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Physiological and Behavioral Responses of Sohagi Ewe Lambs Exposed to Direct Sunlight Under Subtropical Climatic Conditions

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ABSTRACT

This study aimed to assess the ability of Sohagi ewe lambs to adapt to heat stress conditions during the summer season in arid regions of Sohag governorate, Egypt. Twenty-one Sohagi ewe lambs (9-11 months old and 25.55±2.69 kg average body weight) were divided into three equal groups. In the 1st group, ewe lambs were housed in an indoor barn and considered as control (DS0), while those in the 2nd and 3rd groups were daily exposed to direct sunlight in the outdoor barns for 4 hours (DS4) and 8 hours (DS8), respectively. Physiological, blood parameters, and daily behavioral activities of each animal in experimental groups were obtained and data were analyzed in a completely randomized design. Results showed that rectal temperature, respiration rate, and water consumption of Sohagi ewe lambs in DS4 and DS8 groups increased significantly (p<0.05) compared with those in the control one. The means of packed cell volume, hemoglobin, red blood cell counts, white blood cell counts, and neutrophil to lymphocyte ratio increased significantly (p<0.05) in ewe lambs in DS4 and DS8 than those in DS0. Glucose and total protein level of ewe lambs in DS4 and DS8 decreased significantly (p<0.05) compared with those in DS0, while potassium levels increased significantly (p<0.05), and sodium levels did not change. Daily behavioral observation illustrated that eating activities increased significantly (p<0.05) at night between sunset and sunrise in DS4 and DS8 than in DS0. Also, standing time in DS4 and DS8 groups increased significantly (p<0.05) compared with DS0. It could be concluded that the productive performance of ewe lamb groups exposed to direct sunlight was not affected. At the same time, physiological responses were significantly increased, reflecting the adaptability of Sohagi ewe lambs to heat stress under subtropical climatic conditions.

Keywords: adaptability; behavioral response; direct sunlight; physiological response; Sohagi ewe lamb

INTRODUCTION

Small ruminants have an essential role in the food and nutritional security of millions of rural people (landless, marginal, and small farmers) in arid and semi-arid rainfed regions (Kumar & Roy, 2013). Because small landowners or landless farmers could not invest in large ruminants, such as buffaloes or cattle, they invested more in small ruminants to cover family needs (Alary *et al.*, 2015). In Upper Egypt, about 1.5 million sheep are reared, mainly in mixed flocks, with goats kept as household animals, in less extensive systems (Othman *et al.*, 2016). Egypt has three major sheep breeds: Rahmani, Ossimi, and Barki. Additionally, there are eight minor sheep breeds located mainly in the southern part of the country and the oases, Sohagi sheep is one of them (FAO, 2014). Sohagi sheep is one of the most prevalent types of sheep in Upper Egypt exploited by small farmers to improve their livelihoods and annual income (Elaref *et al.*, 2021). Sohagi sheep lambs have capabilities that qualify them for premium products, but with the availability of appropriate environmental conditions (Elaref *et al.*, 2020). In the summer, sheep in arid regions were grazing for long distances during the daytime under the influence of direct sunlight, which is a source of heat stress. Heat stress in domesticated livestock arises when combinations of environmental conditions challenge the animal's thermoregulatory mechanisms such as temperature, humidity, solar radiation, and wind speed that exceed the animal's ability to thermoregulate (Sejian *et al.*, 2018). Small ruminants are very rustic animals that can cope with extreme living conditions. However, full information on how these animals can adapt and survive in the novel and transforming environments are lacking (Berihulay *et al.*, 2019). This study aimed to assess the physiological and behavioral responses of Sohagi ewe lambs to adapt to heat stress under subtropical climatic conditions in the Sohag governorate in Upper Egypt.

MATERIALS AND METHODS

The present study was conducted at the experimental sheep farm of Animal Production Department, Faculty of Agriculture, El-kawthar city Sohag University, located in western arid regions of Sohag governorate, Egypt. Experimental animals were managed according to Sohag Institutional Animal Care and Use Committee (Sohag-IACUC approval protocol No: 61220211).

