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Effect of the Silvopastoral System on the Thermal Comfort of Lambs in a Subtropical Climate: A Preliminary Study

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Abstract: The silvopastoral system has the potential to alleviate the negative impacts of heat stress on livestock. Through a preliminary study, we assessed the thermal environment experienced by hair coat lambs, as well as the impacts on their bio-thermal and behavioural responses, when either kept in either the silvopastoral system, or exposed to full sun. Twelve hair coat lambs (Dorper × Santa Ines) were randomly assigned to a silvopastoral system or full sun exposure during the summer (from January to February 2017). Parameters, including air temperature, black globe temperature, relative humidity, wind speed, and ground surface temperature, were measured daily for both thermal environments. From 14:00 to 16:00, lambs kept in silvopastoral areas experienced lower levels of air temperature, radiant heat load, and ground surface temperature. Consequently, they had a lower hair coat surface and lower body rectal temperatures. Lambs exposed to a shaded environment spent more time grazing and walking, and less time standing at rest. In conclusion, lambs kept in a silvopastoral system experienced lower levels of radiant heat load and ground surface temperature. In addition, the animals showed a reduced requirement for evaporative cooling and expressed behaviours that indicated a comfortable thermal environment.

Keywords: agroforestry systems; biometeorology; thermal comfort; behaviour; sheep production

1. Introduction

The search for sustainable animal production systems has attracted increasing attention because of due to the increasing socially and environmentally conscious consumer profile. With this new demand, it is necessary to seek more collaborative systems that encompass these concerns for the environment and animal welfare. In this respect, the silvopastoral system (SP) has been highlighted for its sustainable and less stressful environment for animal production [1].

SP improves pasture quality under tree canopies [2], increases biodiversity [3], has higher carbon sequestration potential than monoculture [4] and open pasture [5], enables more thermal comfort for animals [6–9], and collaborates with animal welfare [10,11].

Silvopastoral areas have the potential to reduce wind speed by 29–58% and solar radiation by 14–58% [12]. Shade can reduce the radiant heat load on animals, providing improved environmental conditions, allowing them to mobilise less energy to maintain homeostasis [13], particularly significant in subtropical and tropical regions. In addition to decreasing the incidence of direct solar radiation, the natural shade provided by trees attenuates the air temperature through evapotranspiration and favours the movement of air under the canopy [14,15].

Sheep have a lower sensitivity to thermal stress at a maintenance feed level [16]. However, lambs are young animals with immature thermoregulatory, and during heat stress exposure, these animals can experience slowing or halting of the growth rate, increase in water intake during the hottest periods of the day, and decrease in nutritional efficiency [17]. In addition, a severe or long period under thermal stress may lead to compromised immune function in lambs [18]. Moreover, when exposed to shade, lambs are more comfortable, have more lying behaviour, and spend more time grazing than animals in open pasture systems in a temperate climate [19]. This evidence shows that if lambs are exposed to a harsh environment in an earlier phase, both productivity and welfare are compromised, resulting in economic loss [16,20]. In a hot and humid climate, silvopasture is a promising system for heat abatement.

The main studies conducted with sheep in the SP system addressed the following topics: weight gain assessment in tropical regions [21–25], productive performance in tropics [22], sheep behaviour in tropical climates [26], grazing impact in a temperate climate [27] and ingestive behaviour in tropical [8] and temperate climates [28,29]. However, most studies have focused on sheep production. Prior research has demonstrated that silvopasture has the potential to alleviate heat stress in young animals, such as dairy heifers [9]. In a recent study, Dada et al. [30] showed that both lambs and ewes exhibited reduced panting and more lying behaviour than animals kept in an unshaded system. However, there are information gaps regarding the influence of SP on thermoregulatory variables and the behaviour and welfare of lambs in a subtropical climate. Here, we assessed the growing lambs exposed to full sun and those in the SP to determine (1) the thermal radiant environment experienced by lambs in the SP, and (2) their behavioural and physiological responses to this environment. Therefore, we hypothesised that the lower radiant heat load experienced by growing lambs in the SP favours incremental grazing time and decreases the requirement for evaporative cooling.

2. Materials and Methods

The experimental procedures were approved by the Ethics Committee on the Use of Animals of the Federal University of Technology–Paraná (CEUA-UTFPR), Paraná, Brazil (protocol no. 2016/026).

2.1. Animals, Management and Study Design

A preliminary trial was conducted in southwestern Parana State, Brazil (25° S, 53° W, and 577 m above sea level) for measurements of thermal conditions and related behavioural and physiological responses over ten consecutive days, from January to February 2017. During this period, the average air temperature in this location was 23.9 ± 3.8 °C, the average relative humidity was 80 ± 16%, and the cumulative rainfall was 151.8 mm. Santa Inês × Dorper crossbreed male lambs (n = 12), with a mean age of 136 ± 6.70 days and an initial average body weight of 23.12 ± 2.23 kg, were allocated to a SP (n = 6) and full sun (OP; n = 6). The animals were adapted to the systems for 41 d before the data were recorded. The SP was established in September 2013 and had a total area of 2160 m^2, consisting of native brown laurel trees (*Cordia trichotoma* (Vell.) Arráb. ex Steud.), with a double-line planting arrangement, and 2 m between individuals and 1.5 m between rows. Each line was 36.5 m and the distance between the trees (between the centres of the trees) was 10 m. The average tree height during the study was 6.20 m and the average diameter at breast height (1.30 m) was 9.28 cm, which corresponded to 18.2 m^3 of wood.

