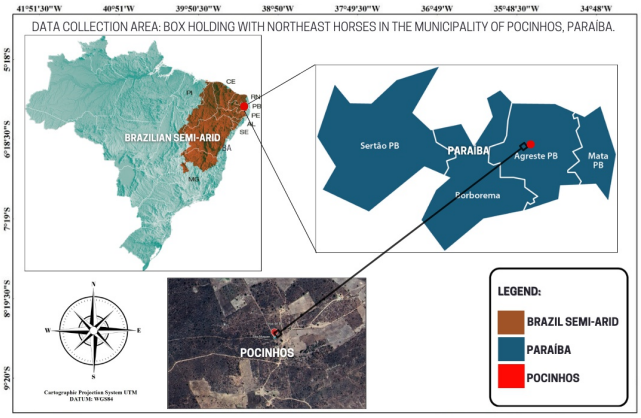
Thermal discomfort triggers thermoregulatory mechanisms like sweating and peripheral vasodilation. This can lead to a decrease in blood pressure, compensated by an increase in heart rate and, subsequently, respiratory rate (Marai; Habeeb, 2010). For horses, heat loss through evaporation is considered the most important, and its effectiveness can be altered due to the influence of environmental factors: air temperature, relative humidity and wind speed. As a result, it is possible to observe characteristic fluctuations in rectal temperature, heart and respiratory rates, surface temperature and high activity of sweat glands (Seabra; Dittrich, 2017). When the animal is in a hot environment with low or moderate relative humidity, under exercise conditions, the sweating process will occur, the objective of which is to increase the efficiency of the evaporative rate, but when subjected to intense exercise, sweating has a negative effect: dehydration. This, in turn, causes a decrease in circulating plasma volume resulting in the activation of baroreceptors and, in a compensatory attempt to maintain adequate tissue perfusion, the heart rate will increase even further (Andrade; Lins; Marques, 2020; Silva; Mariz; Escodro, 2022).

The aim of this study was to analyse the physiological parameters and heat exchange of horses remnants of the Nordestino Horse breed used in cattle handling, before and after the working activity.

MATERIAL AND METHODS

The brazilian cattle-catching took place in the municipality of Pocinhos in the state of Paraíba/Brazil (6°58'44.5"S 36°04'35.1"W) (Figure 1), which has a semi-arid climate according to the Koppen-Geiger classification BSh, with the Caatinga as its predominant biome. It has an annual maximum temperature of 28°C, a minimum of 19°C and an annual average of 22°C, with an average annual rainfall of 386.0 mm, at an altitude of 587 m.

Figure 1 – Municipality of Pocinhos in the state of Paraíba/Brazil.



Source: Author.

We analyzed the horses morphologically (Table 1), and the animals that were considered to be within the Nordestina breed standard were used in the research, 20 geldings stallions were used, their age was determined by their dentition, and they were all between 6 and 7 years old.

The following environmental variables: air temperature (AT °C), relative humidity (RH), and black globe temperature (BGT) were obtained using a HOBO datalogger with an external cable attached to the black globe, and installed at the animals' location. The equipment is an electronic device that records data over time and works like an automatic meteorological station. The datalogger was programmed through its software to record data every fifteen minutes before and during the brazilian cattle-catching. The weather data was recorded from 8 am to 4 pm, but in the statistical analysis we used the data from the period we collected the measurements before and after the animals returned from the brazilian cattle-catching.

The environmental data obtained was calculated:

1. Thermal comfort index (TCI), being: TCI = (AT (°C)*1.8+32)+RH(%), where AT = air temperature (°C) and RH = relative humidity (%) (Jones, 2009).

2. Humidity temperature index (HTI): HTI = (1.8*AT + 32) - (0.55 - 0.55*RH/100)*1.8*AT - 26, where AT = air temperature and RH = relative humidity according to Silva et al. (2018).

Table 1 – Measurements of the Nordestina horse breed used to brazilian cattle-catching.

