DOI: 10.5433/1679-0359.2020v41n1p283

# Adaptability of sheep to three salinity levels in different environments

# Adaptabilidade de ovinos consumindo água com três níveis de salinidade em diferentes ambientes

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## Abstract

The objective of this study is to evaluate physiological parameters and the adaptability of Santa Inês sheep to two climatic conditions 25ºC (within the thermal comfort zone [TCZ) and 32ºC (above the TCZ) and three salinity levels (2.0, 4.0, and 8.0 dS $m^{-1}$). The study was developed in a climatic chamber using 36 uncastrated male sheep. The experimental design was completely randomized with a 2 ´ 3 factorial scheme composed of two temperatures, three water salinity levels, and six repetitions. The physiological variables were not affected by the salinity levels. The rectal and skin temperature and the heart and respiratory rate were higher at 32 °C. However, the rectal temperature was within the normal range for the species. The consumption of water with different salt concentrations did not affect the adaptive responses of the animals and could be an alternative water source for sheep in regions where water has a high salinity level. The respiratory rate of sheep exposed to 32 °C increased to eliminate body heat, and exposure to 25 °C provided greater thermal comfort for the animals.

**Key words:** Saline water. Climatic chamber. Sheep. Physiological variables.

## Resumo

O objetivo do trabalho foi avaliar as variáveis fisiológicas e a adaptabilidade de ovinos da raça Santa Inês, submetidos a duas condições climáticas, 25 ºC - dentro da zona de conforto térmico (ZCT) e 32 ºC - acima da ZCT, consumindo água com três níveis de salinidade (2,0, 4,0 e 8,0 dS $m^{-1}$). O estudo foi desenvolvido em câmara climática, utilizando-se 36 ovinos machos inteiros, sendo o delineamento experimental inteiramente casualizado em esquema fatorial 2 x 3, composto por duas temperaturas (parcelas repetidas no tempo) e três níveis de salinidade da água, com seis repetições. As variáveis fisiológicas não foram afetadas pelos níveis de sais na água e, na temperatura de 32 ºC a temperatura retal, superficial e a frequência cardíaca e respiratória foram mais elevadas, sendo que a temperatura retal manteve-se dentro da normalidade para a espécie. O consumo de água com diferentes concentrações de sais não afetou as respostas adaptativas dos animais, podendo ser uma alternativa de consumo para ovinos em regiões onde houver água com nível elevado de salinidade. Os ovinos ao serem expostos a temperaturas mais elevadas (32 °C) utilizaram o aumento da frequência respiratória como forma de eliminação do calor corporal e a temperatura de 25 °C forneceu maior conforto térmico para os animais.

**Palavras-chave:** Água salina. Câmara climática. Ovinocultura. Variáveis fisiológicas.

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Received: Apr. 04, 2019 - Approved: July 25, 2019

## Introduction

Sodium, potassium, calcium, and chlorine are essential electrolytes found in body fluids and structural components of bones and tissues. These electrolytes are involved in multiple functions, including acid-base balance, maintenance of osmotic pressure, membrane potential, and nerve impulse transmission, and the excess or lack of some macrominerals decreases animal performance (Reece & Dukes, 2006). Sodium concentrations above normal may cause water movement from the intracellular to the extracellular compartment, usually accompanied by excessive salt intake, potentially leading to hypertension, tachypnea, tachycardia, dehydration, severe thirst, weight loss, and death (Duarte et al., 2014).

Small ruminants use water efficiently because of their small size, optimal utilization of ingested water (Araújo, Voltolini, Chizzoti, Turco, & Carvalho, 2010; Kumar, Singh, Kumar, Sahoo, Naqvi, 2016.), ability to retain water and excrete dry stools and concentrated urine, high tolerance to water stress (Silva, Araújo, Oliveira, Azevedo, & Furtado, 2016), and tolerance to foods with high salt concentrations (Moreno et al., 2015; Castro et al., 2017) and high salinity water (Moura et al., 2016; Yousfi, Marques, Betti, Araus, & Serret, 2016). Potter (1968) reported that the consumption of high salinity water by sheep might increase the osmotic pressure in the rumen, without affecting the ruminal microbiota, and change the heart and respiratory rate of the animals (Duarte et al., 2014).