The tree component corresponded to an occupation of 18.25% in each paddock (400 m^2). The average shading area (spherical) was 90.93 m^2 per tree and the percentage of shaded area was 22.73%. In both treatments, the animals were maintained on a pasture (*Panicum maximum* Jacq cv. Aruana) without pad-dock rotation (remaining in the same paddocks from the beginning to the end of the experiment). All animals were supplemented with a concentrate of 1% body weight. Water and mineral salts were provided ad libitum. The feed composition provided was 66.15% cornmeal, 22.89% soybean meal, 9.85% wheat bran, and 1.11% limestone. Regarding the pasture of both systems, the dry mass total forage during the trial in the open pasture and silvopasture system was 2440.87 kg MS^{-1} ha^{-1} (average height of 12.43 cm) and 2048.89 kg MS^{-1} ha^{-1} (average height of 13.48 cm), respectively. The chemical composition of the pasture components (leaves, stems, senescent material, and other materials) is shown in Table 1.

Table 1. Chemical compounds (percentage ± SD) of pasture components in both productive systems: DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; MM = mineral matter.

Variables	Leaf	Stem	Senescent Material	Others *
Open pasture (*P. maximum* cv. Aruana without shading)				
DM	90.97 ± 2.02	91.33 ± 1.54	91.02 ± 1.05	-
	---	--% on DM--	---	
CP	15.93 ± 1.63	9.6 ± 1.12	10.24 ± 0.87	-
NDF	56.94 ± 1.63	62.33 ± 2.27	62.77 ± 2.21	-
ADF	46.84 ± 2.11	44.21 ± 2.48	48.85 ± 5.41	-
MM	8.94 ± 0.35	9.79 ± 0.46	9.45 ± 0.88	-
Silvopasture (*P. maximum* cv. Aruana with shading by trees)				
DM	90.42 ± 1.27	89.92 ± 1.53	90.73 ± 0.94	89.86 ± 1.35
	---	--% on DM--	---	
CP	14.71 ± 0.58	7.8 ± 0.91	8.86 ± 0.93	11.76 ± 2.89
NDF	57.82 ± 1.64	63.01 ± 2.56	64.79 ± 2.39	56.15 ± 1.75
ADF	48.43 ± 1.55	47.67 ± 4.27	48.07 ± 2.69	42.63 ± 2.94
MM	9.75 ± 1.10	10.12 ± 0.98	10.11 ± 1.19	10.00 ± 1.50

* Unwanted species.

2.2. Study Measurements

The study variables were recorded every minute for 12 h (07:00 to 19:00). The variables of air temperature (TA, °C), black-globe temperature (BGT, °C), and relative humidity (RH, %) were measured through five data loggers (three in SP system–each paddock-and two in OP system), model HOBO U12-013 (Onset Computer Corporation, Bourne, MA, USA), installed at a 1.5 m height in OP and SP areas, in the geometric centre of the paddock, distant 1.1 m between loggers in the same treatment. These devices comprised one external channel and two internal channels. The external channel used a thermocouple cable (sensor) with a black globe. The wind speed (WS, m s^{-1}) was measured using a digital anemometer (model MS6252A, Mastech, Dongguan, China). The surface ground temperature (Tg, °C) was determined using an infrared thermometer model TG165 (Flir, Wilsonville, OR, USA), by adopting measure points (one per paddock) in both systems in regions with covered soil, that is, forage.

In the SP, measurements were taken in the shade provided by the trees, in the geometric centre of the paddocks, between the two tree lines. Based on microclimatic measurements, we estimated the radiant heat load (RHL, W m^{-2}; [31]) and the black globe humidity index (BGHI, [32]).

Physiological measurements were performed at 09:00 and 15:00 on the days following the behavioural observational period, and animals were physically contained. The lambs were restrained by grouping the animals in a corner near the paddock fences. The containment procedure took approximately 2 min per lamb. All animals were adapted to the procedure and did not resist immobilisation. The rectal temperature (RT, °C) was measured using a flexible high-end digital clinical thermometer, model G-Tech TH400 (Instrutemp, São Paulo, Brazil), and the respiratory (RR, breaths min^{-1}) and heart rate (HR, beats min^{-1}) were determined by auscultation. For RR, we auscultated at the laryngotracheal level for 30 s and the result was multiplied by two, which reflects the breaths per minute. The lambs' hair coat surface temperature (Ts, °C) was measured at five body points: head, neck, back, flank, and posterior limb (thigh height), and the average of the points was calculated. To obtain this variable, we used an infrared thermometer with a laser sight, model TG165 (Flir, Wilsonville, OR, USA), positioned 1-m away from the animal.

The behavioural observations were realised by 0/1 sampling by four trained individuals, using the focal method described by Broom and Fraser [33], over 10 consecutive days (without other handling procedures, avoiding altering the behaviours of the animals). The activities were recorded for 10 min with an interval of 30 min between observations throughout the 12-h diurnal period (from 07:00 to 19:00). Grazing was defined when the head of the lamb was pointing towards the ground, and the sheep were searching for or ingesting grass. Walking was distinguished by the animals moving throughout the paddock. Lying at rest was defined when the flank of the lamb was in direct contact with the ground; otherwise, standing at rest was recorded.

