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ORIGINAL PAPER

Ethology, physiological, and ingestive responses of sheep subjected to different temperatures and salinity levels of water

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Abstract

The objective of this study was to evaluate the physiological responses, ethology, and ingestive behavior of female Morada Nova sheep kept in a thermoneutral environment, after thermal stress and after consuming water with different levels of salinity. Thirty-six Morada Nova females with a mean age of 10.0 ± 2.0 months and a mean weight of 25.0 ± 3.0 kg were evaluated and distributed in a climatic chamber. The experimental design was completely randomized, with a factorial scheme of 2 (air temperature (AT)) × 3 (salinity levels (SLs)) and six replications. The sheep's physiological responses, ethology (day/night), and ingestive behavior were evaluated while they were subjected to ATs of 26.0 and 32.0 °C and SLs of 3.0, 6.0, and 9.0 dS/m. With elevation in AT, the animals experienced increased ($P < 0.05$) rectal temperatures (RTs), respiratory rates (RFs), and surface temperatures (STs) and exhibited reduced ($P < 0.05$) heart rates (HRs). When consuming water with an SL of 9.0 dS/m, a HR reduction ($P < 0.05$) was observed. Sleep behavior increased ($P < 0.05$) with the increase in SL during the day. Sleeping and drinking behaviors increased ($P < 0.05$), and the time of inactivity was reduced ($P < 0.05$) during the nocturnal period with increased SLs. With increased SLs, sheep consumed more water ($P < 0.05$) and reduced ($P < 0.05$) the number of regurgitated ruminal boluses per day (NRBD). Under the conditions of thermal stress (32.0 °C), sheep need to make physiological adjustments to maintain homeothermy. Water consumption of SLs up to 9.0 dS/m causes a higher state of dormancy in female Morada Nova sheep.

Keywords Animal environment · Ethology · Saline water · Small ruminants · Temperature and humidity index

Introduction

Sheep breeding is a widespread practice in all regions of Brazil, with the highest concentration in the northeastern semi-arid region, which holds 60.6% of the Brazilian herd (IBGE 2015), representing an important economic activity, mainly for family farming (Rodrigues et al. 2014), where animals are raised primarily for meat production, supplying a part of the demand for animal protein. The semi-arid regions are characterized by high air temperatures and a high incidence of solar radiation, and these factors can negatively affect the biological functions of the animals, thus compromising their production and reproduction (Marai et al. 2007).

Sheep reared in Brazilian semi-arid regions may be affected by scarcity and/or low water quality due to the elevated surface water evaporation, with the result being that the only alternative for watering animals is groundwater. These sources are generally characterized by contained water with high salinity levels, a characteristic that is typical of the aquifers of the northeastern Brazilian semi-arid regions, and that is present in lands with a predominance of crystalline rocks. Excessively hard water is also observed in some areas with occurrences of limestone rocks (ANA 2007).

Sheep and goats are animals that are tolerant to water restriction (Al-Ramamneh et al. 2012), as well as to nutrients with high salt concentrations (Fahmy et al. 2010). Melo et al. (2017), when analyzing the groundwater of the Brazilian semi-arid regions, reported that they contained high concentrations of salts, with maximum values of 8.9 dS/m. This value

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is higher than that recommended for sheep and goats, which according to Luke (1987), should be below 8.0 dS/m.

High water salinity may affect nutrient digestibility in sheep (Fahmy et al. 2010). Assad and El-Sherif (2002) cited decreases in extracellular and interstitial fluids, and the plasma and blood volume of sheep provided with elevated water salinity. Moura et al. (2016) reported changes in feed efficiency, rumination and water consumption with the elevation in salinity levels of water offered to sheep.

Therefore, the objective of this study was to evaluate the physiological responses, ethology, and ingestive behavior of Morada Nova sheep kept in thermoneutral environment and under thermal stress, while consuming water with different levels of salinity.

Materials and methods

General

The research was approved by the Research Ethics Committee (CEP) of the Federal University of Campina Grande, Paraíba, Brazil, under Protocol CEP 284-2015.

Animals and housing

Thirty-six Morada Nova females, with a mean age of 10.0 ± 2.0 months and a mean weight of 25.0 ± 3.0 kg, were kept in a climatic chamber (6.1 × 2.8 × 2.5 m width, length, and height, respectively) and housed individually in stalls with dimensions of 1.1 × 0.5 × 0.8 m (length, width, and height, respectively). The experiment was performed in four stages of nine animals each due to the chamber housing capacity, as shown in Fig. 1.

