

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

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ABSTRACT

This study was conducted at Maryout Experimental Station near Alexandria, 32° latitude affiliated to the Desert Research Center in Cairo. 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 (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.

Keywords: Camels, dehydration, season, shelter, thermoregulation.

INTRODUCTION

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-Fillali 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.

MATERIALS AND METHODS

Animals and management

This study was conducted at Maryout Experimental Station near Alexandria, 32° latitude affiliated to the Desert Research Center in Cairo. Eight female dromedary camels were used in this experiment. All were adults, non- pregnant and non- lactating. 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 will be 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, °C, and RH is relative humidity, % .

THI categories (Mader *et al.* 2002) available at present were developed for high yielding dairy cattle. These are: 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.

The experiment was carried out at Maryout Experimental Station, affiliated to the Desert Research Center in Cairo, 32° latitude , a site 35 km south-west the city of Alexandria, about 20 km from the Mediterranean Sea shore. Table 1 summarizes the main climatic elements observed during the three experimental periods. They were typical of conditions prevailing in desert areas close to seashores. However, deep in the desert, The environmental conditions were characterized 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. The morning and afternoon data were statistically analyzed 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 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.

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).

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.

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)

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	
Rectal T, 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	
Rectal T, 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

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 (Fig. 1). The same trend was observed in the afternoon (Fig. 1).

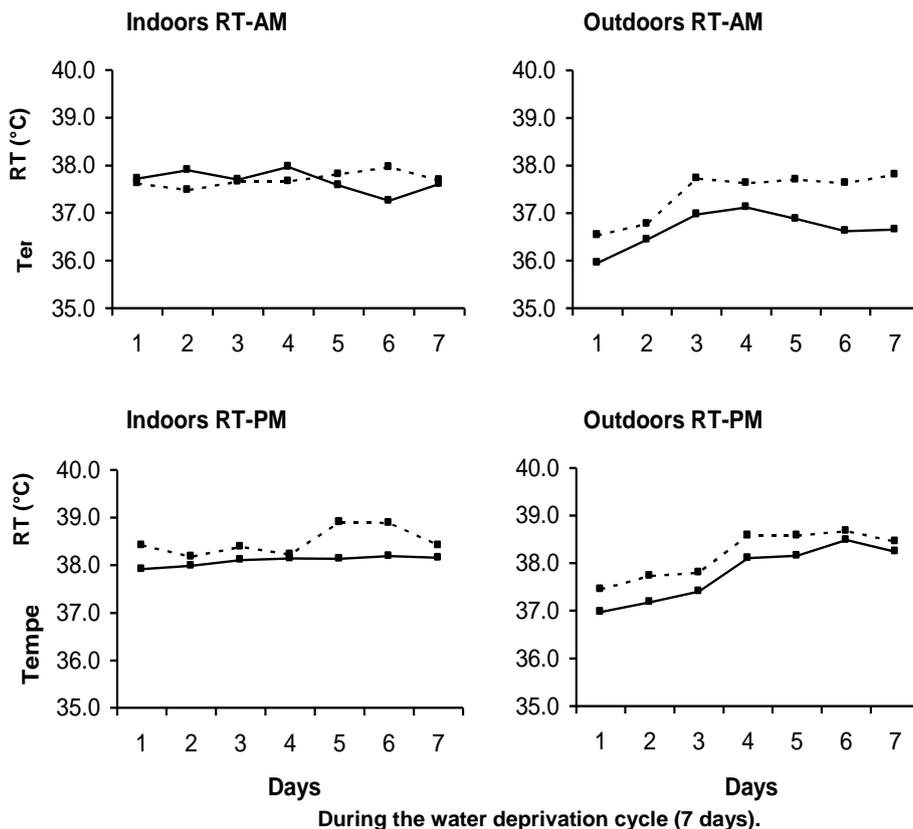


Figure 1: Rectal temperature (RT) of watered (dashed line) and water deprived (solid line) camels indoors and outdoors, in the morning (AM) and afternoon (PM).

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 watering day), and (RT) of the water deprived camels was lower than the controls (Fig. 2). 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

