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

A. A. Al-Haidary, R. S. Aljumaah, M. A. Alshaikh, K. A. Abdoun*, E. M. Samara, A. B. Okab and M. M. Alfuraiji

Department of Animal Production, College of Food and Agriculture Sciences, King Saud University, PO Box 2460; Riyadh 11451, Kingdom of Saudi Arabia
*Corresponding author: abdounn@yahoo.com, kabdoun@ksu.edu.sa

ARTICLE HISTORY
Received: October 20, 2011
Revised: February 12, 2012
Accepted: February 29, 2012

Key words:
Albumin
Glucose
Heat load
Sheep
Thermoregulation

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 (Tcore) showed circadian rhythm characterized by biphasic acrophases, which were associated with the feeding times during both seasons. Average daily Tcore 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 (Tre) and skin temperatures (Tsk) 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.

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<sub>a</sub>) 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: \[ THI = T_d - \left\{0.31 - 0.31 \times RH\right\} (T_d - 14.4) \]

Where, \( T_d \) = 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<sub>c</sub>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 (5°C, 3000 rpm) for 10 min. Thereafter, serum was separated and transferred into 1.5 ml Eppendorf tubes and stored at -20°C 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<sub>a</sub>),
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±0.34% and 38.13±0.10) 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).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Day time (hour)</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_a$ (°C)</td>
<td>8:00</td>
<td>12.83±0.15</td>
<td>33.81±0.34</td>
</tr>
<tr>
<td></td>
<td>12:00</td>
<td>20.72±0.45</td>
<td>39.85±0.21</td>
</tr>
<tr>
<td></td>
<td>15:00</td>
<td>25.81±0.30</td>
<td>41.36±0.03</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>19.79±0.41</td>
<td>38.34±0.32</td>
</tr>
<tr>
<td>RH (%)</td>
<td>8:00</td>
<td>38.23±0.31</td>
<td>09.25±0.19</td>
</tr>
<tr>
<td></td>
<td>12:00</td>
<td>24.14±0.04</td>
<td>06.41±0.10</td>
</tr>
<tr>
<td></td>
<td>15:00</td>
<td>16.30±0.30</td>
<td>05.29±0.03</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>22.62±0.65</td>
<td>06.89±0.16</td>
</tr>
<tr>
<td>THI</td>
<td>8:00</td>
<td>13.12±0.12</td>
<td>28.34±0.23</td>
</tr>
<tr>
<td></td>
<td>12:00</td>
<td>19.20±0.33</td>
<td>32.44±0.14</td>
</tr>
<tr>
<td></td>
<td>15:00</td>
<td>22.83±0.21</td>
<td>33.44±0.02</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>18.38±0.21</td>
<td>31.41±0.22</td>
</tr>
</tbody>
</table>

*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).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Winter</th>
<th>Summer</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Protein</td>
<td>4.91±0.21</td>
<td>5.63±0.26</td>
<td>0.047</td>
</tr>
<tr>
<td>Albumin</td>
<td>3.57±0.07</td>
<td>3.44±0.08</td>
<td>0.045</td>
</tr>
<tr>
<td>Globulin</td>
<td>1.53±0.21</td>
<td>2.22±0.28</td>
<td>0.035</td>
</tr>
<tr>
<td>Glucose</td>
<td>71.29±2.80</td>
<td>95.07±2.16</td>
<td>0.001</td>
</tr>
<tr>
<td>Na+</td>
<td>141.00±8.10</td>
<td>159.51±3.63</td>
<td>0.037</td>
</tr>
<tr>
<td>K+</td>
<td>6.00±0.20</td>
<td>5.64±0.23</td>
<td>0.37</td>
</tr>
<tr>
<td>Cl-</td>
<td>109.46±1.63</td>
<td>116.15±1.94</td>
<td>0.062</td>
</tr>
<tr>
<td>Ca2+</td>
<td>12.65±0.35</td>
<td>10.14±0.48</td>
<td>0.010</td>
</tr>
</tbody>
</table>

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

**Acknowledgement:** The study was supported by King Abdul-Aziz City for Science and Technology (KACST) under the grant GP-25-49.

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