Treatments and experimental design

The animals were distributed in a completely randomized design, in a 2 × 3 factorial scheme, with two air temperatures (ATs), three water salinity levels (SLs), and six replications. Each animal was considered as one experimental plot.

The values of the ATs used in the experiment were defined based on the thermal comfort zone (TCZ) for sheep, mentioned by Ramón et al. (2016), where the animals were submitted to two controlled temperatures: T26 = 26.0 °C (within the TCZ) and T32 = 32.0 °C (above the TCZ), with the mean air humidity and mean wind velocity at 68.0 ± 4.0% and 1.0 ± 0.4 m/s, respectively.

The SLs of the water provided were 3.0, 6.0, and 9.0 dS/m and were chosen based on a study by Luke (1987), which recommended the supply of brackish water to sheep with salinity levels of up to 8.0 dS/m but only for short periods of time.

Experimental procedures

The rations and water were supplied ad libitum. The diet was composed of 45% of concentrates, based on corn bran (25%), soybean meal (18%), and mineral supplementation (2%), and 55% roughage (tifton hay), making up a chemical composition of 13.2% crude protein (PC) and 2.55 Mcal/kg metabolizable energy (ME), according to the composition nutrients indicated by NRC (2007), for maintenance. Each of the four experimental phases lasted 15 days, with 10 days for data

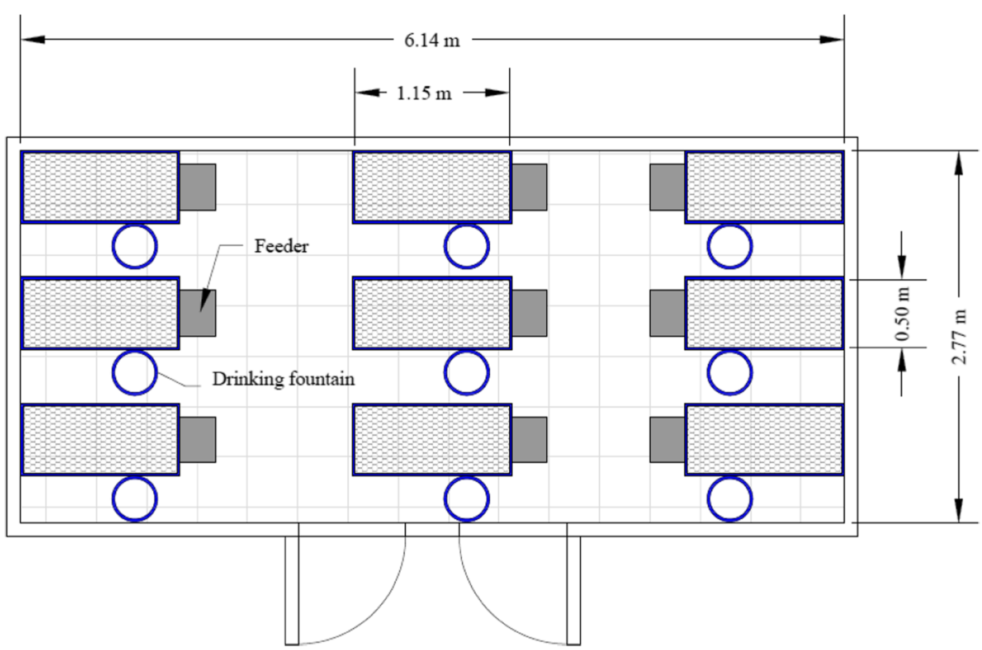

Fig. 1 Floor plan of the climatic chamber with the distribution scheme of the stalls

collection and 5 days of a pre-experimental period for acclimatization and adaptation of the animals to the experimental management and installation, with a total period of 60 days for the whole experiment, according to the flowchart shown in Fig. 2.

The climatic chamber was sealed at 6:00 a.m., and it was only opened for the input of the evaluator at the time of data collection, remaining closed for a period of 12 consecutive hours per day. At 6:00 p.m., the chamber was opened, and the animals were exposed to 12 h of room temperature. This methodology was used to simulate the climatic conditions of the Brazilian semi-arid regions, where mild temperatures occur during the nocturnal period (Mendes et al. 2014). At night (6:01 p.m. to 5:59 a.m.), mean ATs were 23.0 ± 2.2 °C and 23.0 ± 4.7 °C for each temperature tested (26.0 and 32.0 °C, respectively), and the chambers were maintained under minimal illumination to allow the animals to adapt and to avoid influencing the behavior of the animals during the collection of behavioral data.

