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Thermoregulation of Girolando cows during summertime, in Pernambuco State, Brazil

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ABSTRACT. This work was carried out to evaluate the physiological thermoregulation responses of Girolando-breed dairy cows kept in feedlot during summertime. A total of 15 animals were used, belonging to three genetic groups: 1/2, 5/8 and 3/4 Holstein-Gir (HG), with five cows from each genetic group, distributed in a completely randomized design, in subplots. The physiological parameters were sweat rate (SR), respiratory rate (RR), epidermis temperature (ET) and coat surface temperature (CST), and were evaluated once a week, during nine weeks, from December 2009 to February 2010, totaling 135 observations. Throughout the experimental period, climatic data were recorded using an automated weather station, and later used to calculate the different thermal comfort indexes: THI (temperature-humidity index), BGHI (black globe temperature and humidity index) and RTL (radiant thermal load). 1/2 HG animals showed the highest SR and lowest RR, ET and CST of all three genetic groups, while 3/4 HG cows had the lowest mean SR and highest ET and CST. 5/8 HG cows had intermediate values for SR, ET and CST. Mean RR values did not differ between 5/8 and 3/4 HG cows. It was concluded that animals from genetic groups 3/4 and 5/8 HG showed greater sensibility to heat stress than 1/2 HG cows.

Keywords: dairy cattle raising, heat stress, physiological parameters.

Termorregulação de vacas da raça Girolando no período de verão, no Estado de Pernambuco, Brasil

RESUMO. Este trabalho foi realizado com o objetivo de avaliar as respostas fisiológicas de termorregulação de vacas leiteiras da raça Girolando, no período de verão, mantidas em confinamento. Foram utilizados 15 animais de três grupos genéticos: 1/2, 5/8 e 3/4 Holandês-Gir (HG), sendo 05 vacas de cada grupo genético, distribuídas num delineamento inteiramente casualizado, em parcelas subdivididas. Os parâmetros fisiológicos: taxa de sudação (Tsud), frequência respiratória (FR), temperatura da epiderme (TE) e temperatura de superfície de pelame (TSP) dos animais foram avaliados uma vez por semana, durante nove semanas, de dezembro de 2009 a fevereiro de 2010, totalizando 135 observações. Durante todo o período experimental os dados climáticos foram registrados através de uma estação meteorológica automática, e usados posteriormente para calcular os índices de conforto térmico: ITU (índice de temperatura e umidade), ITGU (índice de temperatura de globo e umidade) e CTR (carga térmica radiante). Os animais 1/2 HG apresentaram Tsud mais alta e FR, TE e TSP mais baixas nos três grupos genéticos, enquanto nas vacas 3/4 HG foram verificadas as médias mais baixas de Tsud e mais altas de TE e TSP. As vacas 5/8 HG ficaram em posição intermediária para os valores de Tsud, TE e TSP. A média de FR dos animais 5/8 e 3/4 HG não diferiram entre si. Concluiu-se que animais de grupos genéticos 3/4 e 5/8 HG demonstram maior sensibilidade ao estresse pelo calor que as vacas 1/2 HG.

Palavras-chave: bovinocultura de leite, estresse pelo calor, parâmetros fisiológicos.

Introduction

Milk production in Brazil has undergone significant transformations as a result of the current worldwide economic reality, which aims to increase productivity by employing modern technologies, while also abiding by principles of sustainability and animal wellbeing during production. This new production model aims to minimize animal stress caused by the production environment, which is important for the physiological and economic efficiency of exploration.

Exposure to environments with high effective temperature reduce heat loss efficacy and increase animal stress, limiting the productive potential expression of dairy cattle due to the activation of physiological mechanisms of thermoregulation for heat dissipation (WEST, 2003). Whenever the ambient temperature exceeds the upper critical limit of the thermoneutral zone, heat dissipation by non-evaporative means becomes inefficient, causing the thermal balance to be maintained by evaporative means, which do not depend on the temperature gradient between animal and environment. The homeostatic response includes increased sweating, respiratory rate and body temperature (core and surface alike) (PERISSINOTO et al., 2007).

The capacity of animals to withstand the thermal environments to which they are exposed is proportional to their ability to dissipate heat, especially by sweating, thus reducing respiratory evaporation. This is more adequate for tropical climate environments (HANSEN, 2004), given the intense radiation to which these animals are subjected most of the time (SILVA et al., 2007). The sweat rate is an adaptive trait that varies between breeds and among individuals of a given breed. Zebu cattle are able to better regulate body temperature in response to thermal stress than *Bos taurus* species, due to the low metabolic heat production and greater sweating ability of the former (HANSEN, 2004).

