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Adaptive Thermophysiological Adjustments of Gazelles to Survive Hot Summer Conditions

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Abstract.- This study was conducted to identify the adaptive thermophysiological adjustments of 24 gazelles (15 - 20 kg and 3 - 4 years old) belonging to 2 gazelle species (*Gazella gazelles* and *Gazella leptoceros*) for 3 months during both summer and winter seasons. The obtained results indicated that gazelles were exposed to heat stress during the summer season, based on the findings that calculated average temperature-humidity index (THI) prevailed during summer season surpass the THI threshold above which most animals enter a state of severe heat stress. Under these supra-neutral conditions, gazelles of both species had manifested noticeable ($P<0.05$) changes in their thermophysiological responses as demonstrated by pronounced elevations in rectal and skin temperatures as well as marked reductions in internal, external, and total body thermal gradients compared to the winter season. Notably, the use of body heterothermy by gazelles resulted in heat storage of 109.65 and 31.92 kJ/day/animal in summer and winter, respectively. Dissipation of these amounts of heat by insensible evaporative avenue would require 45.61 and 13.82 ml H_2O/day/animal in summer and winter, respectively. Furthermore, exposure of gazelles to hot environmental conditions during the summer season elicited marked ($P<0.05$) alterations in blood haematological and biochemical parameters as revealed by the reduced ($P<0.05$) erythrocytic indices, total protein and globulin concentrations as well as the elevated ($P<0.05$) heterophil/lymphocyte ratio, serum albumin, glucose and haptoglobin concentrations compared to the winter season. These findings collectively prove that gazelles can apply remarkable adaptive thermophysiological adjustments in order to survive the harsh bioclimate at their habitats.

Key words: Adaptation, gazelle, heterothermy, thermal gradients, thermoregulation

INTRODUCTION

Most climatologists agree that the ongoing aridification and global warming constitute the major factors that possess a clear and notable danger to the abundance and distribution of wildlife animal's worldwide (Johnson, 1997; Thompson, 2010; Chowdhury and Al-Zahrani, 2013). Therefore, these animals are expected to adjust their body physiology (either by short-term acclimation through functional changes or by long-term evolutionary shifts in their phenotype through natural selection) as well as to alter their behaviour patterns in order to survive (Chown *et al.*, 2010; Qiao *et al.*, 2011; Renaudeau *et al.*, 2012).

Extended periods of high temperature and drought that extend for more than seven months with erratic precipitation and presence of low-quality forages clearly describe the bioclimatic conditions of any arid environment such as the Arabian Peninsula. Camels, goats, and gazelles are the most suitable desert animals that live in such habitats. Although thermophysiological mechanisms that enabled camels and goats to cope with this harsh bioclimate are well documented (Alamer, 2006; Abdoun *et al.*, 2012; Samara *et al.*, 2012), comparably little is known about the ecophysiology of gazelles. These animals, as homeotherms, demand to maintain a state of body thermal homeokinesis within a specific range of ambient temperatures; the thermo-neutral zone (Robertshaw, 1981). Exposure of gazelles to supra-neutral conditions is therefore expected to force these animals to reduce their water expenditure and thermogenic mechanisms as well as to recruit their water conservation and thermolytic mechanisms (Al-Johany *et al.*, 1998; Williams *et al.*, 2001; Ostrowski *et al.*, 2003, 2006; Hetem *et al.*, 2012). Subsequently, noticeable changes would thereby be observed in their body temperature and biophysiological responses. Failure to do so, however, can result in severe body hyperthermia,

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denaturation of body protein, loss of organ functions, and eventually the death of animals (Renaudeau *et al.*, 2012).

The present study was designed with the aim to determine the effect of seasonal variation on some thermophysiological responses of two gazelle species (Idmi, *Gazella gazelles*; and Rhim, *Gazella leptoceros*) normally inhabiting the Arabian Peninsula. A study dealing with this aspect may very well show some of their remarkable adaptive thermoregulatory mechanisms applied to endure such harsh bioclimate.

MATERIALS AND METHODS

Animals and management

Twenty four healthy gazelles of different genders belonging to Idmi (*Gazella gazelles*) and Rhim (*Gazella leptoceros*) species with an average live body weight of 15 - 20 kg and age of 3 - 4 years were used in this study during both summer and winter seasons. In each season, the study was conducted for 3 months comprising of preliminary and experimental periods. The preliminary period lasted for three weeks and served as an acclimation period during which animals were allowed to adapt to study conditions. On the other hand, climatic data, thermophysiological measurements, and blood samples were collected weekly during the experimental period. Throughout the study all animals were kept under semi-free environment similar to their natural habitat at the King Khalid Wildlife Research Centre, Riyadh, Saudi Arabia. They were fed on alfalfa hay *ad libitum*, and had free access to clean tap water. We did not observe any apparent discomfort during handling the animals. Study design was approved by the Faculty Research Ethics Committee at the King Saud University.

