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Heat tolerance in naturalized Brazilian cattle breeds☆

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Abstract

Research carried out at the Sucupira Farm of Embrapa Recursos Genéticos e Biotecnologia, in Brasilia-DF, aimed to evaluate heat tolerance in five naturalized and two exotic breeds of cattle, at different temperatures and humidity, based upon physiological and blood parameters. The data collected included heart rate (HR), rectal temperature (RT), respiratory rate (RR), and sweating rate (SR). Blood was also collected for hemogram analysis and cortisol level. The measurements were taken at 7 am and at 2 pm after the animals were exposed to the sun, with water *ad libitum*. This procedure was repeated for six days, three in the middle of the dry season when temperatures and humidity were lower and three at the start of the rainy season when temperatures and humidity were higher. Significant statistical differences were observed in RR and HR for day, breed and animal within breed. The analysis indicated that the Junqueira and Nellore breeds are most adapted to climatic conditions in Brasilia; while Mocho Nacional and Holstein breeds were the least adapted. Although sample size is limited, these results are important to identify which breeds are most resistant towards climatic variations observed in the Brasilia region, as well as which physiological parameters are the most indicated for use in animal breeding programs intended to select animals and breeds adapted to thermal stress conditions.

Keywords: Bioclimatology; Conservation; Genetic resources; Heat stress

1. Introduction

In the search for equilibrium between the environment and animal genotype, the adaptability factor is a constant worry (Euclides Filho et al., 1999), with heat tolerance being one of the more important aspects. The adaptability or capacity to adapt can be estimated by the ability of the animal to adjust to average environmental conditions, as well as climatic extremes. According to Baccari Jr (1986), well adapted animals are characterized by the maintenance of homothermia and/or minimum loss of production performance (weight gain and milk production) during stress, high reproductive efficiency, high resistance to illness, longevity and low mortality rates.

In Brazil, various breeds of naturalized breeds of cattle were developed from Iberian breeds that were introduced by the colonizers. According to Mariante and Egito (2002), these animals were distributed over all the national territory and, through natural selection, they adapted to the environmental conditions. These breeds

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developed unique adaptive characteristics to the natural environment and specific production systems (Bicalho, 1985). In recent decades animal breeding programs have aimed to develop highly efficient and specialized groups of animals which have substituted these more adapted breeds (Mariante and Egito, 2002).

The need to preserve less productive breeds has received more attention in recent years as the possibility to transfer genes which promote adaptive traits to highly productive animals has become a possibility. More information is needed on these naturalized breeds to identify possible genes of interest and rational development of future breeding programs, as well as to assist in germplasm conservation programs.

Brazilian native bovine breeds have developed from those brought by the colonizers soon after the discovery. Over the centuries, these breeds have been submitted to natural election in the environment, so that they present specific characteristics for these usually harsh conditions (Primo, 1993; Mariante and Cavalcante, 2006). With importation, at the beginning of the last century, of some exotic breeds, mainly zebus, the native animals have gradually been substituted for the exotic ones, making most of them threatened with extinction. Although the exotic breeds are considered more productive, they do not necessarily possess the adaptation and resistance to illnesses and parasites found in the native breeds. Muller (1989) stated that climatic factors, such as temperature, relative humidity, wind speed and solar radiation, may cause stress. These factors interact causing greater or lesser degrees of stress thereby affecting growth, milk production, reproductive success etc. In a previous study conducted in the dry (winter) season of 2002, McManus et al. (2005) evaluated some physiological measures of heat tolerance (heart, sweating and respiratory rate, and rectal temperature) as well as body measurements (cannon bone and thoracic circumference, body length and shoulder height, number of hairs per cm^2 and hair length) in five naturalized Brazilian breeds, one tropcally adapted beef breed, one tropically adapted beef breed (Nellore) and one European dairy breed (Holstein). In the current study, conducted in 2004 and 2005, we evaluated these same physiological measures as well as several blood parameters in the same seven breeds to further investigate heat tolerance in naturalized Brazilian cattle breeds.

2. Materials and methods

Cattle from the Brazilian Animal Germplasm bank on the Sucupira Farm of EMBRAPA Genetic Resources and Biotechnology Research Center near Brasilia, Brazil were used in this study. All animals were acclimatized (Horowitz, 2001) although natural habitats for the breeds examined varied.