Zebu-taurine crossbreeding is done in order to increase milk production potential in the tropics. The Girolando breed, resulting from the cross between Holstein and Gir species, has shown good adaptability (FACÓ et al., 2005) and is currently part of Brazil's dairy herd, at various degrees of crossing or in the pure synthetic 5/8 Holstein-Gir, contributing with a significant share of the milk produced in the country. Nevertheless, the different genetic makeups of the various groups that constitute the Girolando breed can result in different responses to heat stress, particularly for the genetic groups with genetics closer to *Bos taurus* species.

Climate conditions and the effects of the thermal environment on the physiological responses of dairy cattle of European origin have been monitored, providing important data and contributing to characterize heat stress situations (ARCARO JÚNIOR et al., 2005; MARTELLO et al., 2004; PERISSINOTO et al., 2007). However, few works have been carried out based on observations with animals belonging to the different genetic groups that make up the Girolando breed, establishing thermoregulation standards for these animals when raised in tropical environments.

Thus, this work was carried out to evaluate the physiological responses to heat stress of 1/2, 5/8 and 3/4 Holstein-Gir Girolando cows in feedlot, in summertime, and compare these genetic groups with regard to their adaptability to environmental conditions.

Material and methods

The research was carried out at Avimalta Farm, located in Paudalho, Pernambuco State, Brazil. The municipality is located in the Pernambuco "Zona da Mata", northern forest micro region, elevation of 70 m at 7°54' south and 35°8' west. The rainy season lasts from March to July, with average annual rainfall of 1634 mm. According to the Köppen classification, the region's climate is As' (humid tropical with hot summers); high and low temperatures happen in December and July, respectively (CPRM, 2005).

Experimental data were recorded between December 2009 and February 2010, during nine consecutive weeks. Two weeks prior to the start of the experiment, an adjustment process was begun for the animals to adapt to the handling and measurements of physiological parameters. A total of 15 multiparous Girolando cows were used for the evaluation, registered by the Brazilian Girolando Breeders Association, averaging 530 kg, with five animals from each of the following genetic groups: 1/2, 5/8 and 3/4 Holstein-Gir (HG), selected from a herd of 105 lactating cows. The average daily milk production for each genetic group was 10.7, 12.1 and 11.8 kg for groups 1/2, 5/8 and 3/4, respectively.

The animals were kept in an open-air feedlot featuring a concrete floor area with a salt lick and collective trough for feeding, covered with fiber cement tile. The remaining area was a dirt field, featuring two drinkers and natural shading provided by the following tree species: *Prosopolis juliflora*, *Eugenia jambolona*, *Ficus benjamim* and *Mangifera indica*. The animals were fed twice a day, after milking, with chopped elephant grass *ad libitum*, cactus pear, brewer's yeast and concentrate prepared and distributed in accordance with the farm's handling system.

Automatic milking was carried out twice a day, at 4 a.m. and 2 p.m., and milk production was controlled with biweekly checks by the farm.

Animal sweat rate was evaluated once a week (Mondays), during nine consecutive weeks, for a total of 135 observations. Measurements were taken only in the afternoon, always after the cows were milked, using the colorimetric method of Scheleger and Turner (1965), which consisted of observing the time required for three paper disks to change color from violet blue to light pink, affixed on the flank of each animal in an area previously shaved and cleansed with rubbing alcohol and ether. The disks were prepared using #1 Whatman chromatography paper, 0.5 cm in diameter, immersed in cobalt chloride hexahydrate, and oven dried at 90°C until becoming violet blue. After being dried, the disks were affixed with adhesive tape onto glass slides and kept in a desiccator until the time of use. The adhesive tape with the paper disks was removed from the slide and immediately and firmly affixed onto the skin in the flank region. The time required for each disk to change color was determined using a digital stopwatch, always by the same observer. The average between the values observed in the three disks was used in the following equations, proposed by Silva (2000): SR = 38446.6019 t^{-1}, in which *SR* is the sweat rate in g m^{-2} $hour^{-1}$; *t* is the average time, in seconds, until color changed in all three disks.

