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Productive, physiological and behavioral sheep profiles housed on facilities with different roofs in the Amazon region

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Abstract The Brazilian Amazon region is characterized by high rainfall, with high temperatures and relative humidity, where sheep are raised in extensive and semi-intensive systems and some regions. This work aimed to evaluate the climatic indices of sheepfolds in the Amazon region, the productive performance, and physiological variables of Santa Inês sheep confined in sheepfolds with fiber cement (FC) and polyvinyl chloride (PC) tiles. Twenty castrated males of Santa Inês sheep were used, with a mean age of 1.5±0.2 years old and a live weight of 23±2.1 kg. The statistical design used was a completely randomized design with two roofs (FC and PC). The temperature, relative humidity of the air, temperature index of the black globe, and thermal radiation load was above the comfort zone for sheep, being higher ($P < 0.05$) in the sheepfold with PVC tile than FC, which contributed to the increase in respiratory rate, as a way to maintain the animals' homeotherm. Furthermore, sheep installed in the sheepfold with FC tile showed the highest weight gain, spent more time feeding, increased feeding efficiency, dry matter and fiber intake, reducing daily water intake.

Keywords: feeding efficiency, fiber cement, humid environment, respiratory rate

1. Introduction

The Brazilian Amazon region is characterized by high rainfall, with high temperatures and relative humidity, where sheep are raised in extensive and semi-intensive systems and, in some regions and times of the year, they are confined to the adult stage to improve rates of productive and reproductive (Furtado et al 2017). As a result, Santa Inês sheep and its crossbreeds have a high degree of rusticity and adaptability (Oliveira et al 2015; Pantoja et al 2017; Furtado et al 2020), but as endothermic animals, they depend on ambient temperature to regulate body temperature, with thermal discomfort being one of the factors responsible for their low productivity (Moraes et al 2020).

Temperatures from 10 to 26 °C can provide thermal comfort to small ruminants, with a relative humidity of 65±5% (Eustáquio Filho et al 2011; Marques et al 2021), and animals exposed to hot environments make physiological adjustments to maintain homeotherms, such as increased rectal temperature, surface temperature, and respiratory rate and cardiac (Seixas et al 2017; Leite et al 2019), reduce food consumption and increase water intake (Torres et al 2017; Leite et al 2019; Furtado et al 2021), with a reduction in heat exchange in the sensitive form and an increase in latent heat exchange (Marques et al 2021).

The roof is an element that helps in thermal protection, providing comfort inside the facilities, having a low acquisition and installation cost, high reflective capacity, low absorption coefficient, and thermal conductivity (Furtado et al 2018). In this perspective, several materials have been used to cover the sheepfolds (Kabavata et al 2013), such as fiber cement and polyvinyl chloride tiles, which are capable of promoting a reduction in the internal temperature of the facilities (Oliveira et al., 2005), providing better comfort conditions. Therefore, the objective of this work was to evaluate the environmental variables of the sheds, the productive performance, and the physiological variables of Santa Inês sheep confined in sheds covered with fiber cement and polyvinyl chloride tile, in the Amazon region, humid tropic Brazilian.

2. Materials and Methods

The work was carried out at the Luiz Lourenço de Souza Exhibition Park, municipality of Parintins, Amazonas, with latitude 2°38' S, longitude 56°44' W, altitude 29 m, characterized by presenting an Am climate, according to classification Köppen, being held from March to June, the rainy season in the region. The project was sent to the Ethics Committee on Animal Use of the Federal University of Campina Grande under protocol Nº 5158181018.

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The experiment lasted 70 days, 14 days of adaptation of the animals, and 51 days for data collection, using two sheepfolds: one covered with fiber cement (FC) tile and the other with polyvinyl chloride (PVC) tile. The bay was divided with wooden slats and galvanized wire mesh, dimensions of 6.0 m wide and 7.5 m long (45 m²), divided into ten bays, each with 3.0 m² (1.5 m²) x 2.0 m), central corridor 2.0 m wide, ceiling height of 2.8 m and axis orientation in the East-West direction.