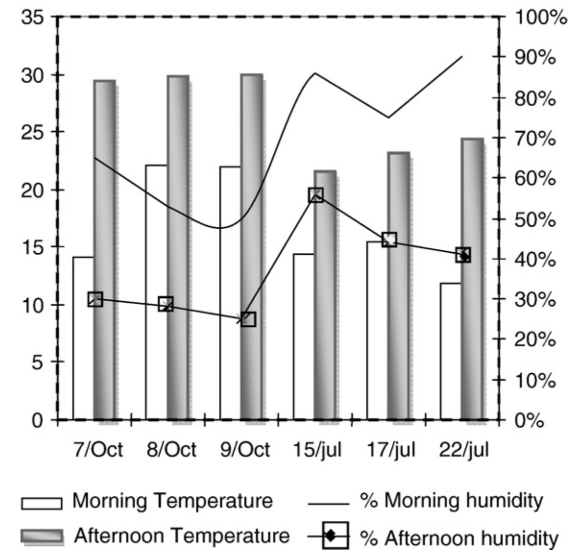

Fig. 1. Climatic factors during the experimental period.

Fifty two animals from naturalized Brazilian cattle breeds: Curraleiro (19), Crioulo Lageano (12), Pantaneiro (10), Junqueira (6) (all *Bos taurus ibericus*) and Mocho Nacional (5) (*taurus ibericus*×*Bos taurus aquitanicus*), as well as eighteen from commercial breeds: eight Holstein (*Bos taurus taurus*) and Nellore (*Bos taurus indicus*), were selected randomly from those available. All animals were adults, and cows were non-lactating and non-pregnant.

These animals did not show any symptoms of illness. The animals were grazed in an extensive system on *Brachiaria decumbens* pasture, receiving mineral salt (Fosbov®[2]) *ad libitum*.

Data was collected at 7am and 2pm on six occasions. Environmental data is shown in Fig. 1. Heart rate (HR) was measured using a stethoscope and stop watch, respiratory rate (RR) was taken by counting flank movements and rectal temperature (RT) was determined using a thermometer against the rectum wall for 3 min. Sweating rate (SR) was measured using the technique described by Schleger and Turner (1965) by immersing Whatman #1 filter paper in a 10% aqueous solution of Cobalt Chloride which was then dried in air and then in an oven at 90 °C. The paper was then cut in 0.5 cm^2 disks, three of which were fixed to a microscope slide with cellotape and stored in a closed jar with silica gel until use. The animal skin was shaved and dried 20 cm below the vertebrae (McDowell et al., 1961) and the cellotape with the three disks were placed over this area. The change of the disk colour from blue to pink was timed. SR was calculated

[2] Tortuga®.

Table 1
Summary for variance analysis of physiological traits in Brazilian Naturalized cattle breeds

	RT	RR	HR	SR	CORT
R^2	0.74	0.69	0.66	0.67	0.99
CV	1.55	23.03	15.21	26.20	14.59
Mean	38.72	31.59	68.12	244.40	13.771
Breed	*	***	***	ns	*
Day	***	***	***	ns	**
Day*breed	*	ns	**	ns	ns
Time	***	***	ns	*	**
Time*Breed	ns	ns	ns	ns	ns
Day*Time	***	***	ns	ns	ns
Day*Time *Breed	*	ns	ns	ns	ns
Animal(Breed)	0.1	***	***	ns	ns
Sex	ns	ns	ns	ns	ns
Breed					
Crioulo Lageano	38.74^a	33.84^b	$64.41^{a,b}$	242.12^a	$14.753^{a,b}$
Curraleiro	38.75^a	$30.97^{b,c}$	70.72^a	250.74^a	11.559^c
Holstein	39.02^b	32.72^b	62.64^b	258.52^a	$13.823^{a,b,c}$
Junqueira	38.67^a	26.37^d	69.88^a	234.21^a	$14.742^{a,b}$
Mocho Nacional	38.77^a	38.83^a	70.63^a	258.61^a	$13.555^{a,b,c}$
Nellore	38.63^a	27.71^d	$68.93^{a,b}$	224.61^a	$12.024^{b,c}$
Pantaneiro	$38.80^{a,b}$	33.28^b	69.88^a	252.47^a	15.876^a
Time					
Morning	38.31^a	28.56^a	67.60^a	236.56^a	25.867^a
Afternoon	39.03^b	33.88^b	68.81^a	251.47^b	33.281^b
Sex					
Male	38.76^a	32.66^a	69.54^a	234.01^a	13.462^a
Female	38.69^a	30.85^b	67.15^b	250.96^a	13.974^a
Reference values	38–39.3[1]	10–35[2]	50–80[3]	90–275[4]	15[5]