Variables	Mean ± standard deviation	CV (%)	Min.-Max.
Wither height (cm)	142±0.004	2.79	137-146
Croup height (cm)	140±0.05	3.22	133-145
Body length (cm)	144±0.06	4.21	135-154
Thoracic perimeter (cm)	164±0.05	2.88	156-172
Cannon girth (cm)	0.18±0.009	5.24	0.17-0.20
Substernal void height (cm)	73.08±5.06	6.92	63.00-80.00
Thoracic depth (cm)	66.00±6.07	9.20	49.00-72.00
Head length (cm)	50.85±3.34	6.56	43.00-57.00
Head width (cm)	17.23±1.42	8.26	15.00-19.00
Neck length (cm)	63.00±4.45	7.07	54.00-69.00
Estimated body weight (kg)	347.92±29.99	8.62	413.00-304.00
Observed body weight (kg)	352.69±30.21	8.57	407.00-303.00

Coefficient of variation = CV.

HTI was considered up to 70 in this study, indicating a nonstressful environment, with 71 and 78 critical, between 79 and 83 dangerous, and above 83 emergency conditions.

The 20 animals were measured before exercise (morning), and the same animals were measured after exercise (afternoon). The rectal temperature was measured using a digital clinical thermometer, inserted into the animal's rectum. Heart rate was measured by counting the number of pulses in the facial artery (submandibular) by palpating it (Melo e Onã *et al*., 2022) for 1 minute. Respiratory rate was measured by counting intercostal movements for 1 minute.

O2 consumption was calculated using the equation according to NRC (2008).

O2 consumption = 0.833*beats/minute-(54.7).

The thermal gradient of surface temperature-air temperature (ST-AT) was calculated.

All animals were photographed following international guidelines for performing thermographic imaging in equine clinical practice (Soroko *et al*., 2018), being photographed on the same day in the morning and in the afternoon, and being photographed indoors, protected from wind and solar radiation, to minimize the influence of external environmental conditions.

Images were taken on the right or left side of the animal's body using a non-contact thermal imaging camera (FLIR Therma CAM E60, FLIR Systems, Brazil; emissivity (e) 0.99) (Howell; Dudek; Soroko, 2020). All images were obtained by the same researcher, positioned at a distance of 2.0 m, with temperature sensitivity <0.02 °C from different points of the animal's body (croup and eyes). The images were interpreted using the FLUKE InsideIRTM 4.0 software (FLUKE Corporation, USA) (Sousa *et al*., 2018).

The thermographic camera temperature characteristics defined in this study were the average temperature of a specific shape (rectangle of 65×139 pixels) of the areas studied to define a sub-area of each image. Using the TRI software toolbox, this sub-area (same shape and size) was used for all the other images. The equations used are described in Ribeiro et al. (2024). The calculated mean values of kinematic viscosity (v), density (ρ), thermal conductivity (k), specific heat of the air (Cp) and partial air vapor pressure (ea), as well as the dimensionless values of Nusselt number (Nu), Reynolds number (Re) and Prandtl (Pr) (Table 2).

The outline used was completely casualized with two treatments before and after the exercise, with 20 repetitions. The data are analyzed using the PROC GLM procedure of SAS ondemand (2001) and the means when significant data are compared using the Tukey test.

Table 2 – Mean values of kinematic viscosity, density, thermal conductivity, specific heat of the air and partial air vapor pressure, as well as the dimensionless values of Nusselt number, Reynolds number and Prandtl.

Variables	Morning (before)	Afternoon (after)
Thermal condition (W m^{-1} K)	0,02622	0,02653
Density (kg m^{3-1})	1,16606	1,14567
Specific heat (J kg^{-1} °C)	1006,54	1006,71
Kinematic viscosity (m^2 s^{-1})	0,00001600	0,00001645
Air vapor presure	3,335	3,335
Prandtl number	0,7162	0,7150
Reynold's number	4687,8	4560,5
Nusselt number	47,676	47,077

RESULTS AND DISCUSSIONS

The air temperature (P<.0001), relative humidity (P<.0001), black globe temperature (P=0.0260), thermal comfort index (P=0.0010), and humidity temperature index (P=0.0035) showed a significant difference when considering the effect before and after the exercise. Air temperature, black globe temperature, and HTI were higher in the afternoon, in contrast to RH and TCI (Table 3).