2.3. Statistical Analysis

In this study, we used the design of subdivided plots, where the data were divided into two factors: A, hours of the day; and B, production systems (silvopastoral-SP and full sun-OP). On each testing day, the measurements were conducted at two different times (09:00 and 15:00), defined as the main plot, with the production systems (SP and OP) as a subplot. The mixed models were adjusted for each variable. The hours of the day and production systems were considered as fixed effects and the days of measurement random effects. When the effects were significant, multiple comparisons of the means were made using the Tukey test, with significance declared at $p < 0.05$.

The analysis of the behavioural data of sheep in the SP and OP was performed using Bayesian inference. The rationale for using this approach was the accurate estimation of small samples using iterative methods, i.e., the procedure of N simulation of a limited dataset [34]. The same author stated some additional features, such as the inclusion of prior information, and random parameters, which results in increased accurate prediction.

The variable of interest (γ) was assumed to follow a Poisson distribution, as it is related to data counts or score assignments, using the parameter θ. The day effect was considered a random behaviour. The prior was considered the fixed part of the model (α = 07:00 to 09:00 and β = 09:00 to 19:00), following a normal distribution with mean = 0 and standard deviation = 0.001. The random effects were considered as a normal distribution, with a mean of 0 and a standard deviation equal to τ. The τ parameter, in turn, was considered a gamma distribution, such as τ~Ga (0.001; 0.001). Data processing and statistical analyses were performed using R statistical software [35].

3. Results and Discussion

In this study, we assessed the thermal environment in different production systems (SP and OP) and the underlying variations in the bio-thermal and behavioural responses of lambs. Information regarding sheep production, especially for lambs, in shading systems in a subtropical climate is scarce. Even with a limited sample size and with the feature of a short-term study, we found differences between the two systems in terms of the radiant thermal load and ground surface temperature. This might lead the animals in the silvopasture to experience a reduced respiratory rate and rectal temperature, as well as more time grazing and less time in a standing position.

3.1. Thermal Environment

The average air temperature difference between the SP and OP was 2.6 and 0.9 °C from 09:00 to 11:00 and from 14:00 to 16:00, respectively (Table 2). The SP presented a higher mean RH (approximately 6%; $p < 0.001$) than the OP in all the assessed periods. In both systems, the average temperature in the afternoon was above the comfort zone for the sheep. Baêta and Souza [36] described a comfort range of 20–30 °C. However, RH values were within this zone for sheep during warmer periods, with approximately 65% relative humidity for Santa Inês sheep [37]. Heat transfer occurs mainly through evaporation at temperatures above 30 °C [13,38], which might have influenced the respiratory rates, as discussed below.

Table 2. Average values (mean ± SEM) of air temperature (Air Temp), relative humidity (RH), black globe-humidity index (BGHI) and radiant heat load (RHL) between the production systems throughout the periods of the day.

Variable	Period	System	
		Silvopasture (SP)	Open Pasture (OP)
Air Temp (°C)	09:00–11:00	24.8 ± 0.5 Bb	26.7 ± 0.3 Ab
	14:00–16:00	31.1 ± 0.8 Ba	32.0 ± 0.8 Aa
RH (%)	09:00–11:00	77 ± 1.6 Aa	71 ± 1.6 Ba
	14:00–16:00	58 ± 3.7 Ab	55 ± 3.8 Bb
BGHI	09:00–11:00	75 ± 0.6 Bb	82 ± 0.6 Aa
	14:00–16:00	83 ± 1.1 Ba	87 ± 1.3 Aa
RHL (W m^{-2})	09:00–11:00	472.4 ± 2.9 Bb	576.0 ± 10.6 Ab
	14:00–16:00	542.9 ± 16.7 Ba	631.1 ± 28.7 Aa

Means with different letters (lowercase for columns and uppercase for rows), within each variable, differ among themselves (Tukey's test; $p < 0.05$).

As expected, the BGHI values and the mean RHL values were higher in the afternoon in both treatments (above 80 and 500 W m^{-2}, respectively), and the SP system was less critical for animals than the open pasture. According to Baêta and Souza [36], BGHI values above 80 are classified as dangerous. A similar value (82.51) was found by Souza et al. [8] in an open pasture, which is very similar to our SP condition. This demonstrates that even in a shaded environment, thermal conditions might be stressful for lambs. Silva et al. [39] found RHL values above 570 W m^{-2} in the warmer time of day (after 13:00), and similar results were reported by Machado et al. [40], with RHL above 500 W m^{-2}.

There was no difference between the periods and treatments for wind speed ($p = 0.45$) (Table 3).

Table 3. Average values (mean ± SEM) of wind speed (WS), ground surface temperature (Tg), respiratory rate (RR), heart rate (HR), rectal temperature (RT), and hair coat surface temperature (Ts) between the productive systems and throughout the periods of the day.