For each sweat rate observation, the respiratory rate (RR) and the temperatures of the epidermis (ET) and coat surface (CST) of each cow were obtained simultaneously. The respiratory rate was measured by counting the respiratory movements in the flank of animals during 30 seconds. The value found was multiplied by two in order to obtain the number of respiratory movements/min. ET and CST were calculated using a digital infrared thermometer with laser sight, placed near the skin and coat (at the same site used to evaluate the sweat rate), on the flank region.

An automated weather station was installed in the vicinity of where the animals were kept, in order to monitor the thermal environment. The station was programmed to record, every three hours, data on air temperature (aT), relative air humidity (RH), wind speed (WS), global solar radiation (sR) and rainfall (RF), as well as daily records of the high and low aT, RH and accumulated daily rainfall. All recorded data were stored in the station's Datalogger and transferred weekly to a computer.

A globe thermometer was placed next to the station to obtain the black globe temperature (Bgt), measured every two hours, on the same days as the evaluation of physiological parameters. Bgt was used both to calculate the black globe temperature and humidity index (BGHI) according to Buffington et al. (1981), and to obtain the radiant thermal load (RTL), using the equation cited by Esmay (1979). THI was calculated using the equation proposed by Kelly and Bond (1971).

The averages of the environmental variables (aT, RH, Bgt, WS) and comfort indexes (THI, BGHI and RTL) were calculated using the values of those variables recorded between 3 and 5 p.m., on the days in which the sweat rate and other physiological parameters were assessed; these measurements were later used in statistical analyses.

The experimental design was completely randomized, in subdivided plots, with data recording dates in the subplot and genetic groups in the main plot, with five replications. The obtained data were initially subjected to the assumptions of normality and homoscedasticity. For those variances that did not show normal distribution, the data were converted into a decimal logarithm. Pearson correlations were performed between the meteorological variables and physiological parameters, and an analysis of variance of physiological parameters was carried out. Once the assumptions of the ANOVA were satisfied, the means were compared by Newman-Keuls test at a 0.05 level of significance. All statistical procedures were performed using SAEG (2007), version 9.1.

Results and discussion

The values of air temperature (Table 1) - average temperature (28.2°C) and mean high temperature (31.9°C) - were above the upper limit of the thermoneutral zone for lactating cows, which according to Yousef (1985) are between 5 and 25°C. In addition, the critical THI values determined by Azevedo et al. (2005) for 1/2 and 3/4 crossbred cows (79 and 77, respectively) were exceeded, indicating that the animals spent periods under THI conditions above the upper critical limit of the thermoneutral zone, characterizing heat stress. It was also observed that the Bgt, with mean value of 32.1°C and maximum of 34.3°C was higher than the value of 29°C cited by Beede et al. (1983) as the critical Bgt capable of interfering with performance of dairy cows.

Table 1. Mean values and variation of climatic elements and thermal comfort indexes recorded on the days and times of evaluation of physiological parameters during the summertime.

	Mean	Variation	
aT (°C)	28.2	26.7	29.3
Tmax (°C)	31.9	29.8	33.5
Tmin (°C)	23.1	21.7	24.3
RH (%)	68.9	60.8	75.6
Bgt (°C)	32.1	27.7	34.3
WS (m s^{-1})	2.3	1.2	3.0
THI	78.5	77.1	80.1
BGHI	81.5	77.2	84.0
RTL (W m^{-2})	576.9	479.2	637.6

aT – air temperature; Tmax – high temperature of the day; Tmin – low temperature of the day; RH – Relative Air Humidity; Bgt – black globe temperature; WS – wind speed; THI – temperature-humidity index; BGHI – black globe temperature and humidity index; RTL – radiant thermal load.

Relative humidity, which presented a mean value of 68.9% and maximum of 75.6%, can be considered high for summertime. According to Pires and Campos (2003), hot and humid areas can compromise the productive performance of dairy cattle whenever air temperature is higher than 21°C combined with RH equal to or greater than 60%, adversely affecting the thermoregulation of animals. The observed mean of 2.3 m s^{-1} for wind speed represents a benefit by contributing to convective heat loss, relieving the sensation of heat and improving the thermal comfort of animals.