In sheep, Eustáquio Filho et al. (2011) observed that temperature of 25 °C and relative air humidity of 65% maximized production and productivity in Santa Inês breed, and animals kept at temperatures above the thermal comfort zone (TCZ) might have difficulty eliminating the excessive load, consequently increasing the rectal and skin temperature (ST) and the respiratory and cardiac rate (Queiroz et al., 2015; Titto et al., 2016; Furtado et al., 2017; Seixas, Melo, Tanure, Peripoli, & McManus, 2017). Thermal stress causes several changes in animal physiology, including a reduction in feed efficiency and intake and disturbances in water, protein, energy, and mineral balance, limiting animal production and reproduction (Marai, El-Darawany, Fadiel, & Abdel-Hafez, 2007).

Sweating animal, including sheep, are more tolerant to thermal stress by dissipating the excess heat through sweating and breathing (Lucena, Furtado, Nascimento, Medeiros, & Souza, 2013; Luz et al., 2014; Araújo, Furtado, Nascimento, Medeiros, & Lopes, 2017). Peripheral vasodilation in these animals increases blood flow to the skin, elevating ST (Luz et al., 2014; Torres et al., 2017), which facilitates heat exchange with the environment by non-evaporative processes.

Adaptability can be analyzed by the ability to adjust to adverse environmental conditions, with minimal loss of performance and small changes in physiological variables. Adaptability can be measured by different tests using individual or combined physiological variables. Animal studies in climatic chambers allow a more detailed and controlled assessment of the effect of environmental factors on thermal comfort, animal production, and social behavior (Lucena et al., 2013; Araújo et al., 2017; Miranda, Silva, Lopes, Nascimento, & Araújo, 2018). The objective of this study is to evaluate the physiological variables and adaptability of Santa Inês sheep under different salinity levels and environmental conditions.

## Material and Methods

The study was carried out in the Laboratory of Rural Constructions and Ambience of the Federal University of Campina Grande using a climatic chamber illuminated with fluorescent lamps, and a heating and cooling system using split-type air conditioners (18,000 BTU). Relative humidity was controlled by humidifiers and dehumidifiers and was measured using sensors. Wind speed was controlled using axial fans and an exhaust system.

The climatic chamber was made of laminated steel sheets, with corrosion protection and Styrofoam filling. An MT-530 PLUS-type controller (Full Gauge Controls®) was used to maintain ambient temperature (AT) and relative humidity, and SITRAD® software was used for data acquisition and monitoring.

Before the beginning of the experiments, the study was submitted to the Research Ethics Committee of the Federal University of Campina Grande, Paraíba (Protocol No. 105-2013) and complied with international guidelines on animal research. Eighteen Santa Inês uncastrated male sheep with an average age of 5.0 ± 0.5 months and an average weight of 17.0 ± 2.3 kg were housed in metabolic cages with elevated floors and equipped with food and water troughs. The animals were subjected to a temperature of 25.0 ± 1.18 °C (within the TCZ) or 32.0 ± 2.03 °C above the TCZ, adapted from (Eustáquio Filho et al., 2011), relative air humidity of 60.0 ± 5.11 (25 °C) or 60.0 ± 3.33% (32 °C), and average wind speed of 1.0 ± 0.3 m $s^{-1}$.

The climatic chamber was closed daily at 8:00 a.m. and was opened only for collecting physiological data by a researcher. The climatic chamber was opened at 4:00 p.m. Therefore, the animals remained 8 hours in a controlled environment and 16 hours at AT, simulating Brazilian semi-arid conditions. Cleaning and supply of feed and water were performed daily from 6:00 to 7:00 a.m. Three water salinity levels were used: 2.0; 4.0, and 8.0 dS $m^{-1}$. The solutions were prepared in large containers by adding sodium chloride without iodine to achieve the desired electrical conductivity. The technical recommendation for the intake of saline water for domestic animals is less than 5.0 dS $m^{-1}$ (Araújo et al., 2010). The concentrations used in the present study were below, close to, and above this threshold. The water was supplied daily *ad libitum*.

The experiments were divided into two phases. In the first phase, the climatic chamber was adjusted to the thermal comfort temperature (25.0 ± 1.18 ºC). At this temperature, six animals were selected for each water salinity level, totaling 18 animals. This phase lasted 15 days, and the first 10 days were used for acclimating the animals to the experimental conditions (environment and animal handling) whereas the remaining 5 days were used for data collection.

