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Evaporative heat loss in *Bos taurus*: Do different cattle breeds cope with heat stress in the same way?

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ABSTRACT

The aim of this study was to compare two Portuguese (Alentejana and Mertolenga) and two exotic (Frisian and Limousine) cattle breeds in terms of the relationship between the increase in ambient temperature and the responses of the evaporative heat loss pathways and the effects on homeothermy. In the experiment, six heifers of the Alentejana, Frisian, and Mertolenga breeds and four heifers of the Limousine breed were used. The animals were placed in four temperature levels, the first one under thermoneutral conditions and the other ones with increase levels of thermal stress. When submitted to severe heat stress, the Frisian developed high thermal tachypnea (125 mov/min) and moderate sweating rates (117 g m^{-2} h^{-1}), which did not prevent an increase in the rectal temperature (from 38.4 °C to 40.0 °C). Moderate increases in rectal temperature were observed in the Alentejana (from 38.8 °C to 39.4 °C) and Limousine (from 38.6 °C to 39.4 °C), especially in the period of highest heat stress. The Limousine showed moderate levels of tachypnea (101 mov/min) while showing the lowest sweating rates. The Alentejana showed significant increases in sweating rate (156 g m^{-2} h^{-1}) that played a major role in homeothermy. The Mertolenga showed a superior stability of body temperature, even in the period of highest heat stress (from 38.5 °C to 39.1 °C). Uncommonly, the maintenance of homeothermy during moderate heat stress was achieved primarily by intense tachypnea (122 mov/min). The sweating rate remained abnormally low under conditions of moderate heat stress, rising significantly (110 g m^{-2} h^{-1}) without evidence of stabilization, only when tendency for heat storage occurred. This unusual response of the evaporative heat loss pathways infers a different thermoregulatory strategy, suggesting a different adaptation to semi-arid environment and strong association with water metabolism.

1. Introduction

In a hot environment, heat loss efficiency is essential in maintaining homeothermy (Bligh, 1998). The ability to change blood flow to the periphery is a feature of all vertebrates and it is a part of their evolutionary process as one of the first physiological functions of thermoregulation. Finch (1985) observed that the *Bos indicus* cattle has higher conductance than *Bos taurus*. Pereira et al. (2008) reported marked differences between sensible heat losses in *B. taurus* breeds during different levels of heat stress. Nevertheless, the increase of the environmental temperature leads to an inevitable evaporative cooling (Gebremedhin et al., 1983; Hansen, 2004). Evolutionarily, pulmonary heat loss seems to precede the sweating (Bligh, 1998). The ability to sweat seems to be a relatively recent product of evolution. In wild and domestic bovines, both sweating and pulmonary heat loss had relevance in homeothermy, although this relative importance is different among species (Jessen, 2001). McLean (1963) showed that European cattle (*B. taurus*) under heat stress dissipated about 75% of latent heat through sweating and within zebu (*B. indicus*) sweating rate still has a major role on heat loss (Finch et al., 1982). Under thermal stress, high respiratory rate is often associated with low heat tolerance (Gaughan et al., 2000). Thus, the higher heat loss ability tends to be dependent on sweating rate ability (Schmidt-Nielsen, 1995). The sweating rate progression is different between *B. taurus* and *B. indicus* (Hahn et al., 1997). In *B. indicus*, increased sweating rate occurs at higher ambient temperatures and the progress is usually superior to *B. taurus*. In *B. taurus*, the stabilization of sweating rate is often observed before rectal temperature reached 40 °C, which does not seem to occur with *B. indicus*, where sweating rate increases without an apparent plateau. However, some results concerning *B. taurus* breeds suggest that significant

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differences may occur in the use of evaporative heat loss with consequences on the ability to maintain homeothermy in different environments (Scharf et al., 2010).

In Mediterranean climate during hot and dry summers, it was observed that animals from different native breeds had different grazing behaviors. The smallest breed remained eating in the sun for a longer time, while showing high respiratory rate. This apparent contradiction supports the idea that the two routes of evaporative heat loss could have different relative importance between breeds

This study aimed to compare the relationship between the controlled increase in ambient temperature and the responses of the evaporative heat loss pathways and the effects on homeothermy in different *B. taurus* cattle breeds.

2. Materials and methods

The experiment was carried out in two climatic chambers, each of 45 m^2 (4.5 m × 10 m), that enabled simultaneous housing of the 12 animals (6 in each chamber). Air temperature control was achieved by heating or chilling the airflow entering the chamber from six openings, placed at 2.8-m height, along its longitudinal axis. The air was heated using a gas boiler, and was cooled by passing through chilled serpentines. Humidity control was carried out using humidifiers and recorded by hygrothermograph. The environmental climatic parameters inside the chambers were set through a main control center, placed outside the chambers. The maintenance of the selected environmental parameters was automatically controlled by temperature/humidity sensors placed in the entrance, in the center and in the exit of the climatic chambers. The temperature and humidity control system responded very rapidly and precisely to the elicited thermal changes. The system has a low thermal inertia. After changing the thermal parameters of the climatic chambers, the new temperature and humidity were reached approximately within 50 min with an accuracy ±1 °C. Twenty-two heifers with similar age were used (20 ± 3 months) consisting of 6 Alentejana, 6 Mertolenga (*B. taurus* Portuguese native cattle breeds), 4 Limousine, and 6 Frisian. The initial average body weights were 450.3 ± 27.8 kg, 308.2 ± 31.3 kg, 470.3 ± 39.3 kg, and 403.8 ± 15.5 kg, respectively. Three months before the experiment, the animals were handled, head haltered and trained, to decrease reactivity and obtain a better adjustment to the new management and environment.