Factors		WS	T_g	RR	HR	RT	T_s
		(m s^{-1})	(°C)	(Breaths min^{-1})	(Beats min^{-1})	(°C)	(°C)
Periods of day	09:00–11:00	1.1 ± 0.1	24.2 ± 0.7 b	74 ± 3.9 b	132 ± 2.8	39.3 ± 0.1 b	33.9 ± 0.4
	14:00–16:00	1.4 ± 0.2	35.1 ± 1.7 a	152 ± 7.8 a	143 ± 2.5	40.0 ± 0.1 a	37.7 ± 0.7
Productive system	Silvopasture	1.2 ± 0.2	25.9 ± 1.0 b	98 ± 7.3 b	98 ± 7.2	39.5 ± 0.1 b	34.7 ± 0.5 b
	Open pasture	1.3 ± 0.2	33.4 ± 1.9 a	128 ± 8.1 a	129 ± 8.1	39.8 ± 0.1 a	36.9 ± 0.7 a

Means with different letters (lowercase for columns), within each factor, differ among themselves (Tukey's test; $p < 0.05$).

The mean values of Tg were 10.9 and 7.5 °C for morning and afternoon and SP and OP, respectively ($p < 0.001$). When the sheep were lying down, the lower air and ground surface temperatures favoured heat dissipation by surface convection and conductive cooling, while lower levels of radiant heat load caused less heat to be absorbed by thermal radiation. Under these circumstances, sheep in the SP have the potential to store less heat over time and therefore require less water to dissipate heat through evaporative cooling mechanisms. However, sheep experiencing a high radiant heat load when fully exposed to the sun will narrow their prescriptive zone, particularly the superior limit [41]. According to Pent et al. [19], a sensitive change by conduction will only be effective if the surface temperature is lower than the body temperature of lambs. The authors also stated that the SP promotes a more effective loss of heat by conduction than open pastures. This result indicates more lying behaviour for lambs in a shaded environment, aiming to increase thermal transfer through conductive avenues.

3.2. Thermoregulation

There was a difference between treatments ($p < 0.001$) in the variation of RR, RT, and Ts, as well as a difference ($p < 0.05$) between the morning and afternoon for RR ($p = 0.02$) and RT ($p = 0.003$) (Table 3). The SP revealed the potential to reduce the hair coat surface temperature (2.2 °C), rectal temperature (0.3 °C), and respiratory rate (30 breaths min^{-1}) when compared to animals allocated to the open pasture.

According to Silanikove [42], respiratory rates between 80 and 120 breaths min^{-1} incite high-stress conditions. Our results indicate that the animals presented medium-high stress only during the morning, whereas in the afternoon, stress was high under all treatments. Changes in respiratory rate preceded changes in other important physiological variables, such as rectal temperature [43].

The animals of the SP presented an RT lower by 0.3 °C, indicating a small variation when compared to hotter environments [44]. The rectal temperature of sheep under thermoneutral conditions varied between 38.3 and 39.9 °C, with temperatures of 42 °C in hyperthermia situations [16]. Our results show that the animals remained within this range in both systems, which is considered a normal realm. Therefore, by activating thermoregulatory mechanisms, the animals were able to maintain a normal temperature range and reduce the harmful effects of thermal stress [45].

A strong correlation is often observed between hair coat surface temperature and fluctuating air temperature, as well as between surface temperature and rectal temperature, which indicates an increase in the internal body temperature of the animal [44,46]. The tree shadow system of the SP sheltered the animals from intense solar radiation, thereby favouring the reduction of surface temperature, which reduced the thermal gradient between the body core and the animal's surface. This result might also explain the standing rest behaviour of lambs, aiming to expose more surface area to facilitate the heat abatement, as discussed below.

3.3. Behaviour

We found differences between productive systems in the following behaviours (Table 4): grazing and lying at rest (throughout the day, $\Delta\alpha$ and $\Delta\beta$ parameters), walking (after 09:00—$\Delta\beta$ parameter), and standing at rest (between 07:00 and 09:00—$\Delta\alpha$ parameter).

Table 4. Posterior parameter estimates (means and 95% credible intervals in parentheses) of behavioural assessment of lambs in silvopasture (SP) and open pasture (OP) systems.

Variables	Behaviours			
	Grazing	Walking	Standing Rest	Lying Rest
α (SP)	0.13 (−0.50, 0.72)	0.08 (−1.24, 0.78)	−1.14 (−2.14, −0.23) *	−2.31 (−3.22, −1.50) *
α (OP)	−1.65 (−3.0, 0.31) *	−0.55 (−1.80, 0.53)	0.34 (−0.52, 1.10)	0.77 (−0.21, 1.73)
β (SP)	0.15 (0.0, 0.30)	0.03 (−0.13, 0.18)	−0.06 (−0.22, 0.09)	0.24 (0.05, 0.44) *
β (OP)	0.57 (0.40, 0.75) *	0.27 (0.13, 0.42) *	−0.22 (−0.36, −0.09) *	−0.39 (−0.53, −0.23) *
Δ (α)	1.78 (0.34, 3.26) *	0.63 (−1.00, 2.10)	−1.48 (−2.83, −0.24) *	−3.08 (−4.41, −1.77) *
Δ (β)	−0.43 (−0.64, −0.19) *	−0.24 (−0.46, −0.03) *	0.17 (−0.04, 0.38)	0.62 (0.36, 0.87) *

* Statistically different based on Bayesian comparisons.

SP animals were more likely to graze throughout the day when compared to OP individuals (Figure 1a), especially during warmer periods (after 15:00). The only exception was recorded from 13:00 to 14:00 h. The grazing behaviour probability remained high, between 70% and 80% for the majority of the day for both systems.