In the second phase, the climatic chamber was adjusted to 32.0 ± 2.03 ºC. Eighteen animals with age and weight similar to the other group were used to eliminate the influence of genetic factors and were exposed to the three salinity levels, respecting the same experimental conditions of the previous phase.

All 36 animals were weighed, tagged, vaccinated, dewormed, and fed *ad libitum*. The amount of ingested feed was calculated to allow 15% of leftovers, and the offered amount was adjusted daily. The feed was composed of Tifton hay (55%), cornmeal (25%), soybean meal (18%), and mineral supplement (2%), with a chemical composition of 88.96% of dry matter, 15.1% of crude protein, 2.23% of ether extract, and 43.22% of neutral detergent fiber. Water consumption was measured daily by weighing, disregarding water losses by evaporation.

Respiratory rate (RR), heart rate (HR), rectal temperature (RT), and ST were measured on days 11 and 14 of each phase and were collected twice a day at 10:00 a.m. and 2:00 p.m. The RR was obtained by indirect auscultation of the heart sound using a stethoscope at the level of the laryngotracheal region. The HR was measured for 1 min in the lateral region of the thorax using a stethoscope. The RT was measured using a veterinary thermometer with a scale of up to 44 °C. The ST was determined with a digital infrared thermometer at a distance of 30 cm from the skin.

To evaluate the degree of heat evaporation, the thermal gradients between RT and ST (RT-ST) and between ST and AT (ST-AT) were calculated.

The Iberia or Rhoad test and the Benezra test were performed, all adapted for sheep (Silva, 2000).

The heat tolerance coefficient (HTC) was determined using the Iberia or Rhoad test with the following formula:

$$HTC = 100 – [18 (RT – 39.1)]$$

Where:

HTC is the heat tolerance coefficient;

100 is the maximum efficiency in maintaining body temperature at 39.1 °C;

18 is a constant;

RT is the final mean rectal temperature;

39.1 ºC is the average RT considered normal for sheep in the TCZ

Benezra's coefficient of adaptability 1 ($CA_1$) was determined as follows:

$$CA_1 = RT/39.1 + RR/19$$

Where:

$CA_1$ is Benezra's coefficient of adaptability;

RT is the rectal temperature (°C);

RR is the respiratory rate (breaths $min^{-1}$);

39.1 is the rectal temperature considered normal for sheep;

19 is the respiratory rate considered normal for sheep.

To increase the efficiency of this test in analyzing animal adaptability, the HR was added to the previous formula, and the coefficient of adaptability 2 ($CA_2$) was obtained.

$$CA_2 = RT/39.1 + RR/19 + HR/75$$

Where:

$CA_2$ is Benezra's coefficient of adaptability;

RT is the rectal temperature (°C);

RR is the respiratory rate (breaths $min^{-1}$);

39.1 is the rectal temperature considered normal for sheep;

19 is the respiratory rate considered normal for sheep;

HR is the heart rate;

75 is the heart rate considered normal for sheep.

The animals were distributed in a completely randomized design in a 2 ´ 3 factorial scheme with two temperatures, three water salinity levels, and six repetitions (36 animals in total). The means were compared using Tukey's test at a level of significance of 5% ($p<0.05$).

## Results and Discussion

There was no significant difference ($p>0.05$) in feed and water consumption between the water salinity levels and the temperatures, demonstrating that sheep were tolerant to saline water, with a mean consumption of feed and water of 0.94 ± 0.04 and 0.74 ± 0.02 kg $animal^{-1}$ $day^{-1}$ and 1.87 ± 0.34 and 2.82 ± 0.27 liters $animal^{-1}$ $day^{-1}$ at 25 °C and 32 °C, respectively (Table 1).