Twenty animals of the Santa Inês breed, male, castrated, mean age of 1.5±0.2 years and live weight of 23±2.1 kg were used, distributed in individual pens, and provided with plastic bucket feeders and drinkers. The ration provided was composed of hay from *Brachiaria brizantha* cv. Marandu and concentrates based on corn grain, soybean meal, and mineral supplement (Table 1), in the form of a complete mixture and formulated based on the NRC (2007), to provide a daily gain of 250 g, with a voluminous ratio of 70:30 concentrate with rations made at will and provided twice a day, at 8 and 16 h. The weight control of the animals was performed weekly in the morning before feeding. The animals were weighed to calculate the daily weight gain (DWG) at the end of the calculation, through the final body weight (FW) minus the initial body weight (IW) divided by the days of confinement (51 days).

Table 1 Chemical composition of experimental feed ingredients, g kg^{-1} of dry matter.

Ingredient	Brachiaria hay	Soybean meal	Corn bran	Mineral supplement
Dry matter	865	900	871	971
Organic matter	876	932	986	-
Mineral matter	128	69	15	860
Crude protein	57	485	92	-
Neutral detergent fiber	729	141	124	-
Acid detergent fiber	488	104	59	-
Ethereal extract	12	14	40	-
Total carbohydrates	814	432	851	-
Non-fibrous carbohydrates	89	292	727	-

The feed offered and leftovers were weighed daily to calculate voluntary consumption and readjust the amount provided, establishing 10% leftovers. The nutrient intake was obtained as the differences between the diet's total nutrients and the amount contained in leftovers. The dry matter intake was obtained based on live weight. The food provided, leftovers and feces were collected for three consecutive days to obtain composite samples, kept in a freezer (-15 °C), and then submitted to pre-drying and analyzed later.

The chemical analyzes were performed at the Animal Nutrition Laboratory of the Federal University of Paraíba. First, Pre-drying was performed in an oven with air circulation at 65 °C for 72 hours; then crushed in a 1 mm mesh mill and stored in jars, and then subjected to analysis of the dry organic matter (OM), mineral matter (MM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF) and acid detergent fiber (ADF), determined according to INCT-CA G-003/1 methods; N-001/1; M-001/1; G-004/1; F-002/1 and F-004/1, respectively, according to methodologies described by Detmann et al (2012).

To estimate total carbohydrates (CHOT), the equation proposed by Sniffen et al (1992), and to estimate non-fibrous carbohydrates (NFC), the equation recommended by Mertens (1997) was used. To estimate the total digestible nutrients (TDN) the equation described by Weiss (1999) was adopted, in which TDN = CP digestible + EE digestible *2.25 + NFC digestible + NDFcpD, where CPD = (ingested CP - CP feces), EED = (EE ingested - EE feces), NFCD = (NFC ingested - NFC feces) and NDFcpD = (NDFcp ingested - NDFcp feces). To calculate the ME (kcal of ME/kg of DM), the digestible energy (DE) was initially calculated as the product between the TDN content and the factor 4.409/100, considering the ME concentration of 82% of the DE (Silva and Leão 1979).

The internal temperature of the tile was collected with an infrared thermometer (ThermoScan, manufactured by BRHUN®) in three places, the front, middle, and back of the folds. Thermocouples measured the dry bulb, wet bulb, and black globe temperatures at 1.7 m from the ground. The wet-bulb temperature was obtained by encapsulating the thermocouple tip in a cotton string moistened with water. For the black globe temperature, thermocouples were inserted into black globes (Livingston Atmometer Go.). Temperatures were continuously measured throughout the experimental period (Datalogger Campbell Scientific Inc. CR23X). The black globe temperature and humidity index (BGHI) was calculated according to the equation of Buffington et al. (1981), and the thermal radiation load (TRL), as quoted by Esmay (1969), the equipment being fixed at the level of the center of mass of the sheep.

