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Physiological responses, water consumption, and feeding behaviour of lamb breeds fed diets containing different proportions of concentrate

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Abstract The use of adapted breeds, such as Santa Inês, is of paramount importance for regions with high temperatures because they develop efficient mechanisms for heat dissipation. Furthermore, some breeds have physiological adaptations, such as more efficient mechanisms for the digestion of fibrous foods (e.g. Rabo Largo), which can reduce the harmful effects of semiarid environments. We studied the ingestive behaviour, water consumption, and physiological parameters during feeding of two native sheep breeds fed diets containing high (700 g/kg DM; HC diet) or low (300 g/kg DM; LC diet) percentages of concentrates, based on dry matter (DM). A total of 40 uncastrated male lambs (20 Rabo Largo [breed 1] and 20 Santa Inês [breed 2], with an average body weight of 16.68 ± 2.78 kg, and 19.29 kg ± 3.28 kg, respectively), were distributed in a randomised block design in a two-by-two factorial scheme (breeds × diets) with 10 repetitions. Santa Inês lambs consumed and ruminated DM (P = 0.029 for both) and neutral detergent fibre (NDF; P = 0.001 and P = 0.004, respectively) more efficiently than RaboLargo lambs, while the latter showed an increase in respiratory rate (+19 breaths/min) and rectal temperature (+1.3 °C) compared to the Santa Inês lambs (P = 0.001). The HC diet negatively affected (P < 0.05) the feeding behaviour of the animals, reflecting the higher (P < 0.05) water consumption. The results showed that diets rich in concentrate negatively affected the thermoregulation of lambs. Santa Inês have greater feed and thermoregulatory efficiency than Rabo Largo lambs under conditions of heat stress in the feedlot.

Keywords: animal welfare, bioclimatology, efficiencies, respiratory rate

1. Introduction

Global warming has resulted in increased public concern about the adaptation of animals to heat (Silva et al 2015), since weather conditions can interfere with physiological parameters and animal behaviour (Santos et al 2019). In addition to being a serious animal welfare problem, thermal stress can lead to losses in profitability in animal production (Maurya et al 2019; Machado et al 2021a).

Brazil is a continental country that is highly suited to agricultural production, and one of the most promising production chains in recent years is sheep farming. Currently, the Brazilian sheep herd holds approximately 19.7 million head, 68.5% of which are concentrated in the northeast region of the country (IBGE 2020) which is historically marked by a high environmental thermal load and water scarcity (Machado et al 2021b).

Small ruminants express their ingestive behaviour through metabolic changes promoted by the amount of nutrients ingested because they readily adapt to different feeding, handling, and environmental conditions (Machado et al 2020). Thus, the evaluation of ingestive behaviour is important for regulation and adjustment in the nutritional management of animals and understanding the feeding habits of ruminants (Perazzo et al 2017).

Adapted breeds are essential, as they are efficient in the heat dissipation process in hot regions, such as the Northeast of Brazil. Among the sheep commonly most found in Northeastern Brazil, Santa Inês has a high degree of adaptability to semi-arid conditions (Santos et al 2006). However, Rabo Largo sheep stand out among the exploited naturalised breeds mainly in the Northeast, with fat deposition on the tail as a striking characteristic (McManus et al 2020).

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Fat-tailed sheep, such as Rabo Largo, have physiological adaptations that allow them to be more rustic and endure seasonalities in food supply and quality in semi-arid environments because they have an efficient digestive mechanism for maximum use of fibre as well as the ability to store energy reserve in their tails (Wilkes et al 2012). However, the latter characteristic can reduce thermoregulatory capacity due to the thermal insulation properties of the fat (Machado et al 2020a).

This study aimed to evaluate ingestive behaviour, water consumption, and physiological parameters during the feeding of two native sheep breeds (Santa Inês and Rabo Largo), fed diets formulated with different levels of concentrates in their composition.

2. Materials and Methods

2.1. Ethical considerations and study location

The study was conducted at the Federal University of Maranhão, Chapadinha, MA, Brazil (03°44'26" S, 43°21'33" W, and 100 m altitude), in strict accordance with the recommendations of the Guide for the Care and Use of Agricultural Animals in Research and Teaching and was approved by the Committee on the Ethics of Animal Experiments of the Federal University of Maranhão, Maranhão, Brazil (Protocol Number 23115.006806/2017-76).

