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Do sheep of different coat colors kept in an equatorial semi-arid environment use solar orientation behavior for thermoregulation?

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ABSTRACT

Shade-seeking behavior and body posture adjustments are key thermoregulatory strategies used by free-ranging animals to minimize heat absorption. We observed these behaviors in grazing sheep, analyzing their orientation relative to solar radiation. Over seven days, we monitored six predominantly black and six white crossbred lambs. We found that shade-seeking behavior was less frequent on cloudy days ($p < 0.05$), with sheep spending more time grazing. Neither the black or the white sheep altered their body orientation to minimize heat absorption, regardless of sunny or rainy conditions. In conclusion, this preliminary investigation showed that body axis orientation seems not to be employed by black and white hair coat sheep as thermoregulatory strategy when exposed to solar radiation in an equatorial semi-arid environment.

1. Introduction

Livestock in equatorial semi-arid environments are frequently exposed to hot days, clear skies, and as much as 1,200 W m^{-2} of solar irradiance, as they are kept mainly on pasture-based systems under shadeless conditions (Da Silva et al., 2010). Studies have documented the behavioral thermoregulation such as seeking-shade behavior and adjustments in body posture as the principal attitude of free-ranging mammals to maintain their body temperature within narrow limits (Maloney et al., 2005a, 2005b; Hetem et al., 2011; Lease et al., 2014). Several studies about body orientation behavior have been conducted in temperate or subtropical regions (Finch et al., 1984; Lease et al., 2014), but as far as we are aware no scientific evidence is reported for equatorial semi-arid conditions.

When compared with subtropical or temperate latitudes, incoming solar radiation reaches the surface of equatorial regions at a higher elevation angle in relation to the horizon (Da Silva, 2006). When the solar angle exceeds 70º (i.e., the sun is close to zenith) the surface area of animals presented to incident solar irradiance becomes independent of body orientation (Hofmeyr and Louw, 1985; Maloney et al., 2005a). The main focus of this study was to see whether sheep, when exposed to solar radiation at equatorial latitudes, change their body posture as a thermoregulatory strategy to reduce radiant heat load. Specifically, we would like to answer the following questions: Firstly, do black- and white-haired sheep use the solar orientation behavior? Secondly, is there any difference in the shade-seeking and body orientation behaviors between black and white haired sheep? Our hypothesis is that the body axis orientation is not used as a thermoregulatory strategy for haired sheep kept in equatorial regions.

2. Material and methods

2.1. Animals and experimental design

All procedures involving animals were reviewed and approved by the Ethics Committee on the Use of Animals of the Federal University of Paraiba (process number: 108/2017). The present study was carried out at the Experimental Research Center Benjamin Maranhão (6° S, 35° W, 188 m altitude) in October and November, with the maximum registered temperature of 30ºC and minimum of 21 °C. This region has a hot and

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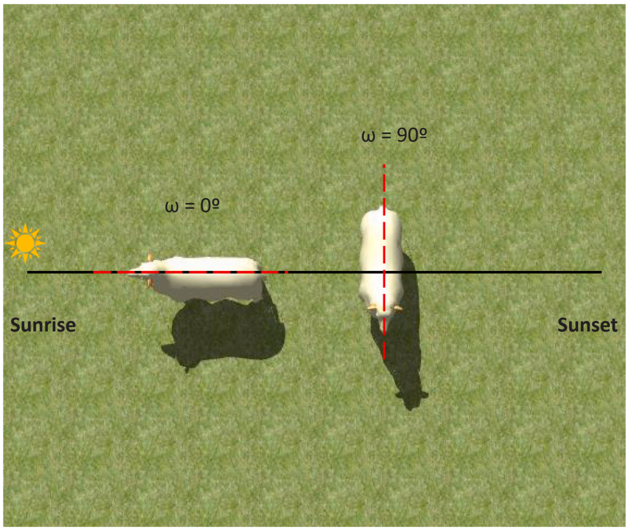