The physiological variables were collected three times a week. The rectal temperature (RT, °C) was obtained by introducing a clinical thermometer, scale up to 44 °C, directly in the animal's rectum at a depth of 5 cm, remaining for 2 min. In addition, the respiratory rate (RR, breaths/min) was performed through indirect auscultation of the heart sounds, with the aid of a flexible stethoscope, at the level of the thoracic region, counting the number of movements for 20 seconds; this value was multiplied by three.

To obtain the coat and skin temperature (ST), an infrared thermometer (ThermoScan, BRHUN®) was used. The readings of the coat were taken on the heads, sides, and legs of the animals, using the average of the animal's three temperatures to calculate the temperature of the fur. A dichotomy was made of a small area on the side to obtain the skin's temperature, where this variable was obtained, adapted from Maia and Silva et al (2013).

Water was offered daily using 5 L buckets placed next to the feeding stalls, with the daily water intake (DWI) being measured to the nearest 10 mL, and the water loss due to evaporation was evaluated by measuring the volume of lost water from an identical bucket, placed out of reach of sheep.

The behaviors (eating, ruminating, idleness, and drinking activities) were recorded according to the methodology proposed by Costa et al (2019) by instantaneous and continuous sampling, using the focal sampling method and sampling intervals of 5 min in a direct fashion, with continuous periods of 24 h from 08:00 to 08:00 h.

The ingestive behavior factors were obtained based on the following equations:

$$FE = DMI/FT \quad (1)$$

$$FE = NDFI/FT \quad (2)$$

$$RE = DMI/RT \quad (3)$$

$$RE = NDFI/RT \quad (4)$$

$$TCT = FT+RT \quad (5)$$

where FE = feeding efficiency (g DM min^{-1}); DMI = dry matter intake (g DM min^{-1}); FT = feeding time (min day^{-1}); RE = rumination efficiency (g DM min^{-1}); NDFI = neutral detergent fiber intake (g NDF min^{-1}); RT = rumination time (min day^{-1}); and TCT = total chewing time (min day^{-1}) (Costa et al., 2019). The strategically positioned trained observers in an alternation system to not promote changes in the animals' routine. During data collection of the nocturnal observation of the animals, the environment was kept under artificial illumination.

The statistical design used was completely randomized, and the data obtained were evaluated by analysis of variance (ANOVA). Means were compared by Tukey's test at 5% probability using the GLM (General Linear Model) procedure of SAS® (2002).

3. Results and Discussion

Air temperature (P = 0.0011), relative air humidity (P = 0.0311), wind speed (P = 0.0414), and roof temperature (P < 0.0001) showed significant differences between the sheds, with the black globe temperature index and humidity (BGHI) and radiant thermal load (RTL) not showing a significant difference (P > 0.05) (Table 2).

Table 2 Environmental variables, climatic indices, and roof temperature of sheds with fiber cement (FC) and polyvinyl chloride (PC) tiles.

Variable	Roof type		SEM	*P-value*
	FC	PC		
Air temperature (°C)	27.66^b	28.56^a	1.76	0.0011
Black globe temperature (°C)	28.49^a	29.14^a	2.29	0.0700
Relative humidity (%)	86.77^a	84.52^b	6.75	0.0311
Wind speed (m/s)	0.43^a	0.24^b	0.59	0.0414
BGHI	78.91^a	79.25^a	2.53	0.3802
Radiant thermal load	472.69^a	474.14^a	19.44	0.6279
Roof temperature (°C)	28.54^b	32.23^a	3.89	<.0001

Black globe temperature and humidity index = BGHI; Means followed by the same letter on the line do not differ at 5% probability by t-test; standard error of the mean =SEM