2.2. Animals, housing and treatments

Forty unecastradet male lambs consisting of twenty Rabo Largo, and twenty Santa Inês with initial average body weights of 16.68 ± 2.78 kg and 19.29 kg ± 3.28 kg respectively, and an average age of 5 months were used in the study. The lambs were housed in individual stalls (1.3 by 2.5 m) with concrete floors, individually equipped with saltshakers, water buckets, and feed troughs for 58 days.

The lambs underwent an adaptive period of nine days. During this time, all animals were treated against internal and external parasites with Moxidectina (Cydectin, Fort Dodge Animal Health, Campinas, SP, Brazil). Lambs received water and mineral salt *ad libitum* and were fed twice daily (09:00 and 16:00). The feed refusals were collected and weighed daily, and the amount of feed offered was adjusted to allow for 10% refusal (Parente et al 2020).

Four experimental treatments were evaluated using the Rabo Largo or Santa Ines lambs, and diets containing high (700 g/kg DM; HC diet) or low (300 g/kg DM; LC diet) concentrate levels (Table 1). The experimental diets were based on Tifton-85 hay (*Cynodon* spp.), ground corn, and soybean meal, and were formulated according to the NRC (2007) guidelines for an average daily gain (ADG) of 150 g/day to LC diet and 200 g/day for the HC diet.

Table 1 Chemical composition of experimental diets.

Ingredients, in g/Kg DM	Diets²	
	HC diet	LC diet
Tifton-85 hay	300.00	700.00
Corn grounded	542.50	141.90
Soybean meal	100.00	100.40
Wheat meal	40.50	40.70
Limestone	8.10	8.00
Mineral Salt¹	8.90	8.90
Chemical composition		
Dry matter	857.80	857.10
Crude protein	127.07	107.12
Acid Detergent Fibre	228.66	354.09
Neutral Detergent Fibre	396.11	638.64
Ethereal Extract	43.70	26.64
Organic matter	940.60	922.20
Ash	59.39	77.77
Non-Fibrous Carbohydrate	373.73	149.83
Total Carbohydrate	769.84	788.47
Metabolic Energy (Kcal/kg)	2.55	2.21

[1]Composition: Ca 13,4%, P 7,5%, Mg 1%, S 7%, Cl 21,8%, Na 14,5%, Mn 1100 mg/kg, Fe 500 mg/kg, Zn 4600 mg/kg, Cu 300 mg/kg, Co 40 mg/kg, I 55 mg/kg, Se 30 mg/kg. [2]HC diet = diet containing high percentage of concentrate (700 g/kg DM) and LC diet = diet containing low percentage of concentrate (300 g/kg DM)

2.3. Experimental procedure

Samples of ingredients, diets, and refusals were collected, weighed, and identified. After were homogenisation, the samples were pre-dried in a forced-air ventilation oven at 55 °C for 72 h, ground in a Wiley knife mill (Marconi, Piracicaba, SP, Brazil) with a sieve size of 1 mm, and subjected to analyses to determine the dry matter (DM; method 967.01), ash (method 942.05), crude protein (CP; method 968.06), and ether extract (EE; method 954.05) contents (AOAC 1990).

Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to Van Soest et al (1991), with changes proposed by Detmann et al (2012), using an autoclave. The non-fiber carbohydrates (NFC) were determined by the equation calculated: NFC (%) = 100 – (%CP + %EE + %Ash + %NDF). Total carbohydrates (TC) were obtained using the equation TC (%) =% CP +% EE +% Ash, according to Sniffen et al. (1992). Total digestible nutrients (TDN) were calculated by the equation: TDN = digestible CP + (digestible EE × 2.25) + digestible NDF + digestible NFC. The metabolizable energy (ME) of each diet was calculated according to NRC (2007).

