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Thermography and physiology of stress in dairy calves in outdoor holding pens covered with geosynthetics[1]

Termografia e fisiologia do estresse em bezerras mantidas em bezerreiros tropicais cobertos com geossintéticos

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HIGHLIGHTS:
The use of shading for dairy calves reduces thermal discomfort in tropical regions.
Geosynthetics can be used as cover material in outdoor holding pens for dairy calves.
The physiological responses of calves are affected by the roofing materials used in the rural installations.

ABSTRACT: This study aimed to assess the environmental variables, thermal comfort indices and physiological responses of calves in outdoor holding pens shaded with geosynthetics. Twenty crossbred females (Giroland, Jersey and Holstein) in the suckling phase (from birth to 90 days old) with an average initial live weight of 40.6 kg were used. A completely randomized block design was used, in a 4 × 3 factorial scheme with five replicates. The roofing materials (polyethylene mesh, geocomposite drainage layer, nonwoven geotextile and woven geotextile) were the first factor and time periods (8 to 10 a.m., 12 to 2 p.m. and 4 to 6 p.m.) the second factor. The following environmental variables were measured to calculate thermal comfort indices: temperature-humidity index, black globe-humidity index and enthalpy. The physiological variables analyzed were respiratory rate, rectal temperature and skin temperature. Environmental variables and thermal comfort indices did not differ between the different roof types, however, a significant difference ($p \leq 0.01$) was observed between the time periods, with 12 to 2 p.m. being the most critical period. The lowest average respiratory rate (60.3 breaths min^{-1}) and rectal temperature (38.9 °C) were recorded for the animals kept under the geocomposite drainage layer roof. There was a significant difference ($p \leq 0.05$) for interaction between treatment and time periods for the cannon area. The geosynthetics studied can be used as roofing material for outdoor holding pens, with the geocomposite drainage layer being the most indicated for tropical regions.

Key words: dairy cows, thermal images, shading, physiological variables

RESUMO: Este estudo teve como objetivo avaliar as variáveis ambientais, índices de conforto térmico e respostas fisiológicas de bezerras criadas em bezerreiro do sistema tropical sombreados com geossintéticos. Foram avaliadas 20 fêmeas das raças (Girolando, Jersey e Holandesa) com peso inicial médio de 40.6 kg durante a fase de aleitamento (nascimento até 90 dias de idade). O delineamento experimental foi de blocos casualizados completos, aplicado em um arranjo fatorial 4 × 3, com 5 repetições. Os materiais de cobertura (malha de polietileno, geocomposto drenante, geotêxtil não-tecido e geotêxtil tecido) foram o primeiro fator e os períodos do dia (08 às 10, 12 às 14 e 16 às 18 horas) foram o segundo fator. Foram mensuradas as variáveis ambientais e calculados os índices de conforto térmico: índice de temperatura e umidade, índice de temperatura do globo negro e umidade e entalpia. As variáveis fisiológicas estudadas foram frequência respiratória, temperatura retal e temperatura de superfície corporal. Não houve diferença significativa para as variáveis ambientais e índices de conforto térmico entre as coberturas, entretanto, houve diferença significativa ($p \leq 0.01$) entre os períodos do dia, sendo o período mais crítico entre 12 e 14 horas. Os animais mantidos sob a cobertura geocomposto drenante apresentaram as menores médias de frequência respiratória (60.3 mov min^{-1}) e temperatura retal (38.9 °C). Houve diferença significativa ($p \leq 0.05$) para a interação entre tratamentos e períodos do dia para a temperatura de canela. Os geossintéticos estudados podem ser utilizados como material de cobertura em bezerreiros, sendo o geocomposto drenante o mais indicado para regiões tropicais.