The air temperature was higher on the PC roof. In both environments, it was above the thermal comfort zone for sheep (Eustáquio Filho et al 2011; Marques et al 2021), which can provide thermal discomfort and affect the productive performance of animals (Kawabata et al., 2013). High values of room temperature (34 °C) were reported by Borges et al. (2018) in work carried out with Santa Inês sheep confined in northern Maranhão. There was a 3.69 °C increase in roof temperature from FC to PC. The BGHI values in the hottest hours characterized the environments as a danger for sheep (Batista et al 2014), being higher than those reported by Kawabata et al (2013), which were 77 in shelters covered with fiber cement tiles in the state of Maranhão and those found by Souza et al (2010), which at 2 pm was 75 in shaded environments.

The relative humidity of the air had the opposite behavior to air temperature. It was higher in the shed with FC tiles, a fact that may be associated with lower air temperature and, from a thermal point of view, this inversion is beneficial to the animals, favoring the processes of latent heat transfer, contributing to the maintenance of thermoregulatory mechanisms of homeothermic animals, especially under high-temperature conditions (Furtado et al 2018). However, the average relative humidity in the sheds was high, above the ideal for sheep (Eustáquio Filho et al 2011; Marques et al 2021), which can compromise their vital functions since the high relative humidity associated with high temperatures make it difficult to lose heat in the sensitive form, as the atmospheric air becomes saturated with water vapor, forcing the animal to resort to latent heat loss mechanisms, with energy expenditure and increased physiological variables (Leite et al 2019).

The wind speed in both sheds was deficient and lower in the shed with PC roof tiles, which may have occurred due to other neighboring installations, which interfered with the shed's air circulation. In addition, reduced wind speeds in the morning (0.30 m.s[1]) were found by Furtado et al (2017) in work with sheep in Curimataú Paraibano, which can hinder the loss of latent heat from the animals to the environment, with higher speeds favoring convective exchanges.

The higher temperature of the roof tiles in the PC-covered house is due to the type of material. This type of tile absorbs more heat, lower reflective capacity, and a higher absorption coefficient and thermal conductivity than PVC-covered. Carneiro et al (2015) found that environments covered with recycled tile (75% polymers and 25% aluminum) had an average temperature inside the facility (27.59 °C) higher than that of fiber cement (27.12 °C). According to Furtado et al (2018), darker colors have a greater capacity to absorb long and short-wave radiation, heating up more and increasing their absorptance and transmittance capacity.

The final weight (P < 0.0001) and daily weight gain (DWG) (P < 0.0001) showed a significant difference between the animals kept in the two sheds, higher in the FC pen, with a final weight of 1.7 kg and 19.7 g of DWG more than that of animals confined in the PC shed (Table 3).

Table 3 Variables of performance, intake, ingestive behavior, and efficiency of sheep installed in a shed with fiber cement (FC) and polyvinyl chloride (PC) tiles.

Variable	Roof type		SEM	*P-value*
	FC	PC		
Performance				
Initial live weight (kg)	23.62	23.29	0.82	0.3655
Final live weight (kg)	28.00^a	26.30^b	0.75	<.0001
Daily weight gain (g)	0.781^a	0.584^b	6.48	<.0001
Intake				
Daily water (L)	1.62^b	1.90^a	0.81	0.0193
Neutral detergent fiber - NDF (g)	290^a	260^b	0.02	0.0305
Dry matter –DM (g)	770^a	710^b	0.04	0.0063
Ingestive behavior (hour/day)				
Feeding	4.03^b	5.39^a	0.87	0.0026
Rumination	7.96	8.11	1.60	0.8367
Idle	12.00	10.50	2.30	0.1593
Mastigação	11.99	13.50	2.30	0.1593
Efficiency (g/min)				
Feeding NDF	0.073^a	0.052^b	0.01	0.0010
Rumination NDF	0.037	0.034	0.007	0.4376
Feeding DM	0.195^a	0.137^b	0.03	0.0050
Rumination DM	0.098	0.092	0.02	0.4768

Means followed by the same letter on the line do not differ at 5% probability by t-test; standard error of the mean =SEM.