Thermophysiological measurements

Ambient temperature (T_a) and relative humidity (RH) were obtained from the Presidency of Metrology and Environment (PME), Riyadh, Saudi Arabia. To estimate the environmental severity on the animals, both collected T_a and RH data were used to calculate temperature-humidity index (THI) using the following formula adopted from Kelly and Bond (1971): [$THI = T_a - (0.55 - 0.55 \times RH) \times (T_a - 58)$], where T_a is the ambient temperature in ^oF, and RH is the relative humidity as a fraction of the unit. On the other hand, rectal (T_r) and skin (T_{sk}) temperatures were measured at middle of the day (12:00-13:00). A calibrated digital rectal thermometer measure to the nearest 0.10 ºC was used to determine T_r, while an infrared thermometer (Traceable Mini IR™ Thermometer, Friendswood, Texas, USA) was used to measure T_{sk} at 4 shaved regions. According to Richards (1973), the following formulas: [T_r-T_{sk}], [T_{sk}-T_a], and [T_r-T_a] were employed thereafter to estimate the internal (physiological), the external (physical), and the total thermal gradients, respectively.

Blood samples (approximately 10 ml) were collected weekly from all animals via jugular venipuncture into EDTA tubes (for hematological analysis) and plain tubes (for serological analysis). Collected samples were placed inside an ice box and immediately transferred to the laboratory for analysis. Within 1 h after collection, a complete heamogram of whole blood was performed using the coulter counter (Coulter Electronics, Luton, Bedfordshire, UK), while sera were separated by centrifugation of plain tubes at 1500 g for 10 min, and then stored at -20^{o}C until analysis. The colorimetric method was applied to spectrophotometrically quantify serum total protein (g/dL), albumin (g/dL), glucose (mg/dL) and haptoglobin (mg/dL) concentrations using commercial kits (United Diagnostics Industry, Dammam, KSA). Serum globulin (g/dL) concentration was calculated as the difference between measured total protein and albumin concentrations.

Data analysis

The obtained data were analyzed as a full factorial design in three factors (season, species, and gender) each at two levels using the PROC FACTEX procedure of statistical analysis system (SAS Inst., Inc., Cary, NC). Data were subjected to ANOVA using $\alpha = 0.05$. Means showing significant differences in ANOVA were tested using the PDIFF option. The probability value denoting statistical significance was $P<0.05$. Unless otherwise indicated, means and their pooled SEM are presented.

RESULTS

Bioclimatic data

The obtained data showed that gazelles were exposed to a higher (P<0.05) T_a and a lower (P <0.05) RH during summer season compared to winter season (Table I). To incorporate the effects of both T_a and RH, THI is commonly used to quantify the degree of heat stress on animals (Bohmanova *et al.*, 2007; Vitali *et al.*, 2009). In the present study, the THI pattern mirrored the T_a pattern. Calculated average THI values prevailed during the winter season ranged from 55 – 63 with an average of 58.57±1.09, while higher (P<0.05) THI values were observed during the summer season that ranged from 76 - 80 with an average of 77.86±0.39 (Table I).

Table I.- Bioclimatic measurements throughout the study.

Parameters[1]	Season		P-value
	Winter	Summer	
T_a (°C)			
Mean ± SE	14.98±0.99	35.41 ± 0.54	<0.0001
Range	12.10–18.70	33.30 – 38.20	
RH (%)			
Mean	44.67±5.04	13.38 ± 0.98	<0.0001
Range	29.00–64.10	10.10 – 19.00	
THI			
Mean	58.57±1.09	77.86± 0.39	<0.0001
Range	54.60–62.70	75.80 – 80.10	

[1]RH, relative humidity; T_a, ambient temperature; THI, temperature humidity index

Thermophysiological adjustments

No differences (P>0.05) were generally observed in the measured parameters as influenced by the species (Idmi vs. Rhim) and gender (Male vs. female) factors; thus, data were averaged and jointly analyzed and presented. Exposure of gazelles to hot summer conditions resulted in pronounced (P<0.05) elevations of their overall means of T_r by 1.20±0.20ºC and T_{sk} by 10.80±0.60ºC compared to the winter season (Fig. 1). Additionally, body thermal gradients had exhibited noticeable (P<0.05) seasonal alterations. Under the summer condition, gazelles showed marked reductions (P<0.05) in internal [T_r–T_{sk}], external [T_{sk}–T_a], as well as total [T_r–T_a] thermal gradients compared to the winter condition (Fig. 2).