Experimental Design, Animals, and Diets

Twenty-one Sohagi ewe lambs (9-11 months old and 25.55±2.69 kg average body weight) were divided into three equal groups. In the 1st group, ewe lambs were housed in an indoor barn and considered as the control group, while those in the 2nd and 3rd treatment groups were daily exposed to direct sunlight in the outdoor barns for 4 hours (DS4, from 9:00 to 13:00) and 8 hours (DS8, from 9:00 to 17:00), respectively. The experiment lasted for 30 days during the summer season (August and September). Ambient temperature (°F) and relative humidity (%) were recorded by using a digital Data logger to calculate average temperature-humidity index (THI) values during 12-h daylight for indoor and outdoor barns by using an equation of (LPHSI, 1990):

THI=db°F-{(0.55-0.55RH)(db°F-58)}

Where db was dry bulb temperature (°F) and RH was relative humidity (%). The level of heat stress in sheep was divided as follows: THI values <82 was the absence of heat stress; 82 to <84 were moderate heat stress; 84 to <86 were severe heat stress, and over 86 was extreme severe heat stress. Calculated THI values during daytime for indoor and outdoor barns were 80.85 and 85.92, respectively, indicating that experimental groups exposed to direct sunlight (DS4 and DS8) were subjected to severe heat stress conditions. Animal groups were fed the same diet according to NRC (2007), composed of 60% concentrate feed mixture (composed of yellow maize, wheat barn, and soybean meal) plus 40% rice straw as a total mixed ration (DM: 88.64%, OM: 87.60%, EE: 2.86%, CP: 12.04%, CF: 22.27%, NFE: 50.44%, ash: 12.4%). Diet was offered at 1 kg/ewe lamb (approximately 4% of the animal's weight) ad libitum once daily in the morning (09:00 h), and the weight of the leftover feed was measured to calculate intake. The experimental ewe lambs had access to fresh water at all times and water consumption was measured. Animals were weighed at the end of the trial to estimate total body gain and average daily gain.

Physiological Responses and Blood Samples

Physiological responses (rectal temperature and respiration rate) for each animal in experimental groups were obtained in the morning at 9:00 before exposure to direct sunlight and in the afternoon at 13:00 for DS0 and DS4 and 17:00 for DS8 at the end of the period of exposure to direct sunlight twice weekly. Blood samples were obtained from all ewe lambs of each group via jugular vein puncture at 13:00 for DS0 and DS4 groups and 17:00 for DS8 group twice weekly. Collected blood samples were divided into two parts; the first part was immediately centrifuged at 3000 rpm for 10 minutes, plasma was separated and stored at -20 °C until analysis for glucose, total protein, triglyceride, sodium, and potassium. At the same time, the second part of the blood sample was obtained in EDTA tube for RBCs, WBCs, PCV%, and Hb% analysis.

Behavioral Activities

The experimental groups were video recorded continuously 24 h/day for 30 days using a digital Surveillance video recording system (Digital video recorder 8 channel, indoor and outdoor Cameras, and digital display monitor 32 inches). Daily behavioral observation data for each animal included eating, ruminating, resting, standing, and lying.

Statistical Analysis

Data were analyzed with the principle of completely randomized design by the PROC MIXED for repeated measurements of SAS (SAS 9.3, SAS Inst. Inc., Cary, NC) and the results were presented as Least Squares Means (LSM). Differences between LSM were determined with the PDIFF option of SAS. The statistical model used was:

$$Y_{ij} = \mu + T_i + \varepsilon_{ij}$$

Where *Yij* was the dependent variable (physiological parameters, blood hematological and constituents, productive performance, and daily behavioral activities of Sohagi ewe lambs), μ was the overall mean, *Ti* was the fixed effect of Treatment (DS0, DS4, and DS8), and ε_{ij} was the random residual error.

