

## Biophysical responses of Santa Inês and crossbred Santa Inês-Dorper (F1) ewes to a hot environment

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**Abstract** This study aimed to evaluate the biophysical responses of Santa Inês ewes and crossbred Santa Inês-Dorper ewes in a hot environment. Physiological parameters were measured: rectal temperature, respiratory rate, coat surface temperature, skin surface temperature, and heart rate. Biophysical parameters were also calculated: heat exchanges by cutaneous convection and radiation, as well as heat storage and thermal conduction in fleece. Throughout the collection period, meteorological variables were similarly monitored. The statistical design was completely randomized in a factorial 2 x 2 (two genotypes and two shifts). According to meteorological variables, the afternoon shift introduced itself with greater heat stress compared with the morning shift. The effect of interaction between genotypes and shifts for respiratory rate, rectal temperature, skin surface temperature, and hair coat surface temperature showed that genotypes exhibit different physiological behavior under similar heat stress situations. Heart rate had the effect of two sources of variation. As for the biophysical parameters, radiation and conduction exchanges in fleece presenting with the shift effect. Heat storage was slightly higher in Santa Inês ewes than in their crossbred Santa Inês-Dorper ewes. It was therefore concluded that crossbred ewes use physiological mechanisms more vigorously to perform heat exchanges, similar to Santa Inês ewes, which have become more adapted to a hot environment.

**Keywords:** heat storage, heat stress, sensible heat exchanges

### Introduction

The sheep industry has contributed for a long time to fix the man in the field, being a more rational alternative to beef cattle, as it offers a greater return of kilograms of meat per hectare in a shorter period of time. Therefore, plays an important socio-economic role, it provides direct income, and represents an excellent food source.

Even with increasing representativeness of sheep breeding in the national scene (MAPA 2014), still failed to meet the demand of domestic consumption, leading Brazil to become in 2013 the largest importer of sheep meat of Uruguay (RuralBR 2013).

In tropical environment there is a constant need for animals to remain in thermal equilibrium with the environment, due to high radiant heat load. As a result, heat stress results in a larger energy need for maintenance, reducing the growth rate and animal productivity, especially when the animals are raised in grazing regime.

In this context, so that the animal can live in a hot environment, there is a physiological, anatomical and behavioral development, aiming to favor their survival. These adjustments are for enable the best possible way to heat loss. For example, the coat interferes directly in sensible heat exchanges, since it constitutes a barrier to the passage of thermal energy flow due to the insulation provided by the physical structure of the fibers and the air layer trapped between them (Smith 2000). Thus, to dissipate the thermal energy of metabolic origin and heat received of the environment, the animal may resort to evaporation or store thermal energy up to specified ceilings, thereby increasing the body temperature.

One of the alternatives most used to improve the results of a production system is the crossbreeding, in order to enjoy the benefits of heterosis and complementarity between breeds. However, knowledge of heat tolerance and adaptive capacity to the imposed conditions and understand how these adjustments act to keep homeothermy these animals is very important for breeding programs, for the nutritional management and defining the ambience of production systems.

Therefore, the aim of this study was to evaluate the biophysical responses of Santa Inês ewes and crossbred Santa Inês-Dorper ewes in a hot environment.

## Materials and Methods

The experiment was conducted at Tapicuru Farm, located in the Nova Porteirinha, North of Minas Gerais, Brazil (15°48' south latitude, 43°18' west longitude and 518 meters of altitude). The local climate is tropical mesothermal, almost megathermal, due the altitude, with features of sub-humid and semi-arid, with irregular rainfall, causing long periods of drought. According to Köppen, the typical climate is Aw, that is, savannah with dry winter and average temperature of the coldest month of the above 18 °C. Annual average rainfall index is 1074.9 mm, with seasonal regime very concentrated, and poorly distributed rains (85% in the months from November to March, while from May to August it rains only 2%).