Palavras-chave: bovinos leiteiros, imagens termográficas, sombreamento, variáveis fisiológicas

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Introduction

Heat stress is one of the limiting factors for animal production (Rashamol et al., 2019). Animals exposed to this condition exhibit altered physiological variables (Cattelam & Vale, 2013). Solar radiation strongly influences heat stress in livestock raised in the field (Roland et al., 2016), making the availability of shade the most important means of minimizing this effect (Berman et al., 2016).

Increased respiratory rate is the first visible sign of heat stress (Barnabé et al., 2015), resulting in the intensification of latent heat loss processes in an attempt to maintain homeothermy (Wang et al., 2020). However, when this mechanism is insufficient, the rectal temperature of animals may increase (Rossarolla, 2007). Thermal imaging is also used to diagnose heat stress in animals (Barreto et al., 2020), since it measures the thermal radiation emitted from the surface of the body (Roberto et al., 2014).

In dairy farming, there are several different types of structures used to house suckling calves. Outdoor holding pens are the most widely used form of shelter. These are typically covered with polyethylene mesh, which is inexpensive and easy to install (Daltro et al., 2020). However, materials such as geosynthetics can also be used to provide shading, although they have yet to be studied for this purpose. Geosynthetics are polymers that can be used with geotechnical engineering material in civil construction, but their application in farming structures needs to be studied and disseminated.

As such, this study aimed to assess different geotextiles used as roof material on outdoor holding pens and their effect on the environmental variables, thermal comfort indices and physiological responses of dairy calves.

Material and Methods

The study was conducted from January to March 2017 (summer) on a farm in the rural area of Bela Vista de Goiás, Goiás state, Brazil (16° 58' 22" S, 48° 57' 12" W, 803 m altitude), in line with ethical standards and approved by the Animal Ethics Committee. Climate in the region is classified as Aw (wet tropical, with a rainy summer and dry winter) according to Köppen's classification system, with average annual temperature and rainfall of 23.1 °C and 1.355 mm, respectively (Climate, 2020).

During the study, 20 crossbred females (Girolando, Jersey and Holstein), in the suckling phase (from birth to 90 days old) with an average initial live weight of 40.6 kg were used. After birth, the calves were separated from their mothers and transferred to the calf sector. Colostrum was supplied (10% of live weight) for three consecutive days after birth. Subsequently, the animals' diet consisted of milk, water and concentrated feed. Milk was offered in individual buckets, twice a day (8 and 15 hours), totaling 6 L day^{-1}. Water was provided ad libitum and the amount of feed was adjusted in accordance with daily intake.

A completely randomized block design (animals' age, 0 ± 5 days) was used, in a 4 × 3 factorial scheme with five replicates. The roofing materials (polyethylene mesh, geocomposite drainage layer, non-woven geotextile and woven geotextile) were the first factor and time periods (morning, midday and afternoon) the second factor.

The roofing materials used were: PEM – polyethylene mesh, 80% UV resistant, 1.60 mm thick, black (control) (a monofilament mesh made from polyethylene commonly used as artificial shading cover with a protective function against weather conditions); GDL – geocomposite drainage layer, 80% UV resistant, 11 mm thick, black (consisting of a drainage kernel thermally connected to a needled nonwoven geotextile, which acts as filter and protection); NWG – Non-woven geotextile, 80% UV resistant, 1.80 mm thick, gray (a blanket made with polypropylene threads interconnected by mechanical needle, the product is appropriate for protection and general coatings); WG – Woven geotextile, 80% UV resistant, 0.40 mm thick, white (a product produced in a transverse direction by interlacing polypropylene strip, with high resistance to chemical and biological degradation). The time periods evaluated were: 8 to 10 a.m. (morning); 12 to 2 p.m. (midday) and 4 to 6 p.m. (afternoon).

The roofing materials were applied to holding pens as part of a tropical shading system, built in the north-south direction. Each covered pen was 19 m long, 2 m wide and 1.55 m high, spaced 3 m apart. The grazing area was planted with bermuda grass (*Cynodon dactylon* cv. Vaquero). Each pen housed five calves, whose collars were attached to a wire rope close to the ground, allowing them to move freely in a 12 m straight line, with access to a covered trough and buckets for water and milk (Figure 1).