RESULTS

Productive Performance of Sohagi Ewe Lambs

The effect of exposure to direct sunlight on the productive performance of Sohagi ewe lambs is shown in Table 1. There was no difference in the initial body weight of ewe lambs in the beginning of the trial. Final body weight, changes in body weight, average daily gain, and feed intake were not significantly affected by exposure to direct sunlight. On the other hand, water consumption for ewe lambs in DS4 and DS8 was increased ($p<0.001$) compared to the control group (3.41 and 3.94 vs. 2.44 L/day, respectively).

Physiological Responses and Blood Analysis

Rectal temperature and respiration rate of Sohagi ewe lambs in experimental groups were not significantly different before exposure to direct sunlight (morning). However, after exposure of Sohagi ewe lambs in DS4 and DS8 to direct sunlight (afternoon), the means of rectal temperature and respiration rate were increased ($p<0.001$) compared with control one (RT: 39.41 °C, 39.47 °C, and 39.15 °C, RR: 89.1, 99.8, and 67.9 breaths/min, respectively) (Table 2).

The PCV%, Hb%, RBC, and WBC concentrations were increased ($p<0.001$) for Groups exposed to direct sunlight than the control group. The highest values were obtained in the DS8 group (38.13%, 12.05%, 6.88, and 8.28, respectively) followed by DS4 (36.49%, 11.57%, 6.75, and 8.10, respectively), while the DS0 group had the least values (35.21%, 11.13%, 6.43, and 7.91, respectively). Neutrophil cells were increased ($p<0.001$) in the treated groups compared to the control one (32.73 and 31.60 vs. 29.53%, respectively). However, lymphocytes were decreased in the treated groups compared to control one ($p<0.001$) (58.73 and 60.07 vs. 61.73%, respectively). This resulted led to a significant increase in the percentage of N/L ratio (0.558 and 0.527 vs. 0.479, respectively). There was no significant difference in Eosinophil, Monocyte, and Basophil among experimental groups (Table 3).

Levels of glucose and total protein were decreased ($p<0.027$) and ($p<0.045$) for DS4 and DS8 compared to the control group (Glucose: 70.14 and 68.33 vs. 73.88 mg/dL, Total protein: 7.03 and 6.87 vs. 7.37 mg/dL, respectively). While, potassium levels were increased ($p<0.034$) for groups exposed to direct sunlight compared to control (6.10 and 5.77 vs. 5.24 mmol/L, respectively). However, there were no significant differences in triglyceride and sodium levels among the experimental groups (Table 4).

Table 1. Productive performance of Sohagi ewe lambs exposure to direct sunlight

Items	Experimental groups			SEM	p-value
	DS0	DS4	DS8		
Initial body weight (kg)	25.9	25.6	26.1	0.82	0.972
Final body weight (kg)	29.07	28.49	28.86	0.86	0.967
Body weight change (kg)	3.21	2.93	2.79	0.09	0.171
Average daily gain (g)	107.1	97.6	92.9	3.14	0.171
Feed intake (g/day)	831	797	784	12.4	0.281
Water consumption (L/day)	2.44^{a}	3.41^{b}	3.94^{c}	0.12	>0.001

Note: DS0= lambs were kept away from direct sunlight, DS4= lambs were exposed to direct sunlight for 4h/day. DS8= lambs were exposed to direct sunlight for 8h/day, SEM= Standard error of mean. ^{a,b,c} Mean in the same row with different superscripts differ significantly ($p<0.05$).

Table 2. Physiological parameters of Sohagi ewe lambs exposure to direct sunlight

Items	Treatments			SEM	p-value
	DS0	DS4	DS8		
Morning					
Rectal temperature (°C)	38.77	38.74	38.74	0.05	0.979
Respiration rate (breaths/min.)	60.20	62.10	63.20	0.88	0.336
Afternoon					
Rectal temperature (°C)	39.15^{b}	39.41^{a}	39.47^{a}	0.03	>0.001
Respiration rate (breaths/min.)	67.9^{c}	89.1^{b}	99.8^{a}	1.31	>0.001

Note: DS0= lambs were kept away from direct sunlight, DS4= lambs were exposed to direct sunlight for 4h/day. DS8= lambs were exposed to direct sunlight for 8h/day, SEM= Standard error of mean. ^{a,b,c} Mean in the same row with different superscripts differ significantly ($p<0.05$).