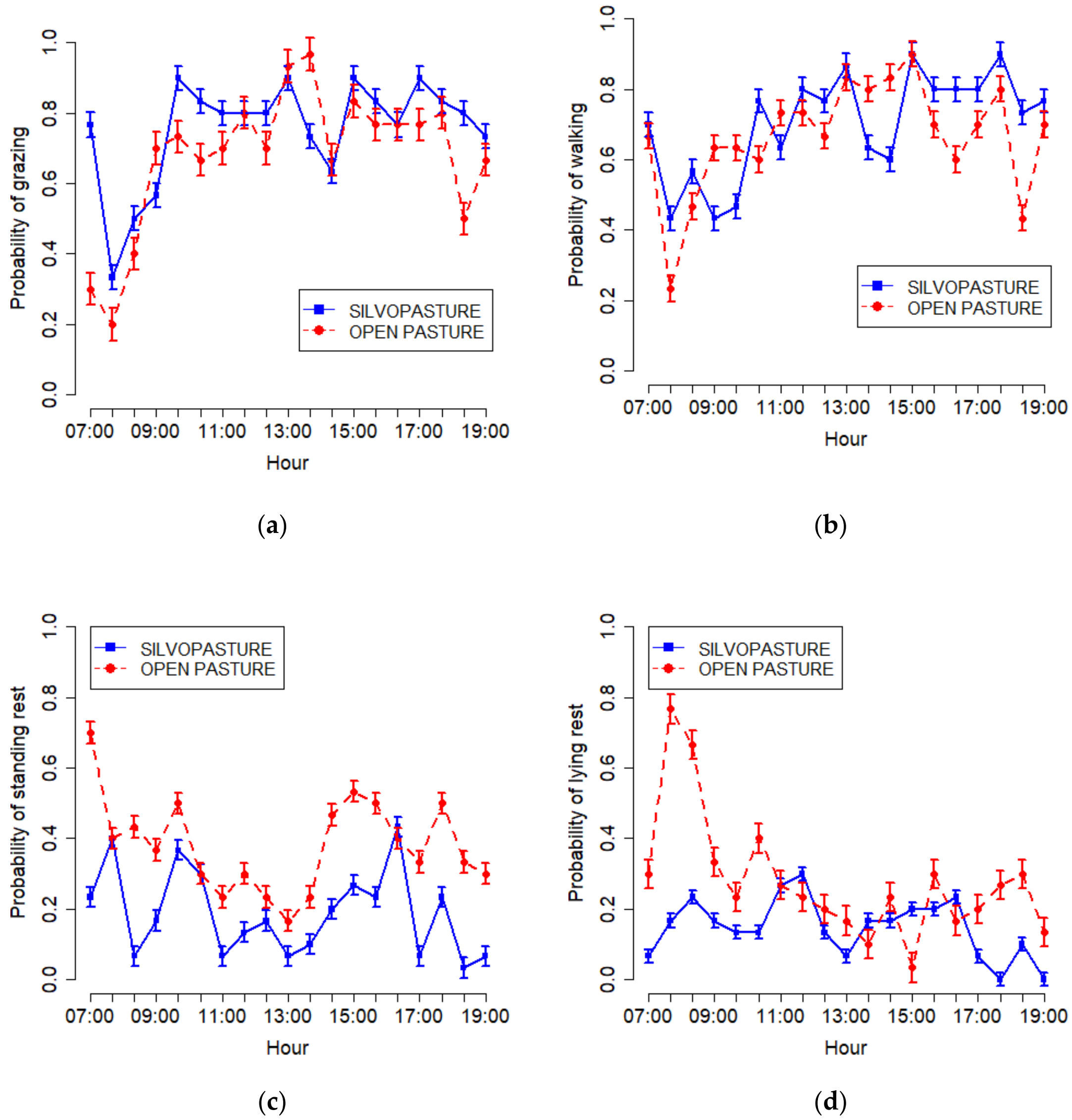

Figure 1. Probability of grazing (**a**), walking (**b**), standing at rest (**c**) and lying at rest (**d**) of lambs in the silvopastoral system (continuous line in blue) and open pasture (dashed line in red) throughout the periods of the day.

Lambs in the SP grazed longer at more critical temperatures than those exposed to the full sun. Although animals in the extensive system performed grazing activity more than half of the time and at different times of the day [47], lambs needs to have a thermal environment that stimulates it to seek food. Pent et al. [19] evaluated the behavioural repertoire of lambs in a SP system with black walnut (*Juglans nigra* L.) and honeylocust (*Gleditisia triacanothose* L.) in the USA and concluded that lambs in the shaded system spent more time grazing. The same authors stated that the activity is performed depending on the comfort conditions when food is not limited.

The lambs of both systems had an initial peak in walking activity at 07:00, which was followed by grazing for the SP animals. In both treatments, there was an increase in the probability of grazing over time (Figure 1b). The highest proportion of walking behaviour was observed in the SP group during periods with a higher thermal load.

The movement and exploration of the area are behavioural activities dependent on the thermal environment. When under thermal stress, sheep reduce their level of activity to avoid energy expenditure, directing their reserves to eliminate internal heat by sensitive and latent methods. This was observed through the physiological variables measured in the present study. However, walking behaviour does not always correlate with thermal comfort. According to Sousa et al. [8], sheep spent more time walking in the full sun (monoculture) system than in the SP. According to the same authors, an attempt to relieve the effects of thermal stress causes greater demand for a microenvironment with better thermal conditions. In studies with artificially shaded areas, walking behaviour was of little relevance concerning other behaviours researched, such as standing [47].

