Vol 17 No 2, p 245-256

SOME ASPECTS OF THERMO-REGULATION IN WATER DEPRIVED CAMELS UNDER THE SEMI-ARID CONDITIONS OF THE NORTH-WESTERN COASTAL DESERT IN EGYPT

Wissam T. El-Zeiny
Animal Physiology Department, Animal and Poultry Research Division
Desert Research Centre, Al-Matareya, Cairo, Egypt

ABSTRACT

In this study, the effect of heat stress resulting from the combined effect of water deprivation, the housing environment and season of the year on the changes of rectal temperature (RT) and skin temperature (ST) and their amplitude (differences between morning and afternoon values), as well as gradients between core and surface temperatures and the ambient temperature were investigated in eight non-pregnant and non lactating female dromedary camels fed at the maintenance level. Half the animals were watered daily whereas the other half was intermittently watered, once every 7 days. Moreover, half the animals were kept outdoors and not sheltered whereas the other half was housed indoors. The experimental treatments were repeated three times between April and August to represent spring, early summer and late summer seasons. Climatic (ambient temperature; Ta), relative humidity (RH%) and temperature humidity index (THI) and animal data (RT and ST) were recorded twice daily at 7:00 am and 2:00 pm for seven consecutive days representing a complete water deprivation cycle.

It was evident that the housing environment in the morning was a significant source of variation affecting both RT and ST and their amplitude, as well as core, skin and ambient temperature gradients. Water deprivation also represented another significant source of variation that affected RT, both in the morning and in the afternoon. However, ST was significantly affected by season only in the morning. All the above parameters were significantly affected by days of the water deprivation cycle.

It was noticeable that the RT of the water deprived camels kept outdoors was consistently lower than their control mates. Largest average RT amplitude was observed in the water deprived camels housed outdoors which was 4 folds of their water deprived mates housed indoors. On the other hand, ST behaved differently in such a way that in the water deprived camels it was frequently higher than in the daily watered controls. Evident was the capacity of camels to maintain constant, the overall rectal-air temperature gradient through varying rectal-skin and skin-air gradients, and invariably in opposite direction. This was aided by the fact that Ta were constantly lower than the RT and ST. Hence, the temperature of the skin and its regulation determines to a large extent the core temperature of camels.

Key words: Camels, dehydration, season, shelter, thermoregulation

Ruminants grazing arid and semi-arid rangelands are frequently exposed to different environmental stresses including, among other stress factors, the adverse climatic conditions and the shortage in quantity and quality of water and feed. Many studies Schmidt-Nielsen *et al* (1957) Ben Goumi *et al* (2003), Zine-Filali and Show (2004) and Achaaban *et al* (2000) were carried out to investigate adaptive responses under these conditions but stress factors were considered separately or in limited combinations, mainly the climate, water deprivation and water salinity (Farid, 1989), and without allowing for gradual and long-term adaptation characterising semi-arid and arid ecosystems (Farid, 1985). Different direct and indirect environmental stressors are known to interact and hence, adaptive responses might be modified.

A research project has been initiated to study physiological and nutritional adaptive responses in dromedary camels to heat stress, water deprivation and protein deficiency. The present study deals with observations on rectal and skin temperature changes in response to the stress of direct exposure to day and night climatic elements, intermittent water intake and protein deficiency imposed concomitantly on the camel during different seasons.

SEND REPRINT REQUEST TO WISSAM T. EL-ZEINY email: wissamtaha49@yahoo.com

Materials and Methods

Animals and management

This study was conducted at Maryout Experimental Station near Alexandria, 32° latitude affiliated to the Desert Research Centre in Cairo. Eight adults, non-pregnant and non- lactating female dromedary camels were used in this experiment. Their live body weight average was 502.2 kg. Half the animals were housed individually in floor pens inside a barn, whereas the other half was kept outside not sheltered from direct solar radiation, wind and other natural environmental elements.

In addition to housing effects, the animals were subjected to two watering treatments, daily vs. intermittent watering once every 7 days. The experiment was repeated on the same animals three times between April and August to represent spring, early summer and late summer seasons. Each period lasted six weeks, a 4-week preliminary period, one week for a digestion and nitrogen balance trial and one week for the studies of animal adaptation, blood chemistry and kidney function. Spring period (March 18-May 7), early summer period (May 08-June 26) and late summer period (June-August); records were taken during the last week of each period. However, only thermo-regulation and animal adaptation reported in the present work.

Animals were weighed periodically every two weeks before feeding and watering. Feeds were offered in the morning as per treatments detailed below. Refusals, if any, were collected in the following morning, and weighed and sampled, before the new feeds were offered. Water was made available free choice for one hour at feeding time, as per treatments, and intake was recorded.

Experimental treatments

Animals were subjected to two water treatments. Half the animals were watered daily whereas the other half was intermittently watered, once every 7 days. More severe water deprivation was not intended in fear of the combined effect of heat stress and the shortage of water on animal welfare especially those that were not sheltered.

Animals were fed at the maintenance level as per requirements determined locally, being 2.15g DCP and 26.8g TDN per kg 0.73 (Farid *et al*, 1990 and Farid, 1995). The ingredients used to formulate rations included a commercial concentrate mixture, corn grains and rice straw as the roughage. All animals received 100% of their estimated maintenance energy requirements.

Experimental procedures

The following climatic elements were measured using standard equipment: 24- hour minimum (Tmin) and maximum (Tmax) temperatures; and dry-bulb ambient temperature (Ta) and relative humidity (RH%) at 7:00 AM and 2:00 PM Egypt standard time (EST= GMT+2). The temperature-humidity index (THI) was calculated according to the following equation of Mader *et al* (2002):

$$THI= (0.8 \times Ta) + [(RH/100) \times (Ta-14.3)] + 46.3$$

where Ta is ambient temperature in °C, and RH is relative humidity %.

THI categories (Mader *et al*, 2002) available at present were developed for high yielding dairy cattle. These were no stress (up to 72), mild stress (73-79), stress (80-89), severe stress (90-99) and fatal (100 and above). These categories may not be directly applicable to other species, especially those adapted to desert conditions, such as dromedary camels.

Table 1 summarises the main climatic elements observed during the three experimental periods. These were typical of conditions prevailing in desert areas close to seashores. However, deep in the desert, the environmental conditions were characterised by extremely low temperatures before sunrise, much higher temperatures in the mid-afternoon and much lower relative humidity.

Rectal (RT) and skin temperatures (ST) were also measured at 7:00 am and 2:00 pm. A thermocouple thermometer was used (Yellow Springs Instruments Co., Inc., Yellow Springs, Idaho, U.S.A.). Skin temperatures were measured from a shaved area in the mid-side region. Both climatic and animal data were recorded for a full water deprivation cycle (seven consecutive days).

Statistical procedures

The analysis of variance was performed using the GLM model of SAS statistical software (SAS, 1998). F-test was carried out for the four main effects and two-way interactions. Higher interactions were pooled together to represent the error term. The main fixed effects were housing environment (H), watering treatment (W), season or periods (P) and days (D). The ambient temperature (Ta), relative humidity (RH%), and temperature humidity index (THI) were included in the model as covariates, animals were included in the model as random effect.

Table 1. Average climatic data during the three experimental periods and for measurements taken at 7:00 am and 2:00 pm.

Housing	Season	Tmin	Tmax	Ambient (Ta)		Humidity %		THI[2]	
		(°C)	(°C)	am	pm	am	pm	am	pm
Indoors	SP	16.79	24.21	19.79	23.21	72.03	58.57	66.56	69.89
	ES	23.29	31.43	25.57	30.64	69.21	45.84	74.23	78.36
	LS	24.14	31.34	25.36	30.71	78.17	59.83	74.84	80.16
Outdoors	Sp	16.64	28.00	20.57	23.93	70.90	53.72	67.40	70.41
	ES	24.43	35.02	25.57	33.71	69.35	36.21	74.24	81.32
	LS	24.07	36.47	26.07	34.36	75.15	43.94	75.51	83.01

1. SP = spring period, (1-7 May), ES = early summer period (20-26 June) and LS = late summer period (4 –10 Aug).
2. THI = temperature-humidity index (Mader *et al*, 2002).

