

# Models to predict both sensible and latent heat transfer in the respiratory tract of Morada Nova sheep under semiarid tropical environment

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**Abstract** The aim of this study was to build a prediction model both sensible and latent heat transfer by respiratory tract for Morada Nova sheep under field conditions in a semi-arid tropical environment, using easily measured physiological and environmental parameters. Twelve dry Morada Nova ewes with an average of  $3 \pm 1.2$  years old and average body weight of  $32.76 \pm 3.72$  kg were used in a Latin square design  $12 \times 12$  (12 days of records and 12 schedules). Tidal volume, respiratory rate, expired air temperature, and partial vapor pressure of the expired air were obtained from the respiratory facial mask and using a physiological measurement system. Ewes were evaluated from 0700 to 1900 h in each day under shade. A simple nonlinear model to estimate tidal volume as a function of respiratory rate was developed. Equation to estimate the expired air temperature was built, and the ambient air temperature was the best predictor together with relative humidity and ambient vapor pressure. In naturalized Morada Nova sheep, respiratory convection seems to be a mechanism of heat transfer of minor importance even under mild air temperature. Evaporation from the respiratory system increased together with ambient air temperature. At ambient air temperature, up to 35 °C respiratory evaporation accounted 90 % of the total heat lost by respiratory system, on average. Models presented

here allow to estimate the heat flow from the respiratory tract for Morada Nova sheep bred in tropical region, using easily measured physiological and environmental traits as respiratory rate, ambient air temperature, and relative humidity.

**Keywords** Genetic adaptation · Naturalized breed · Prediction model · Tidal volume

## Introduction

Mathematical models have been developed to evaluate heat exchange at the respiratory surfaces in cattle and sheep (Stevens 1981; da Silva et al., 2002; Berman, 2005; Maia et al., 2005). These models were conceived using easily measured environmental and physiological parameters to estimate heat dissipation through the respiratory tract via convection and evaporation under field conditions. Models of evaporation in the respiratory system of animals generally assume that expired air is saturated at a temperature lower than deep body temperature, evincing that environmental air temperature, humidity, and body temperature are important factors for the determination of evaporation in the respiratory tract (Stevens 1981; da Silva et al., 2002; Maia et al., 2005).

Equations to estimate heat loss via the respiratory tract should take factors like species, breed, and environment which they were selected. Maia et al. (2005) showed that using functions estimated from animals bred in temperate climates were inappropriate for animals bred under tropical conditions. They studied Holstein cows acclimatized to a tropical environment and observed that measures like tidal volume were underestimated when they used equations developed by Stevens (1981) for Holstein cows bred in a temperate zone.

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In the case of sheep, da Silva et al. (2002) developed functions with Corriedale sheep, but these are evolutionarily distinct from breeds naturalized to the semiarid tropical environment. Morada Nova sheep are known to be well adapted to the semiarid environment of Brazil (Egito et al., 2002; Fonsêca et al., 2014). By contrast, Corriedale sheep were selected for temperate climates and are characterized by a wool coat.

Studies have shown that evaporation in the respiratory tract is the main avenue of heat dissipation at high ambient temperatures in wool sheep (Alexander and Williams, 1962; Hofmeyr et al., 1969; Hofman and Riegle, 1977). Starling et al. (2002) showed that at high ambient temperature, respiratory heat transfer accounted for approximately 70 % of total heat loss in Corriedale bred in a tropical zone. On the other hand, in a study of naturalized goats from a semiarid tropical zone, Maia et al. (2015) documented that evaporative heat loss by the respiratory tract was only 7 % of total heat loss under conditions of high temperature.

In sum, specific physiological responses in animals are related to the environment that they are adapted to. Therefore, mathematical models of heat transfer should take this into account. No attempt has been made to evaluate the characteristics of the respiratory system in heat exchange in naturalized sheep bred in a semiarid tropical environment. Thus, the aim of this study was to build predictive models of both sensible and latent heat transfer in the respiratory tract of Morada Nova sheep under field conditions in a semiarid tropical environment, using easily measured physiological and environmental traits.