There was an increase of 3.02 °C in the air temperature from the morning (before exercise) to the afternoon (after exercise) and the RH decreased by 10.37%. The TCI values in the morning (before exercise) and afternoon (after exercise) showed values that demonstrate that the animal was subjected to a stressful environment. The TCI helps characterize whether or not the thermal environment during the monitoring period was stressful for the horses. If the TCI < 130 (in ° C <65), the animal is in thermal comfort and the thermoregulatory system is not activated, whereas a TCI > 130 (in °C >65) may indicate that the environment is thermally uncomfortable and heat dissipation may be compromised. The higher respiratory rate may explain this in the afternoon (before exercise) (Table 3). The HTI value shows us that the animal is subjected to a stressful environment either in the morning (before exercise) or in the afternoon (after exercise), as the value was between 71-78 critical stress level and 79-83 in the afternoon dangerous stress level.

Table 3 – Mean ± standard deviation of climate data collected at the brazilian cattle-catching site.

Variables	Morning (before)	Afternoon (after)	P-*value*
Air temperature – AT (°C)	28.12±1.77b	31.14±0.95a	<.0001
Relative humidity – RH (%)	58.64±7.52a	48.27±3.20b	<.0001
Black globe temperature - BGT (°C)	34.53±2.77b	37.38±2.90a	0.0260
Thermal comfort index - TCI	82.60±3.19b	88.06±1.72a	0.0010
Humidity temperature index - HTI	76.89±1.57b	79.49±1.02a	<.0001

Different letters in the line differ from each other by t-test.

The AT was outside the thermal comfort zone for horses, which, according to Morgan (1997), is between 5 and 25°C. These data show that the average daily course of RH is inverse to AT. We remark that the thermal comfort of animals depends on a high degree of relative humidity levels in association with air temperature (Otani *et al*., 2019). Lisboa *et al*. (2023)evaluated horses before and after exercise and observed that the average RH was higher (87.21%) before exercise than after (82.70%).

Santos *et al.* (2022) evaluated Pantaneiro horses under different types of exercises and observed that the comfort index was higher (174.96) than the value recommended by Jones (2009), which is less than 130. The authors suggest that even Pantaneiro horses at rest were under thermal stress. The animals had difficulty releasing heat into the environment due to the already stressful environmental conditions (high temperature and relative humidity).

According to Silva *et al*. (2018), the HTI is considered to be up to 70 as indicative of a non-stressful environment, between 71 and 78 critical, between 79 and 83 dangerous, and above 83, an emergency condition. Lisboa *et al.* (2023) evaluated horses before physical exercise (78.48) and after (80.77) and observed that the HTI was classified as critical and dangerous. This indicates that breeders should avoid exposing animals to the sun and performing physical activities in times of higher air temperature, as thermogenesis can be accentuated. These factors lead to cerebral hyperthermia (Mccutcheon; Geor, 2008).

Rectal temperature (P=0.4356), respiratory rate (P=0.3257), heart rate (P=0.6182), and O2 consumption (P=0.7680) showed no significant difference before and after exercise (Table 4). On the other hand, surface temperature (P<.0001) and the thermal gradient surface temperature - air temperature (P=0.0345) showed significant differences before and after brazilian cattle-catching. Both variables showed higher values after the competition.

