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RESEARCH ARTICLE

Thermoregulatory and Physiological Responses of Najdi Sheep Exposed to Environmental Heat Load Prevailing in Saudi Arabia

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ABSTRACT

The objective of this study was to evaluate the thermoregulatory and physiological responses of Najdi rams raised under hot summer conditions prevailing in Kingdom Saudi Arabia. The core temperature (T_{core}) showed circadian rhythm characterized by biphasic achrophases, which were associated with the feeding times during both seasons. Average daily T_{core} was significantly (P<0.05) higher under hot summer conditions. However, the amplitudes of the rhythmic oscillation during winter and summer seasons were 0.85 and 0.56°C, respectively. Rectal (T_{re}) and skin temperatures (T_{sk}) were significantly (P<0.05) higher under hot summer conditions and exhibited similar patterns during both seasons concurrent with the pattern of temperature humidity index (THI), reaching the maximum values late in the afternoon and the minimum values early in the morning. Respiratory rate (RR) and heart rate (HR) showed the same pattern of the thermal parameters and were significantly (P<0.05) higher under hot summer conditions. Serum concentrations of total protein, globulin, glucose, sodium and chloride were significantly (P<0.05) increased while those of albumin and calcium were decreased under hot summer conditions. The results obtained from this study indicate that hot summer conditions of Saudi Arabia is thermally stressful to Najdi rams. Therefore, Najdi sheep production under such conditions would require environmental and/or nutritional modification to alleviate the impact of heat stress.

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INTRODUCTION

The Najdi is a breed of domestic sheep native to the Najd region (central part) of the Arabian Peninsula. The Najdi is the principal native sheep breed in the central region of Saudi Arabia, which is adapted to live under desert conditions, though it is less drought tolerant than Awassi breed (Alamer and Al-Hozab, 2004). As far as phenotypic picture is concerned, Najdi sheep is a fat-tailed black-coated animal with long coarse fleece. The average summer temperature in Najd region is 45°C, but readings of up to 54°C are common. Tropical regions characterized by high levels of solar radiation and temperature are known to adversely affect animal production (McManus *et al.*, 2009b, Naqvi and Sejian, 2010). The maintenance of body temperature within physiological limits is necessary for animal to remain healthy, survive and maintain its productivity (Marai *et al*., 2007). It has been demonstrated that the ability of ruminants to regulate body temperature is species and breed dependent (Bernabucci *et al.*, 2010). Higher-producing animals are more susceptible to heat stress because they generate more metabolic heat. During heat stress, ruminants, like other homeothermic animals, increase avenues of heat loss and reduce heat production in an attempt to maintain euthermia. The immediate responses to heat load are increased respiration rates, decreased feed intake and increased water intake. Acclimatization is a process by which animals adapt to environmental conditions and engage behavioral, hormonal and metabolic changes. Alterations in the hormonal profile are mainly characterized by a decline and increase in anabolic and catabolic hormones, respectively. It has been reported that higher circulating prolactin during heat stress may modulate some mechanisms of heat dissipation and heat production oriented to support homeothermy (Alamer, 2011). It is also well known that heat acclimation decreases endogenous levels of thyroid hormones in an attempt to reduce endogenous heat production, and results in higher level of circulating cortisol (Sejian *et al.*, 2010).

Evaluations of heat tolerance and adaptability to hot environments have been carried out using physiological adaptation tests involving respiration, heart rate, body and skin temperatures, sweating rate, packed cell volume, potassium content in erythrocytes, individual heat tolerance coefficient, hormonal secretion and decreased rate of production (Marai and Habeeb, 2010; Castanheira *et al.*, 2010; Li *et al.*, 2011; Charoensook *et al.*, 2012).