2.4. Ingestive behaviour and water intake

Dry matter (DMI) and neutral detergent fibre (NDFI) intake were calculated as the difference between the amount of diet supplied and the refusals (Table 2). Between the 20th and 41st days of the experimental period, the animal's activities were observed and recorded by two trained evaluators for feeding, rumination, and idling activities (Bürger et al 2000) at 5 min intervals for 24 h according the method of Johnson and Combs (1991).

Total chewing time was documented during three rumination periods throughout the day, between 11:00 and 13:00, 15:00 and 17:00 and, 19:00 and 21:00. The number of chews per ruminal bolus and the time spent ruminating on each bolus (seconds/bolus) were determined using a digital timer as described by Carvalho et al (2011). The number of ruminated boli (BOL), chewing time per bolus (CTPB), total number of chew (NTC), and the number of chews per bolus (NCPB) were determined according to Polli et al (1996).

Feeding and rumination efficiency were obtained according to Azevedo et al (2013), using the following equations: DM feeding efficiency (g DM/day) = dry matter intake/feeding time (hours/day), and NDF feeding efficiency (g NDF/hour) = neutral detergent fibre intake/feeding time (hours/day).

DM rumination efficiency (g MS/h) = dry matter intake/rumination time (hours/day), and NDF rumination efficiency (g NDF/hour) = neutral detergent fiber intake/rumination time (hours/day). Total chewing time = feeding time + rumination time (hours/day).

Water intake (WI, kg/day) was determined based on the feed offered, feed refused, and water evaporated (Machado et al 2020a). The water intake from feed (1), a total of water intake (2), the ratio between water intake and dry matter intake (3), and the ratio between the total of water intake and dry matter intake (4) were calculated by the following equations:

$$WFI = DMI \times ((1000-DM)/100) \quad (1)$$

$$TWI = WI + WFI \quad (2)$$

$$RWDM = WI/DMI \quad (3)$$

$$RTWDM = TWI/DMI \quad (4)$$

where: WFI is the intake from feed (kg); DMI is the dry matter intake (g); TWI is the total of water intake (kg), RWDM is the ratio between water intake and dry matter intake (kg/kg), and RTWDM is the ratio between the total of water intake and dry matter intake (kg/kg).

2.5. Microclimate assessment

Temperature (TA, °C), relative humidity (RH, %), black globe temperature (BGT, °C), and wind speed (WS, m/s) were recorded at 6:00, 10:00, 14:00 and, 18:00. The TA and RH were measured using two thermo-hygrometers (HOBO U12-12, São José dos Campos, SP, Brazil) spatially distributed in the experimental shed at a height of 1.20 m as detailed by Santos et al (2019).

WS was measured using a digital thermo-anemometer (TAFR-180, Sao Paulo, Brazil) and BGT using a globe thermometer (WBGT8778, ASKO®, San Leopoldo, Brazil). The thermal profile of the microclimate in the shed was measured by enthalpy (5), radiant heat load (6), and black globe temperature and humidity index using equations (7) according to Rodrigues et al (2011), Esmay (1969), and Buffington et al (1981), respectively.

$$H = 1.006.TA + \frac{UR}{Pb}.10^{7.5TA(237.3+TA)^{-1}}.(71.28+0.052\,TA) \quad (5)$$

$$RHL = 5.67 \times 10^{-8}\left(100\sqrt{2.51\sqrt{WS\,(BGT-TA)+(BGT \times 100^{-1}}^{4}}\right)^{4} \quad (6)$$

$$BGHI = BGT + 0.36 \times Dpt + 41.5 \quad (7)$$

where: H is the enthalpy comfort index (Kj/Kg dry air); TA is the air temperature (°C); RH is the relative humidity (%); BP is local barometric pressure (mmHg); RHL is the radiant heat load (W/m^2); BGHI is the black globe temperature and humidity index, Dpt is the dewpoint temperature (°C), WS is the wind speed (m/s), and BGT is the black globe temperature (°C).

2.6. Physiological parameters

From the 42nd to the 55th days of the experimental period, the rectal temperature, respiratory rate, and skin temperature of the animals were determined. The rectal temperature (°C) was measured using a digital clinical thermometer (rigid digital thermometer MC-245, OMRON). The respiratory rate (breaths/min) was obtained by experts observing the flank for 15 s (Machado et al 2021) with an infrared thermometer (Akrom KR380, Porto Alegre, RS, Brazil), at a distance of 0.50 cm between the animal and observer. The temperatures of the muzzle, forehead, flank, and base of the tail were obtained. Skin temperature was calculated using the arithmetic mean of these body regions (Santos et al 2019).