Latent heat exchange showed a significant difference (P<0.05) before and after exercise, being higher after exercise, with the cutaneous route being used more than the respiratory route. According to Cunningham (2004) the horse regulates its body temperature between 37.5°C and 38.5°C, measured rectally. As the air temperature rises, the respiratory rate increases, rising above 29°C. Above 30°C, the proportional contribution of respiratory activity decreases due to the increase in heat loss through evaporation of water from the body's surface via sweating (Silva *et al.*, 2005). According to Silva *et al*. (2005) and Titto *et al.* (2009), respiratory activity and sweating complement each other in the sense that animals with a low capacity for sweat secretion normally have a high capacity for panting, this mechanism is used as a thermolytic as a thermolytic pathway for heat loss through evaporation. Mariz *et al*. (2014) analyzed the remaining horses of the Nordestina breed in the Alagoas hinterland and found that the animals had a heart rate of 26.8 mov. Min before tacking up and 32.3 mov.min after tacking up, an increase of 5 mov.min.

The heart and respiratory rate results before and after tacking up prove the adaptive value that native horses have about the environment in which they were developed, selected, and remain. When exposed to thermal comfort conditions, horses' respiratory rate ranges from 8 to 16 mov min-1 (Niedzwied; Kubiak; Nicpón, 2013).

At rest, the equine heart rate varies from 20 to 40 beats per minute (bpm), depending on the animal's

Table 4 – Mean and standard deviation of physiological variables before and after exercise.

Variables	Morning (before)	Afternoon (after)	P-*value*
Rectal temperature (°C)	37.80±0.95a	37.65±0.51a	0.4356
Respiratory rate (mov.min)	38.00±6.36a	35.70±3.86a	0.3257
Heart rate (bat.min)	45.23±12.05a	47.60±9.78a	0.6182
Infrared croup surface temperature (°C)	32.00±2.45b	37.60±1.65a	<.0001
ST-AT thermal gradiente (°C)	2.97±2.81b	6.04±1.64a	0.0345
O2 consumption (ml kg-1)	16.30±10.03a	18.28±8.14a	0.7680
Thermographic photos (°C)			
Croup temperature	35.5±1.44b	40.6±1.59a	0.0123
Eye temperature	31.0±1.22b	34.8±1.32a	0.0254
Thermal exchange (W/m²)			
Radiation	19.05±0.35a	19.48±0.84a	0.0567
Convection	9.44±0.06a	9.20±0.14a	0.6754
Total sensitive	28.34±0.37a	28.77±0.80a	0.2345
Respiratory	35.01±16.00b	38.43±12.00a	0.0234
Cutaneous	44.22±3.16b	49.82±2.50a	0.0345
Total latent	79.91±25.12b	88.25±15.00a	0.0234
Total heat Exchange	107.99±35.05b	116.59±33.58a	0.0345

Different letters in the line differ from each other by t-test; ST=surface temperature; AT= air temperature.

size, breed, age, and temperament, and can quickly reach 100 bpm due to excitement, fear, pain, and in anticipation of exercise. During physical work, the cardiovascular system is responsible for transporting oxygen and energy substrates to the muscle fibers and removing metabolites such as lactate and carbon dioxide (Clayton, 1991). It can be said that these animals are already aroused in the environment where the cattle handing will take place; the external stimuli make them alert even at rest, which justifies the high heart and respiratory rates even before the bullfight.

This increase is linked to the higher demand for oxygen by the tissues, culminating in a greater need for blood pumping and more excellent pulmonary ventilation, which can, in extreme situations, reach a maximum threshold of 210 to 240 beats/min when high-intensity exercise is carried out out (Paludo *et al*., 2002; Cunningham, 2004). The highest surface temperature value after exercise occurs when the horse activates its thermoregulatory system; there is an increase in blood flow from the central region of the body to its periphery, causing peripheral vasodilation in an attempt to eliminate heat, which increases surface temperature (Fonseca *et al*., 2015).

Considering the CI value, it can be seen that the thermoregulatory system was activated before and after tacking, and from the thermal gradient (surface temperature - air temperature), the animal dissipated more heat after tacking than it stored. The convective heat loss system helped these horses adapt to the heat stress caused by the work activity, as it was already around 4ºC higher than the environmental temperature and became 6ºC higher after exercise; a similar result was observed by Mariz *et al.* (2014).