Table 3. Blood hematological values of Sohagi ewe lambs exposure to direct sunlight

Items	Experimental groups			SEM	p-value
	DS0	DS4	DS8		
PCV%	35.21^{a}	36.49^{b}	38.13^{c}	0.22	>0.001
Hb%	11.13^{a}	11.57^{b}	12.05^{c}	0.09	>0.001
RBC ($\times10^{9}$)	6.43^{a}	6.75^{b}	6.88^{b}	0.04	>0.001
WBC ($\times10^{6}$)	7.91^{a}	8.10^{ab}	8.28^{b}	0.04	0.002
Neutrophil	29.53^{a}	31.60^{b}	32.73^{c}	0.29	>0.001
Lymphocyte	61.73^{a}	60.07^{b}	58.73^{c}	0.27	>0.001
N/L ratio	0.479^{a}	0.527^{b}	0.558^{c}	0.01	>0.001
Eosinophil	4.13	4.07	4.27	0.11	0.76
Monocyte	3.73	3.47	3.53	0.10	0.556
Basophil	0.867	0.8	0.733	0.10	0.864

Note: DS0= lambs were kept away from direct sunlight, DS4= lambs were exposed to direct sunlight for 4h/day. DS8= lambs were exposed to direct sunlight for 8h/day, SEM= Standard error of mean. ^{a,b,c} Mean in the same row with different superscripts differ significantly ($p<0.05$).

Table 4. Daily behavioral activities of Sohagi ewe lambs exposure to direct sunlight

Items	Experimental groups			SEM	p-value
	DS0	DS4	DS8		
Glucose (mg/dL)	73.88[a]	70.14[b]	68.33[b]	1.22	0.027
Total protein (mg/dL)	7.37[a]	7.03[b]	6.87[b]	0.11	0.045
Triglyceride (mg/dL)	45.68	46.19	46.22	2.63	0.996
Sodium (mmol/L)	155.01	153.17	150.63	11.46	0.989
Potassium (mmol/L)	5.24[a]	5.77[ab]	6.10[b]	0.14	0.034

Note: DS0= lambs were kept away from direct sunlight, DS4= lambs were exposed to direct sunlight for 4h/day. DS8= lambs were exposed to direct sunlight for 8h/day, SEM= Standard error of mean. [a,b,c] Mean in the same row with different superscripts differ significantly ($p<0.05$).

Behavioral Response

Daily behavioral activities of Sohagi ewe lambs as affected by exposure to direct sunlight are shown in Table 5. Exposure of ewe lambs in treated groups to direct sunlight does not affect daily eating, ruminating, and resting time. Eating time for ewe lambs in DS0, DS4, and DS8 groups were 338, 334, and 327 min/day, respectively. The distribution of eating behavior throughout the day was varied significantly between the treated groups and the control group (Figure 1). Eating activities increased significantly at night in DS4 and DS8 than control (50.30 and 54.43 vs. 45.13%. respectively). Standing time was increased ($p<0.006$) for ewe lambs in DS4 and DS8 than DS0 (688.5 and 694.8 vs. 672.8 min, respectively), and consequently, lying time was decreased (751.5 and 745.2 vs. 767.2 min, respectively).

DISCUSSION

Results in Table 1 show that final body weight, changes in body weight, and average daily gain of Sohagi ewe lambs were not significantly affected by the exposure to direct sunlight. In contrast, Sejian *et al.* (2013) and Indu *et al.* (2014) found that final body weight and average daily gain were significantly lower in heat-stressed ewes than in control. Furthermore, the negative effect of heat stress on the body weight of animals has been documented by Al-Haidary *et al.* (2012), who found that loss in body weight was greater during the hot period compared with the loss in body weight during the thermoneutral period. Marai *et al.* (2007) explain that the loss in body weight during hot conditions is essential due to reduced dry matter intake and an increase in maintenance requirements caused by the increased respiration rate. In our results, feed intake was not significantly affected by exposure to direct sunlight. It may be due to the ewe lambs in heat-stressed groups modifying their daily feeding behavior, where the eating time at night has increased in the heat-stressed groups than in the control group (Figure 1). Herrera *et al*. (2017) obtained a similar result, who noticed that animals on hot days tended to graze during lower temperatures hours, such as at dawn, dusk, and night.