2.7. Statistical analysis

A randomised complete block design was used in a 2 × 2 factorial (2 diets × 2 breeds) scheme, with 10 repetitions. The blocks were defined according to the weight of the lambs at the beginning of the experiment. Data residues were checked for normality using the SAS UNIVARIATE procedure (SAS Inst. Inc., Cary, NC, USA), followed by ANOVA using the MIXED procedure and comparison of the means by the Tukey test ($P < 0.05$).

The statistical model used for intake and animal behavior was: $Y_{ij} = \mu + D_i + B_j + (DB)_{ij} + \varepsilon_{ij}$, where: Y_{ij}: was the observed value; μ: was the overall mean; D_i: was the effect of the ratio of concentrate in the diets; B_j: was the effect of the breed; $(DB)_{ij}$: was the effect of interaction between diets and breed; εij: was the effect of experimental error.

The physiological parameter data were analysed as repeated measures over time using the mathematical model: $Y_{ijk} = \mu + D_i + B_j + T_k + (DB)_{ij} + (DT)_{ik} + (BT)_{jk} + \varepsilon_{ijk}$, where: Y_{ij}: was the observed value; μ: was the overall mean; D_i: was the effect of the ratio of concentrate in the diets; B_j: was the effect of the breed; T_k: was the effect of collection time; $(DB)_{ij}$: was the effect of interaction between diets and breed; $(DT)_{ik}$: was the effect of interaction between diets and collection time; $(BT)_{jk}$ was the effect of interaction between breed and collection time; ε_{ij}: was the effect of experimental error.

3. Results

Santa Inês sheep showed a higher consumption of DM and NDFI, but there were no significant differences in DM and NDFI consumption as a function of the body weight between the breeds (Table 2). Regarding the evaluated diets, the HC diet increased the intake of DM and reduced the NDFI intake in animals.

Table 3 shows the averages of the micrometeorological variables recorded at the time of collecting the physiological parameters of the animals. The highest thermal load occurred between 10:00 and 14:00, coinciding with the higher incidence of sunlight.

Santa Inês lambs showed higher intakes of water from feed ($P = 0.03$) than Rabo Largo lambs. The HC diet increased ($P < 0.05$) water intake, water intake from feed, and total water intake. We did not observe, effect ($P > 0.05$) of the interaction between diet and breed on the time spent on ingestive activities. The HC diet increased the time spent with idling, also reduced ($P < 0.05$) the time spent feeding and ruminating, and the total chewing time (Table 4).

Santa Inês lambs showed better feed and rumination efficiency of DM and NDF in the diets ($P < 0.05$) than Rabo Largo lambs. The HC diet increased DM feeding and rumination efficiencies, but did not affect ($P > 0.05$) the interaction between diets and breeds for the time spent on ingestive activities (Table 4).

Table 2 Dry matter intake (DMI), Neutral Detergent Fibre (NDFI) intake, and ratio between intakes and body weight from lamb's breeds fed with experimental diets.

Item	Breeds	Diets[1]		Means	SEM
		HC diet	LC diet		
DMI (g)	Rabo Largo	850.36^{Ba}	440.99^{Bb}	645.67^{B}	42.710
	Santa Inês	893.73^{Aa}	692.69^{Ab}	793.21^{A}	
	Means	872.04^{a}	566.8^{4b}		
DMI (% BW)	Rabo Largo	3.38^{Aa}	2.51^{Bb}	2.95^{A}	0.096
	Santa Inês	3.13^{Aa}	2.99^{Aa}	3.06^{A}	
	Means	3.26^{a}	2.75^{b}		
NDFI (g)	Rabo Largo	300.13^{Aa}	264.70^{Ba}	282.42^{B}	16.365
	Santa Inês	305.27^{Ab}	416.55^{Aa}	360.91^{A}	
	Means	302.70^{a}	340.63^{a}		
NDFI (% BW)	Rabo Largo	1.20^{Ab}	$1.52B^{a}$	1.36^{A}	0.065
	Santa Inês	1.07^{Ab}	$1.79A^{a}$	1.43^{A}	
	Means	1.13^{b}	1.66^{a}		