Ten Santa Inês ewes were selected, with average age of three years, non-pregnant and non-lactating, with black coat, weight average of 42±11.5 kg and fleece thickness 0.67±0.17 cm; and 10 crossbred ewes Dorper x Santa Inês (F1), with an average age of two years, with black and white coat, and only black head, average weight of 35±15.3 kg and fleece thickness 2.15±1.96 cm. The ewes were kept in star grass pasture (*Cynodon plectostachyus*) and received mineral salt in the trough and treated water *ad libitum*.

During the day remained loose in the pasture areas and *Leucaena spp.* At night the ewes were taken to a covered shelter with French tile, ceiling height of 2.5 m and to about 1 m<sup>2</sup>/animal. In this facility, physiological and meteorological data were measured. Prior to the beginning of the experiment, the animals were habituated to experimental management and workers. This habituation was made to respect the peaceful entry of animals to the collection site. This adaptation occurred during three weeks.

Physiological parameters were measured twice a week throughout the experimental period (three months = October to December), in the morning shift (9:00 to 10:00) and afternoon (15:00 to 16:00). Heart rate (HR, beats/min) was obtained by counting the heartbeat with a stethoscope placed between the third and fourth intercostal space near costochondral joint, for 15 seconds, and the result multiplied by four, yielding so the frequency in a minute. Respiratory rate (RR, mov/min) was measured through observation of right flank movements, for 15 seconds, and the result multiplied by four, thus obtaining the frequency for one minute. Rectal temperature (RT, °C) was measured by introducing a digital thermometer until the stabilization of measure. Skin surface temperature (SST, °C) and coat surface temperature (CST, °C) were obtained through digital infrared thermometer (IncoTerm, ST-700), on the side. For the measurement of SST opened the fleece to expose the skin.

During physiological measurements were monitored meteorological variables with a weather station (Meteor

instruments, MI), formed by three digital thermometer with an accuracy of 1 °C, being the black globe (BGT, °C), a dry bulb (AT, °C) and a wet bulb (WBT, °C) and wind speed (WS, m/s) by an anemometer (Instrutherm, THAL-300). Meteorological variables were determined at the beginning and end of measurements, subsequently calculated the arithmetic average of each variable.

Meteorological variables were used to calculate the relative humidity (RH, %), mean radiant temperature (MRT, °C), radiant heat load (RHL, W/m<sup>2</sup>) as described by Silva (2000) and to calculate the Globe Temperature and Humidity Index (BGHI) (Buffington et al 1981) and Thermal Comfort Index proposed by Barbosa and Silva (1995).

Biophysical parameters were calculated from the physiological and meteorological variables. To determine the heat transfer by convection (HC, W/m<sup>2</sup>) in the coat surface to air the "neighborhood", the animal was considered a horizontal cylinder, except head and legs, as Silva (2000) and Turnpenny et al (2000):

$$HC = \frac{\rho C_p}{r_H} (CST - AT) \text{ W/m}^2$$

In that,  $\rho$  is the density of air (kg.m<sup>-3</sup>);  $C_p$  is the specific heat of air (J.Kg<sup>-1</sup>°C<sup>-1</sup>);  $r_H$  is the resistance to heat transfer by convection (s.m<sup>-1</sup>).

The heat transfer long-wave radiation (RL, W/m<sup>2</sup>) between body surface of the animal and environment was obtained according Silva (2000) and Turnpenny et al (2000):

$$RL = \frac{\rho C_p}{r_R} (CST - MRT) \text{ (W/m}^2\text{)}$$

In that,  $r_R$  is the resistance boundary layer resistance to radiation heat transfer. (s.m<sup>-1</sup>).

The thermal conductivity of the fleece (HK, W/m<sup>2</sup>) was calculated according to Silva (2000):

$$HK = \frac{CST - SST}{(x/k)} \text{ (W/m}^2\text{)}$$

Where  $x$  = fleece thickness and  $k = 0.064 \text{ W.m}^{-2}.\text{°C}^{-1}$  is the thermal conductivity of the fleece.