Fig. 1. Graphic representation of the body axis orientation of sheep in relation to solar radiation. This simulation was done using the same latitude of the present study, with the solar elevation angle of 70°, at 10:00h, January 05, 2024.

dry climate, according to the Köppen classification (BSh group). Twelve crossbred lambs (F1, Dorper x Santa Inês ewe) with black spots on the coat (n = 6) and a predominance of white (n = 6) coats, weighing 18 ± 1.2 kg of body mass were randomly assigned (groups of six, containing both coats) in two paddocks of 0.8 ha with Panicum maximum cv. Aruana for assessments of their behavioral responses for seven consecutive days. The sheep grazed from 06:00 to 17:00 h in which water and mineral supplementation were freely available. Both paddocks had natural shade (*Ziziphus joazeiro*) with a shaded projected area giving close to 1 m^2/animal, estimated for spherical canopy trees according to Da Silva (2006).

2.2. Meteorological variables

Meteorological data were recorded at each second, using a portable weather station (HOBO® - Model RX3000 Remote Monitoring System) placed near to the paddock (1.0 m). The recorded meteorological data were solar irradiance (R_s, W m^{-2}; range: 0 to 1280 W m^{-2}; accuracy: ± 10 W m^{-2}), air temperature (T_A, °C; range: −40 °C to 75 °C; accuracy: ± 0.2 °C), relative humidity (R_H, %; range: 0 to 100%; accuracy: ± 2.5%), and wind speed (W_S, m s^{-1}; range: 0 to 76 m s^{-1}; accuracy: ± 1.1 m s^{-1}). The black globe temperatures (T_{GN}, °C) were measured at the full sun and shade at one-hour regular intervals, using a plastic sphere painted of black (0.15 m of diameter) and with a thermometer (range: −10 °C to + 60 °C; accuracy ± 1 °C) placed into the globe. Meteorological data were not collected on two rainy days (e.g., days 6 and 7).

2.3. Behavioral responses

The time budget of grazing lambs, shade-seeking behavior and body axis orientation (i.e. azimuthal angle) in relation to incident solar radiation were recorded by direct observation and focal animal sampling, from 06:00 to 17:00h (Martin and Bateson, 1986). Before starting the behavioral observations, eight people were subjected to an inter-observer agreement in order to achieve correlation of ~95% (Fonsêca et al., 2014). The body orientation was recorded only when the sheep were exposed to solar radiation. By defining the magnetic north, the arcs of 0° and 180° were considered as animals oriented parallel to the azimuth direction of the sun, while 90° and 270° as a perpendicular orientation to the azimuth direction of the sun (Fig. 1). The shade use was defined when at least the head or one of the hooves of the sheep was within the shade (Maia, 2020); while grazing behavior was defined when the head of the sheep was pointing towards the ground and the sheep was searching for, or ingesting, grass (Schütz et al., 2014).

2.4. Statistical analysis

The proportion of the time spent for each behavioral variable was calculated each hour as the total time spent in each behavior divided by 60 min. For body orientation behavior, the proportion of the time spent either in parallel or perpendicular orientation was calculated as the total time spent in each behavior divided by the total time sheep were exposed to the full sun. Data were analyzed using generalized least squares means with the general linear model procedure (PROC GLM) of the Statistical Analysis System (SAS, Institute, 1999). The general linear model used to describe the behavioral responses (expressed in percentage, with a logarithmic transformation) was expressed as:

$$Y_{ijklm} = \mu + C_i + Aj(Ci) + D_k + Aj(CD)_{ik} + T_l + CT_{il}(D)_k + \varepsilon_{ijklm}$$

where, Y_{ijkLm} is the mth observation of the behavioral activity (e.g., grazing, shade use, body axis orientation); Ci is the fixed effect of the ith coat color (i = predominantly black or white sheep); Aj(Ci) is the random effect of the jth animal within the ith coat color (if i = black sheep then j = 1,…,6; if i = white sheep, then j 7,…,12); D_k is the fixed effect of the kth day of observation (k = 1,…,7); $Aj(CD)_{ik}$ is random effect of the j_{th} animal within the interaction between ith coat color and kth day of evaluation; T_l is the fixed effect of the time of day (l = 10:00.14:00 h); $CT_{il}(D)_k$ is the interaction between the fixed effects of the ith coat color and lth time of day within the kth days of evaluation; ε_{ijklm} is the residual term is the overall mean.