Table 2. Regression of ambient temperature (Ta), relative humidity (RH%) and temperature humidity index (THI) on rectal temperature (RT) and Skin temperature (ST) in the morning (am) and in afternoon (pm) during the water deprivation cycle (seven days).

Factor	Rectal temperature (RT)		Skin temperature (ST)	
	am	pm	am	pm
Ambient temperature (Ta)	0.001±0.023$^{N.S}$	0.10±0.142$^{N.S}$	0.05±0.031$^{N.S}$	0.30±0.185$^{N.S}$
Relative humidity (RH%)	-0.04±0.025$^{N.S}$	0.06±0.078$^{N.S}$	-0.05±0.033$^{N.S}$	0.02±0.101$^{N.S}$
Temperature humidity index (THI)	0.07±0.045$^{N.S}$	-0.01±0.011$^{N.S}$	0.06±0.058$^{N.S}$	-0.01±0.015$^{N.S}$

$^{N.S}$ ($P>0.05$)

The morning and afternoon data were statistically analysed separately.

Results

Observed T-min and T-max were lower in spring than those in early and late summer (Table 1). Minimum temperature were practically similar indoors and outdoor, but the maximum were 4-5°C higher to outdoors. The same applies to am and pm ambient temperatures, measured at 7:00 am and 2:00 pm, except that the am temperatures were greater than the minimum and the pm temperatures were less than the maximum. As anticipated, RH% was higher in the cool morning than that in the afternoon, and higher at indoors than outdoors. It was particularly low outdoors in early summer during pm times.

Considering the THI values in Table (1), it could be suggested that animals were not under thermal stress during the spring period. During the summer periods, on the other hand, animals may have been under mild stress in the morning, but were apparently stressed in the afternoon, and with no difference between those kept indoors (high humidity) or outdoors (high ambient temperature).

Rectal temperature (RT)

The climatic variables (AT,RH% and THI) were found to be non significant sources of variation that affected RT and ST as illustrated in (Table 2). However, RT and ST may have been affected by other climatic factors such as solar radiation. This was aided by the fact that Ta were constantly lower than the RT and ST throughout the experiment.

In general, morning RT was significantly ($P<0.05$) lower in the water deprived camels kept outdoors than indoors as compared to their control mates (Table 3). However, the effect of water deprivation was significantly ($P<0.05$) evident only in camels housed outdoors. The lowest observed average morning of RT was in the water deprived camels housed outdoors (Table 3). A similar trend was observed in the afternoon.

The morning RT of daily watered and water deprived camels were lowest on the first two days of the 7-day cycle, but only in those housed outdoors. The same trend was observed in the afternoon (Fig 1).

In spring, RT tended to increase as water deprivation progressed, and the controls had lower RT than their water deprived mates ($P>0.05$). In early and late summer, morning RT was practically constant or tended to decrease slightly (Table 3). It was also interesting to note that the water deprived camels had lower RT in summer than the controls. The afternoon RT, on the other hand, was less ($P>0.05$) in late than in early summer (Table 3).

The pattern of (RT) changes of the water deprived camels and controls through the seven days both am and pm, are presented in Fig 2. In general, the lowest (RT) was on the first day of the cycle (the

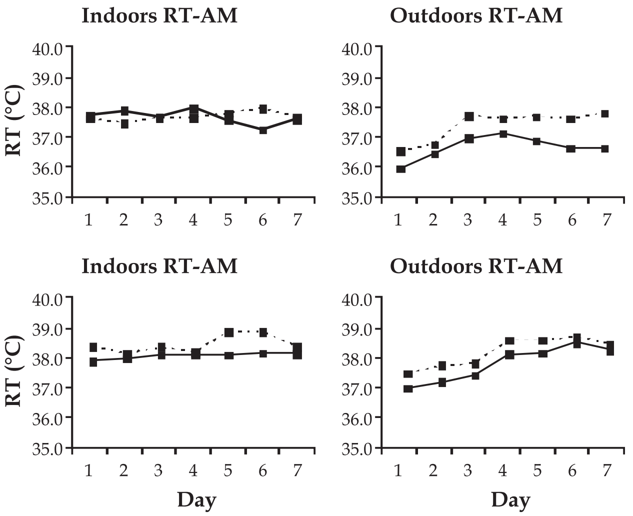

Fig 1. Rectal temperature (RT) of watered (dashed line) and water deprived (solid line) camels indoors and outdoors, in the morning (AM) and afternoon (PM). During the water deprivation cycle (7 days).

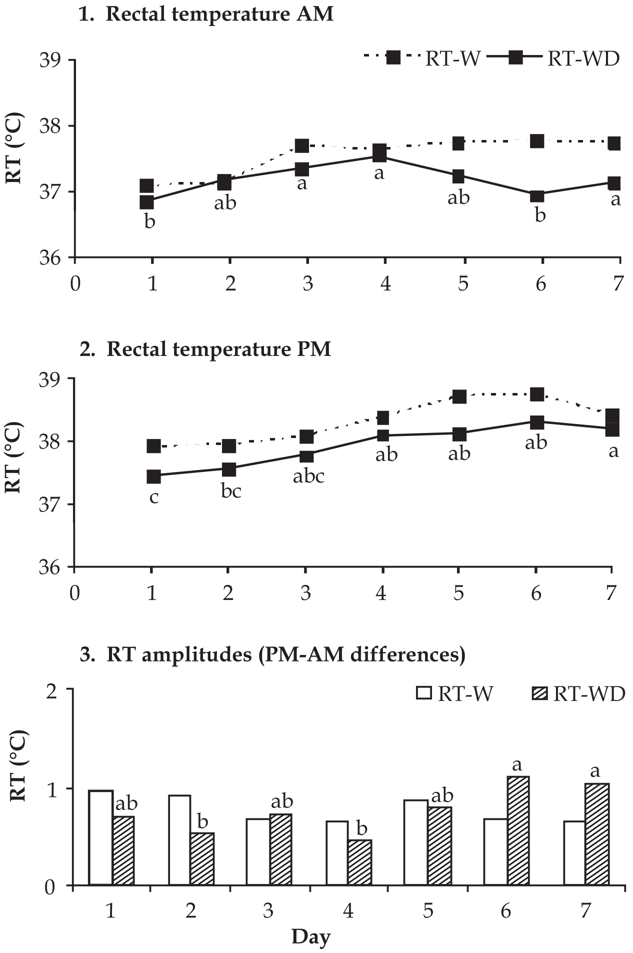

Fig 2. Rectal temperatures (RT) AM and PM, of daily watered (W) and water deprived (W.D) camels and their PM-AM amplitudes during the water deprivation cycle (7 days). a, b, c different letters are significantly different at ($P<0.05$) level.

watering day), and RT of the water deprived camels was lower than the controls. It was higher on the seventh day than the first. After the third day of water deprivation the morning RT of water deprived animals showed an opposite trend to that observed in the afternoon as it decreased after the fourth day. It increased significantly on the fourth day, but was still lower than that of the controls; it then decreased till the end of the cycle. In the afternoon, it was still increasing till the end of the cycle.