The heat storage (HS, W/m<sup>2</sup>) was calculated using the equation of McLean et al (1983):

$$HS = \frac{[0,86 DT_C + 0,14DT_S] Ce * P}{t A} \text{ (W/m}^2\text{)}$$

Where DTc and DTs are the differences of rectal temperature and skin between the morning and afternoon shift, Ce is the specific heat of the tissue, assumed to be 3470 J/kg.°C, P is body weight (kg), t is the time in seconds (six hours), and A is the total body surface area (m<sup>2</sup>) estimated by the formula Bennett (1973):

$$A = 0.094 W^{2/3} \text{ (m}^2\text{)}$$

The statistical design was completely randomized in a factorial 2x2 (two genotypes and two shifts) with 23 repetitions for all variables, except the heat storage that was completely randomized (two genotypes) with 23 repetitions using it statistical software "statistical Analysis System" (SAS 9.1, SAS Institute, Cary, NC, USA). The Tukey test was used to compare means (P < 0.05).

**Results and Discussion**

Table 1 shows means of environmental variables during the days of the collect of physiological variables according to the turn. There was a significant difference (P < 0.05) between shifts for all variables. The AT values and RH are within the thermal comfort range, which according Baêta and Souza (2012) to sheep must be in a temperature range between 20 and 30 °C and relative humidity between 50 and 80%, so both parameters were within the range of thermal comfort.

For MRT, which is average temperature of all areas, real and virtual surfaces surrounding the animal (Silva 2000), the afternoon shift showed higher, exceeding 35 °C which according to Oliveira (2007), from this temperature, sensible

heat exchanges become gain and not loss. Consequently, the RHL also showed higher in the afternoon.

According Buffington et al (1981), BGHI values up to 74, 74-79, 79-84 and above 84 define comfort situation, alert, danger and emergency, respectively. Following this classification, the environmental conditions found in this study led the animals to danger situations in the afternoon and the morning shift the environment provided alert situation. Both situations are considered as thermal discomfort. However these values should be reviewed for sheep, as were designed for cattle.

The TCI values found by Barbosa and Smith (1995) in fleece sheep (Ideal (35), Suffolk and Corriedale (20)) indicated a thermal discomfort, because the animals showed an increase in rectal temperature. However, Neves et al (2009) with Santa Inês sheep with brown pelage, black and white, only would the situation of thermal discomfort with TCI above 38.

The means of heart rate showed significant differences (P < 0.05) between genotypes (Santa Inês = 83.43±0.79 and crossbreed = 94.47±0.97 beats/min) and shift (morning = 84.10±0.81 and afternoon = 93.79±0.96 beats/min).

Crossbred ewes showed higher HR values than Santa Inês. The heart rate was higher in the afternoon than in the morning shift. Similar results were found by Cezar et al (2004), working with Santa Inês lambs and crossbred Santa Inês-Dorper. In the same study, the authors found that the heart rate was significantly influenced (P < 0.05) by shift, where the heart rate during the afternoon (115.30 beats/min) was higher than the morning (105.67 beats/min). The increase in heart rate occurs so that the animal's body to perform peripheral vasodilation.

**Table 1** Means of air temperature (AT, °C), relative humidity (RH, %), wind speed (WS, m/s), mean radiant temperature (MRT, °C), radiant heat load (RHL, W/m<sup>2</sup>), temperature index globe humidity (BGHI), thermal comfort index (TCI) per shift.

Environmental variables	Morning	Maximum	Minimum	Afternoon	Maximum	Minimum
AT	25.22±0.09 <sup>b</sup>	28.00	21.00	28.69±0.15 <sup>a</sup>	34.00	24.00
RH	71.39±0.43 <sup>a</sup>	91.57	58.60	64.55±0.62 <sup>b</sup>	93.20	39.01
WS	0.43±0.02 <sup>a</sup>	1.5	0.1	0.40±0.09 <sup>a</sup>	24.00	0.10
MRT	31.87±0.56 <sup>b</sup>	69.59	21.00	43.23±0.09 <sup>a</sup>	103.79	24.00
RHL	495.53±4.00 <sup>b</sup>	782.46	424.46	577.67±5.91 <sup>a</sup>	1144.54	442.04
BGHI	75.15±0.12 <sup>b</sup>	79.80	69.29	79.71±0.19 <sup>a</sup>	86.44	73.64
TCI	31.94±0.12 <sup>b</sup>	35.85	26.48	36.52±0.19 <sup>a</sup>	43.52	30.26

Means followed by the same letter do not differ statistically by the Tukey test (P > 0.05).