The daily water intake (P = 0.0193), neutral detergent fiber (P = 0.0305), and dry matter (P = 0.0063) showed significant differences between the sheds, with the water intake being higher in the shed with PC roof, NDF intake (P = 0.0305), and DM (P = 0.0063) were higher in the CF sheep fold (Table 3). The feeding (P = 0.0026) of the sheep showed a significant difference between the sheds, being higher in the shed with PC. The feeding efficiencies (NDF and DM) showed a significant difference between the sheds, higher in the shed with FC (Table 3).

The daily weight gain of the animals was 78.1- and 58.4-grams.day^{-1} for the animals installed in the sheds with FC and PC tiles, respectively, below the established by the NRC (2007), which can be justified by adverse environmental conditions in which the animals were and due to their high age, facts that can compromise the performance of the animals (Gomes et al (2017; Leite et al 2019). Animals in comfortable environments, such as access to shade, can produce more meat than animals under heat stress (Moraes et al 2020). The rise in ambient temperature can decrease the feeding activity and increase the leisure activity of the animals. The accelerated and continuous respiratory rate can interfere in food intake and rumination for several hours, affecting animal performance (McDowell 1989).

The daily intakes of dry matter, expressed as a percentage of the live weight of the animals, were 2.8 and 2.5% in animals kept in the sheds with FC and PC, respectively, and are following the value recommended by the NRC (2007), which is 2.5 to 3.5% for native goats. The NRC (2007) suggests a relationship between dry matter intake and water intake of 1 kg of DM to 2.87 liters of water. The best relationship observed was in animals kept in the shed as FC tile (2.20 liters of water/kg of DM), being above/ideal/below recommended by the NRC (2007), demonstrating that sheep are efficient in the use of water, and this was enough for the maintenance and proper functioning of their ruminal microbiota, which can undoubtedly favor microorganisms and consequently the metabolic processes in the organism of these animals.

The neutral detergent fiber consumption is consistent with an increase in the rumination activity performed by animals since rumination is considered a physiological characteristic that reduces fiber particle size (Miranda et al., 1999), where the increased intake of NDF feed tends to reduce rumination time per gram of feed consumed (Van Soest 1994). The diet's fiber content and physical form affect rumination time (Van Soest 1994). Therefore, diets composed of forage fiber sources provide a favorable environment for the proper functioning of the rumen. That particle size determines the time in the rumen, which maintains masticatory activity.

Animals can show behavioral changes related to stress due to exposure to intense solar radiation, such as decreased food consumption and increased water intake (Dantas et al 2015). In addition, exposure to high temperatures causes changes in animal biological functions, which include disturbances in the efficiency of feed consumption, in the metabolism of water, protein, energy, minerals, enzymatic reactions, hormonal secretions, and in blood metabolites, causing decreased performance by a deficit in the proper development of the animal organism.

The animals kept in the shelter with a PC roof had a higher RR ($P < 0.0001$), corresponding to an increase of 11% (Figure 1).