In order to measure the environmental variables, a microstation data logger (HOBO ONSET® H21-002) was installed in the geometric center of each pen, 1.5 m above the ground. Each device was equipped with three sensors to measure dry and wet bulb temperature as well as black globe temperature (S-TMB-M002), recorded every 5 min over six nonconsecutive days with no cloud cover. Wind speed data (W) were obtained daily from a weather station on the farm. Based on these records, the following thermal comfort indices were calculated: temperature-humidity index (THI), black globe-humidity index (BGHI) and enthalpy (H). Dew point temperature (DPT) and enthalpy (H) values were obtained using Grapsi® computer software, developed by Melo et al. (2004), and information on dry and wet bulb temperature as well as location altitude (803 m) were input into the program to obtain dew point and enthalpy.

Figure 1. Calves kept in outdoor holding pens in a tropical system containing geosynthetics used as coverage to provide shade

THI was calculated using Eq. 1, developed by Thom (1959).

$$THI = DBT + 0.36WBT + 41.5 \quad (1)$$

where:

DBT - dry bulb temperature, °C; and,

WBT- wet bulb temperature, °C.

BGHI was calculated using Eq. 2, proposed by Buffington et al. (1981).

$$BGHI = BGT + 0.36DPT + 41.5 \quad (2)$$

where:

BGT - black globe temperature, °C; and,

DPT - dew point temperature, °C.

Respiratory rate (RR) and rectal temperature (RT) were measured in the morning (8 to 10 a.m.), at midday (12 to 2 p.m.) and in the afternoon (4 to 6 p.m.). Thus, the physiological data were collected at the beginning of each of these periods (8 a.m., 12 p.m. and 4 p.m.). Respiratory rate (RR) was determined by counting the number of flank movements in a 15 seconds interval and multiplying it by 4 to obtain the number of breaths per min (Mac-Lean, 2012). Rectal temperature (RT) was measured using a veterinary thermometer (20 to 50 °C ± 0.1 °C), kept in direct contact with the rectal mucosa for around 2 min.

Skin temperature (ST) was determined by thermal imaging, on the same days and time periods established for the physiological and environmental variables, using an infrared camera (FLIR TR420). Images were recorded on the left side of the animals, at a distance of approximately 2.5 m. Skin temperature was measured in five body regions (head, neck, back, cannon and rump), with the average body temperature (ABT) corresponding to the arithmetic mean of the five values recorded. The images were analyzed in FLIR QuickReport® software, adopting an emissivity factor of 0.98, in accordance with Montanholi et al. (2009), and recording the ambient temperature for the time period when the images were captured.

The data were submitted to analysis of variance. The means for the environmental variables (dry bulb temperature, black globe temperature, relative air humidity, temperature-humidity index, black globe-humidity index and enthalpy) were compared by the Scott-Knott test at $p \leq 0.01$ and those for the physiological variables (respiratory rate, rectal temperature and skin temperature of body regions) by Tukey's test at $p \leq 0.05$. The statistical model included the effects of treatments, time periods and interaction between the treatments and time periods for the variables analyzed. Data were analyzed using SisVar 5.6® software (Ferreira, 2014).

Results and Discussion

There was no significant interaction between roofing materials and time periods for the environmental variables or thermal comfort indices ($p \leq 0.01$). No significant differences were found between roofing materials for the environmental variables or thermal comfort indices ($p > 0.05$); however, there were significant differences between time periods. According to Table 1, the midday period (12 to 2 p.m.) obtained the worst values for the variables. The mean values for dry bulb temperature (DBT), black globe temperature (BGT), relative humidity (RH), temperature-humidity index (THI), black globe-humidity index (BGHI) and enthalpy (H) were 28.74, 32.51 °C, 71.94%, 77.11, 80.97 and 68.59 kJ kg^{-1}, respectively.