The means of physiological variables found by genotype and shift are shown in Table 2. There was a significant interaction between the factors. It was observed

that the crossbred ewes and the afternoon shift, for the two genotypes, showed the highest values for RR and RT. However it was lower than the values found by Cezar et al

(2004) under conditions similar BGHI. In addition, several authors (Oliveira et al 2005; Santos et al 2006; Andrade et al 2007) found this difference between shifts, showing that ewes activate thermoregulatory mechanisms in heat conditions.

Santos et al (2006) working with crossbred Santa Inês, Morada Nova and their crossbreeds with Dorper sheep also found interaction between genotypes and shifts for RR, RT and HR, and the latter was not found in this study. The results found in the same genotypes (SI and SIxDO) by these authors were higher in the morning. These differences were mainly due to animal model used, they were lambs, which are more sensitive to environmental conditions than adult animals.

Oliveira (2007) noted that the increase in respiratory rate is influenced by the increase in humidity and can be explained as an attempt of heat loss by the respiratory route mainly by convective mechanism, since there was a decrease in the heat loss by respiratory evaporation, inhibited by high humidity. According to the same author, animals can still store thermal energy. This usually occurs to reduce the latent heat loss, which is lower when the humidity rises.

The high respiratory rates suggest that the animal is in heat stress. This physiological action mainly occurs due to sheep brain maintain its temperature below core temperature by countercurrent mechanism of the carotid sinus carvenosus described by Smith (2000). Thus the animal has a time so that the sensible heat loss mechanisms are efficient, otherwise the latent heat loss mechanisms through the cutaneous and respiratory will be the most efficient tool for thermolysis.

The RT was higher in crossbred ewes both in the afternoon as in the morning. RT values for the two genetic groups and the two shifts were within the advocated for rectal temperature in sheep and goats ranges from 38.5 to 40.0 °C. However, various factors can cause changes in body temperature, among which are: age, sex, season, time of day, exercise, feed intake and feed digestion. Therefore, the rectal temperature is measurement considered as best represents the core temperature, and is often used to verify the degree of adaptability of animals to be considered a good indicator of heat stress.

The increase of the rectal temperature is an indicative of heat stored by organism. This mechanism is of great importance for water economy by animals (Mitchell et al 2002), as it suppresses the water loss by evaporation, mechanism that has a higher cost to the animal organism.

The animals of the two genetic groups during the morning shift did not show significant differences in the SST, but in the afternoon shift the crossbred ewes showed higher SST when compared with the Santa Inês ewes. Probably, this is related to greater difficulty in heat loss due to thicker fleece, making it difficult the heat conduction

through the hair coat to the external environment. It is noteworthy that the fleece color on the side of the crossbred animals was white and black in the Santa Inês ewes.

The CST in the morning shift, the Santa Inês ewes showed higher value than the crossbred, this was due to the higher heat absorption by the black pelage of the Santa Inês ewes. However, it was not found significant change between the two genotypes in the afternoon, showing that during a larger thermal challenge, the thicker of white fleece of crossbred was equivalent to black color of the Santa Inês ewes. However, the gradient between CST and SST features that the fleece was leading heat from the skin to the coat surface.

The means of heat transfer by convection (HC), heat transfer by radiation (RL), heat transfer by conduction (HK) and heat storage (HS) according to genetic group and shift are shown in Table 3.

**Table 2** Means of Respiratory rate (RR, mov/min), Rectal temperature (RT, °C), Skin surface temperature (SST, °C) e Coat surface temperature (CST, °C) according to genotype and shift.