Rectal temperature amplitude (pm-am difference)

On average, morning and afternoon RT differences were similar in control and water deprived animals (0.78°C and 0.77°C, respectively, Table 3). However, it was greater at outdoors than that at indoors ($P<0.05$). Camels housed 0.5°C. Largest average RT difference was observed in water deprived camels housed outdoors, 1.2°C (Table 3), which was 4 folds of the water deprived animals kept indoors. Therefore, the WxH interaction was significant ($P<0.05$). On the other hand, RT difference was similar in spring and early summer but lower in late summer (0.88°C and 0.85°C *vs*, 0.58°C) but these differences were not significant ($P>0.05$).

During the water deprivation cycle, difference decreased progressively in controls, whereas it increased in the water deprived animals (Fig 2).

Skin temperature (ST)

The ST of camels was found to be significantly ($P<0.05$) affected by the housing environment and time of the year only in the morning (Table 4). In general, morning skin temperature was higher

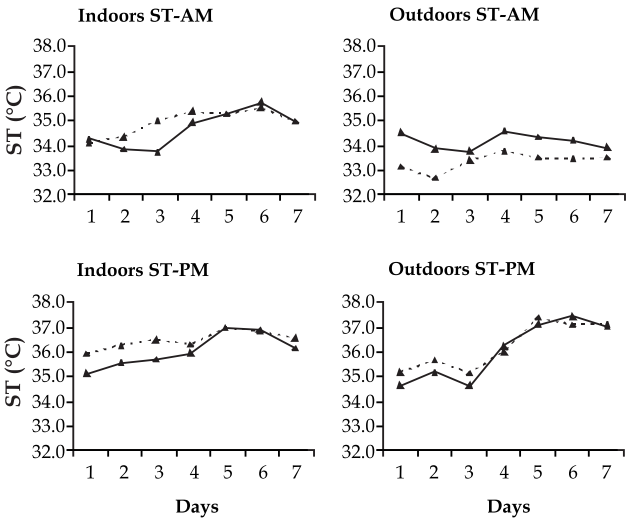

Fig 3. Skin temperatures (ST) AM and PM, of daily watered (dashed line) and water deprived (solid line) camels during the water deprivation cycle (7 days).

Table 3. Rectal temperatures (RT, °C) in the morning (7:00 am) and in the afternoon (2:00 pm) and their amplitude (pm – am) values in daily watered (W) and water-deprived (W.D.) camels housed indoors or outdoors and during different seasons (L.S. Means ± SEM).

Item	Water	Housing		Season			Overall means (water)
		indoors	outdoors	spring	E-summer	L-summer	
RT, am	W	37.7^{a}±0.15	37.4^{a}±0.16	37.4^{a}±0.27	37.8^{a}±0.21	37.4^{a}±0.23	37.5^{a}±0.08
	W.D.	37.7^{a}±0.12	36.7^{b}±0.15	37.8^{a}±0.30	36.6^{b}±0.19	37.1^{a}±0.30	37.2^{b}±0.09
	Overall Means	37.7^{a}±0.08	37.0^{b}±0.09	37.6^{a}±0.26	37.2^{a}±0.14	37.3^{a}±0.22	
RT, pm	W	38.5^{a}±0.19	38.2^{a}±0.20	39.00^{a}±0.74	38.3^{a}±0.35	37.7^{a}±0.45	38.3^{a}±0.07
	W.D.	38.1^{ab}±0.17	37.8^{b}±0.20	39.2^{a}±0.73	37.5^{a}±0.34	37.1^{a}±0.47	37.9^{b}±0.08
	Overall Means	38.3^{a}±0.15	38.00^{a}±0.16	39.1^{a}±0.73	37.9^{a}±0.32	37.4^{a}±0.44	
Amplitude	W	0.7^{b}±0.14	0.9^{ab}±0.15	0.9^{a}±0.16	0.7^{a}±0.18	0.7^{a}±0.14	0.78^{a}±0.08
	W.D.	0.3^{b}±0.12	1.2^{a}±0.14	0.8^{a}±0.18	1.0^{a}±0.14	0.5^{a}±0.21	0.77^{a}±0.08
	Overall Means	0.5^{b}±0.08	1.0^{a}±0.09	0.88^{a}±0.12	0.85^{a}±0.10	0.58^{a}±0.11	

Means with different superscripts in each subcell differ significantly at (P<0.05) level

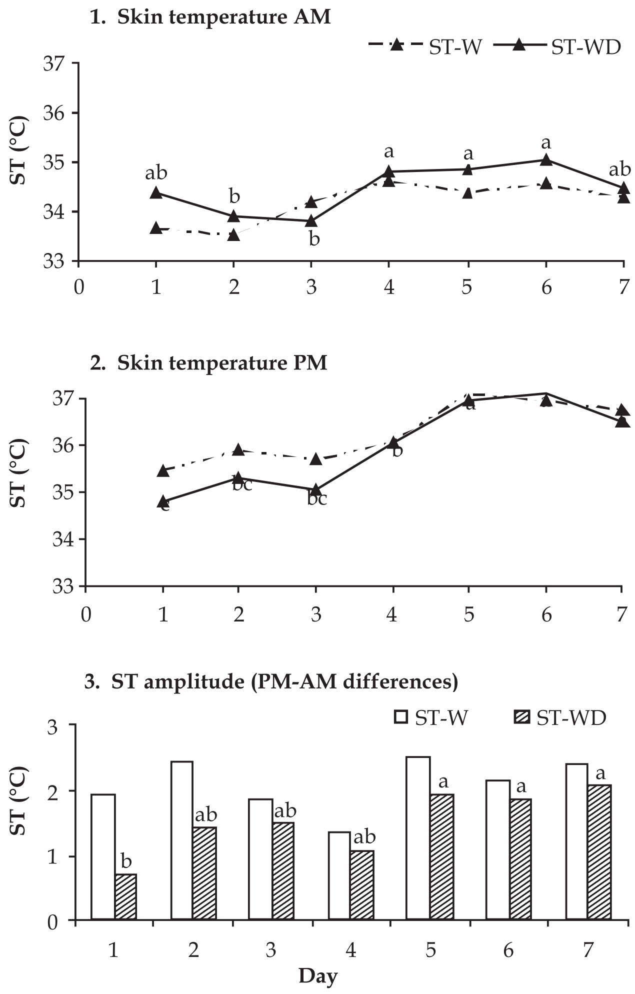

Fig 4. Skin temperatures (ST) AM and PM, of daily watered (W) and water deprived (W.D) camels and their PM-AM amplitudes during the water deprivation cycle (7 days).

a, b, c different letters are significantly different at (P<0.05) level.

indoors than outdoors, 34.8 *vs.* 33.8°C, respectively. However, the effect of water deprivation was significant (P<0.05) only in water deprived camels housed outdoors, and in the morning only (Table 4). The morning ST of water deprived camels at outdoors was higher (about 0.8°C) than their control mates (Table 4, Fig 3). This was the opposite trend to that observed for morning RT in the controls. On the other hand, there was no significant difference between the ST of control and water deprived animals kept indoors. Thus, WxH interaction was significant (P<0.05) in the morning only (Table 4).

In the afternoon, these changes were not significant (P>0.05) as shown in Table 4. On the other hand, morning ST of camels was significantly (P<0.05) higher in early and late summer than in spring. The same trend was observed in the afternoon but differences were not significant (P>0.05).

In spring the water deprived camels had significantly (P<0.05) lower ST than the controls, while in early and late summer the opposite was observed. The ST of water deprived camels were significantly (P<0.05) higher only in the morning (Table 4).

The pattern of change of ST of the water deprived camels throughout the 7-day water deprivation cycle is presented in Figs 3 and 4. In the morning, ST of water deprived camels was higher than the controls on watering day, then it decreased (P>0.05) till the third day and thereafter increased (P<0.05) progressively afterwards till the end of the cycle. Again, this trend was the opposite of that observed in the RT.

Table 4. Skin temperatures (ST, °C) in the morning (7:00 am) and in the afternoon (2:00 pm) and their amplitude (pm – am) values in daily watered (W) and water-deprived (W.D.) camels housed indoors or outdoors and during different seasons (L.S. Means±SEM).