OP lambs were likely to have a high standing rate at rest throughout the day (Figure 1c). The probability of lying behaviour of the lambs in OP was higher after 17:00 (Figure 1d). In the SP, the probability of the behaviour was higher than that of the OP at 12:00 and 15:00, and decreased after 16:00. The positioning of the animals and the time in which this behaviour was performed is also a variable that evidences thermal exchanges with the environment. We found that animals in the OP system were more likely to stand at rest during most of the day. Due to the high incidence of direct solar radiation on the pasture, the full sun environment offered unfavourable conditions for lying down and performing the changes by conduction [19]. According to the same authors, in a shaded environment, the surface temperature of the soil was reduced, favouring changes by conduction. In our study, the higher ground surface temperature in an open pasture system might explain this behaviour, with a higher probability of standing behaviour correlated with high surface temperatures. In contrast, unshaded environments can cause animals to position themselves in windy areas to maximise their body area for convective exchanges [48]. This was confirmed by the high hair coat surface temperature of lambs kept in the open pasture compared to SP animals. Environments that favour lying behaviours and reduce standing time increase the chances of optimal animal welfare conditions [47].

4. Conclusions

The present study revealed that implementation of the SP could influence the microclimate-attenuating air temperature, as well as rectal temperature, respiratory rate, and hair coat surface temperature of lambs, as compared to the open pasture. The behaviour of lambs in the open pasture showed signs of greater thermal discomfort than the SP because there was a higher probability of standing at rest during the hottest hours of the day. In the SP, the probability of grazing, lying at rest, and walking was higher, which indicates that the SP provided an environment of greater thermal comfort for lambs. Further research is needed to elucidate the effect of a silvopasture pasture, in different seasons and climate regions, on the behaviour and thermal comfort of lambs, as well as to mitigate the effects of heat waves on livestock production.