An individual animal's susceptibility to heat stress is influenced by several factors including species, condition score, temperament, sex, and previous exposure (Brown Brandl, 2009). Properties of the skin and coat also affect energy exchange including colour, density, diameter, depth, transmissivity and heat absorption (Bianchini *et al.*, 2006). Colour differences between breeds appear to be an important factor influencing body temperature and heat tolerance (Otoikhian *et al.*, 2009, McManus *et al.*, 2011). Skin pigmentation is necessary to protect deep tissues against excess exposure to solar radiation in tropical zones (Castanheira *et al.*, 2010). Light coats have been considered as the most desirable ones for livestock in tropical areas (McManus *et al.*, 2009a, Otoikhian *et al.*, 2009) as dark-coated animals tend to acquire greater heat load from solar radiation than light-colored ones (Bianchini *et al.*, 2006). Protective properties depend on the characteristics of the skin (color, thickness, sweat glands) and of the hair coat (thickness, texture, intensity, diameter, length, angle to the skin surface) which allow the animal to exchange heat with the environment through radiation, convection, evaporation and conduction (da Silva *et al.*, 2003). Shape, size and surface area of animals are also known as important morphological traits in body thermal balance (Marai *et al.*, 2007). Small animals with relative large surface area are more vulnerable to environmental temperature.

The phenotypic traits of Najdi sheep might impede heat dissipation and affect the thermoregulatory efficiency of this breed under hot environmental conditions. Therefore, this study was designed to evaluate the thermoregulatory and physiological responses of Najdi rams raised under hot summer conditions of Saudi Arabia.

MATERIALS AND METHODS

Animals and housing: Twelve (1 year old) Najdi rams with an average body weight of 41.75±7.64 Kg were used in this study. Six Najdi rams were used for summer season experiment, while other six Najdi rams were used for winter season experiment. All animals were clinically healthy and were housed individually under open-shaded pens in Experimental Farm Unit affiliated to the Department of Animal Production, Faculty of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia.

Feeding: During both season animals were fed on a commercial total mixed ration (ME 1950 kcal/kg, Crude protein 13%, Crude fat 2%, Crude fiber 10%, Ash 8% on DM basis; Al-wafi pellets, ARASCO, KSA). Feed at a level of 2.5% of the animal body weight was offered twice daily at 7:00 am and 3:00 pm, and the animals had free access to clean fresh tap water throughout the study.

Climatic data: Ambient temperature (T_a) and relative humidity (RH) were recorded at 30 minutes intervals through out the experimental periods using data logger (HOBO Pro Series, ONSET, USA). Temperature-humidity index (THI) was calculated using the following equation: THI = Td – {(0.31- 0.31 x RH) (Td - 14.4)}. Where, Td = Dry bulb temperature (ºC), and RH = Relative humidity (%).

Experimental procedure: The experiments were conducted for six weeks during summer and winter seasons. The first two weeks served as a preliminary period and followed by four weeks of experimental period. The animals were surgically implanted with sterilized telemetric temperature transmitters (CorTemp™ system, Wireless Sensing Systems & Design HQ Inc, Palmetto, Florida) for measuring core body temperature (T_{core}). Data recorder (Miniaturized Ambulatory Data Recorder, Wireless Sensing Systems & Design HQInc, Palmetto, Florida, USA) were programmed to receive the signal from temperature transmitters at 30 minutes interval throughout the study and placed above the animal back in specially-designed pouches. Rams were ear tagged and shaved in four regions (right and left shoulder, right and left hips) for surface skin temperature measurements. Skin temperature and rectal temperature were measured three days per week at 8:00, 12:00 and 15:00 h, using infrared thermometer (Traceable MiniIR™ Thermometer, Friendswood, Texas, USA) and digital thermometer (ARTSANA, Grandate Co, Italy), respectively. Respiratory and heart rates were also recorded three days per week at 8:00, 12:00 and 15:00 h, using medical stethoscope. Blood samples were collected by jugular venipuncture weekly at 8:00 am into plain tubes for serological analysis. The serum samples were prepared by centrifugation of whole blood (5ºC, 3000 rpm) for 10 min. Thereafter, serum was separated and transferred into 1.5 ml Eppendorf tubes and stored at -20ºC until further analysis. Serum concentrations of total protein, albumin, glucose, sodium, potassium, chloride and calcium were determined using commercial kits (United Diagnostics Industry, Dammam, KSA), while that of globulin was calculated as the difference between total protein and albumin concentrations.