Item	Water	Housing		Season			Overall means (water)
		indoors	outdoors	spring	E-summer	L-summer	
ST, am	W	$35.0^{a}\pm0.20$	$33.4^{c}\pm0.21$	$33.2^{c}\pm0.36$	$34.3^{b}\pm0.29$	$35.0^{b}\pm0.31$	$34.2^{a}\pm0.10$
	W.D.	$34.7^{a}\pm0.16$	$34.2^{b}\pm0.20$	$32.5^{d}\pm0.39$	$35.0^{b}\pm0.25$	$35.8^{a}\pm0.39$	$34.5^{a}\pm0.12$
	Overall Means	$34.8^{a}\pm0.10$	$33.8^{b}\pm0.12$	$32.8^{c}\pm0.34$	$34.7^{b}\pm0.19$	$35.4^{a}\pm0.29$	
ST, pm	W	$36.4^{a}\pm0.25$	$36.2^{a}\pm0.26$	$35.9^{a}\pm1.00$	$36.7^{a}\pm0.46$	$36.2^{a}\pm0.58$	$36.3^{a}\pm0.10$
	W.D.	$35.9^{a}\pm0.22$	$36.0\ ^{b}\pm0.25$	$35.5^{a}\pm0.95$	$36.3^{a}\pm0.44$	$36.1^{a}\pm0.61$	$35.9^{a}\pm0.11$
	Overall Means	$36.2^{a}\pm0.20$	$36.05^{a}\pm0.21$	$35.7^{a}\pm0.94$	$36.5^{a}\pm0.42$	$36.1^{a}\pm0.57$	
Amplitude	W	$1.37\ ^{bc}\pm0.24$	$2.9^{a}\pm0.26$	$1.7^{bc}\pm0.27$	$2.7^{a}\pm0.31$	$1.8^{bc}\pm0.25$	$2.1^{a}\pm0.13$
	W.D.	$1.0^{c}\pm0.21$	$2.0^{b}\pm0.25$	$1.9^{bc}\pm0.31$	$1.7^{b}\pm0.25$	$0.9^{c}\pm0.36$	$1.5^{b}\pm0.14$
	Overall Means	$1.1^{b}\pm0.14$	$2.4^{a}\pm0.16$	$1.8^{ab}\pm0.21$	$2.2^{b}\pm0.17$	$1.4^{b}\pm0.19$	

Means with different superscripts in each subcell differ significantly at ($P<0.05$) level.

Table 5. Rectal-Skin temperature gradients (RT - ST, °C) in daily watered (W) and water-deprived (W.D.) camels housed indoors or outdoors and during different seasons (L.S. means±SEM).

Time of day	Water	Housing		Season			Overall means (water)
		indoors	outdoors	spring	E-summer	L-summer	
7:00 am	W	$2.8^{b}\pm0.24$	$3.9^{a}\pm0.26$	$4.3^{b}\pm0.44$	$3.3^{b}\pm0.34$	$2.4^{b}\pm0.37$	$3.3^{a}\pm0.13$
	W.D.	$3.0^{b}\pm0.97$	$2.5^{b}\pm0.24$	$5.3^{a}\pm0.48$	$1.5^{b}\pm0.30$	$1.5^{b}\pm0.48$	$2.8^{b}\pm0.14$
	Overall means	$2.9^{a}\pm0.12$	$3.2^{a}\pm0.15$	$4.8^{a}\pm0.41$	$2.4^{b}\pm0.23$	$1.9^{b}\pm0.35$	
2:00 pm	W	$2.2^{a}\pm0.28$	$1.9^{a}\pm0.29$	$3.3^{a}\pm1.07$	$1.4^{a}\pm0.51$	$1.4^{a}\pm0.65$	$2.1^{a}\pm0.11$
	W.D.	$2.2^{a}\pm0.25$	$1.9^{a}\pm0.28$	$3.8^{a}\pm1.05$	$1.3^{a}\pm0.49$	$1.0^{a}\pm0.67$	$2.0^{a}\pm0.12$
	Overall means	$2.2^{a}\pm0.22$	$1.9^{a}\pm0.23$	$3.5^{a}\pm1.05$	$1.4^{a}\pm0.46$	$1.2^{a}\pm0.63$	

Means with different superscripts in each subcell differ significantly at ($P<0.05$) level.

Table 6. Skin-air temperature gradients (ST - Ta, °C) in daily watered (W) and water-deprived (W.D.) camels housed indoors or outdoors and during different seasons (L.S. means±SEM).

Time of day	Water	Housing		Season			Overall means (water)
		indoors	outdoors	spring	E-summer	L-summer	
7:00 am	W	$11.0^{a}\pm0.32$	$9.4^{b}\pm0.34$	$13.0^{a}\pm0.58$	$8.7^{c}\pm0.44$	$8.9^{c}\pm0.49$	$10.2^{b}\pm0.17$
	W.D.	$11.0^{a}\pm0.25$	$10.3^{ab}\pm0.32$	$11.8^{b}\pm0.63$	$10.4^{b}\pm0.40$	$9.7^{bc}\pm0.63$	$10.6^{a}\pm0.19$
	Overall Means	$11.0^{a}\pm0.16$	$9.8^{b}\pm0.20$	$12.4^{a}\pm0.54$	$9.6^{b}\pm0.30$	$9.3^{b}\pm0.40$	
2:00 pm	W	$6.8^{a}\pm0.27$	$6.9^{a}\pm0.27$	$5.6^{a}\pm1.04$	$7.7^{a}\pm0.49$	$7.2^{a}\pm0.63$	$6.8^{a}\pm0.10$
	W.D.	$6.3^{a}\pm0.24$	$6.7^{a}\pm0.27$	$5.2^{a}\pm1.02$	$7.3^{a}\pm0.47$	$7.1^{a}\pm0.65$	$6.5^{a}\pm0.11$
	Overall Means	$6.6^{a}\pm0.20$	$6.8^{a}\pm0.22$	$5.4^{a}\pm0.10$	$7.5^{a}\pm0.45$	$7.2^{a}\pm0.61$	

Means with different superscripts in each subcell differ significantly at ($P<0.05$) level.

In the afternoon the ST of water deprived camels was lower than the control on watering day, and up to day 3, then they were similar afterwards till the end of the cycle (Figs 3 and 4). The magnitude of temperature increase was greater in the afternoon than that in the morning and in outdoors than that indoors (Figs 3 and 4).

Skin temperature amplitude (pm-am difference)

Water deprivation significantly affected the ST difference ($P<0.05$). The ST differences of the water deprived animals were significantly lower than the control (1.5°C *vs.* 2.1°C, respectively, Table 4).

The housing environment was also found to be a significant ($P<0.05$) source of variation affecting ST differences (Table 4). The outdoor camels had twice the ST difference as their indoor mates. The highest ST difference was observed in the control animals outdoors (2.9°C, on average) and the lowest was that of the water deprived camels indoors (1.0°C) (Table 4).