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References

1. Broom, D.M. Components of sustainable animal production and the use of silvopastoral systems. *Rev. Bras. Zootec.* **2017**, *46*, 683688. [CrossRef]
2. Fedrigo, J.K.; Santa Cruz, R.; Benítez, V.; Courdin, V.; Ferreira, G.; Posse, J.P.; Viñoles, C. Dynamics of forage mass, air temperature and animal performance in a silvopastoral system of Uruguay. *Agrofor. Syst.* **2019**, *93*, 2197–2204. [CrossRef]
3. Mcadam, J.H.; Sibbald, A.R.; Teklehaimanot, Z.; Eason, W.R. Developing silvopastoral systems and their effects on diversity of fauna. *Agrofor. Syst.* **2007**, *70*, 81–89. [CrossRef]
4. López-Santiago, J.G.; Casanova-Lugo, F.; Villanueva-López, G.; Díaz-Echeverría, V.F.; Solorio-Sánchez, F.J.; Martínez-Zurimendi, P.; Aryal, D.R.; Chay-Canul, A.J. Carbon storage in a silvopastoral system compared to that in a deciduous dry forest in Michoacán, Mexico. *Agrofor. Syst.* **2019**, *93*, 199–211. [CrossRef]
5. Aryal, D.R.; Gómez-González, R.R.; Hernández-Nuriasmú, R.; Morales-Ruiz, D.E. Carbon stocks and tree diversity in scattered tree silvopastoral systems in Chiapas, Mexico. *Agrofor. Syst.* **2019**, *93*, 213–227. [CrossRef]
6. Deniz, M.; Schmitt Filho, A.L.; Farley, J.; de Quadros, S.F.; Hötzel, M.J. High biodiversity silvopastoral system as an alternative to improve the thermal environment in the dairy farms. *Int. J. Biometeorol.* **2019**, *63*, 83–92. [CrossRef] [PubMed]
7. Karki, U.; Goodman, M.S. Cattle distribution and behavior in southern-pine silvopasture versus open-pasture. *Agrofor. Syst.* **2010**, *78*, 159–168. [CrossRef]
8. Sousa, L.F.; Maurício, R.M.; Paciullo, D.S.C.C.; Silveira, S.R.; Ribeiro, R.S.; Calsavara, L.H.; Moreira, G.R. Forage intake, feeding behavior and bio-climatological indices of pasture grass, under the influence of trees, in a silvopastoral system. *Trop. Grassl.-Forrajes Trop.* **2015**, *3*, 129–141. [CrossRef]
9. Vieira, F.M.C.; Deniz, M.; Vismara, E.S.; Herbut, P.; Pilatti, J.A.; Sponchiado, M.Z.; de Oliveira Puretz, B. Thermoregulatory and Behaviour Responses of Dairy Heifers Raised on a Silvopastoral System in a Subtropical Climate. *Ann. Anim. Sci.* **2020**, *20*, 613–627. [CrossRef]
10. Améndola, L.; Solorio, F.J.; Ku-Vera, J.C.; Améndola-Massiotti, R.D.; Zarza, H.; Galindo, F. Social behaviour of cattle in tropical silvopastoral and monoculture systems. *Animal* **2016**, *10*, 863–867. [CrossRef]
11. Deniz, M.; Schmitt Filho, A.L.; Hötzel, M.J.; de Sousa, K.T.; Pinheiro Machado Filho, L.C.; Sinisgalli, P.A. Microclimate and pasture area preferences by dairy cows under high biodiversity silvopastoral system in Southern Brazil. *Int. J. Biometeorol.* **2020**, *64*, 1877–1887. [CrossRef]
12. Karki, U.; Goodman, M.S. Microclimatic differences between mature loblolly-pine silvopasture and open-pasture. *Agrofor. Syst.* **2015**, *89*, 319–325. [CrossRef]
13. Collier, R.J.; Gebremedhin, K.G. Thermal biology of domestic animals. *Annu. Rev. Anim. Biosci.* **2015**, *3*, 513–532. [CrossRef]
14. Ainsworth, J.A.W.; Moe, S.R.; Skarpe, C. Pasture shade and farm management effects on cow productivity in the tropics. *Agric. Ecosyst. Environ.* **2012**, *155*, 105–110. [CrossRef]
15. Armstrong, D.V. Heat Stress Interaction with Shade and Cooling. *J. Dairy Sci.* **1994**, *77*, 2044–2050. [CrossRef]
16. Marai, I.F.M.; El-Darawany, A.A.; Fadiel, A.; Abdel-Hafez, M.A.M. Physiological traits as affected by heat stress in sheep—A review. *Small Rumin. Res.* **2007**, *71*, 1–12. [CrossRef]
17. Pérez, R.V.; Cruz, U.M.; Reyes, L.A.; Correa-Calderón, A.; de los Ángeles López Baca, M.; Lara Rivera, A.L. Heat stress impacts in hair sheep production. Review. *Rev. Mex. Cienc. Pecu.* **2020**, *11*, 205–222. [CrossRef]
18. Shi, L.; Xu, Y.; Mao, C.; Wang, Z.; Guo, S.; Jin, X.; Yan, S.; Shi, B. Effects of heat stress on antioxidant status and immune function and expression of related genes in lambs. *Int. J. Biometeorol.* **2020**, *64*, 2093–2104. [CrossRef] [PubMed]
19. Pent, G.J.; Greiner, S.P.; Munsell, J.F.; Tracy, B.F.; Fike, J.H. Lamb performance in hardwood silvopastures, II: Animal behavior in summer 1. *Transl. Anim. Sci.* **2019**, *4*, 363–375. [CrossRef]
20. Sejian, V.; Bhatta, R.; Gaughan, J.B.; Dunshea, F.R.; Lacetera, N. Review: Adaptation of animals to heat stress. *Animal* **2018**, *12*, S431–S444. [CrossRef]
21. Couto, L.; Roath, R.L.; Betters, D.R.; Garcia, R.; Almeida, J.C.C. Cattle and sheep in eucalypt plantations: A silvopastoral alternative in Minas Gerais, Brazil. *Agrofor. Syst.* **1994**, *28*, 173–185. [CrossRef]
22. Manríquez-Mendoza, L.Y.; López-Ortiz, S.; Olguín-Palacios, C.; Pérez-Hernández, P.; Díaz-Rivera, P.; López-Tecpoyotl, Z.G. Productivity of a silvopastoral system under intensive mixed species grazing by cattle and sheep. *Trop. Subtrop. Agroecosyst.* **2011**, *13*, 573–584.
23. Peri, P.L. Respuesta de ovinos a pastizales creciendo en diferentes cobertura de copas en sistemas silvopastoriles de ñire (Nothofagus antarctica) en Patagonia Sur, Argentina. *Zootec. Trop.* **2008**, *26*, 363–366.
24. Santos, F.R.; Santos, M.J.C. Avaliação do ganho de peso de ovinos santa inês mantidos em sistema silvipastoril no semi-árido nordestino. *Sci. Plena* **2012**, *8*, 1–5.
25. Santos, P.M.; Santos, A.C.; Neiva, J.N.M.; Neves Neto, D.N. Desempenho de ovinos em sistema agroflorestal alternativo no ecótono Cerrado: Amazônia. *Rev. Bras. Saude E Prod. Anim.* **2016**, *17*, 584–598. [CrossRef]
26. Ferreira, R.A.; Estrada, L.H.C.; Thiébaut, J.T.L.; Granados, L.B.C.; de Souza, V.R. Avaliação do comportamento de ovinos santa inês em sistema silvipastoril no norte fluminense. *Cienc. E Agrotecnologia* **2011**, *35*, 399–403. [CrossRef]
27. Ruiz-Mirazo, J.; Robles, A.B. Impact of targeted sheep grazing on herbage and holm oak saplings in a silvopastoral wildfire prevention system in south-eastern Spain. *Agrofor. Syst.* **2012**, *86*, 477–491. [CrossRef]