**Table 1**
**Mean and standard deviation of daily feed and water intake by sheep under different temperatures and salinity levels**

| | Salinity levels | Air temperature (ºC) | |
|---|---|---|---|
| | | 25 ºC | 32 ºC |
| Daily feed intake (kg) | 2 dS $m^{-1}$ | 0.94 ± 0.03 aA | 0.74 ± 0.02 bA |
| | 4 dS $m^{-1}$ | 0.95 ± 0.03 aA | 0.75 ± 0.02 bA |
| | 8 dS $m^{-1}$ | 0.93 ± 0.06 aA | 0.75 ± 0.03 bA |
| Daily water consumption (L) | 2 dS $m^{-1}$ | 1.86 ± 0.26 bA | 2.81 ± 0.30 aA |
| | 4 dS $m^{-1}$ | 1.78 ± 0.47 bA | 2.78 ± 0.21 aA |
| | 8 dS $m^{-1}$ | 1.98 ± 0.28 bA | 2.86 ± 0.30 aA |

Means with the same lowercase letter in each row and uppercase letters in each column were not significantly different from each other at a level of significance of 5% using the Tukey test.

Feed intake was lower at 32 °C ($p<0.05$), suggesting that caloric intake was decreased to reduce endogenous heat production. It is known that high temperatures can cause stress in animals, inducing a voluntary reduction in food intake as a mechanism to decrease heat production from ruminal fermentation (Silva, 2000; Reece & Dukes, 2006).

Water consumption was higher at 32 °C ($p<0.05$), and this increase is due to the need to cool the body by conduction and restore the water evaporated through the airways and skin (Brasil, Wechesler, Baccari, Gonçalves, & Bonassi, 2000). Araújo et al. (2010) have shown that heat, dry matter intake, and mineral supplementation affect water consumption.

Feed and water intake was more strongly affected by temperature than by salt concentration, indicating that sheep were tolerant to water salinity. Kumar et al. (2016) have shown that sheep can adjust their physical and reproductive responses by reducing water intake by up to 20% of the total consumption during summer. Moura et al. (2016) found no significant changes in the ingestive behavior of Santa Inês sheep consuming water with up to 8,326 mg of total dissolved solids.

There was no interaction between temperature and water salinity levels for the analyzed physiological variables. At both temperatures, there was no significant difference ($p>0.05$) in the RT, ST, and HR as a function of water salinity. Nonetheless, there was a significant difference ($p<0.05$) in the RR according to water salinity at both temperatures (Table 2). Moreover, there was a significant difference ($p<0.05$) in all physiological variables between the two temperatures, with higher values at 32 °C.

The salt concentration at each temperature did not significantly affect the RT ($p<0.05$), which was within the normal range for the species (38.5–39.9 ºC) (Cunningham, 2004), demonstrating the tolerance of sheep to water salinity (Moura et al., 2016; Yousfi et al., 2016). The RT increased at 32 °C regardless of the salinity level but remained within the normal range, indicating that the RT is increased when evaporative processes of heat exchange are insufficient and that sheep have difficulty dissipating heat under high temperatures (Eustáquio Filho et al., 2011). Titto et al. (2016) emphasize the adaptability of Santa Inês sheep since the RT decreased when animals were exposed to solar radiation and returned to baseline values faster than in other sheep breeds.

**Table 2**
**Mean rectal temperature, ST, respiratory rate, and heart rate of sheep under different temperatures and water salinity levels**

| Salinity levels | Rectal temperature (°C) | | Skin temperature (° C) | |
|---|---|---|---|---|
| | 25 °C | 32 °C | 25 °C | 32 °C |
| 2 dS $m^{-1}$ | 38.9 ± 0.18bA | 39.4 ± 0.18aA | 29.7 ± 0.27bA | 34.4 ± 0.62aA |
| 4 dS $m^{-1}$ | 38.9 ± 0.26bA | 39.3 ± 0.11aA | 29.4 ± 0.37bA | 34.2 ± 0.38aA |
| 8 dS $m^{-1}$ | 38.8 ± 0.23bA | 39.1 ± 0.32aA | 29.5 ± 0.34bA | 34.5 ± 0.21aA |
| | Heart rate (beats $min^{-1}$) | | Respiratory rate (breaths $min^{-1}$) | |
| | 25 °C | 32 °C | 25 °C | 32 °C |
| 2 dS $m^{-1}$ | 97.5 ± 1.17bA | 107.5 ± 1.17aA | 33.5 ± 1.17bB | 98.9 ± 1.17aA |
| 4 dS $m^{-1}$ | 98.3 ± 1.06bA | 109.8 ± 3.65aA | 34.0 ± 2.12bA | 99.5 ± 1.17aA |
| 8 dS $m^{-1}$ | 100.5 ± 1.41bA | 110.7 ± 3.18aA | 35.0 ± 2.94bA | 100.0 ± 1.06aA |

Means with the same lowercase letter in each row and uppercase letters in each column were not significantly different from each other at a level of significance of 5% using the Tukey test.