* $P<0.05$; ** $P<0.01$; *** $P<0.001$; ns—not significant; R^2—coefficient of determination; cv—coefficient of variation; HR—heart rate (beats/min); RR—respiratory rate (movements/min); RT—rectal temperature (°C), SR—sweating rate ($g\,m^{-2}\,h^{-1}$), CORT—cortisol level (ng/mL). Means in the same column followed by different letters are significantly different ($P<0.05$) by the Tukey test. [1]Rosenberger, 1993; [2]Swenson and Reece, 1996; [3]Silva, 2000; [4]Smith, 1993; [5]Tume and Shaw, 1992 (base line).

using the following equation: $S=38.446{,}6\times t$ ($gm^{-2}h^{-1}$) (grams per square meter per hour) according to Schleger and Turner (1965) where t is the time in second for color change to occur.

Blood was collected by caudal venopuncture using vacutainer with EDTA when the physiological traits were measured. The number of erythrocytes, leukocytes and the concentration of hemoglobin were carried out in an automatic cell counter (CC550, Cellm™). The hematimetric parameters (Mean Corpuscular Volume—MCV and Mean Corpuscular Hemoglobin Concentration—MCHC) were determined by calculation. The number of neutrophils, eosinophils, lymphocytes, monocytes, and basophils were determined by manual counting of 100 cells in Wright-stained blood smears under optical microscope.

Packed cell volume (PCV in %) was determined using capillary tubes in microcentrifuge based on the technique described by Wintrobe (1976). The concentration of total plasma proteins (TPP in g/100 ml) was determined using a manual refractometer and the plasma retained in a capillary tube.

Blood samples without anticoagulant were submitted to centrifugation by 1600 ×g for 5 min in order to obtain serum. This was then transferred to sterile glass flasks and stored at −20 °C for future cortisol level determination. Cortisol concentrations were determined using commercial kits (Kit CORT CI_2) based on cortisol marked with radioactive Iodine (^{125}I). Readings were taken using an ^{125}I gama counter. A standard curve was

Table 2
Blood parameters for naturalized and exotic cattle breeds in central Brazil

	PCV	ERY	HB	MCV	MCHC	TPP
R^2	0.73	0.67	0.82	0.68	0.47	0.60
CV	10.98	12.67	8.60	9.72	12.58	6.50
Mean	33.18	6.70	12.54	50.00	37.81	7.31
Breed	***	***	***	*	ns	*
Day	***	***	***	**	**	***
Day*Breed	ns	*	ns	***	ns	ns
Time	**	ns	**	ns	ns	**
Time*Breed	ns	ns	ns	ns	ns	ns
Day*Time	ns	ns	ns	ns	ns	**
Day*Time *Breed	ns	ns	ns	ns	ns	ns
Animal(Breed)	***	***	***	***	*	***
Sex	ns	ns	ns	ns	ns	ns
Breed						
Crioulo Lageano	32.06^d	6.24^b	12.03^c	51.31^a	38.03^a	7.34^a
Curraleiro	$34.32^{b,c}$	6.97^a	13.21^b	50.36^a	38.94^a	7.34^a
Holstein	37.72^e	6.27^b	10.10^d	44.36^b	36.77^a	7.34^a
Junqueira	$32.71^{c,d}$	6.20^b	12.49^c	52.96^a	38.33^a	7.40^a
Mocho Nacional	$35.03^{a,b}$	6.96^a	13.29^b	50.58^a	36.66^a	$7.23^{a,b}$
Nellore	$3305^{b,c,d}$	7.23^a	12.22^c	45.93^b	36.27^a	6.99^b
Pantaneiro	36.80^a	6.94^a	14.01^a	53.38^a	38.51^a	7.50^a
Time						
Morning	34.61^a	6.78^a	12.96^a	51.29^b	37.21^a	7.37^b
Afternoon	32.09^b	6.62^a	12.19^b	48.91^a	38.34^b	7.27^a
Sex						
Macho	32.40^b	6.91^a	$12{,}07^a$	47.15^b	$37{,}01^a$	7.15^a
Female	33.72^a	6.55^b	$12{,}86^b$	51.87^a	$38{,}34^b$	7.42^b
Reference Value[1]	24–46	5–10	8–15	40–60	30–36	7–8.5