## Materials and methods

Twelve dry Morada Nova, *Ovis aries*, ewes averaging  $3 \pm 1.2$  years in age and  $32.76 \pm 3.72$  kg in body weight were studied in a  $12 \times 12$  Latin square design (12 days of records and 12 schedules). Observations were made from April to May 2015. Ewes were evaluated under ambient conditions in São João do Cariri, PB, Brazil ( $07^\circ 23' 27''$  S,  $36^\circ 31' 58''$  W, 458 m altitude), from 0700 to 1900 h each day under shade. Physiological parameters were recorded in the first animal between 0700 and 0800 h, the second between 0800 and 0900 h, and so on. Thus, the twelfth animal was evaluated between 1800 and 1900 h. By the end of the trial, every animal had been evaluated on each of the 12 days in all the schedules. Ewes were fed twice a day (0530 and 1910 h) with forage (elephant grass hay) and concentrate (corn, soybean, wheat, and mineral supplementation) in a ratio of 74:26. Water was provided ad libitum. Daily feed consumption was estimated at approximately 1.5 % of average body weight.

Sensible and latent heat flows from the respiratory tract were determined according to the methods described by

Maia et al. (2005) and da Silva and Maia (2013). The sensible heat flow ( $C_R$ ;  $W m^{-2}$ ) from the respiratory system is given by

$$C_R = A^{-1} V_T p c_p F (T_E - T_{ar}) \quad (1)$$

and the latent heat flow ( $E_R$ ;  $W m^{-2}$ ) by

$$E_R = A^{-1} \lambda V_T F (\psi_E - \psi_{atm}) \quad (2)$$

where  $T_{ar}$  and  $T_E$  are the temperatures of the ambient and expired air ( $^\circ K$ ), respectively;  $p$  is the air density ( $kg m^{-3}$ ),  $c_p$  is the specific heat of the air ( $J kg^{-1} ^\circ C^{-1}$ ),  $\lambda$  is the latent heat of water vaporization ( $J g^{-1}$ ),  $V_T$  is the tidal volume ( $L breaths^{-1}$ ),  $F$  is the respiratory rate ( $breaths s^{-1}$ ), and  $A$  is the body surface area of the animal, which is estimated as (Bennett, 1973):

$$A = 0.171 B_W^{-0.05025} \quad (3)$$

where,  $B_W$  is body weight of the animal (Kg). The absolute humidity of the ambient air ( $\psi_{atm}$ ;  $g m^{-3}$ ) and of the expired air ( $\psi_E$ ;  $g m^{-3}$ ) are given by

$$\psi_{atm} = T_{ar}^{-1} 2166.87 e(T_{ar}) \quad (4)$$

$$\psi_E = T_E^{-1} 2166.87 e(T_E) \quad (5)$$

which  $e(T_{ar})$  and  $e(T_E)$  are the partial vapor pressures (kPa) of the ambient and expired air, respectively. Thermal properties of the air ( $p$ ,  $\lambda$ , and  $c_p$ ) were obtained from a simple function of  $T_{ar}$  (Da Silva, 2008).

The respiratory parameters tidal volume ( $L breaths^{-1}$ ), respiratory rate, expired air temperature ( $^\circ C$ ), and partial vapor pressure of the expired air (kPa) were obtained using a respiratory facial mask and a physiological measurement system (Maia et al., 2016). Ambient air temperature ( $^\circ C$ ; model HOBO, onset), relative humidity (%; model HOBO, onset), partial vapor pressure of the air (kPa), rectal temperature ( $^\circ C$ ), and wind speed ( $m s^{-1}$ ; model APM-360, USA) were also collected. In addition, black globe temperature ( $^\circ C$ ) was measured with a thermocouple (Model type T, Salcas, Brazil. Accuracy  $0.2 ^\circ C$ ) inserted into the centre of a hollow 0.15-m-diameter copper sphere, matt black painted, which was placed 50 cm above the ground near the animals. The mean radiant temperature (K) was obtained according to da Silva et al. (2010). Prior to the study, the ewes were habituated and conditioned to the use of the respiratory mask using operant conditioning principles employing feed as a positive reinforcement. This habituation period extended from December 2014 to March 2015.