The increase in water consumption by ewes in groups exposed to direct sunlight in this study was also observed by Omran (2013) and Omran *et al.* (2019), who reported that water intake increased significantly with the increase in ambient temperature. Also, Sejian *et al.* (2013) observed an increase in water consumption when animals are exposed to high ambient temperatures under a hot semiarid environment. Moreover, Markwick

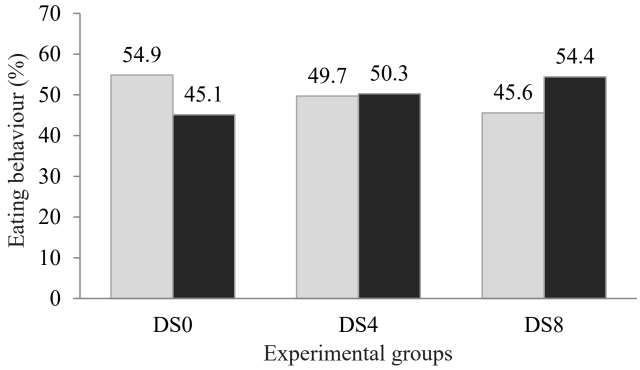

Figure 1. Eating behavior distribution during daylight and night of Sohagi ewe lambs. DS0= lambs were kept away from direct sunlight, DS4= lambs were exposed to direct sunlight for 4h/day. DS8= lambs were exposed to direct sunlight for 8h/day. ■= daylight; ■= night.

Table 5. Daily behavioral activities of Sohagi ewe lambs exposure to direct sunlight

Daily behavioral activities	Experimental groups			SEM	p-value
	DS0	DS4	DS8		
Eating time (min/day)	338.1	334.5	327.2	2.50	0.193
Ruminating time (min/day)	562.2	557.4	559.5	2.31	0.701
Resting time (min/day)	539.7	548.1	553.3	2.39	0.062
Lying time (min/day)	767.2[b]	751.5[a]	745.2[a]	2.94	0.006
Standing time (min/day)	672.8[a]	688.5[b]	694.8[b]	2.94	0.006

Note: DS0= lambs were kept away from direct sunlight, DS4= lambs were exposed to direct sunlight for 4h/day. DS8= lambs were exposed to direct sunlight for 8h/day, SEM= Standard error of mean. [a,b,c] Mean in the same row with different superscripts differ significantly ($p<0.05$).

(2007) reported that sheep increase water consumption by 78% for evaporative cooling during hot weather conditions.

Breeders can enhance the productivity of their sheep by protecting them from exposure to direct sunlight and keeping it away from heat stressors in the summer by using sheds during morning grazing and offering cool water.

Results of rectal temperature and respiration rate of Sohagi ewe lambs were in agreement with those by Sejian *et al.* (2013), who obtained that exposure to high ambient temperatures under a hot semiarid environment augments the efforts to dissipate body heat, leading to an increase in respiration rate and body temperature. On the other hand, Rathwa *et al.* (2017) reported that physiological parameters of indigenous sheep such as rectal temperature and respiration rate were significantly higher during the summer season compared to the winter season. Nejad & Sung (2017) explain that heat-stressed sheep and goats first increased respiratory rate as a thermoregulation mechanism to help maintain their body temperatures, and panting is another physiological response in sheep to hot conditions.

The present results show a significant increase in PCV% and Hb% of ewe lambs exposed to direct sunlight than those in the control group. In the same regard, Indu *et al.* (2014) and Rana *et al.* (2014) reported that exposure to heat stress resulted in a significant increase in PCV% and Hb%. They considered that a higher value of PCV% is an adapted mechanism to save water necessary for the evaporative cooling process. The increased PCV% and Hb% could be due to severe dehydration during heat stress in ewes (Sejian *et al.*, 2010). Rana *et al.* (2014) suggested that increasing levels of PCV% and Hb% could be due to either increased attack of free radicals on the RBC membrane, which is rich in lipid content, and ultimate lysis of RBC or adequate nutrient availability for hemoglobin synthesis as the animal decreases voluntary intake under heat stress.