Averages followed by different letters on the same line, upper case for the breed factor and lower case for the diet factor, did not differ by the Tukey test at 5% ($P < 0.05$). SEM standard error of means. [1]HC diet = diet containing high percentage of concentrate (700 g/kg DM) and LC diet = diet containing low percentage of concentrate (300 g/kg DM)

Table 3 Average of climatic variables recorded at the time of analysis of physiological parameters from lambs fed with diets containing high (HC) and low (LC) concentrate.

Environmental Parameters	Hours			
	6 a.m.	10 a.m.	2 p.m.	6 p.m.
Temperature (°C)	24.90	29.70	31.40	27.60
Air relative humidity (%)	92.10	92.80	68.8	66.30
Black globe temperature and humidity index	73.70	77.20	79.1	76.20
Radiant heat load (W/m²)	551.00	558.10	553.10	547.80

Regarding chewing activity, the lamb breed did not affect the variables. The LC diet increased ($P < 0.05$) the number of ruminated cakes per day (BOL) (Table 4). However, we did not observe an effect ($P > 0.05$) on the interaction between diets and breeds for the BOL, total chew number, and number of chews per bolus (Table 4).

In this study, water intake (WI), water intake from feed (WFI), total water intake (TWI), and chewing time per bolus (CTPB) of lambs showed significant effects on the interaction between diet and breed ($P < 0.05$). Rabo Largo lambs fed LC diets showed lower WI, WFI, and TWI than Santa Inês lambs, while the latter showed lower CTPB when fed with HC diets (Table 5).

In general, Rabo Largo lambs had a higher ($P < 0.05$) respiratory rate and rectal temperature. However, higher skin temperatures were observed in Santa Inês lambs fed the HC diet (Table 6). There was an effect of the interaction between breed and diet ($P < 0.05$) on skin temperature and respiratory rate, whereby Santa Inês lambs fed with LC diets tended to present lower ($P < 0.05$) respiratory frequency (Table 7).

Table 4 Water intake and ingestive behaviour from lamb's breeds fed with experimental diets.

Item	Breed (B)		Diets (D)¹		SEM	P-value		
	Rabo argo	Santa Inês	HC diet	LC diet		B	D	B *vs* D
Water intake								
WI (kg/day)	1.54	1.69	1.80^a	1.43^b	0.086	0.306	0.014	0.006
WFI (kg/day)	0.10^B	0.12^A	0.13^a	0.09^b	0.006	0.030	0.001	0.048
TWI (kg/day)	1.64	1.81	1.93^a	1.52^b	0.089	0.252	0.008	0.005
RWDM (kg/kg)	2.83	2.41	2.43	2.80	0.154	0.179	0.236	0.997
RTWDM (kg/kg)	2.99	2.57	2.60	2.97	0.153	0.179	0.234	0.999
Time of activities (h/day)								
Feeding	4.07	4.04	3.58^b	4.52^a	0.164	0.916	0.003	0.978
Rumination	8.73	9.13	8.29^b	9.58^a	0.234	0.340	0.005	0.340
Idling	11.19	10.83	12.13^a	9.90^b	0.334	0.530	0.001	0.506
TCT	12.81	13.17	11.87^b	14.10ª	0.334	0.530	0.001	0.507
Efficiencies (g/h)								
FE_{DM}	166.90^B	205.58^A	240.5^a	131.97^b	14.710	0.029	0.001	0.995
FE_{NDF}	75.01^B	92.82^A	90.82	78.43	4.968	0.029	0.115	0.451
RE_{DM}	68.90^B	86.74^A	97.53^a	58.12b	4.240	0.001	0.001	0.348
RE_{NDF}	31.67^B	39.60^A	36.47	34.80	1.255	0.004	0.403	0.095
Chewing								
BOL (bolus/day)	728.76	698.27	660.68^b	766.35^a	25.034	0.535	0.037	0.678
CT_{PB} (seg/bolus)	71.49	68.29	69.89	69.89	1.470	0.210	0.998	0.020
NTC (chewing/day)	48568	45544	44392	49720	1450.8	0.476	0.308	0.513
NC_{PB} (chewing/bolu)	46.57	49.74	47.34	48.98	1.136	0.164	0.466	0.147