During each breath, the inlet flow (inspired air) and the outlet flow (expired air) were carried through two valves of the measurement system (Fig. 1). The expired air leaving the facial mask was directed through a tracheal tube (MLA1015 Breathing Tube, ADInstruments, Australia) to a flow head (MLT1.000, ADInstruments, Australia). The flow head was directed to a gas mixing-chamber (MLA246, ADInstruments, Australia) connected to a spirometer (ML141, ADInstruments, Australia) providing the ventilation ( $V_R$ ;  $L s^{-1}$ ) and respiratory rates ( $min^{-1}$ ). From these measurements, we calculated the tidal volume ( $V_T$ ;  $L breaths^{-1}$ ). The gas-mixing chamber was connected to a Field Metabolic System (FMS-1201-05, Sable System, USA) through a plastic tube (Bevaline Tubing, Sable System, USA). Inside the tube, a sample of expired air (150 mL/min) was continuously pumped into a gas analyzer ( $H_2O$ ) to measure the partial vapor pressure of the expired air (kPa). These measurements were performed every time a facial mask was placed on an animal's muzzle.

Atmospheric vapor pressure was continuously recorded by an external  $H_2O$  vapor analyzer ( $P_v$ , kPa; RH-300, Sable System, USA) connected to a pump (SS4, Sable System, USA), which continuously aspirated atmospheric air ( $150 ml min^{-1}$ ) close to the mask's inlet valve. The expired air temperature was recorded with a nasal temperature probe (MLT 415/AL, ADInstruments, Australia, accuracy  $\pm 0.3$  °C) placed inside the facial mask. The rectal temperature (°C) was continuously recorded with a rectal thermocouple (MLT 1404, ADInstruments, Australia, accuracy  $\pm 0.3$  °C). The FMS, spirometer,  $H_2O$  vapor analyzer, and thermocouples were connected to a data acquisition system (PowerLab 16/32, ADInstruments, Australia) and linked to a computer that continuously and simultaneously recorded all measurements at a rate of one observation per second.

Data were analyzed using general linear models and least squares methods. Nonlinear regression was used to estimate  $V_T$  as a function of the respiratory rate. Multiple regression

was used to develop a model for  $F$ ,  $T_E$ ,  $C_R$ , and  $E_R$ , as a function of several variables, given the initial model:

$$y_{ijkl} = \alpha + a_i + t_j + d_k + b_1(\text{Tar}) + b_2(R_H) + b_3e(\text{Tar}) + b_4(T_B) + \varepsilon_{ijkl}$$

where  $y_{ijkl}$  is the  $l^{\text{th}}$  observation of  $T_E$ ,  $F$ ,  $C_R$ , and  $E_R$  in the  $i^{\text{th}}$  animal,  $j^{\text{th}}$  time of the day and  $k^{\text{th}}$  day of records,  $\alpha$  is the intercept,  $a_i$  is the effect of the  $i^{\text{th}}$  animal ( $i = 1, \dots, 12$ ),  $t_j$  is the effect of  $j^{\text{th}}$  time of the day ( $k = 0700, \dots, 1800$  h), and  $d_k$  is the effect of the  $k^{\text{th}}$  day of records ( $k = 1, \dots, 12$ ). The values of  $b_1$ ,  $b_2$ ,  $b_3$ , and  $b_4$  are partial linear regression coefficients and  $\varepsilon_{ijkl}$  is the random error associated with the  $l^{\text{th}}$  observation on the  $i^{\text{th}}$  animal,  $j^{\text{th}}$  time of the day, and  $k^{\text{th}}$  day of record. Starting with Tar, independent variables were successively added to the model until the largest coefficient of determination ( $R^2$ ) was reached. At each step, a set of simultaneous equations was built and then solved by stepwise selection. The statistical package used for all analyses was SAS version 9.3 (SAS Inst. Inc., Cary, NC).

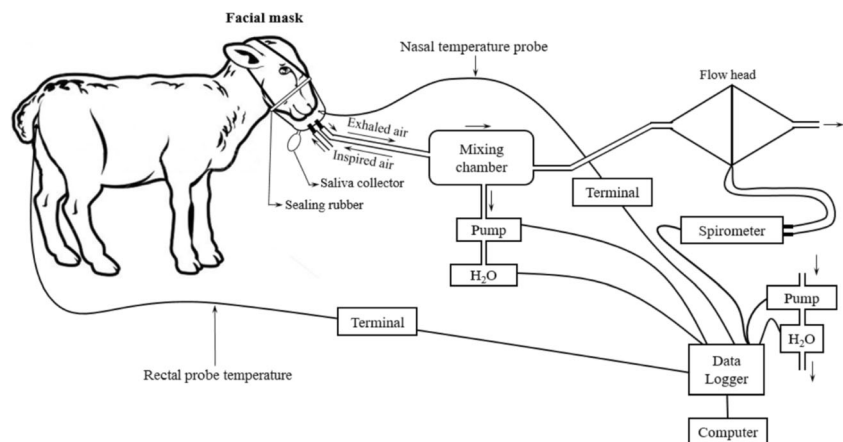
## Results and discussion

From the data obtained in our study, we estimated the relationship between tidal volume and respiratory rate for woolless Morada Nova sheep bred in semiarid environment ( $R^2 = 0.95$ ; Fig. 2) as