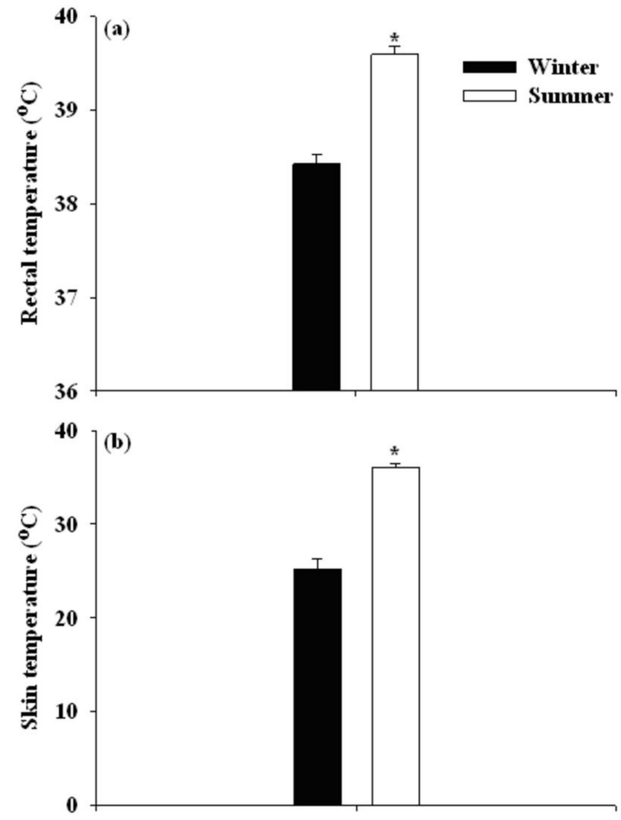

Fig. 1. Means (± SE) of rectal (a) and skin (b) temperatures (ºC) of gazelles during winter and summer seasons. Bars bearing an asterisk are significantly different at P <0.05.

As presented in Table II, exposure of gazelles to hot environmental conditions during the summer season elicited clear (P<0.05) reductions in red blood cells count (RBCs), mean corpuscular haemoglobin content (MCH), haemoglobin concentration (Hb), and mean corpuscular haemoglobin concentration (MCHC) compared to the winter season. Meanwhile, mean corpuscular volume (MCV), total leucocytes (WBCs) count, and heterophil/lymphocyte (H/L) ratio were all exhibited increases (P<0.05) during the summer season compared to the winter season. However, no seasonal influence (P>0.05) was observed on the packed cell volume (Table II).

Table II.- Changes of blood haematological indices of gazelles during winter and summer seasons.

Parameters[1]	Season Winter	Season Summer	SEM	*P* value
Haematology				
RBCs ($10^6/\mu L$)	11.89	10.71	0.09	<0.0001
WBCs ($10^3/\mu L$)	5.18	7.77	0.29	<0.0001
PCV (%)	48.99	48.33	0.37	0.225
Hb (g/dL)	15.13	12.53	0.33	<0.0001
Haematometric				
MCV (fL)	41.45	45.63	0.43	<0.0001
MCH (pg)	12.76	11.79	0.28	0.022
MCHC (%)	30.87	26.10	0.73	<0.0001
N/L ratio	2.76	3.68	0.14	<0.0001

[1]Hb, haemoglobin; MCH: mean corpuscular haemoglobin; MCHC, mean corpuscular haemoglobin concentration; MCV, mean corpuscular volume; N/L, Neutrophil/lymphocyte ratio; PCV, packed cell volume; RBCs, red blood cells count; WBCs, white blood cells count;

On the other hand, overall means of serum albumin, glucose and haptoglobin concentrations showed (P>0.05) higher values during the summer season over the winter season (Table III), while serum total protein and globulin concentrations were reduced (P<0.05) during the summer season compared to the winter season (Table III).

Table III.- Changes of blood biochemical parameters of gazelles during winter and summer seasons.