Environmental variables

The temperature and relative humidity of the air inside the climatic chamber was monitored, controlled, and recorded 24 h a day throughout the experimental period with a microcomputer using SITRAD® free software connected to a MT-530 PLUS type controller (Full Gauge Controls®) through the sensors, i.e., the thermistor and humidistat; data were recorded every 15 min, and they are later presented as hourly averages.

The temperature and humidity index (THI) were calculated to quantify the thermal stress levels experienced by the animals (24 h per day) during the whole experimental period according to Eq. 1 (Marai et al. 2006).

$$\mathrm{THI} = \mathrm{TA}-[(0.31-0.31 \times \mathrm{RH}) \times (\mathrm{TA}-14.4)] \quad (1)$$

where

AT (°C) is the dry air temperature (in units of °C), and RH is the relative humidity (RH%)/100. The values obtained indicate the following: < 27.8 = absence of heat stress, 27.8–28.9 = moderate heat stress, 28.9–30.0 = severe heat stress, and 30.0 and more = very severe heat stress (Marai et al. 2006).

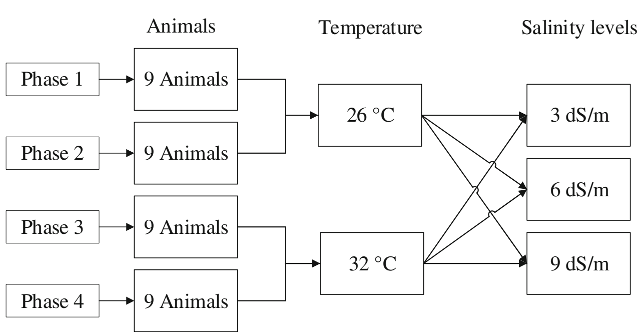

Fig. 2 Experimental execution flowchart

Physiological responses

The recorded physiological variables were rectal temperature (RT), respiratory and cardiac frequencies, and surface temperature (ST), which were collected on the third, sixth, and ninth days of each experimental period. Respiratory rate (RF, mov/min) was obtained by counting respiratory movements for 1 min through direct observation of the flank movements.

Rectal temperature (°C) was determined using a digital veterinary clinical thermometer (Incoterm®, Termomed, Rio Grande do Sul, Brazil, temperature range 32.0~43.0 °C and accuracy of ± 0.1 °C) ~ 2.0 cm into the rectum of the animals, until the reading was stabilized. Heart rate (beats/min) was measured by counting the HR for 1 min with a veterinary stethoscope (Incoterm®, Rappaport ER100, Rio Grande do Sul, Brazil).

The ST of the animals was collected using a digital laser infrared thermometer (Benetech®, GM550, Serra, Espirito Santo, Brazil, temperature range − 50.0 to 550.0 °C, accuracy of ± 1.5 °C), and the surface temperature was expressed as the arithmetic mean of the temperatures of the forehead, neck, loin, side, belly, and forearm.

Ethology and ingestive behavior

During each experimental phase, the behavior of the animals was monitored and recorded for 24 h during the third, sixth, and ninth days of each experimental period, totaling 72 h of observations. The data were collected through direct observations, where three observers remained inside the climatic chamber for 24 h, observing and recording the actions of each animal, according to behavioral criteria established by the methodology proposed by Barreto et al. (2011), described in Table 1. The behaviors were sampled every 5 min, totaling 12 samples per hour, with a total of 864 observations (12 samplings × 72 h) per animal during each experimental phase.

The behavioral data were evaluated during two distinct periods: night (from 6:01 p.m. to 5:59 a.m.) and day (from 6:00 a.m. to 6:00 p.m.) and expressed in proportions of time, according to Eq. 2.

$$\%\mathrm{ETEA} = (\mathrm{ETEA}/12) \times 100 \quad (2)$$

where

% ETEA	percentage of time in which the animals performed a certain activity (in units of %)
ETEA	time spent by the animals in the execution of a given activity (in units of h)
12	sum of the execution time of all activities performed in each period (in units of h).