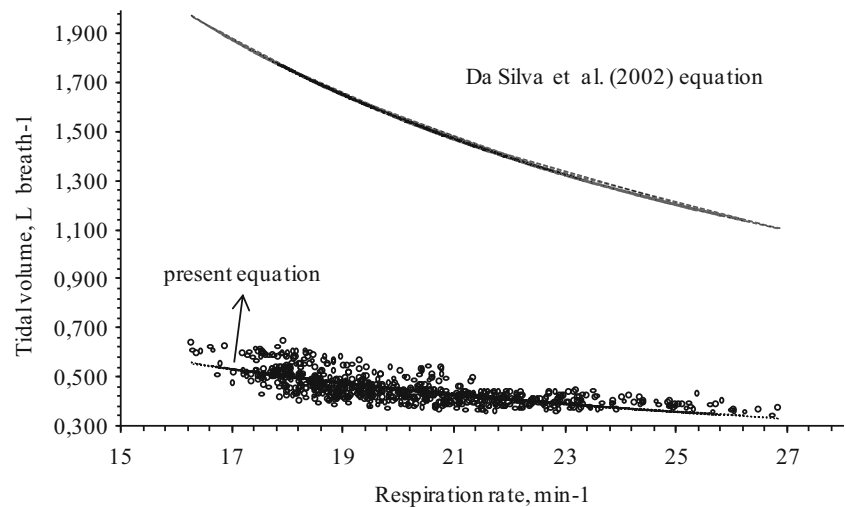
$$V_T (L breath^{-1}) = 10.0351 F^{-1.0376}, \quad (6)$$

$V_T$  ranged from 0.345 to 0.644 L/breath under ambient conditions of air temperature (25.07 to 35.56 °C), radiant mean temperature (25.22 to 46.39 °C), relative humidity (35.84 % to 78.47 %), and vapor pressure (1.42 to 2.82 kPa; Table 1). Previous findings of sheep described similar

**Fig. 1** Physiological measurement system using facial mask developed for sheep



**Fig. 2** Tidal volume as a function of the respiration rate



variation for tidal volume on resting conditions (Mitchell 1972; Hofman and Riegle 1977; Schmidt-Nielsen 1991; da Silva et al. 2002). For example, Schmidt-Nielsen (1991) measured a tidal volume of 0.403 L/breath for a 60-kg sheep. Da Silva et al. (2002), working with Corriedale ewes under ambient temperatures ranging from 17.5 to 40 °C, documented tidal volumes from 0.200 to 0.700 L/breath. Similarly, shorn and unshorn Dorset ewes presented tidal volumes from 0.150 to 0.400 L/breath (Hofman and Riegle, 1977).

According to this model, an increase in  $F$  (breaths  $\text{min}^{-1}$ ) decreased the  $V_T$ , consistent with other studies of sheep (Hofman and Riegle, 1977; da Silva et al. 2002; Silva, 2013) and cattle (Stevens, 1981; Maia et al., 2005). Variation in the respiratory rate as a function of ambient air temperature was described by the equation ( $R^2 = 0.61$ ):

$$F = 49.86 - 2.472\text{Tar} + 0.047\text{Tar}^2, \quad (7)$$

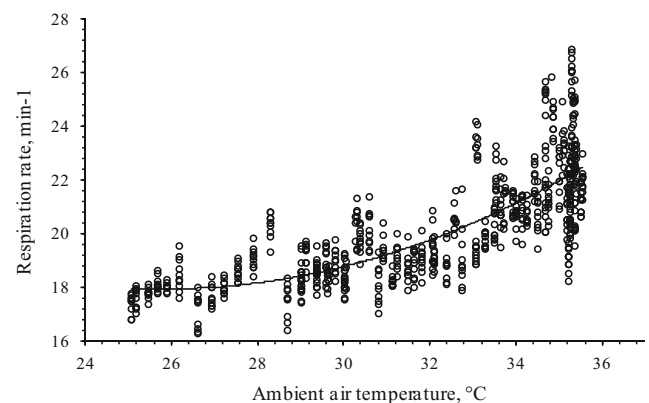
$F$  ranged from 16.26 to 26.83 (Fig. 3). When other variables such as ambient vapor pressure, relative humidity, and rectal temperature were included in the model,  $R^2$  did not increase. In the present study, the range of ambient and mean