Statistical analysis: Statistical analysis of the data was performed using the general linear model (GLM) procedure for repeated measurements analysis of variance (ANOVA) using the software program SAS (Versión 8, Cary, N.C., SAS Institute, Inc.). Completely randomized design (CRD) was applied to analyze the experimental data. Means±standard error of the mean (SEM) are presented in the tables and differences were considered statistically significant at P<0.05.

RESULTS

Climatic data: The average climatic data throughout the experimental period including ambient temperature (T_a), relative humidity (RH) and temperature humidity index (THI) are presented in Table 1. The average T_a (38.34 ±0.32°C) and THI (31.41±0.22) values were significantly (P<0.05) higher, while the average RH (6.89±0.16%) value was significantly (P<0.05) lower under summer conditions. The minimum average T_a (12.83±0.15 and 33.81±0.34°C) and THI (13.12±0.12 and 28.34±0.23) values and the maximum average RH (38.23±0.31 and 9.25±0.19%) value were measured early in the morning, while the average maximum T_a (25.81±0.30 and 41.36±0.03°C) and THI (22.83±0.21 and 33.44±0.02) values and the minimum average RH (16.30±0.30 and 5.29±0.03%) value were measured late in the afternoon during winter and summer seasons, respectively.

Table 1: Diurnal pattern of the average climatic data during the experimental period (means±SEM).

Parameter	Day time	Winter	Summer
T_a (°C)	8:00	12.83±0.15	33.81±0.34*
	12:00	20.72±0.45	39.85±0.21*
	15:00	25.81±0.30	41.36±0.03*
	Mean	19.79±0.41	38.34±0.32*
RH (%)	8:00	38.23±0.31	09.25±0.19*
	12:00	24.14±0.84	06.41±0.10*
	15:00	16.30±0.30	05.29±0.03*
	Mean	26.22±0.65	06.89±0.16*
THI	8:00	13.12±0.12	28.34±0.23*
	12:00	19.20±0.33	32.44±0.14*
	15:00	22.83±0.21	33.44±0.02*
	Mean	18.38±0.21	31.41±0.22*

*Means within the same row are significantly different at P<0.05.

Body temperature: The core body temperature (T_{core}) showed circadian rhythm characterized by biphasic acrophases which were associated with the feeding times during both seasons (Fig. 1). The daily average T_{core} value was significantly (P<0.05) higher under hot summer conditions (39.32±0.01°C). However, the amplitudes of the rhythmic oscillation during winter and summer seasons were 0.85 and 0.56° C, respectively.

The daily average values of rectal temperature (T_{re}) and skin temperature (T_{sk}) also showed diurnal variation concurrent with that of THI during both seasons (Fig. 2). The average values of T_{re} and T_{sk} were significantly (P<0.05) higher under hot summer conditions (38.99±0.02 and 38.13±0.10°C, respectively).

Respiratory and heart rates: The variation in the average values of respiratory and heart rates during the day time and the impact of the thermal load are presented in Fig. 3. The daily average values of RR and HR were minimal early in the morning and peaked late in the afternoon during both seasons, where THI were maximal. The daily average values of RR and HR were significantly (P<0.05) elevated under hot summer conditions (74.04±2.05 breaths/minute, and 82.52±1.32 beats/minute, respectively).

Serum metabolites and minerals: The exposure of Najdi rams to thermal load under hot summer conditions resulted in a significant (P<0.05) increase in the serum concentrations of total protein, globulin, glucose and sodium. However, the serum concentrations of albumin and calcium were significantly (P<0.05) reduced (Table 2).

Table 2: Effect of thermal load on some serum metabolites and minerals concentrations of Najdi sheep (mean±SEM, n=6).