* $P<0.05$; ** $P<0.01$; *** $P<0.001$; ns—not significant; R^2—coefficient of determination; cv—coefficient of variation; [1]Jain, 1993; PCV—packed cell volume; ERY—erythrocytes; HB—hemoglobin concentration; Mean Corpuscular Volume—MCV; Mean Corpuscular Hemoglobin Concentration—MCHC; TPP—total plasma proteins. Means in the same column followed by different letters are significantly different ($P<0.05$) by the Tukey test.

used to calculate concentration in nmol/L and converted to ng/mL using the equation Cortisol (ng/ml) = Cortisol nmol/l × 0.3625.

Statistical analyses were carried out using the PROC MIXED procedure in the Statistical Analysis System® package. The general linear model included day (six), time of day (morning and afternoon), breed (seven), their interactions and sex as fixed effects. Animal within breed was fitted as a random effect. Other analyses included correlations, principal components and Euclidean distances were calculated between breeds based on the parameters measured.

3. Results

The summary of variance analysis and means for principal fixed effects for physiological traits are presented in Table 1. In general, breed and time of day were significant factors affecting the traits examined. The interaction between time of day and breed was not significant for any of the traits examined, meaning that the breeds reacted in the same manner independent of time of day.

Breed was generally a significant source of variation for blood parameters in cattle (Table 2) except for MCHC. Means for erythrogram data were within reference values for cattle (Silveira, 1988; Jain, 1993), except for MCHC that were higher in all breeds. Increasing in MCHC should be caused by sample hemolisis, as a real one it's not possible to occur.

Table 3 shows the summary of analysis of variance for white cell parameters. There were significant differences between breeds for all parameters examined. There was slight leukocytosis for the Holstein (13840) and Curraleiro (12380) breeds.

The first two autovectors are shown in Fig. 2. An increase in RT was accompanied by an increase in SR, RR, PCV, HB and monocytes as well as a decrease in lymphocytes, leukocytes, and basophils while TPP, MCV and MCHC remained unaffected. A second group of traits showed an increase in hemoglobin, TPP and MCHC accompanied by a decrease in MCV and other

Table 3
White blood cell analysis in naturalized and commercial cattle breeds in Brazil

	LEU	SEG	EOS	BAS	LINF	MON
R^2	0.47	0.51	0.58	0.77	0.44	0.81
CV	39.28	50.76	70.43	96.67	56.23	56.35
Mean	11.40	2801.18	1632.93	351.83	5319.72	1582.11
Breed	*	*	**	*	*	**
Day	ns	ns	ns	ns	ns	***
Day*Breed	ns	ns	ns	ns	ns	ns
Time	ns	ns	ns	*	ns	*
Time*Breed	ns	ns	ns	ns	ns	ns
Day*Time	ns	ns	ns	***	ns	ns
Day*Time*Breed	ns	ns	ns	ns	ns	ns
Animal(Breed)	*	ns	***	*	ns	***
Sex	ns	ns	ns	ns	ns	*
Breed						
Crioulo Lageano	11,600^{a,b}	3022.90^{a,b}	2159.78^{a}	289.45^{b}	4847.87^{b}	1508.56^{b,c,d}
Curraleiro	12,380^{a,b}	3318.80^{a}	2002.57^{a}	322.98^{b}	5134.85^{b}	2303.00^{a,b}
Holstein	13,840^{a}	3280.75^{a}	2193.56^{b,c}	665.21^{a}	7356.00^{a}	1774.34^{a,b,c}
Junqueiro	11,940^{a,b}	2793.23^{a,b}	1201.79^{b,c}	430.26^{a,b}	5782.89^{a,b}	2128.89^{a}
Mocho Nacional	7900^{c}	1729.24^{c}	1549.00^{a,b}	294.87^{b}	3955.56^{b}	843.78^{e}
Nellore	10,500^{b,c}	2674.01^{a,b}	1010.67^{c}	373.24^{a,b}	5238.34^{b}	1303.12^{c,d,e}
Pantaneiro	10,280^{b,c}	2226.00^{b,c}	1808.64^{a,b}	217.68^{b}	5004.98^{b}	1154.12^{d,e}
Time						
Morning	11,580	2684.11	1607.57	256.77^{a}	5775.80	1368.72^{a}
Afternoon	11,250	2920.56	1658.81	474.76^{b}	4861.09	1798.14^{b}
Sex						
Male	11,370	2935.43	1333.7	343.45	5220.90	1736.65
Female	11,430	2712.67	1830.54	356.67	5384.84	1480.91
Reference Values	4–12	600–4000	0–2400	0–200	2500–7500	25–840