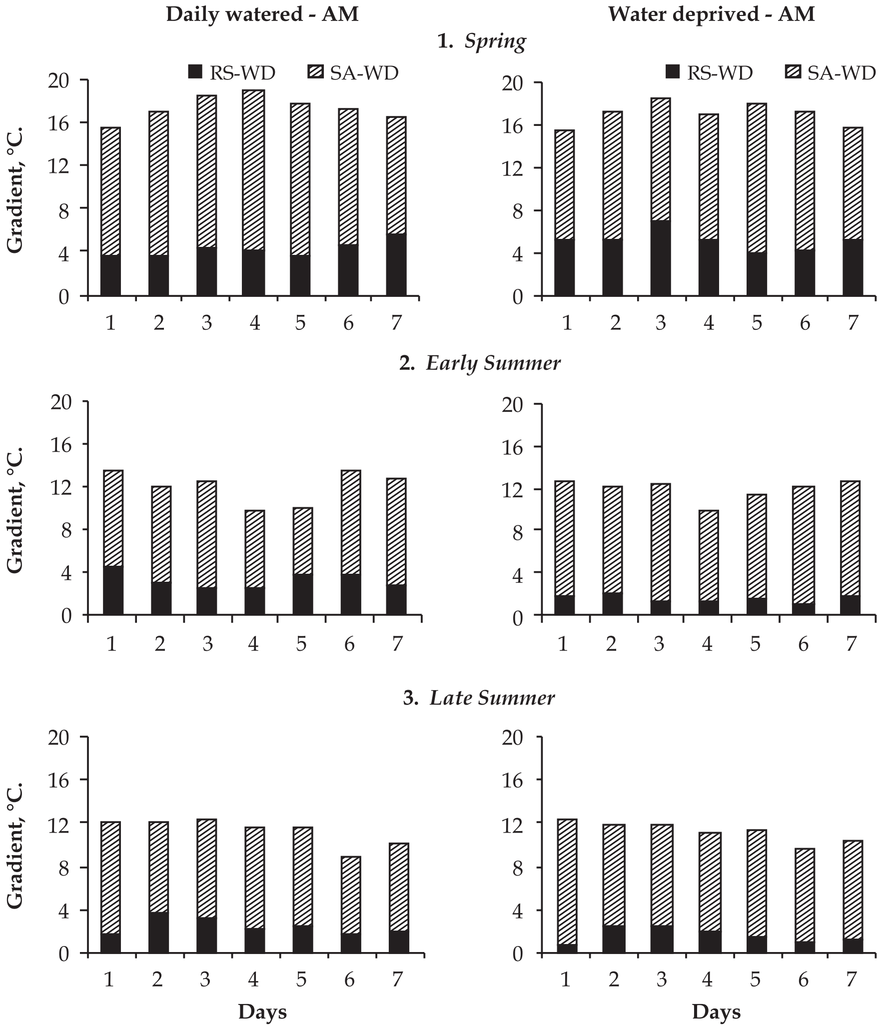

Fig 5. Morning (AM) Rectal-Skin (RS) and Skin-Air (SA) temperature gradients of daily watered (W) and water deprived (WD) camels during different seasons.

(Note: RS+SA gradients= Total Core-Ambient temperature gradient).

The control animals had the greatest ST difference (2.7°C) in early summer than in spring and late summer (Table 4). However, their water deprived mates had the greatest difference in spring (1.9°C) and it decreased in early and late summer. During the 7 day deprivation cycle (Fig 4), the ST difference in water deprived camels increased progressively. The highest values were those of the last three days of the cycle, but were still lower than those of the controls.

Temperature gradients

The skin might be considered a protective barrier between the core temperature and the surrounding environment, i.e. temperature, humidity, solar radiation, wind velocity, etc. Therefore, the R/S and S/A gradients are of paramount importance to heat dissipation to the environment, as well as protection against heat gain from the environment, as the case might be.

The ambient temperature was always found lower than both core and skin temperatures irrespective of the housing environment or the water treatment. There was no direct net heat gain from the environment except from solar radiation. However, as gradients varied between seasons, housing and water treatments male effective heat dissipation different.

Irrespective of treatments, all three gradients, R/S, S/A and R/A, were greater in the morning than in the afternoon (Tables 5, 6 and 7; Figs 5 and 6) because of the lower morning ambient temperature. Similarly, these were greater ($P<0.05$) in spring morning than in the morning of the two summer periods, possibly because of the lower spring ambient temperature. The seasonal effect was greater in magnitude on the S/A gradient as compared to R/S gradient. As a matter of fact, and in the afternoon as the R/S gradient decreased in summer, the S/A gradient increased, and the R/A gradient remained practically constant across seasons (Table 6 and Figs 5 and 6).

The effect of the housing environment was apparently and primarily related to the ambient temperature and the other climatic variables. Of particular importance were the afternoon gradients, and the morning to lesser extent. The capacity of the camels to maintain constant the overall R/A gradient through minimal variations in R/S and S/A gradients was evident. In the afternoon for example, R/S gradient was less at outdoors than indoors (1.9°C *vs.* 2.1°C) whereas S/A gradient was greater outdoors than indoors (6.8° vs. 6.6°C) and R/A was therefore, similar indoors and outdoors (8.8°C vs. 8.7°C) as illustrated in Table 7 and Figs 5 and 6. Differences were not significant ($P>0.05$). In the cooler morning, the opposite trend was observed.

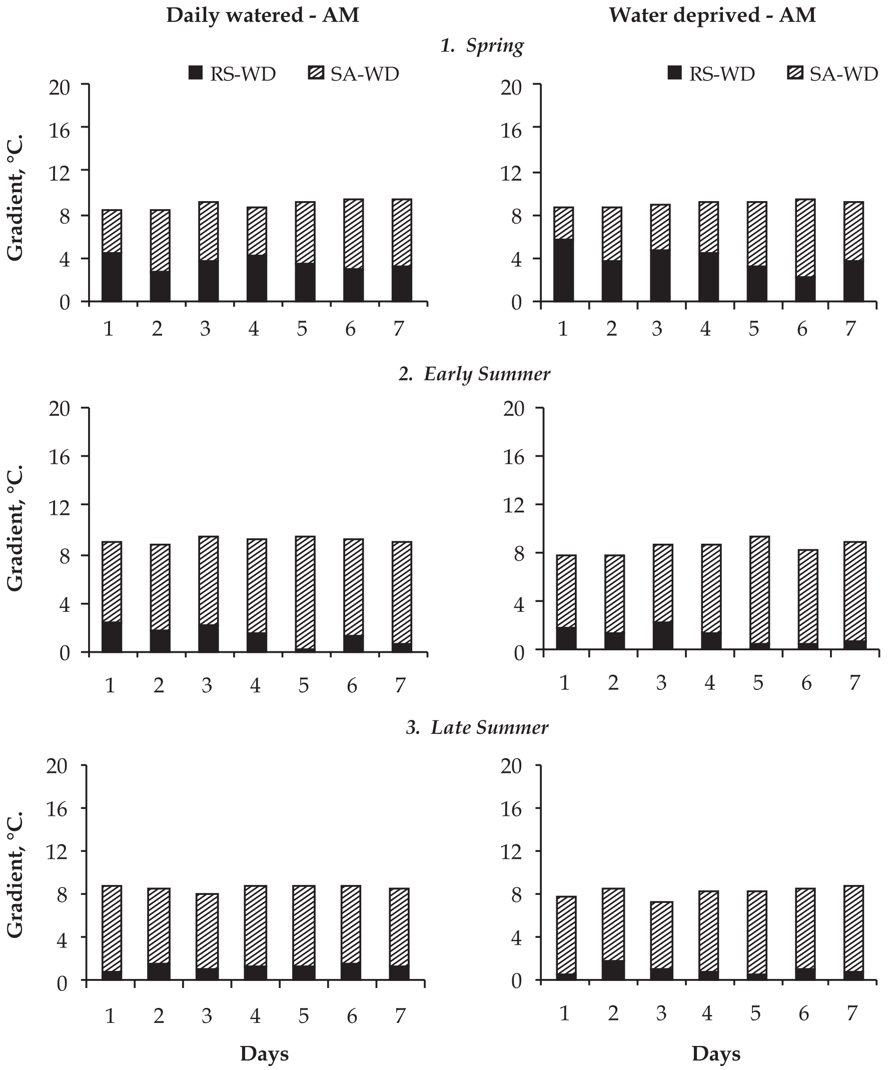

Fig 6. Afternoon (PM) Rectal-Skin (RS) and Skin-Air (SA) temperature gradients of daily watered (W) and water deprived (WD) camels during different seasons.