WI: water intake; WFI: water from feed intake; TWI: total water intake; RWDM: ratio between water intake and dry matter intake; RTWDM: ratio between total of water intake and dry matter intake. TCT: total chewing time; FE_{DM}: feeding efficiency of dry matter; FE_{NDF}: feeding efficiency of neutral detergent fibre; RE_{DM}: rumination efficiency of dry matter; RE_{NDF}: rumination efficiency of neutral detergent fibre; BOL: number of ruminated bolus; CT_{PB}: chewing time per bolus; NTC: number total of chewing; NC_{PB}: number of chewing per bolus. Averages followed by different letters on the same line, upper case for the breed factor and lower case for the diet factor, did not differ by the Tukey test at 5% ($P < 0.05$). SEM standard error of means. ¹HC diet = diet containing high percentage of concentrate (700 g/kg DM) and LC diet = diet containing low percentage of concentrate (300 g/kg DM)

4. Discussion

The diet containing a high (700 g/kg DM; HC diet) percentage of concentrate increased water intake (WI) for both breeds (Table 5), which is likely a physiological defence mechanism of the animal to avoid metabolic disorders, such as acidosis, and thus maintain rumen health (Mendes et al 2020).

However, Rabo Largo lambs had lower WI compared to Santa Inês lambs, when both were fed diets containing a low (300 g/kg DM; LC diet) percentage of concentrates. According to Kaliber et al (2016), there is a strong relationship between dry matter intake (DMI) and WI, derived from the amount of energy ingested and the water flow. Thus, the higher WI by animals fed the HC diet could be attributed to the higher DMI (Table 2).

Differences in NDF content between diets (Table 1) may be responsible for the variances in DMI and NDFI (Table 2). NDF is highly correlated with low energy density of the diet, as it increases the fraction that is digestion slowly, and therefore is associated with rumen filling and reduced DM intake (Van Soest 1994).

In this study, the HC diet (composed of 70% of grains) promoted a higher concentration of NFC and reduced NDF (Table 1). NFC-fermenting microorganisms grow faster than those that ferment fibre (Russel et al 1992). Therefore, the rate of degradability and passage increased with the removal of food in the rumen.

The DMI increased until there was satiety of animals by energy density signalled by higher production of short-chain fatty acids (SCFA), especially propionate. This behaviour has already been observed in studies on lambs (Sousa et al 2012; Silva et al 2015; Nascimento et al 2020).

Due to the larger size, the Santa Inês lambs presented higher DMI; however, when the body weight, was adjusted for, there was no effect of the breed (Table 2), proving that both breeds have adequate DMI/BW (2.5–3.0 % by NRC, 2007), even when confined in severe microclimatic conditions. These results are noteworthy in that both races, from the point of view of feed ingestion, are adapted to the semi-arid climate conditions characteristic of Northeastern Brazil (Peixoto et al 2021).

Lambs fed the LC diet had longer feeding and rumination times (Table 4), even when they had lower DMIs (in g/day and% BW). A possible explanation is that fibre requires more time to be fermented, causing a lower energy density (Silva et al 2015). This requires that the animal, in addition to requiring more feeding time to meet its nutritional demands, increasing its physical filling, causing less DMI (Perazzo et al 2017), but also increasing the rumination time and consequently the quantity of ruminated boli (Nascimento et al 2020).

The HC diet decreased the time spent on feeding due to the high energy density of the diet, amplifying ruminal degradability and passage rate, allowing lambs to spend less feeding time to meet their nutritional needs (Ferro et al 2019). The smaller size of particulate matter and higher density of the feed particulate of the concentrate when compared to the forage, caused the microorganisms to have greater access to the feed, as well faster growth and replication of the NFC-fermenting microorganisms (Mazza et al 2020), thus giving the lambs a greater supply of SCFA.