Parameters	Winter	Summer	P value
Total Protein (g/dl)	4.91±0.21	5.63±0.26*	0.047
Albumin (g/dl)	3.57±0.07	3.44±0.08*	0.045
Globulin (g/dl)	1.53±0.21	2.22±0.28*	0.035
Glucose (mg/dl)	71.29±2.80	95.07±2.16*	0.001
Na^+ (mmol/l)	141.00±8.10	159.51±3.63*	0.037
K^+ (mmol/l)	6.00±0.20	5.64±0.23	0.37
Cl^- (mmol/l)	109.46±1.63	116.15±1.94	0.062
Ca^{+2} (mmol/l)	12.65±0.35	10.14±0.48*	0.010

*Means within the same row are significantly different at P<0.05.

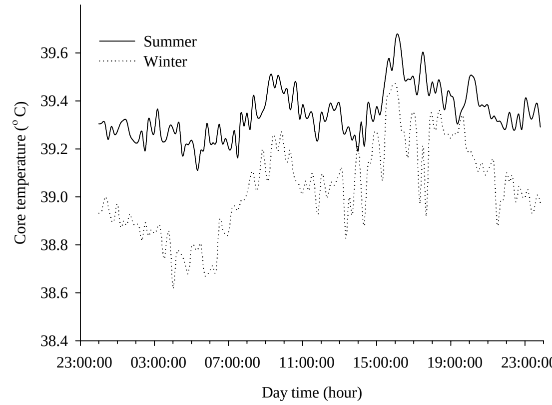

Fig. 1: Circadian rhythm in T_{core} of Najdi sheep during winter and summer seasons.

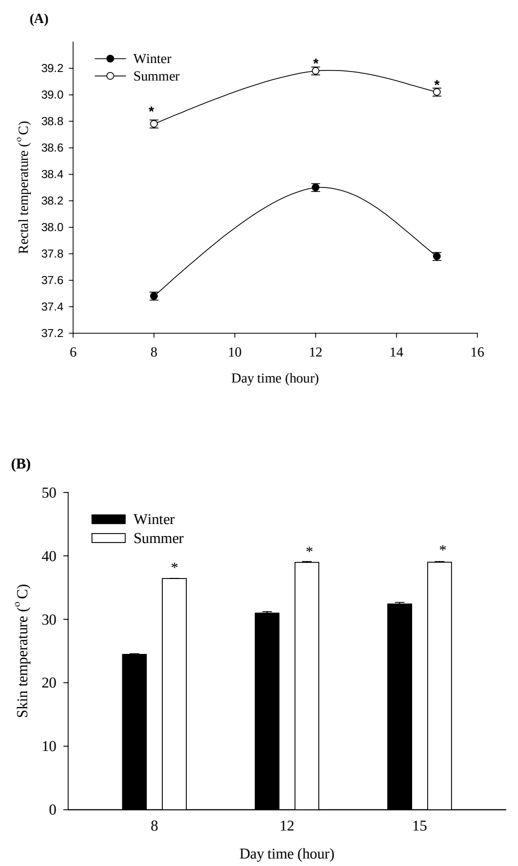

Fig. 2: Diurnal pattern and the seasonal variation in rectal temperature (A) and skin temperature (B) of Najdi sheep (means±SEM, n=6, *P<0.05 compared to winter values).

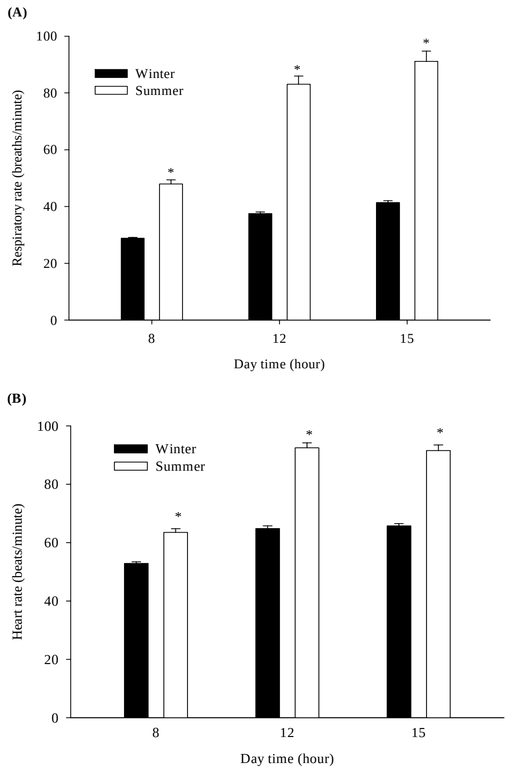

Fig. 3: Diurnal pattern and seasonal variation in Respiratory rate (A) and heart rate (B) of Najdi sheep (means±SEM, n=6, *P<0.05 compared to winter values.