Table 1 Ethogram used for the behavioral evaluation of the sheep

Item	Description
Sleeping	In a state of dormancy and inert.
Feeding	Ingestion of food with the head in the feeder and movements of the mouth or chewing.
Inactive	Standing, sitting or lying, alert and idleness.
Drinking	Ingestion of water with the muzzle inside the drinking fountain.
Ruminating	Regurgitation and remastication of food.

The dry matter intake and water consumption were recorded daily, and the feed offered and residue left were weighed and kept for to calculate dry matter intake (DMI) individually for each sheep. The sheeps were offered water individually daily in calibrated buckets (12-L capacity) of polyvinyl chloride (Vonder®, Paraná, Brazil) two times a day at 06:00 and 18:00 h ad libitum. Ingestion of water (WI) was recorded by deducting the amount of water left in bucket from the initial volume offered. The ingestive behavior of the animals was evaluated according to a methodology adapted by Canizares et al. (2014), through the following equations:

$$\mathrm{DMIR} = \mathrm{DMI}/\mathrm{FT} \quad (3)$$

$$\mathrm{RR} = \mathrm{DMI}/\mathrm{RT} \quad (4)$$

$$\mathrm{NRBD} = \mathrm{RT}/\mathrm{TSCB} \quad (5)$$

$$\mathrm{NRCD} = \mathrm{NRB} \times \mathrm{NRCB} \quad (6)$$

where

DMIR	dry matter ingestion rate (in units of kg/h)
DMI	dry matter intake (in units of kg)
FT	feed time (in units of h)
RR	rumination rate (in units of kg/h)
RT	ruminating time (in units of h)
NRBD	number of ruminal boli per day (in units of *n*/day)
TSCB	time spent chewing by boli (in units of h)
NRCD	number of ruminal chews per day (in units of *n*/day)
NRB	number of ruminal boli
NRCB	number of ruminal chews per boli.

Statistical analysis

The hourly mean values of AT, relative humidity, and THI at the two AT conditions evaluated were presented in the form of ± SEM dispersion charts.

For the statistical analysis of the data the package ExpDes.pt (version 1.1.2, Ferreira et al. 2013, Brazil) of statistical software R version 3.4.1 was used. Residual normality and homogeneity of the sample variances were tested using the Shapiro–Wilk and Bartlett tests, respectively. To evaluate the effects of ATs and SLs on the physiological responses, ethology, and ingestive behavior of the animals, ANOVA and *F* tests were used, according to the statistical model shown in Eq. 7. Tukey's test was used to compare the means, with a probability of error of 5% ($P < 0.05$).

$$y_{ijr} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijr} \quad (7)$$

where

y_{ijr} is the *r*th response that received the *i*th level of factor α and *j*th level of factor β; μ is the constant (average); α_i is the effect of the *i*th factor α (temperature), $i = 1, 2, 3,... a$; β_j is the effect of the *j*th level of the factor β (salinity), $j = 1, 2, 3,... b$; $\alpha\beta_{ij}$ is the interaction effect; and ε_{ijk} is the experimental error.

Results

Environmental variables

At the comfortable thermal temperature, the mean values of 25.9 °C, 72.0%, and 24.9 were obtained for AT, RH, and THI, respectively, during the day with the chamber closed, and the mean values of 22.8 °C, 80.3%, and 22.2 for AT, RH, and THI, respectively, were obtained at night when the chamber was left with the door open (Fig. 3).

At the stressful thermal temperature, the mean values of 31.8 °C, 66.6%, and 30.0 were obtained for AT, RH, and THI, respectively, during the day, and the mean values of 23.0 °C, 75.4%, and 22.2 for AT, RH, and THI, respectively, were obtained at night (Fig. 3b).

Physiological responses

There was no significant interaction ($P > 0.05$) between ATs and SLs on the physiological responses of the animals, and the AT significantly affected ($P < 0.05$) the physiological responses, causing an increase of 0.3, 51.1. and 16.6% in the RT, RF and ST, respectively, as well as a reduction of 10.2% in the HR and, with the increase of the salinity level from 6.0 to 9.0 dS/m, a significant reduction ($P = 0.023$) of 12.2% in the animals' HR (Table 2).