3. Results and discussion

The sheep were exposed to five sunny days with air temperatures ranging from 24 to 36°C, black-globe temperature from 26 to 47°C, and solar irradiance between 0 and 1,223 W m^{-2} (Table 1), in addition to two rainy days with a high proportion of cloud cover. On sunny days, between 08:00 and 13:00h, the solar irradiance had mean levels greater than 500 W m^{-2}, and mean peak of 800 W m^{-2} between 10:00 and 12:00h. During this period, the sheep spent more time in shade (Table 2; Fig. 2). Similarly, cows and wool sheep on tropical pastures also used more shade when levels of solar irradiance were above 500 W m^{-2} (Oliveira et al., 2014; Maia et al., 2020; Fonsêca et al., 2023).

The radiant heat load is the most important meteorological factor that influences the shade-seeking behavior of animals in open field and

Table 1
Mean, minimum and maximum recorded values of air temperature, black globe temperature, and solar irradiance across the five sunny days.

Day	Temperature, °C			Black globe temperature, °C			Solar irradiance, W m^{-2}		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1	31.29	24.51	35.96	40.58	34.00	46.20	469.87	5.60	1126.90
2	31.07	24.58	36.15	40.45	33.00	47.00	430.48	8.10	1201.90
3	31.31	24.20	35.64	37.14	26.00	42.00	537.71	9.40	1214.40
4	31.72	24.22	36.15	37.72	30.00	43.50	547.86	21.90	1084.40
5	31.58	24.63	36.20	39.32	30.50	47.00	475.56	13.00	1223.10

Table 2
Overall means for the proportion of time spent in the grazing (%), shade use (%), and parallel orientation (%); air temperature (T_A), solar irradiance (R_S), and solar elevation angle (θ).

	%, Grazing		%, Shade Use		%, Parallel		T_A	R_S	θ
	Hair coat color								
	Black	White	Black	White	Black	White			
Days of evaluation									
Day 1	76.72	77.06	25.28	26.50	37.61	38.06	33.86	604.75	
Day 2	61.67	60.56	40.83	46.06	30.11	25.33	33.50	558.70	
Day 3	62.61	62.39	38.39	41.39	30.94	29.11	33.74	705.08	
Day 4	62.44	62.28	38.72	40.44	26.39	24.00	34.52	756.72	
Day 5	52.28	56.50	46.89	43.44	23.89	29.78	34.11	650.01	
*Day 6	83.33	79.22	12.83	13.56	39.89	40.61	-	-	
*Day 7	72.28	73.94	30.72	29.22	29.72	29.17	-	-	
Time of the day, h									
06:00	94.68	96.19	1.11	0.91	51.03	49.33	25.56	225.53	11.38
07:00	97.98	97.62	0.83	0.40	46.35	48.97	27.62	391.32	25.56
08:00	96.39	97.38	3.69	1.83	49.05	46.47	29.96	553.91	39.67
09:00	85.12	85.24	13.45	15.71	43.25	40.91	31.84	674.26	53.53
10:00	39.40	40.83	59.21	57.26	19.09	18.77	33.53	803.15	66.56
11:00	59.64	62.66	40.60	37.14	28.29	26.83	34.20	742.32	76.07
12:00	58.73	58.65	40.44	42.42	32.34	32.38	34.45	682.15	73.71
13:00	82.54	80.40	20.00	22.86	31.71	34.13	34.30	609.76	62.38
14:00	96.35	94.56	6.67	12.18	44.68	42.22	33.24	437.88	48.96
15:00	97.78	96.55	1.71	5.52	40.20	40.28	31.45	228.41	34.98
16:00	96.19	94.44	8.89	9.88	42.54	35.00	29.19	66.72	20.83
	P-value								
Sources of variation									
Hair coat color	0.9814		0.4461		0.2608				
Animal (hair coat color)	0.2327		0.4186		0.0001				
Days of evaluation	0.0001		0.0001		0.0628				
Animal (Hair coat color*days of evaluation)	0.9590		0.9996		0.6636				
Hair coat color*time of the day	0.0001		0.0001		0.0001				
Time of the day (day)	0.0001		0.0001		0.0001				