Leukocytes (LEU—/μL); Neutrophils (NEUT—/μL); Eosinophils (EOS); basophils (BAS—/μL); lymphocytes (LINF—/μL), monocytes (MON—/μL); * $P<0.05$; ** $P<0.01$; *** $P<0.001$; ns—not significant; R^2—coefficient of determination; CV—coefficient of variation. Means in the same column followed by different letters are significantly different ($P<0.05$) by the Tukey test.

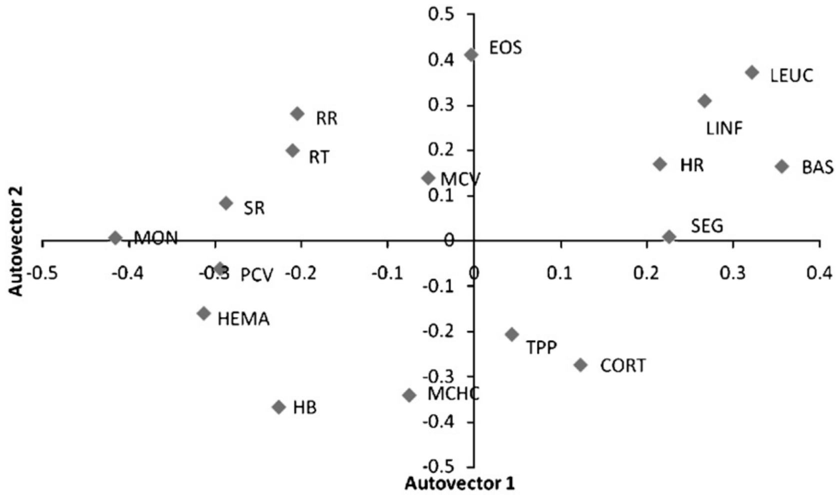

Fig. 2. First two autovectors for blood and physiological traits in naturalized and exotic cattle in Brazil. Rectal temperature (RT), respiratory rate (RR), heart rate (HR), packed cell volume (PCV), total plasma proteins (TPP), erythrocytes (ERY) hemoglobin concentration (HB), Leukocytes (LEU); neutrophils (NEU); eosinophils (EOS); basophils (BAS); lymphocytes (LINF), monocytes (MON); sweating rate (SR).

white cell parameters. The relationship shown in the first autovector is to be expected, since sweating and increased RR are the primary reactions of the body in releasing heat (Swenson and Reece, 1996).

The tree diagram (Fig. 3) shows that the Holstein breed (*B. taurus taurus*) and Mocho Nacional (cross between *B. taurus aquitanicus* with *B. taurus ibericus*) are closest as well as Curraleiro with Pantaneiro. The Junqueira (*B. taurus ibericus*) and Nellore with the Crioulo Lageno formed the last group.

4. Discussion

Differences between breeds of sheep and cattle (McManus and Miranda, 1997; McManus et al., 1999) as well as horses (Paludo et al., 2002) for these traits measured in the Federal District of Brazil were also noted.

Rectal temperature varied between 39.02 (Holstein) and 38.63 (Nellore), but these are within normal range for cattle. Some individual animals presented values above reference values, especially for Holstein, Pantaneiro and Mocho Nacional breeds. RT may vary between 38.1 °C and 39.1 °C for beef cattle, 38.0 °C and 39.3 °C, for dairy cattle (Robinson, 1999) and 38.0 °C to 39.0 °C in adult cattle generally (Dirksen et al., 1993). The physiological reference for these traits is between 38 and 39.5 °C under thermoneutral conditions (DuPreez, 2000). Similar results were found by Ferreira et al. (2006) with crossbred cattle. It should be noted that in its natural habitat, the Pantanal (or swamp land) of Mato Grosso state, under intense heat these animals (Pantaneiro cattle) immerse themselves in the water to cool down, which was not possible in this experiment.