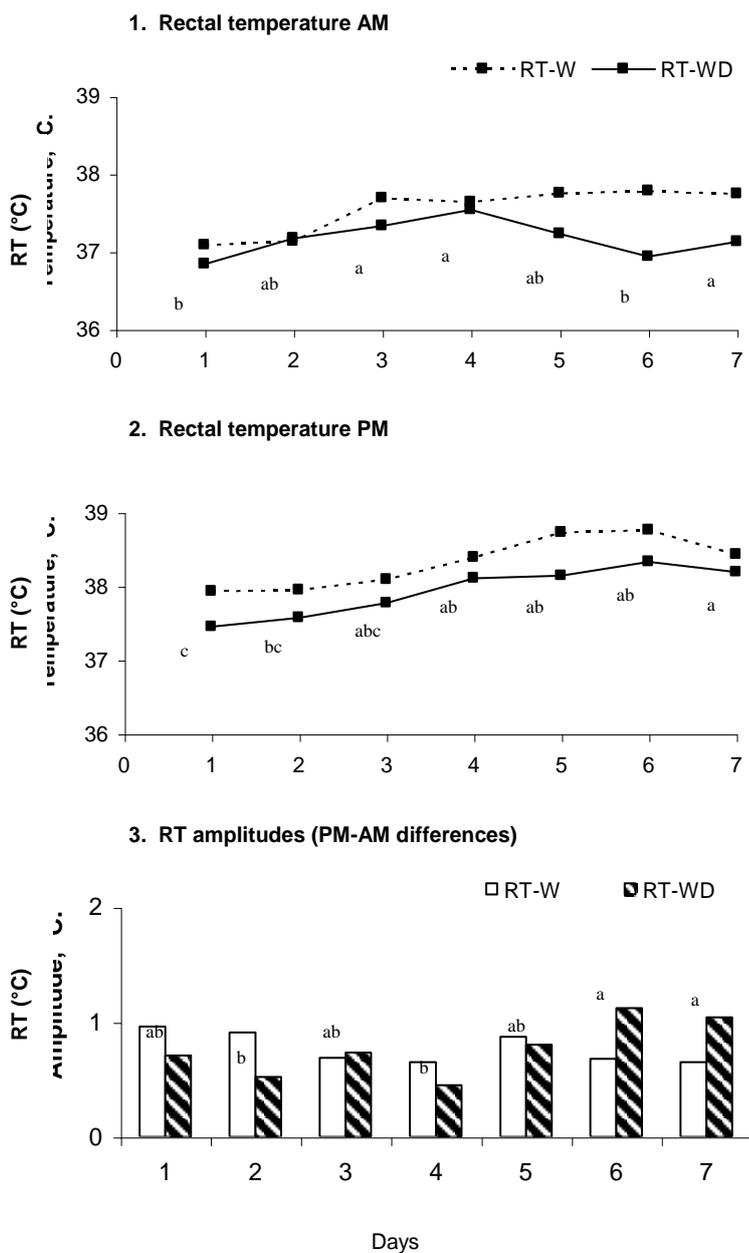


Figure 2: Rectal temperatures (RT) AM and PM, of daily watered (W) and water deprived (W.D) camels and their PM-AM amplitudes during the water deprivation cycle (7 days).
 a, b, c different letters are significantly different at (P<0.05) level.

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 temp was higher 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 outdoors was higher (about 0.8°C) than their control mates (Table 4, Fig. 3).

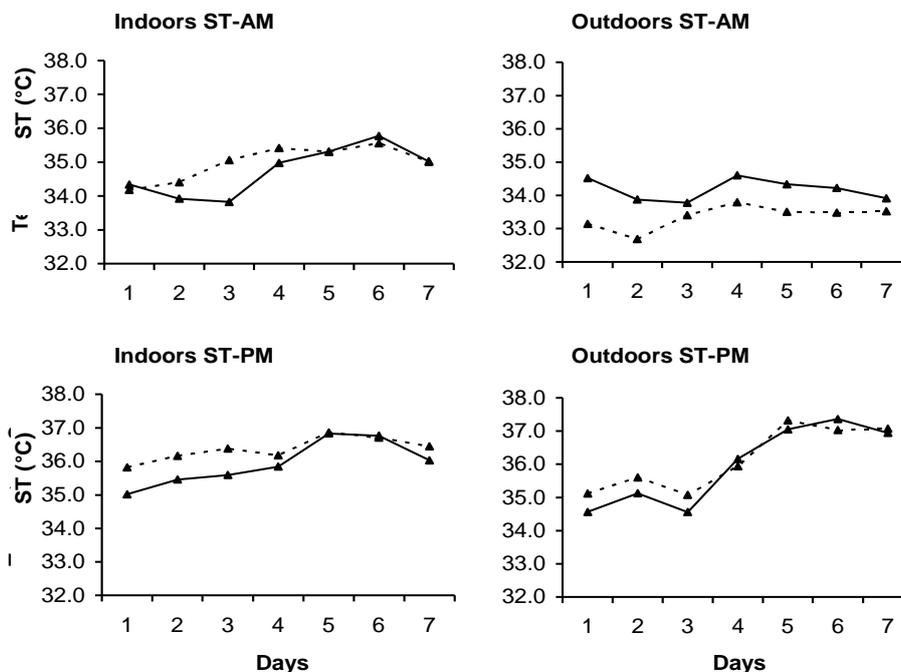


Figure 3: Skin temperatures (ST) AM and PM, of daily watered (dashed line) and water deprived (solid line) camels during the water deprivation cycle (7 days).

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).