The greater intake in shorter feeding time provided to the HC diets improved DM efficiencies in feeding and rumination, since the Santa Inês lambs had larger size and presented greater DMI, and even without affecting the feeding time, Santa Inês lambs showed greater DM and NDF efficiencies of feeding and rumination.

The high NDF provided by the content, LC diet increased the rumination time and, consequently, the number of boluses (Bürger et al 2000). Chewing reduces the size of fibrous particles to increase the contact surface for ruminal microorganisms, thereby enhancing microbial activity, in addition to facilitating the degradation and use of nutrients (Perazzo et al 2017).

The values of the black globe-humidity index (BGHI) were higher in the 14:00 readings, were higher (79.1;Table 3). Therefore, these indications of BGHI are considered promoters of severe heat stress in sheep (Habeeb et al 2018). This greater thermal radiation received during the hours considered to be have the highest temperatures, between 11:00 and 15:00, can reduce thyroid hormones (T3 and T4) by inhibiting feed intake (Koluman and Daskiran 2011).

Table 5 Averages of water intake variables and chewing time per bolus (CT_{PB}) from lambs in the interaction between breeds and diets.

Item	Breeds (B)	Diets (D)[1]		SEM	*P*-value
		HC diet	LC diet		B *vs* D
WI (kg/day)	Rabo Largo	1.94^{Aa}	1.15^{Bb}	0.086	0.006
	Santa Inês	1.67^{Aa}	1.72^{Aa}		
WFI (kg/day)	Rabo Largo	0.13^{Aa}	0.07^{Bb}	0.006	0.048
	Santa Inês	0.13^{Aa}	0.11^{Ab}		
TWI (kg/day)	Rabo Largo	2.07^{Aa}	1.22^{Bb}	0.089	0.005
	Santa Inês	1.79^{Aa}	1.83^{Aa}		
Chewing					
CT_{PB} (seg/bolus)	Rabo Largo	74.59^{Aa}	68.40^{Aa}	1.470	0.020
	Santa Inês	65.20^{Ba}	71.38^{Aa}		

WI: water intake; WFI: water from feed intake; TWI: total water intake; CT_{PB}: chewing time per bolus. Averages followed by different letters on the same line, upper case for the breed factor and lower case for the diet factor, did not differ by the Tukey test at 5% ($P < 0.05$). SEM standard error of means. [1]HC diet = diet containing high percentage of concentrate (700 g/kg DM) and LC diet = diet containing low percentage of concentrate (300 g/kg DM)

The assessment of the impact of heat stress on the animal is essential for associating the BGHI with physiological parameters. In this study, the skin temperature (ST) was affected by the ambient temperature (Table 6), which by radiation and convection can trigger physiological mechanisms of sweating and vasodilation (Machado et al 2020b). When these mechanisms are not fully effective in reducing ST, the rectal temperature can also be elevated by both the aforementioned and other factors related to internal heat resulting from digestive processes (mainly ruminal fermentation), thus causing the animal to increase heart and respiratory rates for heat dissipation (Eustáquio Filho et al 2011; Peixoto et al 2021).

Santa Inês lambs obtained the highest mean ST (Table 6) due to their greater body surface when compared to Rabo Largo lambs. In addition, the colour of the pelage influenced the result since the Santa Inês lambs in this study had black pelage, and Rabo Largo lambs were red (Souza-Junior et al 2018). McManus et al (2020) claimed that black pelage absorbs greater thermal radiation, and thus, is more susceptible to thermal stress when compared to animals with red, yellow, or white pelage.

The HC diet presented the highest average physiological parameters since animals fed with this diet had higher DMIs. This diet is more quickly fermentable with a caloric increase in the body, causing greater water intake to dissipate the high concentration of SCFA and heat (Machado et al 2020b).

According to McManus et al (2020), when sheep are subjected to heat stress, there is an increase in skin temperature due to the difficulty in dispersing heat. These animals use thermoregulatory mechanisms, such as increased respiratory and heart rates, allowing the animal to adapt to environmental conditions. Such mechanisms cause energy expenditure and can reduce feeding and rumination activities, therefore reducing performance (Santos et al 2019).