Table 1. Mean values for dry bulb temperature (DBT, °C), black globe temperature (BGT, °C), relative air humidity (RH, %), temperature-humidity index (THI), black globe-humidity index (BGHI) and enthalpy (H, kJ kg^{-1}) in different time periods

Variable	Time periods			
	8-10 a.m.	12-2 p.m.	4-6 p.m.	CV (%)
DBT	25.67 c	31.52 a	29.03 b	6.83
BGT	28.58 c	35.91 a	33.03 b	7.62
RH	88.25 a	66.27 b	61.29 c	5.52
THI	74.32 c	79.63 a	77.37 b	2.32
BGHI	77.05 c	84.37 a	81.49 b	3.06
H	65.42 c	71.45 a	68.89 b	2.96

CV – Coefficient of variation; Means followed by different letters in the rows differ according to the Scott-Knott test ($p \leq 0.01$)

For the different roofing materials, neither the environmental variables nor the thermal comfort indices showed significant differences, possibly because the pens had no side covering and the roofing materials provided 80% protection against UV rays. Wind speed during the experimental period was the same because the pens are open and in the same location. As such, all the treatments exhibited minimum average and maximum values of zero, 1.48 m s^{-1} and 2.0 m s^{-1}, respectively. According to Almeida et al. (2015), holding pens without side coverings favor greater internal air circulation. These results corroborate those of Fiorelli et al. (2009), who found no statistical differences ($p > 0.05$) in temperature humidity index in husbandry facilities with open sides and covered using recycled and cement fiber tiles. The roofing materials evaluated in the present study had different thicknesses and colors; however, the geosynthetics performed the same function as the control treatment, demonstrating efficiency in providing shade and protection against solar radiation.

The ideal DBT for dairy calves is between 18 and 21 °C, with temperatures exceeding 26 °C exposing the animals to heat stress (Baêta & Souza, 2010). The animals in the present study were exposed to temperatures above the thermal comfort zone in all the treatments assessed. This was due to the effects of the tropical climate, with high air temperatures and the formation of hot air masses throughout the year.

The average BGT recorded was 32.51 °C, indicating that the calves were experiencing heat stress since, according to Mota (2001), the thermal comfort zone for dairy cattle is between 7 and 26 °C. Mean relative air humidity (RH) for the treatments was 71.94%, which, according to Baêta & Souza (2010), exceeds the acceptable values of 50 to 70%.

None of the average THI (77.11) and BGHI (80.97) values obtained for any of the roofing materials assessed were within the ideal range for dairy calves. Baêta & Souza (2010) emphasized that ideal values are between ≤ 70 (THI) and ≤ 74 (BGHI). The BGHI values observed in the present study indicated that the animals were in danger. When the black globe humidity index surpasses 80, animals seek out shaded areas to avoid absorbing heat via direct sunlight. These values exceeded the limit, possibly because the study was carried out in summer, the hottest season of the year.

Barnabé et al. (2015) studied the thermal comfort of Girolando calves in individual hutches with different roofing materials and found an average THI of 71.6 for 4 mm thick recycled polymer tile (75% polyethylene and 25% aluminum), 72.0 for 4 mm thick cement fiber and 76.3 for palm straw (*Syagrus olearacea*). The same authors reported average BGHI < 74, indicating thermal comfort and differing from the results found here.

Enthalpy measurements for all the roof types assessed indicated heat stress, since values above 66.1 kJ kg^{-1} are considered critical for calves (Kawabata et al., 2005). Although the roofing materials evaluated minimized the effects of thermal stress throughout the day, the only time period in which this critical limit was not exceeded was 8 to 10 a.m. (65.42 kJ kg^{-1}), indicating that the animals may experience thermal comfort during this period.