The black globe temperature and humidity index (BGHI) showed mean value of 81.5 and maximum value of 84.0, which according to the classification of the National Weather Service - USA (NWS, 1976) can characterize a situation of danger to dairy cattle from *Bos taurus* species. However, for crossbred cows, which are more tolerant to heat, the impact is the same and the physiological responses are likely different. Radiant thermal load showed values of 576.9 and 637.6 w m^{-2} for mean and maximum RTL, respectively. This index is directly linked to the thermal exchanges by radiation that take place between animal and environment, which according to Silva (2008) can represent the difference between a comfortable or stressful environment. It is important to remember that the experimental animals were kept in an open-air feedlot, but with good availability of natural shade (where they remained most of the day), which reduces the impact of direct solar radiation, decreasing heat storage and favoring the maintenance of constant body temperature.

No interaction was found ($p > 0.05$) between genetic groups and experimental days for all physiological parameters evaluated, demonstrating that the variations in these parameters occurred in all three genetic groups, regardless of the day under evaluation.

Animals of group 1/2 HG showed higher sweating rates ($p < 0.05$) than the 5/8 and 3/4 HG genetic groups (Table 2). The higher sweat rate observed in 1/2 HG animals, whose mean value was 127 g m^{-2} h^{-1}, is in accordance with the results found by Pires et al. (2010), who also verified higher mean SR for 1/2 Holstein/Zebu cows (197.5 g m^{-2} h^{-1}) when compared to the mean values of the 3/4 (147.3 g m^{-2} h^{-1}) and 7/8 HZ genetic groups (133.7 g m^{-2} h^{-1}), which did not differ from one another.

Table 2. Mean values and standard deviations of the physiological parameters of Girolando cows during summertime.

	Physiological parameters			
GG	SR (g m^{-2} h^{-1})	RR (mov $min.^{-1}$)	ET (°C)	CST (°C)
1/2 HG	127.0 (± 35.1)a	42.0 (± 10.1)b	33.9 (± 1.4)c	33.4 (± 1.2)c
5/8 HG	104.9 (± 17.0)b	49.5 (± 12.5)a	34.6 (± 1.5)b	34.0 (± 1.3)b
3/4 HG	90.5 (± 11.5)c	58.0 (± 23.5) a	35.2 (± 1.4)a	34.7 (± 1.6)a
CV (%)	4.0	7.3	4.1	4.0

Means followed by different letters in the columns differ from one another ($p < 0.05$) by Newman-Keuls test. GG – genetic group; SR – sweat rate; RR – respiratory rate; ET – epidermis temperature; CST – coat surface temperature; CV – coefficient of variation.

The body's ability to lose heat to the environment under thermal stress conditions becomes essential to maintain body temperature in equilibrium. Thus, the ability of an animal to resist high temperatures is proportional to its capacity to eliminate latent heat through water evaporation, which is considered the main way to dissipate thermal energy in animals, as it does not depend on a temperature gradient between animal and environment (MAIA et al., 2005; SILVA; STARLING, 2003). In cattle, heat loss through evaporation occurs mainly by sweating when aT exceeds 21°C, representing approximately 80% of total evaporative losses (MAIA et al., 2005; PIRES; CAMPOS, 2003). Zebu animals are able to better regulate body temperature than *Bos taurus* species in response to thermal stress, by increasing the sweat rate, which is much higher than that of taurines (HANSEN, 2004).

Based on this information, the response of 1/2 HG cows to the higher SR (127.0 g m^{-2} h^{-1}) compared to the average observed for 5/8 (104.9 g m^{-2} h^{-1}) and 3/4 HG animals (90.5 g m^{-2} h^{-1}) indicates a better thermoregulatory ability by these animals with stronger Zebu genetics. This advantage in evaporative heat loss through sweating occurred in all the days that were evaluated sweat rates of genetic groups, as is shown in Figure 1. It can be seen that the rates of sweating of the 1/2 HG animals was always higher (over 100 g m^{-2} h^{-1}) that observed rates for the animals 5/8 HG, and especially when compared with rates 3/4 HG cows, which did not exceed in any of the evaluations 100 g m^{-2} h^{-1}. According to Silva and Starling (2003), selecting animals with high sweating rates can be an alternative to develop improvement programs for dairy cows raised in tropical environments.