(note: RS+SA gradients= Total Core-Ambient temperature gradient).

The effect of water deprivation on temperature gradients was of great benefit to the camels. In the morning, water deprivation decreased R/S gradient (2.8 *vs.* 3.3°C, $P<0.05$), increased S/A gradient (10.6°C *vs.* 10.2, $P>0.05$), and the R/A did not differ from the control (Tables 5, 6 & 7; Figs. 5 and 6). This facilitates the heat dissipation in the morning from the skin of water deprived camels to the environment by physical means (i.e., radiation, convection and conduction) with minimum expenditure of water. In the afternoon, on the other hand, R/S gradient was not different between control and water deprived animals, but S/A gradient decreased slightly (6.5°C *vs.* 6.8°C) in water deprived camels and their R/A gradient was therefore less ($P>0.05$). The decreased S/A gradient in this group in the afternoon, was possibly an attempt on behalf of the water deprived camel to conserve water by minimising the heat gain from the environment.

Discussion

Heat stress occurs when any combination of environmental settings such as air temperature, relative humidity, wind velocity and solar radiation cause the effective temperature of the environment to be higher than the upper limit of the animal's thermo-neutral zone (Bianca, 1962 and Nienaber *et al,* 1999).

When heat stressed, normally-hydrated desert-adapted ungulates including ruminants with free access to drinking water typically maintain body temperature within a fairly narrow range. This is achieved by activating evaporative cooling mechanisms (Taylor, 1970a and 1970b). While some species must maintain body temperature within narrow range regardless of their state of hydration, body temperatures of other species fluctuate over a wider range when dehydrated (Schmidt-Nielsen *et al,* 1957, Taylor, 1969, Finch, 1972). The larger range over which body temperature fluctuates in dehydrated versus hydrated animals is often attributed to "adaptive heterothermy" which is a heat-dissipating but water-conserving function (Schmidt-Nielsen *et al,* 1957; Taylor 1970a, 1970b, 1972; Taylor and Lyman, 1972; Schoen, 1972).

"Selective brain cooling", i.e. the reduction of brain temperature below that of arterial blood, is most evident in animals which possess a carotid rete. Traditionally it has been considered to protect the brain during exertional hyperthermia. Rather, it has also been found that animals use it at rest under moderate heat load (Baker, 1979). Selective brain cooling is enhanced in animals under conditions of drinking water deficit (Jessen, 1998). Countercurrent heat exchange at the carotid rete can result in arterial blood entering the brain to be ≤ 3.9°C cooler than the

Table 7. Rectal-air temperature gradients (RT - Ta, °C) in daily watered (W) and water-deprived (W.D.) camels housed indoors or outdoors and during different seasons (L.S. means±SEM).

Time of day	Water	Housing		Season			Overall means (water)
		indoors	outdoors	spring	E-summer	L-summer	
7:00 am	W	$13.7^{ab}\pm0.33$	$13.3^{ab}\pm0.35$	$17.3^{a}\pm0.60$	$12.0^{b}\pm0.46$	$11.3^{b}\pm0.51$	$13.5^{a}\pm0.17$
	W.D.	$14.0^{a}\pm0.26$	$12.8^{b}\pm0.33$	$17.1^{a}\pm0.65$	$11.9^{b}\pm0.41$	$11.2^{b}\pm0.65$	$13.4^{a}\pm0.19$
	Overall Means	$13.9^{a}\pm0.17$	$13.1^{b}\pm0.21$	$17.2^{a}\pm0.56$	$12.0^{b}\pm0.31$	$11.2^{b}\pm0.48$	
2:00 pm	W	$9.0^{a}\pm0.23$	$8.8^{a}\pm0.24$	$8.9^{a}\pm0.88$	$9.2^{a}\pm0.42$	$8.6^{a}\pm0.53$	$8.9^{a}\pm0.87$
	W.D.	$8.5^{a}\pm0.20$	$8.6^{a}\pm0.23$	$9.0^{a}\pm0.86$	$8.5^{a}\pm0.40$	$8.1^{a}\pm0.55$	$8.6^{a}\pm0.10$
	Overall Means	$8.8^{a}\pm0.18$	$8.7^{a}\pm0.19$	$9.0^{a}\pm0.86$	$8.8^{a}\pm0.38$	$8.4^{a}\pm0.51$	

Means with different superscripts in each subcell differ significantly at ($P<0.05$) level.

rest of the body (Taylor, 1972). Moreover, Mitchell *et al* (2002) hypothesised that "selective brain cooling" is used in free ranging animals to switch from evaporative to non-evaporative routes of heat dissipation and therefore has a water conserving thermo-regulatory function unrelated to "adaptive heterothermy" and may be an addition to it.

The one species for which there is evidence for enhanced amplitude of the nychthermal rhythm, resulting from both higher diurnal and lower nocturnal temperatures, is the camel (Schmidt-Nielsen *et al*, 1957). The camel has been lately reported to also employ selective brain cooling during exertional hyperthermia (Schroter *et al*, 1989) and during dehydration and heat stress (Dahlborn *et al*, 1987; El-Khawad, 1992).

In the present work, camels were able to maintain their body temperatures within fairly narrow range, even under conditions of water deprivation in the hot environment of unsheltered outdoor housing. Housing environment and water deprivation were found to affect rectal and skin temperatures significantly in the morning. Days of water deprivation had significant effects at both, am and pm. On the other hand, time of the year (spring, early and late summer) was a statistically significant ($P<0.05$) source of variation affecting ST in the morning, whereas RT was not affected significantly by season. The latter result revealed that the ST of camels was more sensitive than RT to the climatic conditions throughout seasons, especially direct solar radiation, contrarily Ta, RH% and THI were not significant sources of variation, that affected RT and ST. The non-significant afternoon results may be attributed to the fact that throughout the experiment, the ambient temperatures were always lower than that of the animal's rectal and skin temperature.

The pattern of changes in RT and ST from day to day and from time to time, with few exceptions, was not simply conclusive. Nevertheless, it was quite obvious that RT of the water deprived outdoor animals were consistently lower than that of the watered ones especially in the morning ($P<0.05$) and therefore had greater RT differences (pm-am) than their control mates. Similar results were reported by Schmidt-Nielsen *et al* (1957), Ben Goumi *et al* (1993) and Shaheen (2001).

On the other hand, ST of water deprived animals was frequently higher than that of the daily watered ones, while the ST amplitudes (pm-am differences) were lower than that of the daily watered ones.

These results could be explained on basis of the fact that in camels and other ungulates arterial blood temperature decreases after dawn, even though the ambient heat load increase, as found by many workers, such as Schmidt-Nielsen *et al* (1957) in camels, Brown and Dawson (1977) in kangaroos and Fuller *et al* (1999) in the eland. This phenomenon has been attributed to cutaneous vasodilatation induced by the impact of solar radiation on the skin. This process is controlled through the cutaneous temperature receptors and signals relayed to the sensitive cells in the anterior hypothalamus. Thus, the skin of camels became warm because cutaneous vasodilatation increased the peripheral blood flow which results in enhanced heat loss from the skin to the environment (Folk, 1974) and also brought relatively cool blood from the extremities to the deeper parts of the body causing the RT to decrease. The skin of the water deprived animals became warmer because of increased plasma osmolarity and reduced plasma volume (Zine Filali *et al*, 1992; Mack and Nadel, 1996). Attenuation of the thermoregulatory drive occurs on evaporative heat loss due to increased selective brain cooling during water deprivation (Jessen, 1998; Dahlborn *et al*, 1987 and El Khawad, 1992). This enhances water conservation by the switch from evaporative heat loss to radiation and convection which require higher surface temperature that could be achieved by increased vasodilatation as described above. Hence, the ST of the water deprived camels became warmer than those of the daily watered ones, and consequently had lower RT in the morning. These results are in agreement with those of Schmidt-Nielsen *et al* (1957), Taylor (1970a) and Ben Goumi *et al* (1993).