The different salt concentrations at each temperature did not significantly change the ST ($P<0.05$). It is known that high salt concentrations may cause changes in the acid-base balance in the blood. Nonetheless, the salt concentrations used were not sufficient to cause detectable changes. Regardless of the salinity level, the animals had higher ST ($P<0.05$) at 32 °C, and this elevation is a physiological mechanism evolved to dissipate heat through the sweat glands and becomes efficient when temperature is high and humidity is low (Luz et al., 2004) because blood flow to the skin is increased, stimulating sweat gland activity (Ligeiro, Maia, Silva, & Loureiro, 2006).

There was no significant change in the HR ($P>0.05$) as a function of the water salinity levels. However, there was a significant difference in this parameter between the two temperatures ($P<0.05$), being higher at 32 °C. At both temperatures, the HR was above normal for the species (70–80 bpm) (Reece, 1996), which can be attributed to the conditions of the climatic chamber, with low air movement. A higher concentration of salts in the bloodstream may affect the HR because water, especially in blood plasma, transports toxic substances and metabolic waste for excretion. Nonetheless, animals consuming excess salts have higher sodium and chloride excretion in urine and feces (Potter, 1968).

The water salt concentrations at both temperatures significantly changed the RR ($P<0.05$), with lower values at the lower water salinity level, and RR values were above normal for the species (20–34 breaths $min^{-1}$) (Reece, 1996). The animals exposed to 32 °C had a higher RR, demonstrating that RR elevation is one of the mechanisms used by sheep to dissipate heat to the environment (Eustáquio Filho et al., 2011; Luz et al., 2014). Duarte et al. (2014) reported that sheep under water stress and ingesting excessive minerals had tachypnea, tachycardia, and dehydration, as well as high concentrations of sodium and potassium in the blood.

Eustáquio Filho et al. (2011) evaluated sheep, and Araújo et al. (2017) and Lucena et al. (2013) evaluated goats in climatic chambers and found that the ST, RT, RR, and HR increased as air temperature increased.

The salt concentrations alone did not significantly change ($P>0.05$) the RT-ST and ST-AT gradients (Table 3), indicating that salinity did not significantly affect internal heat exchange and intracellular and extracellular water concentrations, i.e., there was no accumulation of salts in tissues, which could limit thermal exchange. Exposure to 25 °C significantly changed ($p<0.05$) RT-ST and ST-AT, and these gradients were lower at 32 °C, decreasing the efficiency of sensible heat loss.

**Table 3**
**Mean thermal gradients (rectal temperature–skin temperature) and (skin temperature–ambient temperature) of sheep at different temperatures**

| Salinity levels | Rectal temperature – skin temperature | | Skin temperature – ambient temperature | |
|---|---|---|---|---|
| | 25 °C | 32 °C | 25 °C | 32 °C |
| 2 dS $m^{-1}$ | 9.00 ± 0.15aA | 4.91 ± 0.52bA | 4.50 ± 0.93aA | 1.81 ± 1.45bA |
| 4 dS $m^{-1}$ | 9.31 ± 0.17aA | 5.05 ± 0.41bA | 4.15 ± 0.83aA | 1.82 ± 1.94bA |
| 8 dS $m^{-1}$ | 9.09 ± 0.17aA | 4.73 ± 0.18bA | 4.38 ± 0.82aA | 2.08 ± 2.00bA |

Means with the same lowercase letter in each row and uppercase letters in each column were not significantly different from each other at a level of significance of 5% using the Tukey test.

In this condition, the animals can maintain body temperature by vasodilation, which increases peripheral blood flow and ST. However, if thermal stress persists, the animals become dependent on heat loss by evaporation during respiration and/or sweating (Araújo et al., 2017).

The animals kept at 25 °C had higher thermal gradients, which may facilitate the transfer of heat from internal tissues to the skin and from the skin to the atmosphere by conduction and, depending on environmental conditions, by convection. Santos, Souza, Souza, Cesar & Tavares (2006) found that the ST was higher in the afternoon, and ST-AT and RT-ST gradients were lower because the air temperature was higher in this period.