However, the mean SR values for all three genetic groups throughout the experimental period (Figure 1) were below the results found by other authors who also evaluated this same thermoregulation trait in crossbred cattle (FERREIRA et al., 2009; PIRES et al., 2010; SOUSA JÚNIOR et al., 2008). This result may be related to the fact that the experimental animals remained during a large part of the day under the canopy of trees in the feedlot area, throughout the experiment, especially at the most stressful times of the day; the same was observed by Borges et al. (2012) while evaluating the behavior of the same animals used in the present study. That means the animals were not sufficiently challenged to the point of stimulating their sweat glands to produce more sweat. According to Scheleger and Turner (1965), the amount of sweat produced depends, in addition to the anatomical and histological characteristics of the sweat glands, on a high ambient temperature, which will lead to increased blood flow to the epidermis, providing greater stimulus and materials so that maximum sweating capacity can be reached.

Maia et al. (2005) observed that at temperatures between 10 and 20°C, skin evaporation represented 20 to 30% of total heat dissipated by the body of cattle. When the temperature exceeded 30°C, skin evaporation reached 85% of total evaporative losses.

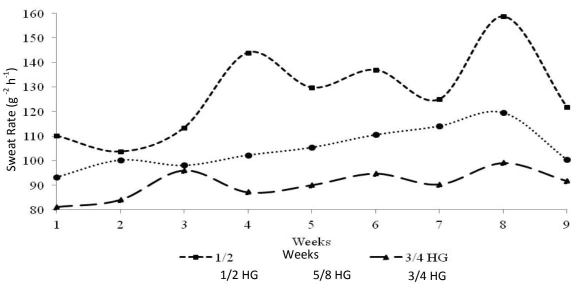

Figure 1. Variation in the sweat rate of 1/2, 5/8 and 3/4 HG Girolando cows during the experimental period.

This result shows the need to provide shade that can afford an environment of favorable thermal comfort, particularly when lactating cows are kept under grazing.

However, even though it did not show particularly high mean values, SR proved to be a very efficient thermoregulation mechanism under a stressful environment, as the 1/2 HG cows, which had the highest mean SR, had lower RR (42 mov. $min.^{-1}$) than 5/8 (49.5 mov. $min.^{-1}$) and 3/4 HG animals (58.0 mov. $min.^{-1}$), which did not differ from one another, as shown in Table 2. A similar result was observed by Ferreira et al. (2009), who verified that 1/2 HG crossbred cattle with higher sweat rates used RR with less intensity. Pires et al. (2010) regarded the higher sweating rates of 1/2 Holstein/Zebu (HZ) cows as a decisive factor fort the lower variations in RR that group presented compared to 3/4 and 7/8 HZ animals.

Although skin evaporative heat loss was used more efficiency, animals from the 1/2 HG genetic group showed average RR (42 mov. $min.^{-1}$) above the physiological limit, which according to Stober (1993) is between 24 and 36 mov. min^{-1}. The cows from groups 5/8 and 3/4 HG followed the same pattern, with mean RR and 49.5 mov. $min.^{-1}$ and 58.0 mov. $min.^{-1}$, respectively. The increase in RR indicates that the animals from all three genetic groups had to activate the physiological adaptation mechanism of heat dissipation, through respiratory evaporative heat loss, in order to reduce the impact of thermal stress imposed by the combination of climatic factors, especially by the higher values observed for THI throughout the entire experimental period.

The variations in RR depend on the intensity and duration of the stress to which the animals are subjected. According to Silanikove (2000), RR between 40 and 60 mov $min.^{-1}$ is indicative of mild stress; that is, according to the mean values observed in the present study (Table 2), all three genetic groups, at least during some times of the day, were under heat stress. The increase in respiratory rate, when used for short periods of time, represents an important mechanism of body heat loss (PIRES; CAMPOS, 2003). However, when used for long periods of time, this strategy results in reduced feed intake and rumination, in addition to diverting energy that should be used in productive processes (KADZERE et al., 2002).

Significant differences ($p < 0,05$) were found for the mean values of ET and CST between the three genetic groups (Table 2), showing for both physiological variables that the cows in group 1/2 HG had significantly lower values (33.9°C for ET and 33.4°C for CST) when compared to those observed for 5/8 HG (34.6 and 34.0°C for ET and CST, respectively) and 3/4 HG animals, for which these parameters were the highest ($p < 0.05$) among all three genetic groups, with mean values for ET equal to 35.2°C, and CST equal to 34.7°C.

Body surface temperature depends mainly on the conditions of air temperature, humidity, solar radiation and air speed, in addition to individual animal physiological characteristics, such as vascularization and evaporation by sweating, contributing to maintain body temperature through heat exchanges with the environment (PERISSINOTO et al., 2007). Surface regions show more variable temperature, more dependent on the influences of the external environment (FERREIRA et al., 2006; MAIA et al., 2005).