radiant temperature was not sufficient to cause panting in the ewes. Working with wool-less Santa Inês sheep bred in a tropical environment, Neiva et al. (2004) documented close range for  $F$  under both shady and sunny conditions. However, large variation in  $F$  under a similar range of ambient temperature was observed in wool sheep under panting state (Hofman and Reagle, 1977; Johnson, 1991; da Silva and Starling, 2003; Silva, 2013). With Merino ewes, Johnson (1991) described variation in the respiration rate from 65 to 120 breaths per minute. Similarly, Silva (2013) observed respiratory rates of 155 to 180 breaths per minute in male Corriedale maintained in a climatic chamber (average ambient temperature of 30 °C).

When we plotted the data of the present study using the nonlinear function of da Silva et al. (2002;  $V_T$  ( $\text{m}^3/\text{breath}$ ) =  $0.0496F^{-0.463}$ ), the curve deviated from the data, showing a large overestimate for the tidal volume (Fig. 2). Maia et al. (2005) worked with Holstein cows acclimatized to a hot environment and observed that when they used a function estimated by Stevens (1981) for Holstein cows bred in a temperate climate, the estimates

**Table 1** Average, minimum, and maximum values of air temperature (Tar), relative humidity ( $R_H$ ), mean radiant temperature ( $T_{RM}$ ), wind speed ( $W_S$ ), and ambient vapor pressure ( $e[\text{Tar}]$ ) observed in São João do Cariri from April to May, 2015

Variable	$n$	Average	Minimum	Maximum
Tar, °C	748	31.84 ± 0.27	25.07	37.02
$R_H$ , %	743	49.04 ± 1.24	25.22	42.39
$T_{RM}$ , °C	702	32.40 ± 0.30	35.84	78.47
$W_S$ , $\text{m s}^{-1}$	452	0.32 ± 0.04	0	1.21
$e(\text{Tar})$ , kPa	740	1.94 ± 0.05	1.42	2.82



**Fig. 3** Respiration rate as a function of ambient air temperature



**Table 2** Correlation coefficients among ambient air temperature (Tar), partial air vapor pressure (Pvatm), rectal temperature (TR), relative humidity (RH), and expired air temperature (TE)

Variable	Tar	e(Tar)	TR	RH	TE	P value
Tar	1	-0.8270	0.3485	-0.9442	0.9588	0.001
e(Tar)	-	1	-0.3854	0.9491	-0.7799	0.001
TR	-	-	1	-0.3820	0.4083	0.001
RH	-	-	-	1	-0.8917	0.001
TE	-	-	-	-	1	0.001

deviated from the data, underestimating tidal volume. A similar pattern was found by Silva and Maia (2011) using a function provided by Gatenby (1986) to estimate cutaneous evaporation in cattle as a function of surface temperature. These authors worked with Holstein cows in a tropical environment while Gatenby (1986) developed the equation for crossbred beef cattle.

Correlation coefficients of TE with respect to ambient air temperature (Tar), ambient vapor pressure e(Tar), rectal temperature (TR), and relative humidity (RH) are shown in Table 2. TE is more a function of the ambient air temperature, relative humidity, and ambient vapor pressure than rectal temperature (Fig. 4a–d). Based on these relationships, we chose two models that estimate TE with good accuracy. The first (R<sup>2</sup> = 0.9778) included Tar and RH and the second (R<sup>2</sup> = 0.9764) included Tar and e(Tar). The inclusion of e(Tar) in the first function and RH in the second did not

increase the R<sup>2</sup>. When we included TR in both equations, the estimate did not improve. Thus, the models are the following:

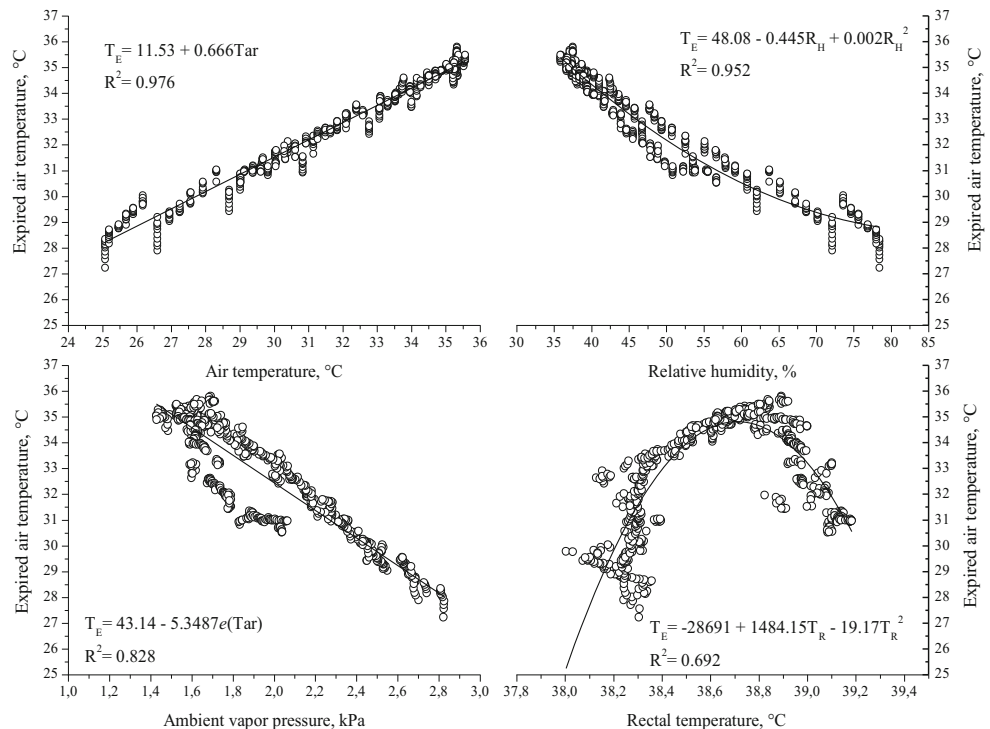
$$T_E \left( \frac{\text{A}}{1} \right) = 14.56 + 0.64\text{Tar} - 0.08R_H + 0.0007R_H^2, \quad (8)$$

$$T_E \left( \frac{\text{A}}{2} \right) = 12.31 + 0.65\text{Tar} - 0.16e(\text{Tar}). \quad (9)$$

However, in both models, the inclusion of only ambient air temperature gave an R<sup>2</sup> of 0.96. Thus, the equation presented in Fig. 4a accurately predicted TE as a function of Tar. Da Silva et al. (2002) described that the best model (R<sup>2</sup> = 0.96) of TE for Corriedale sheep included Tar, RH, and deep body temperature (TR). Stevens (1981) reported that the best model of TE included ambient air temperature and relative humidity. Meanwhile, Maia et al. (2005) reported the best model of TE was a function of Tar (R<sup>2</sup> = 0.91).

Deep body temperature (TR) ranged from 38 to 39.18. The minimum and maximum values were observed at 0700 and 1800 h, respectively. Da Silva and Minomo (1995) reported a similar pattern for Corriedale sheep bred in a tropical environment. According to our investigation, the amount of body thermal energy did not coincide with the highest values of expired air temperature or respiratory rate, which may be an indication that the great part of heat was dissipated in other ways (Fig. 5).

**Fig. 4** Expired air temperature as a function of ambient air temperature (a), relative humidity (b), ambient air vapor pressure (c), and rectal temperature (d)