Due to the limited space of the two chambers, the experiment was conducted during two followed trials. The heifers were kept in individual stalls (3.0–1.1 m) and restrained by a head halter. Based on previous results (pilot test), which have found some heterogeneity in thermal tolerance among breeds, the decision was made to put only animals of the same breed in each chamber. Therefore, this decision has avoided major differences in the intensity of thermal stress among breeds and meant better individual control. Each trial lasted 16 days, 4 for adaptation and 12 for data collection. The adaptation period (under thermoneutral conditions) was only for the adjustment or habituation of the animals to the physical environment and to the various routines they would face during the test. To identify the intensity of the evaporative thermolysis responses, the experiment was designed with four different periods, the first one in thermoneutrality and the other three with increasing thermically stressful conditions (Table 1). Based on previous results, the cycles of the chambers temperature during the fourth period were different among breeds. Due to lower heat tolerance of the Limousine and Frisian breeds, the maximum chamber temperature was 36 °C compared with 40 °C for the Alentejana and Mertolenga.

Diet was composed of 85% maize silage and 15% sunflower meal (Table 2). Food and water were available ad libitum, with fresh food provided twice per day at 08:30 and 16:30 h. Complete mineral mixture supplementation was provided ad libitum. Water was provided using automatic waterers and measured through a dispenser (accuracy ±0.01 l). Daily water (wt) intakes were expressed on a metabolic weight base (body weight $^{0.75}$). Respiratory frequencies (RF) were measured by observing costal movements during 30 s. Rectal temperatures (RT) were measured using a digital thermometer (Digitron, with an 8-cm flexible probe). Respiratory frequency and rectal temperature measurements were carried out every day at 08:00, 12:00, 15:00, and 18:00 h. Sweating rates were measured all days at 14:00 h using a methodology described by Schleger and Turner (1965) and modified by Pereira et al. (2010). All procedures concerning the animals were approved by the welfare committee, with guidance of the European Union Laboratory Animal Experimentation Regulations, supervised by FELASA-trained scientists. Different statistical models were used to analyze different variables. Respiratory frequency and rectal temperatures data were analyzed according to a general linear model procedure with three fixed factors and one nested factor:

$$Y_{ijklm} = \mu + B_i + B(A)_{i(j)} + P_k + H_l + B.\,P_{ik} + B.\,P_{il} + P.\,H_{kl} + B.\,P.\,H_{ikl} + \varepsilon_{ijklm}$$

where Y_{ijklm} are the observed values of rectal temperature or respiratory rate or skin temperature, μ is the observed mean value, B_i is the fixed effect of breed; $B(A)_{i(j)}$ is the nested effect of an animal within breed, P_k is the fixed effect of temperatures period, H_l is the fixed effect of the hour, $B.P_{ik}$ is the interaction breed–period, $B.H_{il}$ is the interaction breed–hour, $P.H_{kl}$ is the interaction period–hour, $B.F.H_{ikl}$ is the triple interaction breed–period–hour, and ε_{ijklm} is the random error or residual effect.

Sweating rate, food an water intake data were analyzed according to a general linear model procedure with two fixed factors and one nested factor:

$$Y_{ijkl} = \mu + B_i + B(A)_{i(j)} + P_k + B.\,P_{ik} + \varepsilon_{ijkl}$$

where Y_{ijklm} are the observed values for water intake or sweating rate, μ is the observed mean value, B_i is the fixed effect of breed, $B(A)_{i(j)}$ is the nested effect of an animal within breed, P_k is the fixed effect of temperatures period, $B.P_{ik}$ is the interaction breed–period, and $\varepsilon_{\text{ijkl}}$ is the random error or residual effect.

Significantly different means were submitted to post-hoc comparisons of means (Tukey–Hsu test) and regarded as significantly different when $P < 0.05$.

Table 1
Thermal parameters during thermoneutrality (P1) and thermically stressful periods (P2, P3, and P4).

	Period 1 – P1	Period 2 – P2	Period 3 – P3	Period 4 – P4
Air temperature (T_a)°C	16.0 ± 1 °C	27 ± 1 °C	30 ± 1 °C	Cycle: 28 ± 1 °C (from 17:00 to 10:00 h) [a]36 ± 1 °C/[b]40 ± 1 °C (from 09:00 to 17:00 h)
Relative Humidity (RH) %	56 ± 3	50 ± 3	40 ± 3	Cycle: 50 ± 3% (from 17:00 to 10:00 h) [a]40 ± 3%/[b]38 ± 3% (from 09:00 to 17:00 h)
Temperature–humidity index – THI	60 ± 1	74 ± 1	77 ± 1	Cycle: 76 ± 1 (from 17:00 to 10:00 h) [a]84 ± 1/[b]88 ± 1 (from 09:00 to 17:00 h)

[a] Cycle of temperatures for Frisian and Limousine breeds.
[b] Cycle of temperatures for Alentejana and Mertolenga breeds.