In the afternoon, the higher ST of the water deprived camels (caused by increase of vasodilatation as indicated above) decreased the skin/air gradients and resulted in reduced heat gain from the environment, which in turn decreased the need for evaporative heat loss and evaporative cooling. This is in consonance with results of researchers on camels and other ungulates (Taylor 1969, 1970a, 1970b; Schmidt-Nielsen *et al,* 1957; Khanna *et al,* 2000).

The reduction of sweating rate in water deprived camels coupled with increased ST in the hot outdoor environment in summer could be explained on the basis that water deprivation resulted in increased plasma osmolarity and decreased plasma volume (Zine Filali *et al,* 1992). The osmo-receptors are largely responsible for anhydrosis, which in turn activates the production of the anti-diuretic hormone "arginine-vasopressin, AVP" (Ben Goumi *et al,* 1993). This hormone helps conserve water, as the infusion of hypertonic saline was reported to increase plasma osmolarity and decrease sweating (Zine Filali *et al*,1992), and/or due to selective brain cooling which is enhanced under conditions of water deficit (Jessen, 1998).

The water deprived camels begin sweating at higher RT (Schmidt-Nielsen *et al,* 1957; Bianca 1965). This delay in sweating may be attributed to resetting thermal threshold in the hypothalamic temperature controlling centre whose sensitivity to thermal stimulation could be lowered (Bianca, 1965). Zine Filali *et al* (1992) concluded that injection of adrenaline into water deprived camels initiated sweating in all regions suggesting that reduction was based on sweat gland stimulation during water deprivation. It was further be attributed to the high holding capacity substances "mucopolysaccharides" abundant in the sweat glands of camels (El-Zeiny, 1986 and Ghanem *et al*, 1999) which constitutes a physical means of reducing the rate of water seepage and loss by evaporation via excretory ducts.

The lower RT of the water deprived camels on the first day of dehydration (watering day) may be due to the larger quantity of water drank and absorbed than that of the controls which was in agreement with Schmidt-Nielsen *et al* (1957), Bianca (1965) and Ben Goumi *et al* (1993) and could be due to the physical effect of the ingestion of large quantities of cool water in the morning. The decrease of RT of water deprived camels from the 4th day of dehydration till the end of the cycle may be explained in relation to water deprivation effect on fluid homeostasis of animals. Dehydration effects in camels include hypovolaemia, hypernatremia and hyperosmolarity of plasma. Such changes act as stimuli for the secretion of hormones involved in water and electrolyte metabolism (Ben Goumi *et al,* 1993; Zine Filali *et al,* 1992). The need for maintaining blood volume was not felt for the first two days of water deprivation (Etzion *et al*, 1984). Dehydration induced a prompt and sharp increase in plasma arginine-vasopressin concentration on the fourth day, which caused hemodilution (Ben Goumi *et al,* 1993; Assad *et al,* 1997). Dehydration by withdrawal of water from the interstitial fluid (Schmidt-Nielsen, 1967; Kawashti and Omar, 1978; El-Hassanien 1989, Assad *et al*, 1997 and Kataria *et al*, 2003) or rumen filed (Macfarlane *et al*, 1963; Hoppe *et al,* 1975; Farid *et al*, 1979; Zine Fillali and Show 2004) and intracellular fluid compartment (Achaaban *et al,* 2002) has been reported in camels.

The relative distribution of water between body compartments and its contribution to total fluid loss during dehydration varies depending on species and rate of dehydration (Maloiy *et al*, 1979; Louw, 1993 and Guerouali *et al*, 1995). The maintenance of a high plasma volume in camels facilitates circulation at a level that prevents circulatory failure and is essential to body temperatures control (Roubicek, 1969) because the circulating blood also provides the skin with water for evaporation and heat dissipation (Folk, 1974).

Additionally, the decrease of rectal temperature of water deprived camels from the fourth day of water deprivation onward may be attributed to reduced feed intake and a lower metabolic rate to minimise metabolic heat gain and reduce water loss (Schmidt-Nielsen *et al,* 1967; Taylor 1969, Finch and King, 1982). Low metabolic rate could be induced by the decrease of the circulating thyroid hormones concentrations (Abdelatif and Ahmed, 1994; Yagil *et al,* 1978; Kataria *et al,* 2000). There was a negative correlation between the RT difference (pm-am) and plasma T3 and T4 concentrations (Ben Goumi *et al,* 2003).

The highest RT amplitude (pm-am) measured between 7:00 am and 2:00 pm in the present study was only about 2°C which is in agreement with Kawashti (1968) and El Hassanien (1989). However, it was lower than that of Ben Goumi *et al* (1993) in Tadla, Morocco, being 3.8°C, and than that of MacFarlane *et al* (1963), being 3.0°C, in Australia. However, Schmidt-Nielsen *et al* (1957) in the Algerian desert and at ambient temperature of 44°C, found that the diurnal variations in the water deprived camels may exceed 6°C (reported only in one animal in one day).

This disagreement may be due to the fact that the present work was carried out at a site about 20 Km from the Mediterranean Sea shore. The prevailing mild climatic conditions were typical of conditions prevailing in other desert areas close to sea shores. However, deep in the desert, extremely low temperatures before sunrise, much higher temperatures in the mid-afternoon and much lower relative humidity (Schmidt-Nielsen *et al,* 1957). In the present work the maximum ambient temperature was always lower than the rectal temperature.

References

Abdelatif AM and Ahmed MM (1994). Water restriction, thermoregulation, blood constituents and endocrine responses in Sudanese desert sheep. Journal of Arid Environments 26:171-180.

Achaaban MR, Schroter RC, Forsling ML and Ouhsins A (2000). Salt balance in camels subjected to heat stress and water deprivation under two different environmental conditions. Journal of Camel Practice and Research 7(1):57-62.

Achaaban MR, Schroter RC, Forsling ML and Ouhsins A (2002). Effect of heat stress and dehydration on body water distribution in the dromedary camel. Journal of Camel Practice and Research 9:101-106.

Assad F, Bayoumi MT and El-Sherif MA (1997). The role of ecosystem stresses on some blood characteristics of camels raised under semi-arid conditions. Egyptian Journal of Applied Sciences 12:1-10.

Baker MA (1979). A brain cooling system in mammals. Scientific American 240:130-139.

Ben Goumi M, Moutaouakil F, De la Farge F and Faye B (2003). Seasonal variation of the plasma thyroid hormone concentrations and the body temperature in the dromedary camel. Journal of Camel Practice and Research 10:115-119.

Ben Goumi M, Riad F, Giry J, De la Farge F, Safwate A, Davico MJ and Barlet JP (1993). Hormonal control of water and sodium in plasma and urine of camels during dehydration and rehydration. General and Comparative Endocrinology 89:378-386.

Bianca W (1962). Relative importance of dry and wet bulb temperatures in cattles. Nature (London) 195:251.

Bianca W (1965). Sweating in dehydrated steers. Research in Veterinary Science 6:33-37.

Brown, GD and Dawson TJ (1977). Seasonal variations in the body temperatures of unrestrained kangaroos (*Marsupialia*). Comparative Biochemistry and Physiology A56:59-67.

Dahlborn K, Robertshow D, Shroter RC and Zine Filali R (1987). Effect of dehydration and heat stress on brain and body temperature in the camel. Journal of Physiology, London 388:28.

El Khawad AO (1992). Selective brain cooling in desert animals: the camel (*Camelus dromedarius*). Comparative Biochemistry and Physiology 101:195-201.