* cloudy day

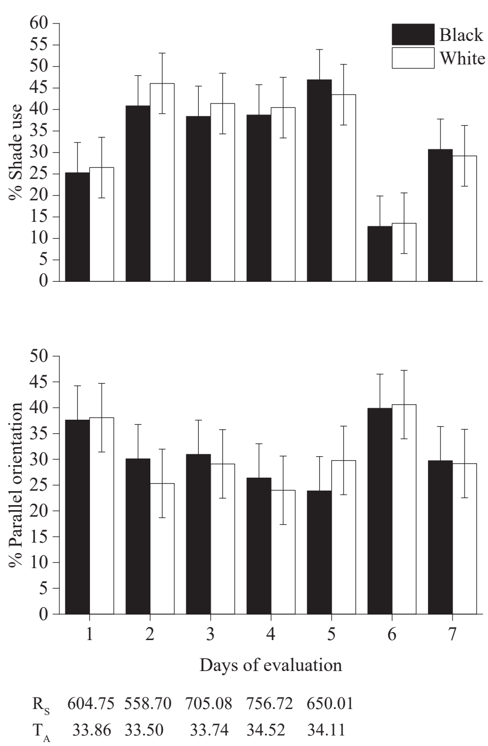

Fig. 2. Least-square means for the proportion of time spent in the shade and parallel orientation both for black and white coat sheep. Means were calculated for the hottest time of day (i.e., from 10:00 to 14:00 h).

sunny conditions (Mitchell et al., 2018). In this study, we expected that the sheep with black coats would be more dependent on seeking shade than those with white coat (Gebremedhin et al., 2023), as the radiative properties of black fur would favor as much as twice heat gain through short-wave solar radiation (Da Silva et al., 2003). However, both black and white sheep demonstrated similar pattern for shade-use (Table 1; Fig. 2). This result was possibly influenced by the social dynamics of gregarious species as sheep. When in group, sheep and other gregarious species are likely to synchronize grazing and resting activities (Penning et al., 1993).

We hypothesized that sheep in this study would not employ body orientation behaviour to reduce the radiant heat gain. Overall, while grazing, neither the black- or white-haired sheep avoided perpendicular body axis orientation or favoured parallel orientation (Table 2; Fig. 2), especially between 10:00 and 14:00, a time period that solar elevation angle was above to 65°. Over this time, the sheep spent less than 30% of the time with body axis oriented parallel. As the solar elevation angle exceeded 70° and became close to zenith, the body surface area illuminated by the sun (i.e., the shape factor) of a quadruped animal is independent of the body axis orientation (Maloney et al., 2005b; DaSilva, 2006). By considering body dimensions (body length and diameter) of sheep in this study, and a solar elevation angle of 70°, the shape factor calculated for perpendicular and parallel orientation was indeed 0.31 and 0.30, respectively. In other words, under such circumstances, close to 30% of the body surface of sheep would be illuminated by the sun either if they were with body axis paralleled or perpendicular oriented.

4. Conclusion

Sheep with black and white coats do not use orientation of the body axis as a thermoregulatory strategy when exposed to solar radiation in an equatorial semi-arid environment.

CRediT authorship contribution statement

L.K.C.Morais: Methodology, Investigation, Data curation, Writing – original draft. **E.P.Saraiva**: Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration. **W.H.Sousa**: Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration. **S.K.Maloney**: Writing – review & editing. **R.S.Hetem**: Writing – review & editing. **J.D.C.Santos**: Methodology, Investigation, Data curation, Writing – original draft. **L.A.A.Lima**: Writing – review & editing. **G.A.B.Moura**: Writing – review & editing. **V.F.C.Fonsêca**: Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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