The different salt concentrations at each temperature did not significantly change the results of the Iberia test. The values at 25 °C and 32 °C were 103.1 and 96.26, respectively (Table 4). These findings are similar to those of Eustáquio et al. (2011), with values of 105.2 and 103.6 in Santa Inês sheep subjected to a temperature of 10 ºC and 20 ºC, respectively, in a climatic chamber.

**Table 4**
**Iberia and Benezra coefficients of adaptability in Santa Inês sheep in a climatic chamber at different temperatures**

| Salinity levels | Iberia test | | $AC_1$ | | $AC_2$ | |
|---|---|---|---|---|---|---|
| | 25 °C | 32 °C | 25 °C | 32 °C | 25 °C | 32 °C |
| 2 dS $m^{-1}$ | 102.7 ± 1.27aA | 95.5 ± 3.39bA | 3.0 ± 0.18bA | 4.5 ± 0.18aA | 4.3 ± 0.21bA | 5.9 ± 0.22aA |
| 4 dS $m^{-1}$ | 103.6 ± 3.81aA | 96.4 ± 2.12bA | 3.3 ± 0.29bA | 4.6 ± 0.18aA | 4.6 ± 0.30bA | 6.1 ± 0.25aA |
| 8 dS $m^{-1}$ | 103.1 ± 0.63aA | 96.9 ± 5.09bA | 3.5 ± 0.34bA | 4.9 ± 0.15aA | 4.8 ± 0.39bA | 6.3 ± 0.22aA |

Means with the same lowercase letter in each row and uppercase letters in each column were not significantly different from each other at a level of significance of 5% using the Tukey's test.

The average value of the Iberia test was similar to the reference value (100) because of the small variation in body temperature, demonstrating that Santa Inês breed have a high ability to maintain RT under normal conditions, even when subjected to high temperatures, evidencing high heat tolerance and the use of other mechanisms to maintain body temperature, such as increase in the RR, HR, and ST.

The salt concentrations did not change $AC_1$, which averaged 3.3 to 4.7 at 25 °C and 32 °C, respectively. The mean values observed at both temperatures were above 2, which is the recommended value (Silva, 2000), especially at 32 °C, because of the increase in RR, demonstrating that this physiological response is an effective mechanism of heat dissipation.

The salt concentrations at the two temperatures did not change $AC_2$, which averaged 4.6 and 6.2 at 25 oC and 32 °C, respectively. $AC_2$ increased as temperature increased, indicating that sheep improve physiological function to increase heat exchange.

The salt concentrations did not affect the adaptive responses of the animals, demonstrating that sheep are tolerant to water salinity. Castro et al. (2017) found that it was possible to supply saline water to sheep and that salinity did not affect carcass characteristics of Santa Inês sheep. Yousfi et al. (2016) found no detectable effect of saline water on the performance and production of sheep.

## Conclusions

A water supply with a salinity level of up to 8 dS $m^{-1}$ did not significantly change the physiological variables of Santa Inês sheep and could be an alternative water source for sheep in regions where water has a high salinity level;

Sheep exposed to temperatures of 32 °C maintained homeothermy by activating mechanisms of heat loss. Moreover, the ST, HR, and RR were increased at this temperature.

The temperature of 25 °C provided greater thermal comfort for Santa Inês sheep, demonstrated by the optimal values obtained in the tolerance tests.

## Acknowledgements

We are grateful to CNPQ for funding this research and CAPES for granting the scholarship.

## References

Araújo, G. G. L., Voltolini, T. V., Chizzotti, M. L., Turco, S. H. N., & Carvalho, F. F. R. (2010). Water and small ruminant production. *Revista Brasileira de Zootecnia*, *39*, 326-336. doi: 10.1590/S1516-35982010001300036

Araújo, T. G. P., Furtado, D. A., Nascimento, J. W. B., Medeiros, A. N., & Lopes, J. P., Neto. (2017). Thermoregulatory responses and adaptability of Anglo-nubian goats maintained in thermoneutral temperature an under heat stress. *Journal of Animal Behaviour and Biometeorology*, *5*(3), 106-111. doi: 10.31893/2318-1265jabb.v5n3p106-111