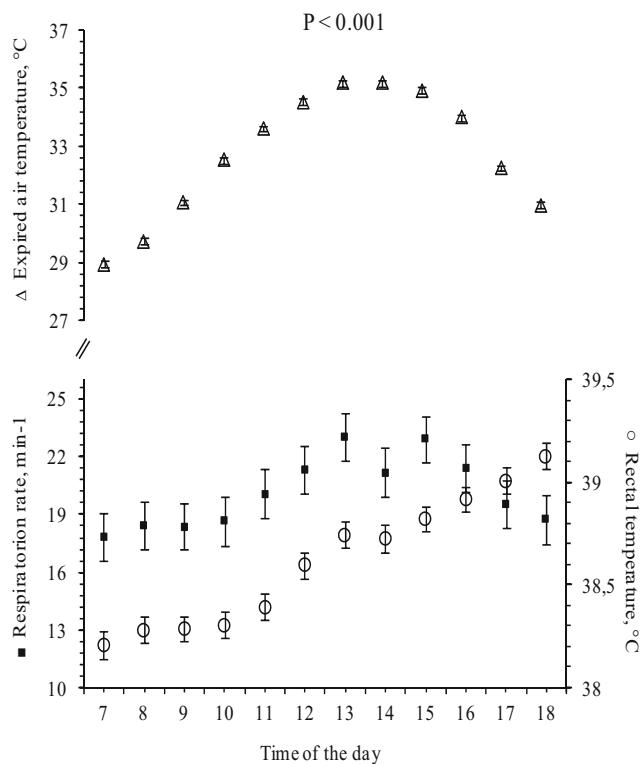


As previously reported in sheep and cattle (Da Silva et al., 2002; Maia et al., 2005), the sensible ( $W m^{-2}$ ) heat loss decreased with increasing ambient temperature, while evaporative heat loss increased together with  $T_{ar}$  (Fig. 6):

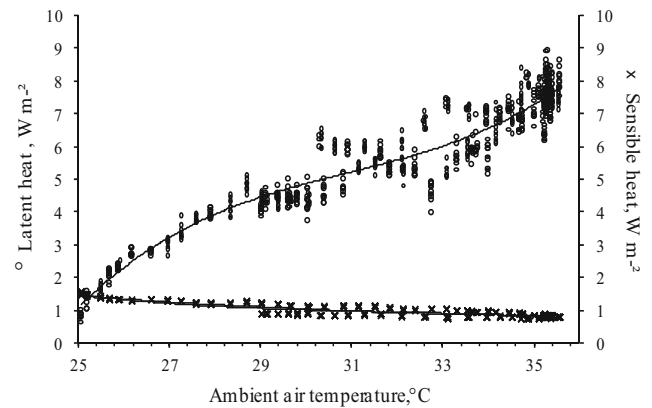
$$C_R = 33.61 - 2.995T_{ar} + 0.092T_{ar}^2 - 0.001T_{ar}^3, (R^2 = 0.76) \quad (10)$$

$$E_R = -295.8 + 28.49T_{ar} - 0.909T_{ar}^2 + 0.009T_{ar}^3 (R^2 = 0.90). \quad (11)$$

Sensible heat loss by the respiratory tract in Morada Nova sheep seems to be of little significance for thermal balance, even under mild air temperatures (25 °C). In a similar situation, da Silva et al. (2002) reported values of respiratory convection in Corriedale sheep that ranged 7 to 9  $W m^{-2}$  when the thermal gradient ( $\Delta t$ ) between ambient and expired air temperature reached 7 °C. In the present study, at 25 °C, the thermal gradient reached 2 or 3 °C, on average. Our study shows that latent heat loss is the main mechanism of respiratory heat loss. At ambient temperatures above 35 °C, respiratory cooling via evaporation accounted for 90 % of total heat lost. As expected, the amount of latent heat lost in Morada Nova sheep is small when compared with the findings of da



**Fig. 5** Respiration rate, rectal temperature, and expired air temperature (mean  $\pm$  SEM) during daylight



**Fig. 6** Heat loss from the convection and evaporation in the respiratory tract of Morada Nova sheep as a function of ambient air temperature

Silva et al. (2002). There is large differences between Morada Nova (weight = 33 kg on average) and Corriedale (weight = 75 kg on average) regarding thermal energy content. In other words, heavier animals have a greater capacity for heat storage than lighter animals.

It is evident that there are large differences between woolly and wool-less naturalized sheep bred in a semiarid tropical environment in terms of heat transfer by the respiratory tract. Maia et al. (2005) and Silva and Maia (2011) had already emphasized that the use of the same models for animals bred under tropical and temperate conditions was inappropriate. As a recent example, in work with Morada Nova ewes in a semiarid tropical region, Oliveira and Costa (2013) used models developed by da Silva et al. (2002) to calculate the heat loss by the respiratory system. They estimated that evaporative heat transfer ranged from 12 to 38  $W m^{-2}$ , while respiratory convection was insignificant, ranging from  $-0.002$  to  $0.004 W m^{-2}$ . However, in the present study, we observed values of  $0.65$ – $8.94 W m^{-2}$  for evaporative heat loss and  $0.74$ – $1.59 W m^{-2}$  for respiratory convection. Therefore, these results confirm that the use of the same functions without considering the environment where animals were selected could cause large errors and the results would not represent the animal's thermal balance.