Sheep reared in covered environments were classified based on their respiratory rate (RR, breaths/minute) to determine the degree of heat stress: 40–60 low, 60–80 medium-high, 80–120 high, and above 200 is considered severe stress (Silanikove 2000). The animals in this study obtained an average of 64 breaths per minute, classified as medium-high stress conditions.

The increase in RR is one of the main physiological mechanisms used to dissipate internal heat, which is associated with vasodilation and promotes sweating and/or evapotranspiration in homeothermic organisms (Leite et al 2019). An accelerated and constant RR for several hours can interfere with the daily activities of the animal, as they attempt to dissipate the endogenous heat, which increases the energy spent (Lima et al 2019) and inhibits activities such as feeding and rumination, consequently decreasing the animal's performance (Machado et al 2020a).

Table 6 Physiological parameters from lamb's breeds fed with diets containing high (HC) and low (LC) concentrate.

Item	Breed (B)		Diets (D)[1]		SEM	*P*-value		
	Rabo Largo	Santa Inês	HC diet	LC diet		B	D	B *vs* D
Skin Temperature (°C)	34.51^{B}	34.77^{A}	34.89^{a}	34.38^{b}	0.126	0.001	0.001	0.013
Rectal Temperature (°C)	39.32^{A}	38.01^{B}	39.33^{a}	38.89^{b}	0.052	0.001	0.001	0.775
Respiratory rate (breaths/min)	74.00^{A}	55.00^{B}	77.00^{a}	52.00^{b}	1.895	0.001	0.001	0.002

Averages followed by different letters on the same line, upper case for the breed factor and lower case for the diet factor, did not differ by the Tukey test at 5% ($P < 0.05$). SEM standard error of means. [1]HC diet = diet containing high percentage of concentrate (700 g/kg DM) and LC diet = diet containing low percentage of concentrate (300 g/kg DM)

Table 7 Averages of skin temperature (ST) and respiratory rate (RR) from lambs in the interaction between breeds and diets.

Item	Breeds (B)	Diets (D)[1]		SEM	*P*-value
		HC diet	LC diet		B *vs* D
Skin temperature (°C)	Rabo Largo	34.68^{Ba}	34.33^{Ab}	0.126	0.013
	Santa Inês	35.10^{Aa}	34.43^{Ab}		
Respiratory rate (breaths/min)	Rabo Largo	90.32^{Aa}	58.44^{Ab}	1.895	0.002
	Santa Inês	64.03^{Ba}	46.41^{Bb}		

Averages followed by different letters on the same line, upper case for the breed factor and lower case for the diet factor, did not differ by the Tukey test at 5% ($P < 0.05$). SEM standard error of means. [1]HC diet = diet containing high percentage of concentrate (700 g/kg DM) and LC diet = diet containing low percentage of concentrate (300 g/kg DM)

Rabo Largo lambs had higher averages for RR in both diets (Table 7) and lower water intake (Table 4), which can be explained by the accumulation of body fat, especially in the rump and breast regions. This accumulation of fat promotes thermal insulation which can compromise heat dissipation (Souza et al 2015). Generally, these animals use this energy reserve of fat to compensate in periods of water and nutrition deficit. At higher temperatures, these energy reserves tend to decrease, making these animals more adapted and rustic to semi-arid environments.

This energy reserve is used when a decrease in rumen bacterial activity (Bernabucci et al 2009) and a lower rate of passage at the time of heat stress (Christopherson and Kennedy 1983) are signalled through metabolic changes, and high temperatures can also cause an increase in water loss through evaporation and sweating (Bhattacharya and Hussain 1974; Costa et al 1992). Animals tend to have a greater amount of endogenous water from lipolysis, thus reducing the need for water intake by fat-tailed animals when consuming low-quality diets, corroborating the results found.

5. Conclusions

High-concentrate diets negatively affect the thermoregulation of lambs in feedlots. Between the two evaluated breeds, Santa Inês lambs had more interesting thermoregulation and feed efficiency characteristics for feedlots under the micrometeorological conditions of the study.

Conflict of Interest

The authors declare that there is no conflict of interest.

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