Thus, the result found in this work, with 1/2 HG cows showing the highest sweating rates and lowest ET and CST among all three genetic groups, once again reflects the superior ability of this group featuring genetic composition closer to the Zebu breed in performing evaporative heat loss by sweating. According to Baeta and Souza (2010), as evaporative losses increase, a significant portion of heat is removed from the epidermis by vaporization; as water passes from the liquid to gaseous state (vapor), it removes a certain amount of heat, resulting in reduced body temperature and cooling the blood that circulates through the skin, reducing surface temperature.

Conclusion

Animals of group 1/2 HG demonstrate greater adaptability to heat, in the summertime, when compared to genetic groups 3/4 and 5/8 HG.

Were suggest further studies comparing the physiological responses associated with milk production between the different groups that form the blood Girolando involving the economic viability of the use of more productive genotypes less thermotolerant in warmer regions.

References

ARCARO JÚNIOR, I.; ARCARO, J. R. P.; POZZI, C. R.; FAVA, C. C.; FAGUNDES, H.; MATARAZO, S. V.; OLIVEIRA, J. E. Respostas fisiológicas de vacas em lactação à ventilação e aspersão na sala de espera. **Ciência Rural**, v. 35, n. 3, p. 639-643, 2005.

AZEVEDO, M.; PIRES, M. F. A.; SATURNINO, H. M.; LANA, A. M. Q.; SAMPAIO, I. B.; MONTEIRO, J. B. M. Estimativa de níveis críticos superiores de índice de temperatura e umidade para vacas leiteiras 1/2, 3/4 e 7/8 Holandês-Zebu em lactação. **Revista Brasileira de Zootecnia**, v. 34, n. 6, p. 2000-2008, 2005.

BAETA, F. C.; SOUZA, C. F. **Ambiência em Edificações Rurais – Conforto Animal**. 2. ed. Viçosa: UFV, 2010.

BEEDE, D. K.; MALLONEE, P. G.; SCHNEIDER, P. L.; WILCOX, C. J.; COLLIER, R. J. Potassium nutrition of heat-stressed lactating dairy cows. **South African Journal of Animal Science**, v. 13, n. 3, p. 198-200, 1983.

BORGES, C. R. A.; AZEVEDO, M.; LIMA, I. A.; BRASIL, L. H. A.; FERREIRA, M. A. Heterogeneous genetic cows of three genetic groups in feedlot system in the state of Pernambuco, Brazil. **Acta Scientiarum. Animal Sciences**, v. 34, n. 1, p. 91-91, 2012.

BUFFINGTON, D. E.; COLLAZO-AROCHO, A.; CANTON, G. H.; PITT, D. Black Globe-Humidity Index (BGHI) as comfort equation for dairy cows. **Transactions of the ASAE**, v. 24, n. 3, p. 711-714, 1981.

CPRM-Serviço Geológico do Brasil. **Projeto cadastro de fontes de abastecimento por água subterrânea**: diagnóstico do Município de Paudalho Estado de Pernambuco. Recife: CPRM/Prodeem, 2005.

ESMAY, M. L. **Principles of animal environment**. Westport: The AVI Publishing Company, 1979. (Environmental Engineering in Agriculture and Food Series).

FACÓ, O.; LOBO, R. N. B.; MARTINS FILHO, R.; LIMA, F. A. M. Idade ao primeiro parto e intervalo de parto de cinco grupos genéticos Holandês x Gir no Brasil. **Revista Brasileira de Zootecnia**, v. 34, n. 6, p. 1920-1926, 2005.

FERREIRA, F.; PIRES, M. F. A.; MARTINEZ, M. L.; COELHO, S. G.; CARVALHO, A. U.; FERREIRA, P. M.; FACURY FILHO, E. J.; CAMPOS, W. E. Parâmetros fisiológicos de bovinos cruzados submetidos ao estresse calórico. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 58, n. 5, p. 732-738, 2006.

FERREIRA, F.; CAMPOS, W. E.; CARVALHO, A. U.; PIRES, M. F. A.; MARTINEZ, M. L.; SILVA, M. V. G. B.; VERNEQUE, R. S.; SILVA, P. F. Taxa de sudação e parâmetros histológicos de bovinos submetidos ao estresse calórico. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 61, n. 4, p. 763-768, 2009.