The mean difference for Holstein cattle between the morning and afternoon for RT was 1.4 °C. All other breeds showed differences below 1.1 °C with the lowest variation for the Crioulo Lageano breed (0.41). This breed was developed in a region of Brazil with very high temperature fluctuations.

RT is frequently used as an adaptability index in hot environments as its increase means that heat dissipation mechanisms have become insufficient to maintain homeothermia (Mota, 1997). Significant differences were observed between breeds in their ability to regulate

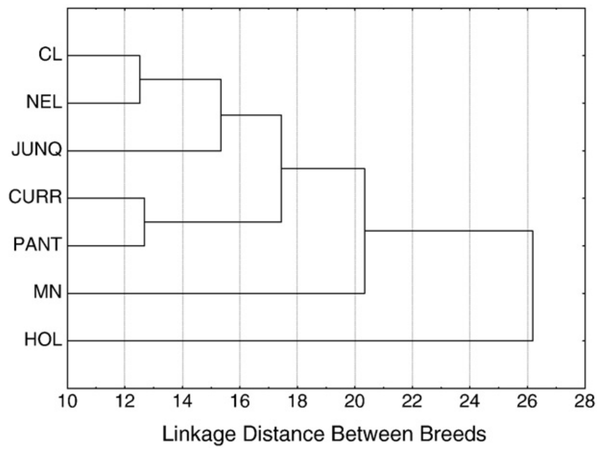

Fig. 3. Tree diagram for mean Euclidean distances between breeds of cattle in Brazil using physiological and blood traits. Mocho Nacional (MN); Holstein (HOL), Pantaneiro (PANT), Curraleiro (CURR), Junqueira (JUNQ), Nellore (NEL) and Crioulo Lageano (CL).

this trait. Breeds derived from *B. taurus* have a lower capacity to prevent increase in RT compared with those derived from *B. indicus*.

The RR mean variation for the Holstein cattle between morning and afternoon was the highest for all breeds (5.7) and the lowest (0.38) was for the Junqueira. In McManus et al. (2005), lowest variations were found for the Pantaneiro breed. Differences here may be due to the higher afternoon temperatures in this experiment and the fact that no significant time of day * breed effects were found in the earlier study. Kellaway and Colditz (1975) also noted that the RR in pure *B. taurus* breeds was higher than in crossbred Holstein–Zebu animals.

The RR in this study were significantly lower for Nellore and Junqueira breeds ($P<0.05$). This is in agreement with McManus et al. (2005). Nevertheless, measurements were within reference limits for cattle. Heat transfer during respiration is an efficient form of heat loss. Swenson and Reece (1996) stated that basal respiration rate in cattle is approximately 20 breaths per minute. Therefore, an increase in respiration up to 40 may be considered as a tachypnea. Normal RR in adult cattle is between 24 and 36 respiratory movements per minute (mov/min) (Stober, 1993), but may vary between 12 and 36 mov/min (Terra, 1993).

Mean HR were within reference values for this species Swenson and Reece, 1996, varying between 62.64 (Holstein) and 70.72 (Pantaneiro). Once again the fact that the Pantaneiro could not take refuge in water may have led to this increased HR. No significant differences were found between time of day for this trait. It should also be noted that respiration and sweating are more efficient forms of heat loss in this species. When heat loss is not controlled by evaporation, the animal then depends on increased HR to lose heat and prevent an increase in body temperature. Silva (2000) studied the variation in HR with a compensatory fall in blood pressure caused by peripheral vasodilation in cattle, but this was not efficient due to the high body mass of the animals examined.