Significant differences were observed for environmental variables and thermal comfort indices in the different time periods ($p \leq 0.01$), 12 to 2 p.m. being the most critical period for the animals (Table 1), with average values of 31.5 °C (DBT), 35.9 °C (BGT), 66.3% (RH), 79.6 (THI), 84.4 (BGHI) and 71.4 kJ kg^{-1} (H). The best results in terms of heat stress and environmental variables were recorded in the morning (8 to 10 a.m.), when temperatures were lower. All the roofing materials obtained unsatisfactory mean values in the hottest period of the day and shade was insufficient to reduce thermal discomfort from 12 to 2 p.m.

The DBT values recorded from 12 to 2 and 4 to 6 p.m. exceeded the critical heat stress threshold of 26 °C proposed by Baêta & Souza (2010), whereas relative air humidity was within the recommended range of 50 to 70% in both periods. Average BGT in the most critical time period (12 to 2 p.m.) was within the thermal comfort zone reported by Mota (2001).

Based on the THI and BGHI values obtained, the calves studied here were in danger of heat stress and impaired function between 12 and 2 p.m. (79.63). According to Costa et al. (2015), values lower than 70 indicate a nonstress situation, 70 to 72 a state of alert, 72 to 78 critical, 78 to 82 dangerous, and above 82 an emergency situation. Thus, the shade provided was insufficient to ensure the thermal comfort of animals during this time period. The best enthalpy measurement (65.42 kJ kg^{-1}) was observed between 8 and 10 a.m., the only time period that did not exceed the critical threshold of 66.1 kJ kg^{-1} described by Kawabata et al. (2005). Although the roofing materials evaluated were efficient in providing artificial shade for the animals, they still experienced thermal stress during the hottest time period (afternoon).

There were no significant differences ($p > 0.05$) for interaction between the roofing materials and time periods for RR and RT, but significant differences were observed ($p \leq 0.05$) for the isolated effect of the roofing materials and time periods (Table 2).

The highest RR values were recorded for the PEM and NWG roofs (68.44 and 70.08 breaths min^{-1}, respectively) and the lowest for GDL (60.31 breaths min^{-1}), with WG exhibiting an intermediate value (67.07 breaths min^{-1}). According to Reece

Table 2. Mean respiratory rate (RR, breaths min^{-1}) and rectal temperature (RT, °C) for the different factors, with their respective coefficients of variation

Sources of variation		RR	RT
Main effects*			
Roofing materials	PEM	68.44 a	39.00 ab
	GDL	60.31 b	38.90 b
	NWG	70.08 a	39.00 ab
	WG	67.07 ab	39.10 a
Time periods	8 – 10am	48.88 b	38.52 c
	12 – 2pm	73.68 a	39.02 b
	4 – 6pm	76.87 a	39.46 a
CV (%)		26.61	1.04

PEM - Polyethylene mesh; GDL – Geocomposite drainage layer; NWG - Non-woven geotextile; WG - Woven geotextile; CV – Coefficient of variation; * - Different lowercase letters in the same column indicate differences for main effects according to Tukey's test ($p \leq 0.05$)

(2006), the normal RR for calves up to one year old is 21 to 25 breaths min^{-1}, meaning the values recorded in the present study were high, indicating a thermoregulatory response to heat stress. Mac-Lean (2012) assessed the RR of purebred and crossbred Jersey calves in individual hutches covered with fiber cement tiles during summer and fall in the state of São Paulo, Brazil, observing values ranging from 27 to 80 breaths min^{-1}, demonstrating heat stress. Almeida et al. (2016) reported that RR is the first thermoregulatory mechanism used when animals are experiencing heat stress. Martello et al. (2004) observed that whether RR increases or decreases depends on the intensity of the heat stress animals are submitted to.