Brasil, L. H. A., Wechesler, F. S., Baccari, F., Jr., Gonçalves, H. C., & Bonassi, I. A. (2000). Efeitos do estresse térmico sobre a produção, composição química do leite e respostas termorreguladoras de cabras da raça Alpina. *Revista Brasileira de Zootecnia*, *29*(6), 1632-1641. doi: 10.1590/S1516-35982000000600006

Castro, D. P. V., Yamamoto, S. M., Araújo, G. G. L., Pinheiro, R. S. B., Queiroz, M. A. A., Albuquerque, I. R. R., & Moura, J. H. A. (2017). Influence of drinking water salinity on carcass characteristics and meat quality of Santa Inês lambs. *Tropical Animal Health and Production*, *49*(6), 1095-1100. doi: 10.1007/s11250-017-1289-5

Cunningham, J. G. (2004). *Tratado de fisiologia veterinária* (3th ed.). Rio de Janeiro: Guanabara Koogan.

Duarte, M. D., Bezerra, P. D., Jr., Lima, D. H. S., Bomjardim, H. A., Oliveira, C. M. C., Silva, N. S., & Barbosa, J. D. (2014). Surto de intoxicação por sal em ovinos no estado do Pará. *Pesquisa Veterinária Brasileira*, *34*(11), 1061-1068. doi: 10.1590/S0100-736X2014001100004

Eustáquio, A., Fº, Teodoro, S. M., Chaves, M. A., Santos, P. E. F., Silva, M. W. R., Murta, R. M., & Souza, L. E. B. (2011). Zona de conforto térmico de ovinos da raça Santa Inês com base nas respostas fisiológicas. *Revista Brasileira de Zootecnia*, *40*(8), 1807-1814. doi: 10.1590/S1516-35982011000800026

Furtado, D. A., Oliveira, F. M. M., Sousa, W. H., Medeiros, G. R., Oliveira, M. E. C., & Veigas, R. R. (2017). Thermal comfort indexes and physiological parameters of Santa Inês and crossbreed ewes in the semi-arid. *Journal of Animal Behaviour and Biometeorology*, *5*(2), 72-77. doi: 10.26667/2318-1265jabb.v5n2p72-77

Kumar, D., De, K., Singh, A. K., Kumar, K., Sahoo, A., & Naqvi, K. (2016). Effect of water restriction on physiological responses and certain reproductive traits of Malpura ewes in a semiarid tropical environment. *Journal of Veterinary Behavior Clinical Applications and Research*, *12*, 54-59. doi: 10.1016/j.jveb.2015.11.006

Ligeiro, E. C., Maia, A. S. C., Silva, R. G., & Loureiro, C. M. B. (2006). Perda de calor por evaporação cutânea associada às características morfológicas do pelame de cabras leiteiras criadas em ambiente tropical. *Revista Brasileira de Zootecnia*, *35*(2), 544-549. doi: 10.1590/S1516-35982006000200029

Lucena, L. F. A., Furtado, D. A., Nascimento, J. W. B., Medeiros, A. N., & Souza, B. B. (2013). Respostas fisiológicas de caprinos nativos mantidos em temperatura termoneutra e em estresse térmico. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *17*(6), 672-679. doi: 10.1590/S1415-43662013000600014

Luz, C. S. M., Fonseca, W. J. L., Barros, C. P., Jr., Sousa, G. G. T., Amorim, R. B., Silva, L. A., & Santos, K. R. (2014). Estimativas de características termorreguladoras de ovinos em período seco e chuvoso criados na região do vale do Gurgéia, sul do estado do Piauí. *Acta Veterinária Brasílica*, *8*(1), 19-24. doi: 10.21708/avb.2014.8.1.3233

Marai, I. F. M., El-Darawany, A. A., Fadiel, A., & Abdel-Hafez, M. A. M. (2007). Physiological traits as affected by heat stress in sheep - a review. *Small Ruminant Research*, *71*(1-3), 1-12. doi: 10.1016/j.smallrumres.2006.10.003

Miranda, J. R., Silva, V. C., Lopes, J. P., Neto, Nascimento, J. W. B., & Araújo, T. G. P. (2018). Variáveis fisiológicas e desempenho produtivo como indicadores de estresse térmico em caprinos mestiços Boer em câmara climática. *Energia na Agricultura*, *33*(3), 201-206. doi: 10.17224/EnergAgric.2018v33n3p201-206

Moreno, G. M., Borba, H., Araújo, G. G. L., Sañudo, C., Sobrinho, A. G., Buzanskas, M. E., Boaventura, O., Neto. (2015). Meat quality of lambs fed different saltbush hay (Atriplex nummularia) levels. *Italian Journal of Animal Science*, 14(2), 251-259. doi: 10.4081/ijas.2015.3302.