Mean sweating rates (SR) were within normal ranges (Smith, 1993) for all breeds in this experiment. Seven animals showed individual measurements outside this range, mainly in the afternoon and on a single day in the wet (summer season). It should also be noted that the Pantaneiro had a relatively high SR (although not significant), possibly due to its adaption to different environmental conditions (wet) than those studied here. This data is in agreement with that noted by Carvalho et al. (1995) as to the size and shape of sweat glands where Nellore (*B. indicus*) showed larger baggy shaped glands compared with the coiled glands of *B. taurus* cattle. Silva (2000) stated that SR increases with increasing external temperature and the Zebu cattle are more efficient in using this method than other types. Bertipaglia et al. (2007) noted an average sweating rate for Braford cattle in Mato Grosso do Sul State, Brazil of 319.97 g m^{-2} h^{-1}, which they considered as a favorable value for animals bred in a tropical environment. Silva et al. (1988) observed lower values for Jersey cows in São Paulo State, Brazil, between 123.3 g m^{-2} h^{-1} (Riberão Preto) and 113.3 g m^{-2} h^{-1} (São Carlos). On the other hand, Schleger and Turner (1965) obtained higher values for Hereford × Shorthorn (488 g $m^{-2}h^{-1}$) and Brahman × Shorthorn cattle (500 g m^{-2} h^{-1}) cattle during summer in Australia. Animals adapted to hot climates tend to show higher SR, reduction in HR and RT (Cheung and McLellan, 1998). In McManus et al. (2005), sweating rates varied from 215.22 g $m^{-2}h^{-1}$ for Nellore to 323.22 $gm^{-2}h^{-1}$ for Mocho Nacional; with an overall mean of 266.79 for all breeds, while here mean sweating rates varied from 224.61 g m^{-2} h^{-1} for Nellore to 258.61 g m^{-2} h^{-1} for Mocho Nacional, with a mean of 244.40 g m^{-2} h^{-1}. These lower means may be due to lower overall environmental temperatures.

Selye (1978) stated that a stress response leads to the liberation of Corticotropin-releasing hormone (CRH) which acts on cells in the anterior lobe of the pituitary to release adrenocorticotropic hormone (ACTH). This in turn stimulates the adrenal cortex, more specifically, the secretion of glucocorticoids (GC) such as cortisol (Sapolsky et al., 2000). According to this latter author, the relationship between GC and stress is complex.

The largest daily increase in PCV was for Holstein (4.32) and lowest for Curraleiro (1.78). An increasing in PCV could be caused by dehydration (higher sweating rate) or by splenic contraction (exercise, fear and stress). In this case, the most probably cause is dehydration, as animals were submitted to heat stress.

TPP concentration relative to a reference interval is used as a broad clinical indicator of health, stress, and well being of terrestrial and aquatic organisms. Lowest values were observed for the Nellore breed. TPP could also be an indicative of plasma reduction, helping in diagnose of dehydration as well as PCV. The highest variation in TPP was also found for Holstein (0.25) but was lowest for Pantaneiro (0.00).

PCV and TPP indicated that Holstein animals were more dehydrated than the others, probably because of the amount of water loss caused by homoeothermic mechanisms. Lowest variation in erythrocytes was for the Curraleiro (0.04) and highest for Crioulo Lageano (0.43) and Nellore (0.45), but this variation could be considered too low to have any significant meaning.

White cells are mostly produced in the bone marrow and other hematopoietic tissues. These include neutrophils, eosinophils, lymphocytes (T e B), monocytes, basophils as well as tissue macrophages and reticular cells from the spleen and bone marrow (Silveira, 1988). The leukogram takes into consideration the total leukocyte count and their morphological alterations. It is used to characterize systemic stress, acute or chronic inflammatory processes, leukemia, and etc.

Jain (1993) and Lassen and Swardson (1995) proposed that physiological leukocytosis normally occurs in stressed animals mediated by the liberation of epinephrine and corticosteroids. Glucocorticosteroides released endogenously typically produce leukocytosis caused by neutrophilia and also induce lymphopenia. Monocytosis occurs inconsistently in cattle. Neutrophilia occurs mainly from the mobilization of segmented neutrophils from the bone marrow reserve and from the decreased diapedesis of cells into the tissues. Lymphopenia occurs mainly from lympholysis in the blood and lymphoid tissue, or from the margination and sequestration of lymphocytes in extravascular sites. The cause of monocytosis remains unknown (Jain, 1993). Breed also affects global leukometry (Jain, 1993; Lassen and Swardson, 1995).

Variation between morning and afternoon in terms of white cell counts per breed included a significant decrease in lymphocytes for Holstein (2446) compared with the other breeds which were less than 1400, with lowest variation for Pantaneiro (43). The greatest increase in neutrophils was for the Mocho Nacional breed (523) followed by Crioulo Lageano (240) and Holstein (147) with lowest for Junqueira (22) and Nellore (30). Highest increase in total number of leukocytes was also for Pantaneiro (0.91) together with Holstein (1.41) while Nellore showed a slight decrease (0.09).