Ethology

There was no significant interaction between AT and SLs ($P > 0.05$) in the day and night behaviors of the animals

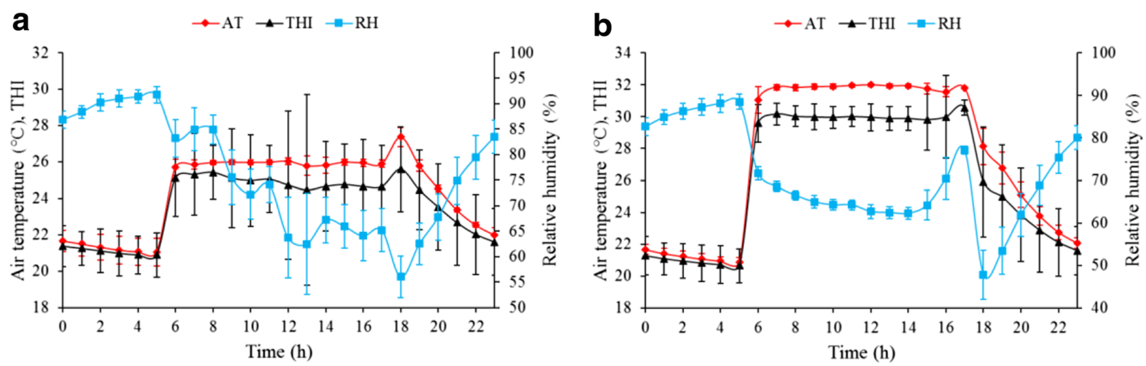

Fig. 3 Behavior of air temperature (AT), relative humidity (RH), and temperature and humidity index (THI) during the application of treatments: (**a**) AT of 26 °C; and (**b**) AT 32 °C

(Table 3). During the day, only the sleeping behavior was affected by temperature, increasing ($P = 0.002$) with the increase in temperature. The time spent asleep under thermoneutral environment was 18.1%, and under heat stress, it was 28.7%, exhibiting an increase of 10.0%; none of the other behaviors were influenced ($P > 0.05$) by SLs during the day.

During the nocturnal period, the AT did not affect ($P > 0.05$) the behavior of the sheep; but sleeping, drinking, and inactive behaviors were affected by the SLs. The ewes fed with water at an SL of 9.0 dS/m spent more time dormant ($P = 0.017$) and drinking water ($P = 0.044$), compared to animals consuming water with a salinity of 3.0 dS/m. Thus, inactive behavior decreased significantly ($P = 0.012$) as the salinity level of the water rose from 3.0 to 9.0 dS/m. The behavior of the ewes that consumed water with a salinity of 6.0 dS/m was similar to that of the other two SLs.

Ingestive behavior

There was no significant interaction between AT and SLs ($P > 0.05$) on dry matter intake, drinking water, and the ingestion responses of the sheep (Table 4). Water intake and the number of ruminal boli per day were significantly affected ($P = 0.002$ and 0.039, respectively) by AT, showing a 15.0% increase in water consumption and a decrease of 68.0 (13.0%) ruminal boli per day at the highest temperature. Among SLs, only water consumption was significantly increased ($P = 0.020$), with the other behaviors remaining similar.

Discussion

Among the factors that influence the comfort and well-being of animals raised in semi-arid regions, certain environmental factors, such as temperature and the relative humidity of air, as well as the quality of water supplied to animals, stand out (Castro et al. 2017). In this research, we evaluated the influence of AT and of SLs on physiological responses and the behavior of Morada Nova sheep kept under controlled conditions.

As shown in Fig. 3, in analyzing the ranges of THI proposed by Marai et al. (2006), it was found that in the T26 treatment, the mean THI was 24.9, which was included in the range considered as no heat stress, whereas the THI (30.0) observed during the T32 treatment was considered as a severe stress condition, during the diurnal period. It is worth noting that at night, the THI values indicated that the animals were in conditions of thermal comfort, with average values of 22.2 for both evaluated treatments. Under severe THI conditions, RT increased from 38.5 to 38.6 °C when compared to the thermal comfort condition but remained within normal limits for the species, which according to Cunningham (2004), can range from 38.5 to 39.9 °C in sheep. Thus, the

Table 2 Mean values of the rectal temperature (RT), respiratory rate (RF), heart rate (HR), and surface temperature (ST) of the sheep subjected to different air temperatures (ATs) and water salinity levels (SLs)

Item	AT (°C)		SL (dS/m)			Pooled SEM	*P* value		
	26	32	3	6	9		AT × SL	AT	SL
RT (°C)	38.53b	38.65a	38.62	38.6	38.56	0.03	0.683	0.042	0.683
RF (mov/min)	29.46b	45.57a	37.37	37.89	37.29	1.59	0.843	0.000	0.955
HR (beats/min)	99.68a	89.48b	95.40a	98.67a	86.67b	2.11	0.658	0.001	0.023
ST (°C)	28.21b	32.34a	30.36	30.22	30.25	0.38	0.994	0.000	0.934