28. Bird, P.R.; Kellas, J.D.; Jackson, T.T.; Kearney, G.A. Pinus radiata and sheep production in silvopastoral systems at Carngham, Victoria, Australia. *Agrofor. Syst.* **2010**, *78*, 203–216. [CrossRef]
29. Yiakoulaki, M.D.; Zarovali, M.P.; Papanastasis, V.P. Foraging behaviour of sheep and goats grazing on silvopastoral systems in Northern Greece. *Nutr. Ecol. Sheep Goats* **2009**, *85*, 79–84.
30. Dada, J.; Santos, M.; Muniz, P.C.; Nunes-Zotti, M.; Vieira, F. Postpartum behavioural response of Santa inês x dorper ewes and lambs in a silvopastoral system. *Small Rumin. Res.* **2021**, *203*, 106495. [CrossRef]
31. Esmay, M.L. *Principles of Animal Environment*; AVI: Westport, Ireland, 1978.
32. Buffington, D.E.; Canton, G.H.; Pitt, D.; Thatcher, W.; Collier, R.J. Black Globe-Humidity Index (BGHI) as comfort equation for dairy cows. *Trans. ASAE* **1981**, *24*, 711–714. [CrossRef]
33. Broom, D.M.; Fraser, A.F. *Domestic Animal Behaviour and Welfare*, 4th ed.; CABI Publishing: Wallingford, UK, 2007; ISBN 9781845932879.
34. McNeish, D. On Using Bayesian Methods to Address Small Sample Problems. *Struct. Equ. Model.* **2016**, *23*, 750–773. [CrossRef]
35. R Development Core Team. R: A Language and Environment for Statistical Computing. Available online: www.R-project.org (accessed on 13 August 2020).
36. Baêta, F.d.C.; Souza, C.d.F. *Ambiência em Edificações Rurais*; Editora UFV: Viçosa, Brazil, 2010; ISBN 9788572693936.
37. Eustáquio Filho, A.; Teodoro, S.M.; Chaves, M.A.; dos Santos, P.E.F.; da Silva, M.W.R.; Murta, R.M.; de Carvalho, G.G.P.; de Souza, L.E.B. Zona de conforto térmico de ovinos da raça Santa Inês com base nas respostas fisiológicas. *Rev. Bras. Zootec.* **2011**, *40*, 1807–1814. [CrossRef]
38. Maia, A.S.C.; Silva, R.G.; Batiston Loureiro, C.M. Sensible and latent heat loss from the body surface of Holstein cows in a tropical environment. *Int. J. Biometeorol.* **2005**, *50*, 17–22. [CrossRef] [PubMed]
39. da Silva, W.E.; Leite, J.H.G.M.; de Sousa, J.E.R.; Costa, W.P.; da Silva, W.S.T.; Guilhermino, M.M.; Asensio, L.A.B.; Façanha, D.A.E. Daily rhythmicity of the thermoregulatory responses of locally adapted Brazilian sheep in a semiarid environment. *Int. J. Biometeorol.* **2017**, *61*, 1221–1231. [CrossRef] [PubMed]
40. Machado, N.A.F.; Barbosa Filho, J.A.D.; de Oliveira, K.P.L.; Parente, M.D.O.M.; de Siqueira, J.C.; Pereira, A.M.; Santos, A.R.D.; Sousa, J.M.S.; Rocha, K.S.; Viveiros, K.K.d.S.; et al. Biological rhythm of goats and sheep in response to heat stress. *Biol. Rhythm Res.* **2020**, *51*, 1044–1052. [CrossRef]
41. Fuller, A.; Mitchell, D.; Maloney, S.K.; Hetem, R.S.; Fonsêca, V.F.C.; Meyer, L.C.R.; Ven, T.M.F.N.V.; Snelling, E.P. How dryland mammals will respond to climate change: The effects of body size, heat load and a lack of food and water. *J. Exp. Biol.* **2021**, *224*, 1–11. [CrossRef]
42. Silanikove, N. Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livest. Prod. Sci.* **2000**, *67*, 1–18. [CrossRef]
43. McManus, C.M.; Faria, D.A.; Lucci, C.M.; Louvandini, H.; Pereira, S.A.; Paiva, S.R. Heat stress effects on sheep: Are hair sheep more heat resistant? *Theriogenology* **2020**, *155*, 157–167. [CrossRef]
44. Fonsêca, V.d.F.C.; Maia, A.S.C.; Saraiva, E.P.; Costa, C.C.d.M.; da Silva, R.G.; Abdoun, K.A.; Al-Haidary, A.A.; Samara, E.M.; Fuller, A. Bio-thermal responses and heat balance of a hair coat sheep breed raised under an equatorial semi-arid environment. *J. Therm. Biol.* **2019**, *84*, 83–91. [CrossRef]
45. Slimen, I.B.; Chniter, M.; Najar, T.; Ghram, A. Meta-analysis of some physiologic, metabolic and oxidative responses of sheep exposed to environmental heat stress. *Livest. Sci.* **2019**, *229*, 179–187. [CrossRef]
46. McManus, C.; Dallago, B.S.L.; Lehugeur, C.; Ribeiro, L.A.; Hermuche, P.; Guimarães, R.F.; de Carvalho Júnior, O.A.; Paiva, S.R. Patterns of heat tolerance in different sheep breeds in Brazil. *Small Rumin. Res.* **2016**, *144*, 290–299. [CrossRef]
47. Solórzano-Montilla, J.; Pinto-Santini, L.; Camacaro-Calvete, S.; Vargas-Guzmán, D.; Ríos-de Álvarez, L. Effect of the presence of shade in sheep grazing areas. 2. Animal activity. *Pastos Forrajes* **2018**, *41*, 41.
48. He, Y.; Jones, P.J.; Rayment, M. A simple parameterisation of windbreak effects on wind speed reduction and resulting thermal benefits to sheep. *Agric. For. Meteorol.* **2017**, *239*, 96–107. [CrossRef]