With respect to RT, the highest value was obtained under the WG roof (39.1 °C) and the lowest for GDL (38.9 °C), with intermediate results for NWG and PEM (39 °C). According to Robertshaw (2006), the normal rectal temperature (RT) range is from 38.0 to 39.3 °C, indicating that the measurements recorded in the present study were normal. Barnabé et al. (2015) reported that RT remained normal due to the physiological mechanism of increased RR. Barnabé et al. (2015) studied the thermal comfort of Girolando calves in individual shelters in Pernambuco state, Brazil, during summer under a DBT of 27 °C, and recorded average RT values between 38.8 and 39.0 °C, similar to the 38.8 to 39.1 °C obtained here during the same season and under average temperatures of 28.7 °C.

The low RR and RT values obtained by the GDL roof may have occurred due to the milder thermal conditions provided by the material because of its greater thickness (11 mm) and the fact that it is composed of two geotextiles, unlike the other materials.

RR and RT showed a similar pattern throughout the study, with lower values in the morning and a gradual increase during the midday period, peaking in the afternoon. Martello et al. (2004) and Kovács et al. (2018) observed that physiological variables behaved differently in each time period, recording higher values in the afternoon than in the morning. From 8 to 10 a.m., values close to the normal RR range reported by Reece (2006) were observed, albeit above the established upper limit of 25 breaths min^{-1}. Almeida et al. (2016) assessed the thermal efficiency of individual shelters for Girolando calves in the Brazilian semiarid and found average RR between 36.5 breaths min^{-1} (in the morning) and 71.5 breaths min^{-1} (in the afternoon), demonstrating that the animals exhibited the highest RR in the afternoon, as observed in the present study (76.87 breaths min^{-1}) due to the cumulative heat load that the calves were exposed to.

From 8 to 10 a.m., RT remained within the normal range (38.52 °C), demonstrating that latent thermoregulatory mechanisms (RR) were able to maintain thermal balance during this period, not altering RT. From 4 to 6 p.m. RT increased (39.46 °C), which, according to Silva et al. (2015), means the animal is suffering from thermal stress and cannot dissipate excess heat, prompting activation of the sensitive mechanism (RT) to help lose heat.

Interaction between the roofing materials and time periods showed significant differences (p ≤ 0.05) for skin temperature in the different body regions (Table 3).

The surface temperature of the different body regions was lower in the morning and higher in the midday and afternoon periods. Between 8 and 10 a.m., the highest average ST in the cannon area was recorded under the WG roof (31.75 °C) and the lowest in the GDL treatment (30.15° C). This result indicated that the GDL cover, with two protective barriers and greater thickness, minimizes the effects of heat absorption for the animal in the holding pen. Furthermore, the difference may be less marked because the pen is open. Despite its high reflection capacity, the WG material may have obtained the highest result due to its small thickness, allowing heat to enter the pen.

Figure 2 illustrates the skin temperature (ST) of the animals between 12 and 2 p.m.

Almeida et al. (2016) investigated the thermal efficiency of individual shelters for Girolando calves in the Brazilian semiarid and recorded average ST and DBT values of 32.58 and 29.2 °C, respectively, unlike the 35.2 and 27.8 °C recorded here. The average skin temperatures measured from 8 to 10 a.m. and 12 to 2 p.m. were similar to those reported by Almeida et al. (2016).

Kotrba et al. (2007) used infrared thermography to study skin temperatures in dairy cows and observed small variations in different parts of the body, namely the neck, barrel, rump and limbs, corroborating the results found here. Skin temperatures in the head, back and rump areas of dairy calves analyzed in the present study exhibited similar minor variations, as observed by Silva & Passini (2017) in dairy cows. However, the calves analyzed here displayed temperatures ± 4 to 6 °C above those reported for lactating cows in the same areas of the body. Barnabé et al. (2015) assessed the thermal comfort of Girolando calves in individual shelters with different roof types and found average body temperatures of 32.2 °C, lower than that observed here (35.2 °C).