Additionally, Rana *et al.* (2014) stated that red blood cell count increased in indigenous sheep exposure to heat stress while white blood cell count was not affected significantly. One of the indicators of a higher level of stress observed during summer is a high neutrophil/lymphocyte ratio (Banerjee *et al.*, 2015). He noticed that the neutrophil percentage increased and lymphocyte percentage decreased during summer. These results matched with our findings with heat-stressed groups of Sohagi ewes.

The similar decrease in serum glucose level of heat-stressed ewes observed in this study has been previously observed by Rathwa *et al.* (2017) on indigenous sheep, Cwynar *et al.* (2014) on Polish Merino sheep, and Indu *et al.* (2014), and Sejian *et al.* (2012) on Malpura ewes. The reduction in glucose level could be related to the decrease in insulin and thyroxine concentrations, which are closely associated with energy metabolism during stress (Rasooli *et al.*, 2004). On the other hand, Sejian *et al.* (2010) and Al-Haidary *et al.* (2012) reported that exposing sheep to hot conditions does not affect serum glucose concentration. Small ruminant studies in biochemical blood parameters often give different results, depending on the species or animal breed (Cwynar *et al.*, 2014).

The results of protein levels in our study are closer to those found in Malpura ewes by Sejian *et al.* (2010; 2012). The lowest total plasma protein concentration was recorded in thermal and nutritional stress groups, and the highest concentration was recorded in the control group. In contrast, Rathwa *et al.* (2017) reported that serum protein concentration was not affected by exposure of sheep to hot conditions during the summer season. The significant decrease in the plasma protein in stressed ewes could be attributed to the increased rate of gluconeogenesis. This is evident from the fact that during heat stress glucocorticoids favor protein catabolism to support gluconeogenesis (Sejian *et al.*, 2010). On the other hand, the thyroxin hormone as a growth promoter plays an important role in protein metabolism. Habeeb *et al.* (2011) found that T3 and T4 values were significantly lower in Friesian calves in summer than in winter, resulting in the decreased protein synthesis.

The increase in serum potassium level of heat-stressed ewes was also observed by Rathwa *et al.* (2017) on indigenous sheep, Cwynar *et al.* (2014) on Polish Merino sheep, and Wojtas *et al.* (2014) on Merino sheep. Rathwa *et al.* (2017) suggest that the increased serum potassium concentrations during the summer season may be due to dehydration and depending on water intake.

Theoretically, results of eating behavior distribution throughout the day agreed with the hypothesis stating that dry matter intake and feeding activities at night will be greater than at daytime, considering the temperature at night tends to be lower than at daytime. However, these results were in opposition with those reported by Nugroho *et al.* (2015), who found that dry matter intake during the day was higher than at night. The factor that is strongly suspected to play a role in this limiting feed intake was the lower intensity of light at night than the day that stimulated sheep to decrease their activities (rest) and reduced their feeding activities.

The standing and lying time results were similar to those observed by Kamal *et al.* (2016). By standing more time, animals can increase the heat loss from the body surface by evaporating and help to dissipate heat by the conductive and radiative heat from the ground surface. Furthermore, Ratnakaran *et al.* (2017) illustrate the increases in standing time during heat stress as an adaptive behavioral mechanism in animals to avoid the additional heat load from the ground and favor easy heat dissipation from the body. Silva *et al.* (2016) reported that sheep spent more time for rumination by standing where the ruminants have been characterized by the use of nighttime to perform lying rumination to mitigate the effects of heat stress.

CONCLUSION

In conclusion, the presented study results showed that the physiological and blood parameters of the Sohagi ewe lambs were significantly affected by exposure to direct sunlight, which represents a source of heat stress for sheep during daytime grazing in hot regions. The productive performance and daily feed intake were not significantly affected. These findings indicate that Sohagi ewe lambs are more adapted to heat stress conditions in arid regions.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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