An animal's surface temperature is, on average, 5ºC lower than that of its body core, and this generates an effective mechanism for maintaining homeothermy, as it promotes heat loss from the body core to the skin and from the skin to the environment through the formation of a sequenced thermal gradient (Baeta; Souza, 2010). The most efficient routes in horses are evaporation (sweating and panting), conduction (cooling), and convection (vasodilation). Peripheral vasodilation raises the animal's surface temperature and facilitates heat exchange between the animal and the environment. The effectiveness of this mechanism depends on the thermal gradient between the animal's body temperature and the atmospheric thermal conditions in the área (Souza *et al.*, 2008).

The croup region comprises all the pelvic limb's intrinsic muscles, which provide the propulsion for equine locomotion (Liebich; Konig; Maierl, 2016). Therefore, the surface temperature observed in this region is also the result of internal heat production due to the energy metabolism of the muscles, which transform chemical energy into mechanical energy, generating heat.

According to Seabra and Dittrich (2017) surface heat dissipation in horses is a considerable thermoregulatory challenge, especially during prolonged exercise. To compensate for the low body surface area per weight, it is necessary to increase the rates of cutaneous and respiratory heat loss. During exercise, a greater blood supply needs to reach the working muscles, resulting in an increase in cardiac output of up to 80%. The blood that reaches the skeletal muscle receives the heat produced during muscle contraction and carries it to the internal organs, generating an increase in body temperature. Faced with this increase, the primary thermoregulatory mechanisms are activated, such as peripheral vasodilation, in order to take the heat to the extremities

of the body to be dissipated into the environment (Moura *et al*., 2011; Hodgson, Mckeever, Mcgowan, 2014).

Mariz *et al*. (2014) in research with northeastern horses kept at temperatures of 30 °C, cite values of the average surface temperature before physical exercise of 34.2 °C, rising to 36.1 °C after physical effort. Pavelsk *et al.* (2025) cite average thermographic temperatures of horses kept in a room with a controlled temperature of 21°C was 29.5±0.2°C for the thoracic, 29.8±0.2 °C for the lombar and 28.2±0.2 °C for pelvic regions.

Changes in temperature and blood flow can be visualized through thermal imaging, but there is little information on the thermal impression of horses (Soroko *et al*., 2018; Zaha *et al.*, 2023). At low environmental temperatures, there is a reduction in blood flow in the distal parts, while at high temperatures, vasodilation causes generalized heating of the extremities, favoring heat loss to the environmentenvironment (Marina *et al*., 2020; Zaha *et al*., 2023). Gerardi *et al.* (2019) cite that heat gain occurs through radiation in horses, where the surface of the animal's body absorbs heat from the surrounding environment through long-wave radiation. Gerardi *et al*. (2019) state that even short-term exercise can cause an increase in ocular temperature in horses. The maintenance of ocular temperature in Northeastern horses may be due to their greater natural protection against the sun's rays, such as eyelash pigmentation.

Brownlow and Mizzi (2022) report that immediately after exercise, during the recovery period, cardiac output is redistributed, with blood flow in the skeletal muscles dropping from 80 to 30%, while there is a significant increase in the skin, from 5 to 40%, in order to dissipate heat through perspiration. In addition, 10% is directed to respiratory blood flow, which at rest and during maximum effort did not show significant values.

Although vasodilation facilitates the animal's heat exchange with the environment through sensitive processes, the effectiveness of this depends on the thermal gradient between the animal's body and the ambient temperature

CONCLUSIONS

The animals used to brazilian cattle-catching in the bush are part of the remnants of the Nordestina horse breed. These animals proved to be resistant and adapted to the semi-arid climate, reinforcing the adaptive qualities of the local genetic resource. As the animals are subjected to prolonged exercise, this increases heat loss through the surface of the skin. Under heat stress and prolonged exercise, the most efficient route of heat loss is latent evaporation.

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