Mean levels were within reference values for cattle (Silveira, 1988). In general the Holstein showed the highest heat stress and the Nellore showed the least, as can be seen by RT and RR levels. Although means were not significantly different, the Nellore also showed lowest SR.

SR had a low and sometimes negative correlation with other traits (Table 4). There was a high correlation between RT and RR (0.70) meaning that an increase in RT was associated with an increase in RR. High correlations were also observed between PCV and HB. Paludo et al. (2002) also noted low and negative correlations between blood and physiological traits in horses in the same region of Brazil.

The distances shown in the tree diagram above are compatible with those found by Serrano et al. (2004) working with RAPD markers in the same breeds. In this latter study the introduction of zebu genes into the Crioulo Lageano, Mocho Nacional and Pantaneiro breeds was noted. In the earlier study (McManus et al., 2005) the Holstein and Mocho Nacional breeds were also closest, while the Nellore was closest to the Junqueiro breed. The closeness between Nellore (*B. taurus indicus*) and Crioulo Lageano (*B. taurus ibericus*) found here may be due to crosses between cows in the Crioulo Lageano conservation nucleus in the 1980s with Nellore bulls (Mariante,

Table 4
Correlation coefficients between heat tolerance measures in naturalized and commercial cattle breeds in Brazil

	RT	BR	HR	PCV	MCV	TPP	ERY	HB	MCHC	LEU	SEG	EOS	BAS	LINF	MON	SR
BR	0.70															
HR	0.23	0.28														
PCV	−0.19	−0.13	0.13													
VCM	−0.16	−0.13	−0.08	0.48												
TPP	−0.12	−0.07	−0.13	0.26	0.22											
HEMA	−0.09	−0.04	0.18	0.64	−0.32	0.14										
HB	−0.13	−0.09	0.14	0.83	0.21	0.24	0.68									
CHCM	0.17	0.10	−0.02	−0.37	−0.49	−0.13	0.00	0.19								
LEUC	0.07	0.05	0.02	−0.06	−0.04	0.01	−0.02	−0.06	0.08							
SEG	0.14	0.06	0.02	−0.14	−0.05	−0.05	−0.07	−0.14	0.06	0.67						
EOS	−0.06	−0.06	−0.18	0.07	0.19	0.09	−0.06	0.08	0.05	0.55	0.30					
BAS	0.03	0.06	0.03	−0.14	−0.09	0.03	−0.02	−0.16	−0.04	0.42	0.36	0.12				
LINF	−0.15	−0.08	−0.02	0.05	−0.03	0.08	0.08	0.06	−0.02	0.82	0.33	0.32	0.39			
MON	0.49	0.35	0.31	−0.26	−0.20	−0.14	−0.12	−0.22	0.10	0.32	0.21	−0.07	−0.20	−0.03		
SR	0.14	0.05	−0.24	0.18	−0.09	0.21	−0.13	−0.08	0.21	−0.08	0.01	0.09	−0.32	−0.28	0.2 2	
CORT	−0.51	−0.34	0.01	0.13	0.10	0.00	0.07	0.09	−0.05	0.13	0.15	−0.09	0.29	0.13	0.20	0.08

Rectal temperature (RT), respiratory rate (RR), heart rate (HR), packed cell volume (PCV), mean corpuscular volume (MCV); total plasma proteins (TPP), erythrocytes (ERY) hemoglobin concentration (HB), mean corpuscular hemoglobin concentration (MCHC); Leukocytes (LEU); neutrophils (NEU); eosinophils (EOS); basophils (BAS); lymphocytes (LINF), monocytes (MON).

2000). In McManus et al. (2005) the Crioulo Lageano was closer to Curraleiro breed.

Cattle breeds in Brazil are distributed over a country which is continental in size and specific breeds can normally only be found in certain regions of the country with unique environmental characteristics. An attempt was made in this study to compare these animals in a single environment. Since sample size per breed is limited and the conditions under which this study was carried out may be very different to the natural environment to which the breed is adapted, further studies are necessary to confirm results found here.

5. Conclusions

In terms of this study it was shown that the Nellore (*B. taurus indicus*) was the best adapted to heat stress conditions. For the naturalized breeds, the Junqueira (*B. taurus ibericus*) was the best adapted and Mocho Nacional (*B. taurus ibericus*×*B. taurus aquitanicus*) least well adapted. The Holstein breed suffered most with the increased heat.

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