Parameters	Season Winter	Season Summer	SEM	*P* value
Total protein (g/dL)	6.93	6.04	0.12	<0.0001
Albumin (g/dL)	4.49	5.04	0.06	<0.0001
Globulin (g/dL)	2.44	1.00	0.13	<0.0001
Glucose (mg/dL)	123.71	157.85	9.56	0.015
Haptoglobin (mg/dL)	0.94	1.03	0.01	<0.0001

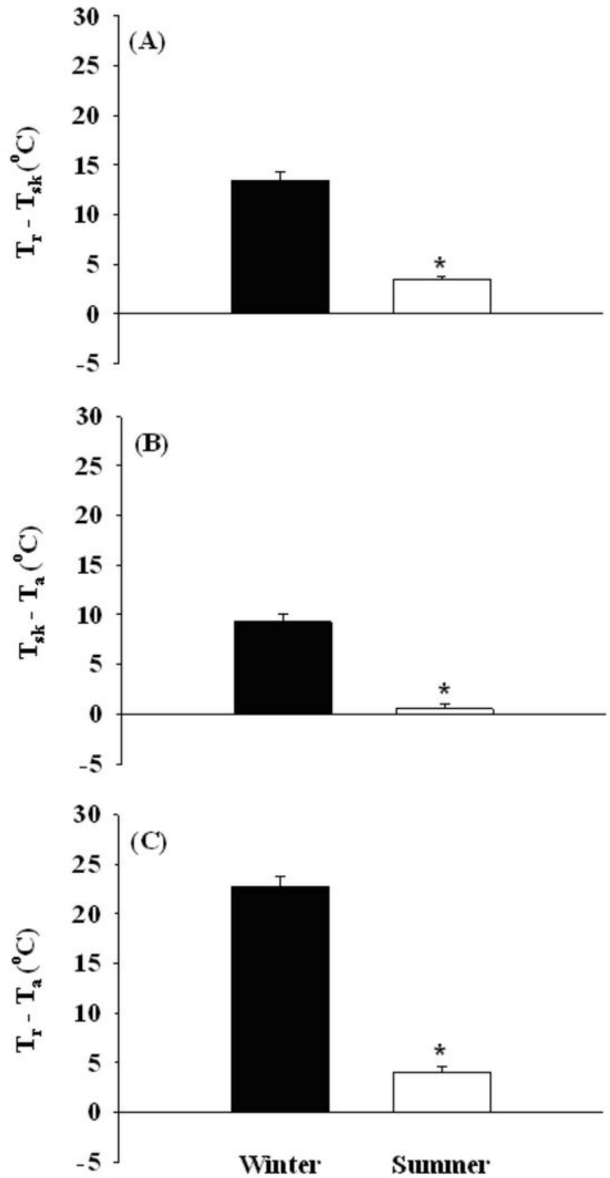

Fig. 2. Means (± SE) of body thermal gradients (ºC) of gazelles during winter and summer seasons. A: rectal-to-skin thermal gradient (T_r-T_{sk}); B: skin-to-ambient thermal gradient (T_s-T_a); and C: total body thermal gradient (T_r-T_a). Bars bearing an asterisk are significantly different at P <0.05.

DISCUSSION

The bioclimate of Arabian Peninsula during the summer season is characterized by extended periods of high T_a (where it usually reaches 45^{o}C and soil surface temperatures regularly exceed 60^{o}C) with erratic precipitation and brief eruption of forages. In fact, simulation of the biometeorological changes in Saudi Arabia predict that daily T_a will increase by 3-5^{o}C while rainfall pattern will remains the same by the end of the 21st century (Chowdhury and Al-Zahrani, 2013), which will further accentuate heat stress-related problems in animals. Because of the recognition that most gazelles inhabiting Saudi Arabia are not migrating, these animals are therefore particularly threatened unless they applies remarkable adaptive thermoregulatory mechanisms in order to survive.