HANSEN, P. J. Physiological and cellular adaptations of Zebu cattle to thermal stress. **Animal Reproduction Science**, v. 82/83, n. 1, p. 349-360, 2004.

KADZERE, C. T.; MURPHY, M. R.; SILANIKOVE, N.; MALTZ, E. Heat stress in lactating dairy cows: a review. **Livestock Production Science**, v. 77, n. 1, p. 59-91, 2002.

KELLY, C. F.; BOND, T. E. Bioclimatic factors and their measurements. In: National Academy of Sciences. **A guide to environmental research on animals**. Washington, D.C.: National Academy of Science, 1971.

MAIA, A. S. C.; SILVA, R. G.; LOUREIRO, C. M. B. Sensible and latent heat loss from the body surface of Holstein cows in a tropical environment. **International Journal of Biometeorology**, v. 50, n. 1, p. 17-22, 2005.

MARTELLO, L. S.; SAVASTANO JÚNIOR, H.; SILVA, S. L.; TITTO, E. A. L. Respostas fisiológicas e produtivas de vacas holandesas em lactação submetidas a diferentes ambientes. **Revista Brasileira de Zootecnia**, v. 33, n. 1, p. 181-191, 2004.

NWS-National Weather Service. Central Region. **Livestock Hot Weather Stress**. Regional Operations Manual Letter, C-31-76, Washington, D.C: National Academy Press, 1976.

PERISSINOTO, M.; MOURA, D. J.; CRUZ, V. F. Avaliação da produção de leite em bovinos utilizando diferentes sistemas de climatização. **Revista Ciências Agrárias**, v. 30, n. 1, p. 135-142, 2007.

PIRES, M. F. A.; CAMPOS, A. T. Relação dos dados climáticos com o desempenho animal. In: RESENDE, H.; CAMPOS, A. T.; PIRES, M. F. A. (Org.). **Dados climáticos e sua utilização na atividade leiteira**. 1. ed. Juiz de Fora: CNPGL, 2003. v.1, p. 250.

PIRES, M. F. A.; AZEVEDO, M.; SATURNINO, H. M. Adaptação de animais mestiços em ambiente tropical. **Informe Agropecuário**, v. 31, n. 258, p. 30-38, 2010.

SCHELEGER, A. V.; TURNER, H. G. Sweating rates of cattle in the field and their reaction to diurnal and seasonal changes. **Australian Journal of Agricultural Research**, v. 16, n. 1, p. 92-106, 1965.

SILANIKOVE, N. Effects of heat stress on the welfare of extensively managed domestic ruminants. **Livestock Production Science**, v. 67, n. 1, p. 1-18, 2000.

SILVA, R. G. **Introdução à bioclimatologia animal**. São Paulo: Nobel, 2000.

SILVA, R. G. **Biofísica ambiental**: os animais e seu ambiente. São Paulo: Funep, 2008.

SILVA, R. G.; STARLING, J. M. C. Evaporação cutânea e respiratória em ovinos sob altas temperaturas ambientes. **Revista Brasileira de Zootecnia**, v. 32, n. 6, p. 1-6, 2003.

SILVA, R. G.; MORAIS, D. A. E. F.; GUILHERMINO, M. M. Evaluation of thermal stress indexes for dairy cows in tropical regions. **Revista Brasileira de Zootecnia**, v. 36, n. 4, p. 1192-1198, 2007.

SOUSA JÚNIOR, S. C.; MORAIS, D. A. E. F.; VASCONCELOS, A. M.; NERY, K. M.; MORAIS, J. H. G.; GUILHERMINO, M. M. Características termorreguladoras de caprinos, ovinos e bovinos em diferentes épocas do ano em região semi-árida. **Revista Científica de Produção Animal**, v. 10, n. 2, p. 127-137, 2008.

STOBER, M. Identificação, anamnese, regiões básicas da técnica do exame clínico. In: ROSEMBERG, M. (Ed.). **Exame clínico dos bovinos**. 3. ed. Rio de Janeiro: Guanabara Koogan, 1993. p. 419.

SAEG-Sistema de Análises Estatísticas e Genéticas. **Manual do Usuário**. Versão 9.1. Viçosa: UFV, 2007.

WEST, J. W. Effects of heat stress on production in dairy cattle. **Journal of Dairy Science**, v. 86, n. 3, p. 2131-2144, 2003.

YOUSEF, M. K. **Stress physiology in livestock**. Boca Raton: CRC Press, 1985.

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