DISCUSSION

The experiments reported above were conducted to test heat tolerance of Najdi sheep to high environmental temperature prevailing under hot summer conditions in Saudi Arabia. Since it has been reported that THI values above 25.6 are considered as sever to extreme heat stress (Marai *et al.,* 2001), the obtained climatic data revealed that Najdi sheep were exposed to extreme heat load during summer season. For adult sheep fed above maintenance the estimated lower critical temperature is 25^{o}C and the estimated upper critical temperature is 31^{o}C (Stockman, 2006). Furthermore, THI below 22.2 is normally considered as comfortable (Marai *et al.,* 2001). Therefore, climatic data recorded during the winter season in this study indicates that the prevailed environmental condition during this season was acceptable for sheep.

The increase of the body core temperature and rectal temperature has been considered as good indicators to the level of heat stress upon animals (Alamer and Al-Hozab, 2004). Therefore, the observed elevation in the body core and rectal temperatures under hot summer conditions indicate that the animals were heat stressed. The observed increase in skin temperature under hot summer conditions is attributed to the exposure to heat stress, which has been reported to cause vasodilatation of skin capillary bed and consequently increase the blood flow to the skin surface to facilitate heat dissipation (McManus *et al.,* 2009b). Skin temperature could also be elevated due to solar radiation, as skin temperature has been shown to be directly related to ambient solar radiation levels (Schütz *et al.,* 2011). Further, the core body temperature showed circadian rhythm with biphasic acrophases associated with the feeding times. This is due to the microbial metabolic processes in the forestomach, where it has been reported that feed intake is followed by a dramatic rise of temperature (Marai *et al.,* 2001). Further, it has been shown that feeding time is in several species and under certain circumstances, able to act as a zeitgeber for the circadian rhythm of body temperature (Jilge, 1991).

Alamer and Al-Hozab (2004) stated that respiration rate can be used as an indicator of heat stress, and to estimate the adverse effects of environmental temperature. Moreover, Silanikove (2000a) suggested that respiration rate was a practical and reliable measure of heat load and stated that respiration rate above 80 breath/minute is an indication of high heat stress. Therefore, the observed acceleration of both respiratory and heart rates of Najdi rams indicate that the animals were exposed to severe heat stress, particularly under afternoon summer conditions. In sheep, panting is the major evaporatory heat loss mechanism and respiratory frequencies tend to follow closely the heat loss by evaporation (Marai *et al.,* 2007). The observed accelerated heart rate could be due to the reported redistribution of blood to peripheral tissues during heat exposure in sheep and goat (Silanikove, 2000b). These findings support the previous reports on other sheep breeds (Marai *et al.,* 2009, McManus *et al.,* 2009b).

The observed variation in the thermo-physiological parameters under hot summer conditions was associated with alterations in some blood parameters. The observed increase in serum total protein and sodium concentrations could be due to dehydration which has been reported to occur as a result of increased breathing rate (Erickson and Poole, 2006). On the other hand, the observed reduction in serum albumin and calcium concentration under hot summer conditions could be attributed to the reduction in the dietary intake which has been reported under heat stress conditions (Marai *et al.,* 2007). The observed elevation of serum glucose concentration under hot summer conditions could be due to the stress induced activation of cortisol secretion and the consequent stimulation of gluconeogenesis and inhibition of cellular glucose uptake and utilization (Marai *et al.,* 2007).

Conclusion: The results of this study indicate that Najdi rams are susceptible to heat stress under hot summer conditions prevailing in Arabian Peninsula. Therefore, Najdi sheep production under such conditions would require environmental and/or nutritional modification to alleviate the impact of heat stress.

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