Averages followed by the same letter are not significantly different from each other. The Tukey test was applied at the 5% probability level

Table 3 Percentage of time spent by the animals executing each activity during the diurnal and nocturnal periods when subjected to different air temperatures (ATs) and consuming water with different salinity levels (SLs)

	Item (%)[a]	AT (°C)		SL (dS/m)			Pooled SEM	*P* value		
		26	32	3	6	9		AT × SL	AT	SL
Day (06:00 to 18:00)	Sleeping	18.06 B	28.74 A	20.37	24.36	25.46	0.88	0.535	0.002	0.382
	Feeding	25.62	23.38	22.92	25.81	24.77	0.38	0.494	0.145	0.292
	Inactive	24.00	18.90	23.21	21.41	19.73	0.79	0.901	0.127	0.686
	Drinking	2.62	1.97	2.26	2.37	2.26	0.09	0.731	0.081	0.956
	Ruminating	29.71	27.01	31.25	26.04	27.78	0.63	0.404	0.281	0.228
	–	–		–			–	–		
		23	23	–	–	–		–	–	–
Night (18:01 to 05:59)	Sleeping	36.54	34.88	32.35 B	33.51 AB	41.26 A	0.69	0.851	0.525	0.017
	Feeding	8.91	8.06	5.61	9.78	10.07	0.42	0.815	0.612	0.063
	Inactive	22.26	27.35	30.50 A	23.84 AB	20.08 B	0.75	0.858	0.066	0.012
	Drinking	1.54	1.89	1.04 B	1.85 AB	2.57 A	0.10	0.535	0.372	0.044
	Ruminating	30.75	27.82	30.50	27.03	30.32	0.50	0.825	0.153	0.295

Averages followed by the same letter are not significantly different from each other. Tukey's test was applied at the 5% probability level

[a] The corresponding data averages are shown below as percentages

Morada Nova breed is well adapted to the conditions of severe thermal stress.

The elevation of AT led to a decrease in the HR, and this event may be due to a higher fluidity of the blood in the arteries that reach the outer layers of the epidermis to increase the heat dissipation of the animals' body core—a fact evidenced by the increase of 4.13 °C when submitted to thermal stress temperature—in an attempt to increase heat dissipation to the environment, causing changes in blood pressure and a consequent decrease in heart rate (Eustáquio Filho et al. 2011). When sheep were added to the T32 treatment, sheep RFs increased by 51.1%. This increase is because when subjected to thermal stress conditions, they dissipate approximately 60.0% of the surplus metabolic heat of organisms by evaporation of moisture of the respiratory tract (Thompson and Thompson 1985).

As shown in Table 2, with increasing SLs from 6.0 to 9.0 dS/m, animals exhibited reduced heart rates. Frohlich et al. (2018), when evaluating the hemodynamic responses and the cardiac mass of rats that were consuming diets with high sodium concentrations, concluded that this nutrient reduces the heart rate of the animals, due to the increases of hypertension and vascular resistance that were progressively elevated. Therefore, a possible explanation for the reduction of the heart rate in the animals that consumed the largest amounts of sodium evaluated in the present study could be alterations in baroreflex function due to hypertensive conditions caused by sodium on the animals.

Table 4 Mean values of water consumption, dry matter and ingestive responses in the animals subjected to different air temperatures (ATs) and consuming water with different salinity levels (SLs)

Item	AT (°C)		SL (dS/m)			Pooled SEM	*P* value		
	26	32	3	6	9		AT × SL	AT	SL
WI (L)	1.80 B	2.07 A	1.83 B	1.87 AB	2.11 A	0.05	0.974	0.002	0.020
DMI (kg)	0.80	0.77	0.80	0.78	0.77	0.01	0.862	0.280	0.518
DMIR (kg/h)	0.21	0.21	0.24	0.20	0.19	0.01	0.975	0.905	0.052
RR (kg/h)	0.11	0.12	0.11	0.12	0.11	0.00	0.409	0.117	0.218
NRBD (*n*/day)	521.79 A	454.14 B	487.83	515.63	460.44	0.76	0.216	0.039	0.368
NRCD (*n*/day)	3160.65	3264.07	3327.4	2991.31	3318.38	1.61	0.063	0.550	0.205