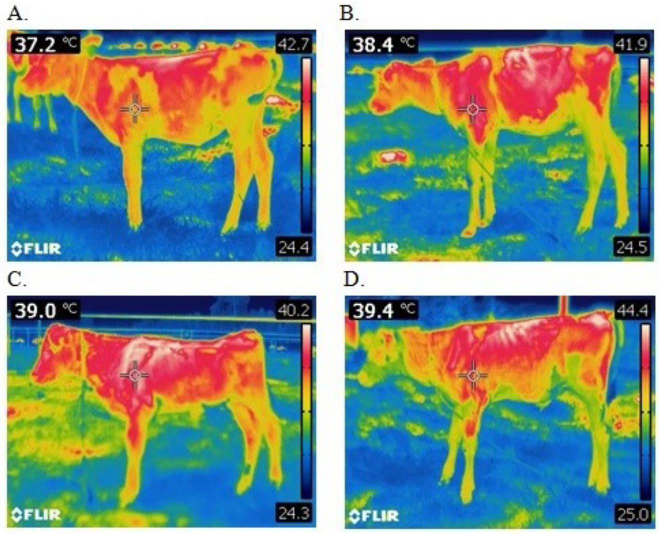

Figure 2. Thermal images showing the skin temperature of dairy calves between 12 and 2 p.m. for the roofing materials (A) polyethylene mesh; (B) geocomposite drainage layer; (C) nonwoven geotextile and (D) woven geotextile

This is a pioneering study in terms of using geosynthetics as artificial shading. As such, further research is recommended to evaluate the durability of these materials and their use in shelters with side closures or other types of rural facilities for better conclusions about their effects.

Conclusions

1. The geocomposite drainage layer, non-woven geotextile and woven geotextile roofing materials evaluated in this study can be used as an alternative shading in farm buildings.

Table 3. Mean skin temperatures for the head, neck, back, rump, cannon and body (°C), for interaction between roofing materials and time periods

Time period	Temperature (°C)	Roofing materials					
		PEM	GDL	NWG	WG	CV (%)	P
8-10am	T head	33.78	33.60	33.39	34.15	5.21	NS
	T neck	33.88	33.74	33.90	34.23	6.77	NS
	T back	34.75	34.35	33.05	34.98	9.65	NS
	T rump	33.10	33.17	33.34	35.32	10.80	NS
	T cannon	30.45 ab	30.15 b	31.24 ab	31.75 a	6.58	0.0191
	Body average	33.19	33.00	32.98	34.09	6.70	NS
12-2pm	T head	35.93	36.32	36.24	36.42	5.21	NS
	T neck	36.04	36.01	36.25	36.41	6.77	NS
	T back	38.50	37.59	37.64	39.06	9.65	NS
	T rump	37.95	36.35	37.32	38.27	10.80	NS
	T cannon	34.01	33.85	34.31	34.45	6.58	NS
	Body average	36.49	36.03	36.35	36.92	6.70	NS
4-6pm	T head	36.42	36.33	35.64	35.39	5.21	NS
	T neck	36.73	36.50	35.99	35.37	6.77	NS
	T back	37.21	36.80	35.99	35.17	9.65	NS
	T rump	36.86	36.31	35.72	35.23	10.80	NS
	T cannon	34.67	34.29	34.29	33.50	6.58	NS
	Body average	36.38	36.25	35.52	34.93	6.70	NS

PEM - Polyethylene mesh; GDL – Geocomposite drainage layer; NWG - Non-woven geotextile; WG - Woven geotextile; Means followed by different letters in the rows differ according to Tukey's test (p ≤ 0.05); CV – Coefficient of variation; NS - Not significant (p > 0.05)

2. The geocomposite drainage layer was the most beneficial roofing material to provide artificial shade for calves reared in tropical regions, based on the values recorded for physiological variables.

3. The skin temperature of dairy calves was not influenced by the different roofing materials studied.

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