Differences between the tropical semiarid zone and temperate regions revolve around the challenge of maintaining animal homeothermy. The main contrast between tropical and temperate latitudes is the radiant environment (Da Silva et al. 2012). In tropical regions, the mean radiant temperature ( $T_{MR}$ ) is usually close to or higher than the air and body temperatures, so animals gain heat by thermal radiation. In contrast, heat loss by radiation almost invariably occurs in animals in temperate latitudes. In other words, genetic adaptation in the tropics gave rise to morphological and physiological characteristics that facilitate heat dissipation and protection from solar radiation (pigmented skin). By contrast, animals adapted to temperate regions have characteristics that help retain heat (great thermal insulation by the presence of

wool). These statements are notable when we observe the animal body surface area and coat traits. Silanikove (2000) pointed out that the larger body surface areas of smaller races make them more efficient heat dissipaters in warm climates while a smaller body surface area may help to conserve heat in cold climates.

Coat surface characteristics can drive differences between individuals and determine the best avenue for heat dissipation under high temperature. The presence of long wool difficult the sensible (main surface convection) and latent heat loss from the skin surface. Several studies have shown that some long-wool sheep breeds selected for temperate zones, the respiratory system is the main avenue for heat transfer at high temperatures, but results are still conflicting (Cheviot and Scottish Blackface, Brockway et al., 1965; Merino, Hofmeyer et al. 1969; Dorset, Hofman and Riegle, 1977; Corriedale, Starling et al., 2002; Silva and Starling, 2003). Starling et al. (2002), working with Corriedale sheep in a tropical environment, reported that respiratory heat loss accounted for 70 % of total heat loss, on average. Similar results were reported by Brockway et al. (1965) and Hofmeyer et al. (1969) in a study with Merino sheep. However, Silva and Starling (2003) described that the heat loss by the respiratory system represented 37 % of total evaporation in Corriedale sheep. Despite these differences, it is clear that the respiratory tract plays a key role in thermal equilibrium of wool sheep selected for cold environments.

On the other hand, cutaneous evaporation seems to be the principal way to eliminate heat loss in animals raised on high ambient temperature as in tropical region. In study with Anglo Nubian goats acclimatized on tropical condition, Maia et al. (2016) described that under ambient temperature close to 30 °C, thermal equilibrium was reached with 15 W m<sup>-2</sup>, 35 W m<sup>-2</sup> and 40 W m<sup>-2</sup> of respiratory evaporation, sensible heat loss (radiation and free convection), and cutaneous evaporation, respectively. Ligeiro et al. (2006) working with crossbred goats acclimatized to a tropical environment and purebred breeds adapted to temperate regions (Saanen and Alpine) observed similar results and greater cutaneous evaporation in crossbred animals. In addition, Maia et al. (2015) reported that under high ambient temperature (36 °C) cutaneous evaporation represented over the 93 % of the total heat loss for “undefined breed goats” protected from direct and diffuse solar radiation in a semiarid tropical region.

According to our findings, the respiratory system is a significant avenue for latent heat loss under high temperatures, but no prior attempts had been made to identify what the main way for latent heat dissipation in wool-less sheep bred in tropical environment. Considering that the heat produced by metabolism in Morada Nova sheep can reach 45 W m<sup>-2</sup> (Fonsêca, unpublished data) and heat loss (convection and evaporation) by respiratory tract of 9 W m<sup>-2</sup> on average, the remaining 36 W m<sup>-2</sup> should be lost in the animal surface by

sensible way (radiation and convection) and cutaneous evaporation for the thermal equilibrium to be reached. In semiarid tropical environment, even in shade, during times of greatest thermal load, low thermal gradient (animal coat surface—ambient) and high radiant mean temperature can impair the elimination of heat by sensible avenues, and probably, sweat evaporation should assume this role. However, more studies are needed to investigate better this hypothesis because some part of the heat can be storage instead dissipated to the environment. The fact is that by the characteristics of the hair coat of Morada Nova sheep, the latent heat can be more easily dissipated at the skin than if it were covered by long wool.

## Conclusions

Models presented here allow estimation of heat flow from the respiratory tract in Morada Nova sheep bred in a tropical region and use easily measured physiological and environmental parameters, such as the respiratory rate, ambient air temperature, and relative humidity.

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