Averages followed by the same letter are not significantly different from each other. Tukey's test was applied at the 5% probability level

WI water intake (L), *DMI* dry matter intake (kg), *DMIR* dry matter ingestion rate (kg/h), *RR* rumination rate (kg/h), *NRBD* number of ruminal boli per day (*n*/day), *NRCD* number of ruminal chews per day (*n*/day)

During the day under thermal stress, the animals spend more time in dormant activity, which can be attributed to a reduction in the metabolic activity in an attempt to reduce the production of endogenous heat, due to the higher AT (Leite et al. 2017). This biological process is also due to the endogenous oscillations of the circadian rhythms (Foster and Kreitzman 2005; Koukkari and Sothern 2006). Many basic behaviors, such as inactivity, are under the control of these rhythms. Circadian rhythms are controlled by genes that activate proteins and neurotransmitters (Foster and Kreitzman 2005; Wood and Loudon 2014). Although these biological processes are endogenous, they adjust to the environment (temperature and humidity of the air) and can be influenced by same (Foster and Kreitzman 2005; Lincoln and Richardson 1998). The increase in the SLs, caused the increase of the time destined by the animals to develop the activity of sleep during the night. Murphy et al. (2016) analyzed the influence of the consumption of foods with different amounts of sodium in the diet of *Drosophila* and found that an increase in sodium consumption increases the time dedicated to sleep. In mammals, elevated salt intake may increase oxytocin signaling, which may influence sleep–wake behavior (Lancel et al. 2003; Krause et al. 2011), and oxytocin released into the brain under stress-free conditions promotes sleep, as it has a calming effect (Uvnas-Moberg et al. 2015). With the increase of SLs, there was a reduction (10.0%) in the time allocated to nocturnal inactive behavior, proportional to the increase in sleeping behavior (~ 9.0%). That is, the animals presented greater sleepiness according to the increase of SLs in the water.

Contrary to what occurred with nighttime drinking activity, SLs did not significantly affect this behavior during the day, a fact that can be justified by the higher frequency of food consumption during this period, which was, on average, three times more feeding time as compared to feeding time during the nocturnal period. With that, it has been observed that during this period, there was a higher rate of turnover and, consequently, a greater digestibility of the ruminal fluid, resulting in a greater assimilation of sodium chloride and its concentration in extracellular liquids; thus, the thirst sensation of the animals increased when they consumed water with higher concentrations of sodium, which led them to consume water more frequently during this period (Assad and El-Sherif 2002).

The intake of water is an important response for establishing the adaptive capacities of sheep (Minka and Ayo 2010; Sejian et al. 2010). The exposure of sheep to conditions of severe thermal stress ($28.9 < \text{THI} < 30.0$ (Marai et al. 2006)) induced a significant increase in water consumption and reduced food intake (Sejian et al. 2010; Indu et al. 2014; De et al. 2017), but in the present experiment, with increasing AT, only an increase in water consumption (Table 4) was observed, and this increase occurred with the intention of restoring the water loss due to the elevation of respiratory rate (51.1%) and sweating to maintain homeothermy (Façanha et al. 2013).

Among the ingestive responses, the only one affected by the increase in AT was NRBD, which showed a reduction of 68.0 boli per day when comparing the two temperatures (26.0 °C and 32.0 °C). The reduction in the number of regurgitated boli was likely due to the increased digestion efficiency and nutrient degradation in the rumen, which, according to Weniger and Stein (1992), becomes higher as the AT increases, up to a limit of 35.0 °C.

Conclusions

When subjected to an AT of 32.0 °C, sheep need to elevate their RTs, RFs, and STs and reduce their HRs to maintain homeothermy. The consumption of water with an SL of 9.0 dS/m causes the reduction of HR in female Morada Nova sheep. At high temperatures, the sheep increased the amount of time spent inactive, increased the amount of water consumed, and reduced the number of ruminal boluses regurgitated per day. In addition, the elevation of water SLs caused increased dormancy times in sheep and reduced the time they remained inactive at the night. During the nocturnal period, animals that consumed water with an SL of 9.0 dS/m spent a greater amount of time drinking water compared to those consuming water with an SL of 3.0 dS/m.

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Compliance with ethical standards

The research was approved by the Research Ethics Committee (CEP) of the Federal University of Campina Grande, Paraíba, Brazil, under Protocol CEP 284-2015.

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