Moura, H. H. A., Araújo, G. G. L., Saraiva, E. P., Albuquerque, I. R. R., Turco, S. H. N., Costa, S. A. P., & Santos, N. M. (2016). Ingestive behaviour of crossbred Santa Inês sheep fed water with different salinity levels. *Semina: Ciências Agrárias*, *37*(2), 1057-1068. doi: 10.5433/1679-0359.2016v37n2p1057

Potter, B. J. (1968). The influence of previous salt ingestion on the renal function of sheep subjected to intravenous hypertonic saline. *Journal Physiology*, *194*(2), 435-455. doi: 10.1113/jphysiol.1968.sp008417

Queiroz, E. O., Macedo, F. A. F., Barbosa, O. R., Zancanela, V., Mora, N. H. A. P., & Baliscei, M. A. (2015). Parâmetros fisiológicos e desempenho para ovelhas Santa Inês e cordeiros ½ Dorper - Santa Inês nas estações verão e inverno. *Revista Brasileira de Saúde e Produção Animal*, *16*(1), 199-209. doi: 10.1590/S1519-99402015000100021

Reece, W. O., & Dukes, H. H. (2006). *Fisiologia dos animais domésticos* (12ed. ed.). Rio de Janeiro: Guanabara Koogan.

Reece, W. O. (1996). Respiração nos mamíferos. In H. H. Dukes, & M. J. Swenson. *Fisiologia dos animais domésticos* (10th ed., Chap. 7, pp. 199-205). Rio de Janeiro: Guanabara Koogan.

Santos, J. R. S., Souza, B. B., Souza, W. H., Cezar, M. F., & Tavares, G. P. (2006). Respostas fisiológicas e gradiente térmicos de ovinos das raças Santa Inês, Morada Nova e seus cruzamentos com a raça Dorper as condições do semiárido nordestino. *Ciência e Agrotecnologia*, *30*(5), 995-1001. doi: 10.1590/S1413-70542006000500025

Seixas, L., Melo, C. B., Tanure, C. B., Peripolli, V., & McManus, C. (2017). Heat tolerance in brazilian hair sheep. *Asian-Australasian Journal of Animal Sciences*, *30*(4), 593-601. doi: 10.5713/ajas.16.0191

Silva, C. M., Araújo, G. G. L., Oliveira, B. Y. S., Azevedo, J. A. G., & Furtado, D. A. (2016). Performance and economic viability of feedlot sheep fed different levels of roughage, concentrate, and water. *Semina: Ciências Agrárias*, *37*(3), 1595-1606. doi: 10.5433/1679-0359.2016v37n3p1595

Silva, R. G. (2000). *Introdução à bioclimatologia animal*. São Paulo: Nobel.

Titto, C. G., Veríssimo, C. J., Pereira, A. M. F., Geraldo, A. M., Katiki, L. M., & Titto, E. A. L. (2016). Thermoregulatory response in hair sheep and shorn wool sheep. *Small Ruminant Research*, *144*(1), 341-345. doi: 10.1016/j.smallrumres.2016.10.015

Torres, T. S., Silva, L. O., Borges, L. S., Sena, L. S., Moreira, A. L., Machado, L. P. M., Sousa, A. Jr. (2017). Behavioral and thermoregulatory characteristics of Dorper Sheep. *Journal of Animal Behaviour and Biometeorology*, *5*(3), 85-90. doi: 10.31893/2318-1265jabb.v5n3p85-90

Yousfi, S., Márquez, A. J., Betti, M., Araus, J. L., & Serret, M. D. (2016). Gene expression and physiological responses to salinity and water stress of contrasting durum wheat genotypes. *Journal of Integrative Plant Biology*, *58*(1), 48-66. doi: 10.1111/jipb.12359