The present study examined the seasonal variations on some thermophysiological responses of two gazelle species (Idmi, *Gazella gazelles*; and Rhim, *Gazella leptoceros*) normally inhabiting the Arabian Peninsula. As expected, the results of the present study indicated that gazelles were under heat stress during the summer season, based on the findings that calculated average THI values prevailed during summer season surpass the THI threshold above which most animals enter a state of severe heat stress (Silanikove, 2000; Marai *et al.*, 2007). Under such supra-neutral conditions, gazelles are expected to gain heat from the environment and subsequently may challenge their survivability. According to Richards (1973), the internal [T_r–T_{sk}] and external [T_{sk}–T_a] body thermal gradients under TNZ conditions drive the heat flux from the body to the environment, while under heat stress conditions heat flows from the external environment to the animal body. In the present study, it was clearly evident that body thermal gradients of gazelles exhibited noticeable reductions during the summer season compared to the winter season, which attesting that gazelles tried to constrict the thermal gradient between their bodies and the surrounding environment in order to regulate their body temperatures. This came in agreement with our previous reports on camels and goats (Abdoun *et al.*, 2012; Samara *et al.*, 2012; Al-Haidary *et al.*, 2013). These observations are attributed to the noticeable elevation of gazelles T_{sk} during the summer season, which in turn is most likely be due to the heat-stress induced vasodilatation of skin capillary bed with the consequent shifting of blood flow to the skin surface (McManus *et al.*, 2009; Schutz *et al.*, 2011). This adjustment gradually impairs the dissipation of body heat by the sensible means and shifts it to the insensible evaporative avenue which in turn may enhance body water loss (Spiers, 2012). Heterothermy was proposed to be a key thermophysiological adaptation for some ungulate living in arid bioclimate, where body heat is stored during the hot diurnal time, with a consequent rise in body temperature, to reduce insensible evaporative heat loss. Then, during the cold nocturnal time, the stored heat can be dissipated using sensible means allowing body temperature to fall (Williams *et al.*, 2001; Fuller *et al.*, 2004). Exposure of gazelles to hot summer conditions in the present study resulted in pronounced elevations of their T_r. In fact, heterothermal characteristic of body heat storage and the corresponding water conservation were estimated for gazelles during both seasons according to Ostrowski *et al.* (2003). Notably, the use of heterothermy by gazelles resulted in storage of 109.65 and 31.92 kJ/day/animal in summer and winter, respectively. Dissipation of these amounts of heat by the insensible evaporative avenue would require 45.61 and 13.82 ml H_2O/day/animal in summer and winter, respectively. This shows that elevation of gazelles T_r during summer compared to winter season is an important physiological adaptation. Notably, these findings are consistent with previous reports on gazelle as well as other ungulate such as oryx and eland inhabiting the same bioclimatic conditions (Williams *et al.*, 2001; Ostrowski *et al.*, 2003, 2006; Hetem *et al.*, 2012). On the contrary in other domestic animals, seasonal high T_a are associated with high T_r, which considered as an indicator of disturbance in their homoeothermic status simply because these animals ineffectively enhanced their body heat loss (Herz and Steinhauf, 1978; Joshi and Tripathy, 1991; Wenz *et al.*, 2011; Ganaie *et al.*, 2013). Therefore, this bears substantial evidence that heterothermy in gazelles during summer season may served as an ideal ecophysiological adjustment to minimize their body water losses.

The observed elevated body temperatures as well as reduced body thermal gradients under summer conditions were associated with noticeable alterations in the blood profile. In the present study, the reduced levels of erythrocyte indices -with the exception of MCV- observed during the summer season may associate with the decreased oxygen demand to meet the reduced energy requirements during hot conditions (Hellgren *et al.*, 1989), which may suggest another adaptive mechanism applied by gazelles during heat acclimation (Patterson *et al.*, 2004). Additionally, exposure of gazelles to hot summer conditions resulted in serum hyperalbuminemia indicating an adjustable mechanism to maintain blood volume by inducing water movement into the vascular system (More *et al.*, 1980; Alamer, 2006). This finding is quite relevant since albumin is the major extracellular source of thiols. Thereby, inducing hyperalbuminemia permitted the utilization of albumin as an antioxidant to scavenge reactive oxygen species which may be produced from the exposure to heat stress during summer season (Halliwel, 1998; Ganaie *et al.*, 2013). Moreover, serum hyperglycaemia was also observed in gazelles kept under summer conditions, which may collectively relate to stress-induced activation of corticosteroid secretion and the consequent stimulation of liver gluconeogenesis and glycogenolysis pathways as well as inhibition of cellular glucose uptake and utilization (Duncan *et al.*, 1994; Marai *et al.*, 2007). A similar trend was also observed in previous studies on camels (Al-Haidary, 2005) and goats (El-Nouty *et al.*, 1990; Samara *et al.*, 2012). Furthermore, results revealed that both H/L ratio and haptoglobin concentration, as direct indicators of stress (Davis *et al.*, 2008; Adenkola *et al.*, 2009), had exhibited elevations during the summer season compared to the winter season, which implies that gazelles were actually under heat stress conditions during the summer season.

CONCLUSIONS

The present study shed some basic lights upon seasonal variations of some thermophysiological adjustments of gazelle normally inhabiting the Arabian Peninsula. These ungulates were proved to be thermally adapted and can endure such harsh bioclimate. This conclusion was demonstrated by the findings that gazelles, under summer conditions, were able to 1) adjust their body temperatures, 2) express numerous water economy mechanisms, and 3) exhibit noticeable adaptive changes in their blood profile, which collectively may enabled these animals to tolerate their natural environment. Research dealing with this aspect will improve our understanding of gazelle's welfare under such harsh bioclimatic conditions.

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