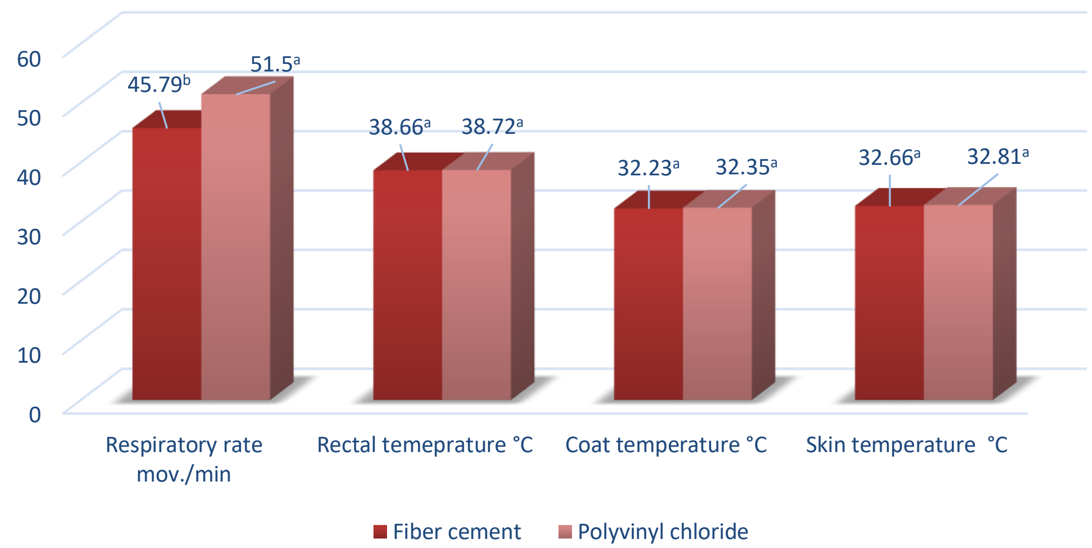

Figure 1 Mean physiological variables of animals installed in a shed with fiber cement (FC) and polyvinyl chloride (PC) tiles. Means followed by the same letter on the line do not differ at 5% probability by t-test.

The fact that can be explained by the increase in air temperature, BGTIH, and RTL (Table 2) and this elevation is a way that sheep used to dissipate heat in latent form, with energy expenditure, to maintain constant body temperature and, in both environments, it was above the average for the species, which must be 34 breaths.min^{-1} (Swenson and Reece 2006). When there is an increase in air temperature, thermoregulatory mechanisms are activated, increasing latent heat loss through sweating and increasing RR (Oliveira et al 2013). Therefore, when subjected to hot environments, sheep raise the RR due to latent heat loss to the environment (Eustáquio Filho et al 2011; Furtado et al 2017; Leite et al 2019).

Rectal temperature was similar in sheep kept in the two sheds and, even kept in environments considered stressful. This variable remained within the normal range for the species, demonstrating the adaptive capacity of Santa Inês sheep to the Amazon region high temperature and relative humidity. Kawabata et al (2013) and Ribeiro et al (2018), analyzing the physiological variables of native goats, concluded that even with the increase in AT, the animals kept the RT within the limit for the goat species

The rectal temperature of sheep in tropical regions may be higher in animals kept in warm environments (Roberto et al 2014; Furtado et al 2017) due to the dissipation of thermal energy produced by metabolism and that received from the external environment, where the animal may not be able to dissipate endogenous heat, causing an increase in rectal temperature.

The coat and skin temperature were similar in the animals kept in the two sheds. Santos et al (2011), in a study with Santa Inês sheep raised on pasture with different coats, found that coat color was not a determining characteristic in the behavior change of animals under heat stress and that the shade provided by the trees reduced the TRL by 40, 5%. The air convection process in installations with a lower degree of radiation reflection presents more significant TRL gains in the period of maximum solar incidence (Fiorelli et al 2012). The greater ease may explain these results in transposing the air inside the installation (Kawabata et al 2013). The higher incidence of air movement in the facilities covered with FC showed greater TRL gain and more significant heat removal.

4. Conclusions

The animals installed in the shed with polyvinyl chloride tile showed an increase in respiratory rate during the hottest times of the day. In addition, the fur temperature of the animals remained higher than the skin temperature.

The animals installed in the shed with fiber cement tile showed better final gain and daily weight gain, spent more time feeding, consumed more dry matter, NDF in the ration ingested less water and presented a more significant number of ruminal cakes per day.

Conflict of Interest

The authors declare no conflict of interest.

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