Genotype	Morning	Afternoon
Respiratory rate		
SI	31.89±0.71 <sup>Bb</sup>	40.43±1.27 <sup>Ba</sup>
SI X DO	48.93±1.27 <sup>Ab</sup>	68.37±1.82 <sup>Aa</sup>
Rectal temperature		
*SI	38.06±0.04 <sup>Bb</sup>	38.71±0.55 <sup>Ba</sup>
**SI X DO	38.98±0.03 <sup>Ab</sup>	39.43±0.02 <sup>Aa</sup>
Skin surface temperature		
SI	34.35±0.12 <sup>Ab</sup>	36.38±0.15 <sup>Ba</sup>
SI X DO	34.20±0.12 <sup>Ab</sup>	37.08±0.13 <sup>Aa</sup>
Coat surface temperature		
SI	32.76±0.14 <sup>Ab</sup>	35.88±0.20 <sup>Aa</sup>
SI X DO	30.64±0.17 <sup>Bb</sup>	35.35±0.22 <sup>Aa</sup>

Means followed by the same letter, capital for column and lower case for line, for each effect, do not differ statistically by the Tukey test (P> 0.05).  
 \*Santa Inês;  
 \*\*Crossbred Santa Inês-Dorper.

Heat loss by convection were similar between genotypes and between shifts, confirming that in tropical environment, where the difference between the body surface temperature and air temperature is small or almost non-existent, this heat exchange becomes little expressive, especially under low wind speeds (table 1). This environmental condition is more troublesome with regard to the radiation exchange, where the two genotypes gained heat by long-wave radiation similarly. Already occurring heat

gain in the morning under MRT 31 °C (table 1), Oliveira (2007) in shaded environment found that this heat gain occurred only under MRT 35° C. The situation was most critical in the afternoon shift, when the heat gain by the animals was 33 times greater than the morning shift.

There was no significant difference between genotypes to the heat transfer by conduction on the fleece, despite the thermal gradient between the CST and SST for crossbred ewes be higher, therefore, it was expected a thermal conduction larger, however, its fleece thick it was higher 2.15±1.96 cm, that of Santa Inês ewes, 0.67±0.17 cm. However there was significant difference of the shift, where the heat transfer by conduction the morning shift was

greater than the afternoon shift. This is due to the fact that the temperature gradient between the CST and SST was higher in the morning shift.

The heat storage values found for Santa Inês and crossbred showed up slightly higher in Santa Inês ewes (5.17 W/m<sup>2</sup>) than in crossbred ewes (4.15 W/m<sup>2</sup>). This show us that crossbred ewes has heat storage capacity close to the animal considered most adapted, for example Santa Inês ewes. According to Mitchell et al (2002), the animal has the capacity to store heat has an important adaptive power to better withstand the heat stress due to the reduced need to overload the thermolysis mechanisms.

**Table 3** Means of heat transfer by convection (HC, W/m<sup>2</sup>), heat transfer by radiation (RL, W/m<sup>2</sup>), heat transfer by conduction (HK, W/m<sup>2</sup>) and heat storage (HS, W/m<sup>2</sup>) according to genotype and shift.

Variables	Genotype		Shift	
	*SI	**SI X DO	Morning	Afternoon
HC	13.72±0.23 <sup>a</sup>	17.45±5.14 <sup>a</sup>	12.29±0.23 <sup>a</sup>	18.88±5.13 <sup>a</sup>
RL	-21.72±4.17 <sup>a</sup>	-30.82±4.20 <sup>a</sup>	-1.55±3.28 <sup>b</sup>	-51.00±4.66 <sup>a</sup>
HK	0.10±0.008 <sup>a</sup>	0.10±0.006 <sup>a</sup>	0.15±0.007 <sup>a</sup>	0.05±0.01 <sup>b</sup>
HS	5.17±0.33 <sup>a</sup>	4.15±0.23 <sup>b</sup>	-	-

(-) heat gain;

Means followed by the same letter do not differ statistically by the Tukey test (P> 0.05).

\*Santa Inês;

\*\*Crossbred Santa Inês-Dorper.

**Conclusions**

Higher values of HR, RR, RT, SST, CST and RL observed in the afternoon shift indicate the need for adopting management techniques in this period, in order to mitigate the effects of thermal environment on the animals. In the conditions studied, the thermal environment in the afternoon shift led the animals, regardless of genotype, to heat stress conditions. Furthermore, crossbred ewes use with more emphasis the physiological mechanisms to perform heat exchanges similar to Santa Inês ewes, which were more adapted to hot environment.

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