El-Hassanien EE (1989). Some ecological and physiological parameters relative to adaptation of camels to the Egyptian desert conditions. Ph.D. Thesis, Faculty of Science, Al-Azhar University, Egypt.

El-Zeiny WT (1986). Functional and structural evaluation of the cutaneous evaporative set-up in desert camels. Ph.D. Thesis. Faculty of Science, Al-Azhar University, Egypt.

Etzion Z, Meyerstein N and Yagil R (1984). Tritiated water metabolism during dehydration and rehydration in the camel. Journal of Applied Physiology 56:217-220.

Farid MFA (1985). Long-term adaptation of sheep to low protein intake under simulated drought conditions. Journal of Arid Environments 8:79-83.

Farid MFA (1989). Water and mineral problems of the dromedary camel: An overview. Options Mediterraneenes, Serie Seminaires 2:111-124.

Farid MFA (1995). Nutrient requirements of dromedary camels: Protein and energy requirements for maintenance. Journal of Arid Environments 30:207-218.

Farid MFA, Shawket SM and Abdel-Rahman MH (1979). The nutrition of camels and sheep under stress. *Proceedings, Workshop on Camels. Khartoum, Sudan, December.* International Foundation for Science (IFS), Sweden, Provisional Report No. 6:125-170.

Farid MFA, Shawket SM and Abou El-Nasr HM (1990). The maintenance requirements of camels: a preliminary evaluation. Alexandria Journal of Agricultural Research 35:59-66.

Finch VA (1972). Thermoregulation and heat balance of the East African eland and heartbeats. American Journal of Physiology 222:1374-1379.

Finch VA and JM King (1982). Energy conserving mechanisms as adaptations under nutrition and water deprivation in the African Zebu. In: Use of Titrated Water in Studies of Production and Adaptation in Ruminants. International Atomic Energy Agency, IAEA, Vienna, Austria. pp 167-178.

Folk GE (1974). Textbook of Environmental Physiology. 2nd Edition, Lea and Febiger, Philadelphia.

Fuller A, Moss DG, Skinner JD, Jessen PT, Mitchell G and Mitchell D (1999). Brain, abdominal and arterial blood temperatures of free-ranging eland in their natural habitat. Pflügers Arch. European Journal of Physiology 438,671-680.

Ghanem YS, El-Gebali A and Mahgoub AS (1999). A Histological study of the sweat glands of the Saudi Arabian camel. Desert Institute Bulletin, Egypt 49:449-466.

Guerouali A, Fillali RZ and Flamant IC (1995). Metabolic adjustments of camel during heat stress and dehydration. Proceedings of The International Symposium on Animal Production and Rural Tourism in Mediterranean Regions. 10-13 October. Evora, Portugal. EAAP Publication. No. 74:57-62.

Hoppe MG, Green JH, Hardcastle J, Sanford PT and Sanford PA (1975). The rumen as a reservoir during dehydration and rehydration in the camel. Journal of Physiology 254:76-77.

Jessen C (1998). Brain cooling: an economy mode of temperature regulation in artiodactyls. News of Physiological Science 13:281-286.

Kataria N, Kataria AK, Agarwal VK, Garg SL and Sahani MS (2003). Changes in body fluid compartments during dehydration and rehydration in Indian dromedary (*Camelus dromedarius*). Journal of Camel Practice and Research 10:99-105.

Kataria N, Kataria AK, Agarwal VK, Garg SL, Sahani MS and Singh R (2000). Thyroid hormone profile in dromedary camel in winter and summer during water restriction. Journal of Camel Practice and Research 7:21-26.

Kawashti IS (1968). Comparative drought resistance in summer of camels, donkeys, sheep and goats under Egyptian desert conditions. Desert Institute. Bulletin, A.R.E. 16:181-204.

Kawashti J and Omar MM (1978). Water economy and water metabolism of camels and donkeys under desert conditions. Desert Institute. Bulletin, A.R.E. 28:637-649.

Khanna Deepti, Gupta ML, Rai AK, Khanna ND and Khanna D (2000). Feed and water adaptive responses of Indian camel (*Camelus dromedarius*) following dehydration and rehydration. International Journal of Animal Science 15:99-103.

Louw GN (1993). Physiological Animal Ecology. Longman, U.K.

Macfarlane WV, Morris RJ and Howard B (1963). Turnover and distribution of water in desert camels, sheep, cattle and kangaroos. Nature, London 197:270-271.

Mack GW and ER Nadel (1996). Body fluid balance during heat stress in humans. In: Fregly, M.J. and C.M. Blatteis (Eds.) Handbook of Physiology: Environmental physiology. Volume 1. Oxford University Press, New York. pp 187-214.

Mader TL, Holt SM, Hahn GL, Davis MS and Spiers DE (2002). Feeding strategies for managing heat load in feedlot cattle. Journal of Animal Science 80:2373-2382.

Maloiy GM, Macfarlane WV and Shkolnik A (1979). Mammalian herbivore. In: G.M.O Maloiy (Ed). Compararative Physiology of Osmoregulation in Animals. Volume 2. Academic Press, London, UK. pp 195-209.

Mitchell D, Maloney SK, Jessen C, Laburn HI, Kamerman PR, Mitchell G and Fuller A (2002). Adaptive brain cooling in arid-zone mammals. Comparative Biochemistry and Physiology B131:571-585.

Nienaber JA, Hahn GL and Eigenberg RA (1999). Quantifying livestock responses for heat stress management: as review. International Journal of Biometeorology 42(4):183-188.

Roubicek CB (1969). Water metabolism. In: Animal Growth and Nutrition. E.S.E. Hafez and I.A. Dyer (Eds.). Lea and Febiger, Philadelphia, USA. pp 353-373.

SAS (1998). SAS Procedures Guide. Release 6.12TS. The SAS Institute. Inc., Cary. NC., USA.

Schmidt-Nilsen K, Crawford EC, Newsome AE, Rawson KS and Hammel HT (1967). Metabolic rate of camel: effect of water deprivation and dehydration. American Journal of Physiology 212:341-346.

Schmidt-Nielsen K, Schmidt-Nielsen B, Jarnum SA and Houpt TR (1957). Body temperature of the camel and its relation to water economy. American Journal of Physiology 188:103-112.

Schoen A (1972). Studies on the environmental physiology of a semi-desert antelope, the dikdik. East African Agricultural and Forestry Journal 40:325-330.

Schroter RC, Robertshow D and Zine Fillali R (1989). Brain cooling and respiratory heat exchange in camels during rest and excrcise. Respiratory Physiology 78:95-105.

Shaheen HM (2001). The effect of feed and water deprivation on ingestive behavior and blood constituents in camel: comparison with sheep and goat. Journal of Camel Practice and Research 8:153-162.

Taylor CR (1969). The eland and the oryx. Scientific American 220:88-97.

Taylor CR (1970a). Strategies of temperature regulation in East African ungulates. American Journal of Physiology 219:1131-1135.

Taylor CR (1970b). Dehydration and heat: effect on temperature regulation of East African ungulates. American Journal of Physiology 219:1136-1139.

Taylor CR (1972). The desert gazelle A paradox resolved. Symposium of The Zoological Society of London 31:215-227.

Taylor CR and Lyman CP (1972). Heat storage in running antelopes: independence of brain and body temperatures. American Journal of Physiology 222:114-117.

Yagil R, Etzion Z and Ganani J (1978). Camel thyroid metabolism: Effect of season and dehydration. Journal of Applied Physiology 45:540-544.

Zine-Filali R, Guerouali A and Oukessou M (1992). Thermoregulation in the heat and water–stressed camel Proceedings of The First International Camel Conference. Dubai, 2-6 February. pp 301-304.

Zine-Filali R and Show R (2004). Water balance in the camel (*Camelus dromedarius*). Journal of Camel Science 1:66-70.