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 \pm SEM)

Item	Water	Housing		Season			Overall means (Water)
		indoors	outdoors	spring	E-summer	L-summer	
Skin T, am	W	35.0 ^a	33.4 ^c	33.2 ^c	34.3 ^b	35.0 ^b	34.2 ^a
		± 0.20	± 0.21	± 0.36	± 0.29	± 0.31	± 0.10
	W.D.	34.7 ^a	34.2 ^b	32.5 ^d	35.0 ^b	35.8 ^a	34.5 ^a
		± 0.16	± 0.20	± 0.39	± 0.25	± 0.39	± 0.12
Overall Means	34.8 ^a	33.8 ^b	32.8 ^c	34.7 ^b	35.4 ^a		
		± 0.10	± 0.12	± 0.34	± 0.19	± 0.29	
Skin T, pm	W	36.4 ^a	36.2 ^a	35.9 ^a	36.7 ^a	36.2 ^a	36.3 ^a
		± 0.25	± 0.26	± 1.00	± 0.46	± 0.58	± 0.10
	W.D.	35.9 ^a	36.0 ^a	35.5 ^a	36.3 ^a	36.1 ^a	35.9 ^a
		± 0.22	± 0.25	± 0.95	± 0.44	± 0.61	± 0.11
Overall Means	36.2 ^a	36.05 ^a	35.7 ^a	36.5 ^a	36.1 ^a		
		± 0.20	± 0.21	± 0.94	± 0.42	± 0.57	
Amplitude	W	1.3 ^{bc}	2.9 ^a	1.7 ^{bc}	2.7 ^a	1.8 ^{bc}	2.1 ^a
		± 0.24	± 0.26	± 0.27	± 0.31	± 0.25	± 0.13
	W.D.	1.0 ^c	2.0 ^b	1.9 ^{bc}	1.7 ^b	0.9 ^c	1.5 ^b
		± 0.21	± 0.25	± 0.31	± 0.25	± 0.36	± 0.14
Overall Means	1.1 ^b	2.4 ^a	1.8 ^{ab}	2.2 ^a	1.4 ^b		
		± 0.14	± 0.16	± 0.21	± 0.17	± 0.19	

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

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, the trend was the opposite of that observed in the RT.

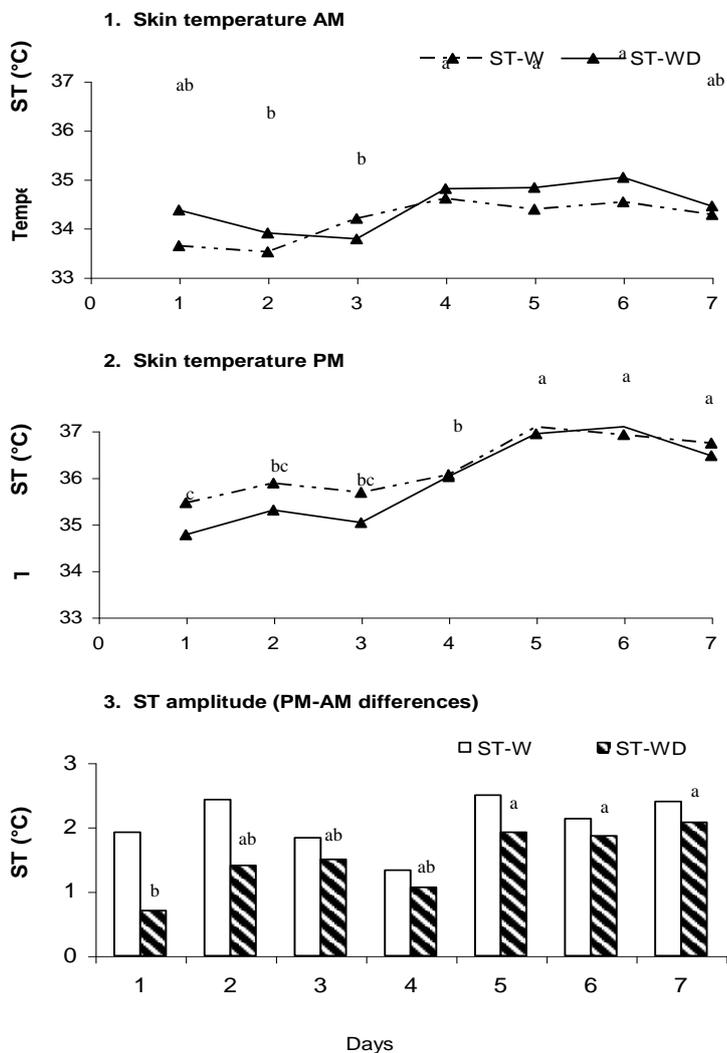


Figure 4: Skin temperatures (ST) AM and PM, of daily watered (W) and water deprived (W.D) camels and their PM-AM amplitudes during the water deprivation cycle (7 days).

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

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).

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. Those gradients were evaluated in the present experiment.

At the outset, it is noteworthy to mention that throughout the experiment the ambient temperature was always lower than both core and skin temperatures irrespective of the housing environment or the water treatment. That is there was no net direct heat gain from the environment except for some from solar radiation. However, as gradients varied between seasons, housing and water treatments effective heat dissipation may have been 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, they were greater ($P < 0.05$) in spring morning than in the morning of the two summer periods, also 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 Fig. 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. Evident was the capacity of the camels to maintain constant the overall R/A gradient through minimal variations in R/S and S/A gradients.

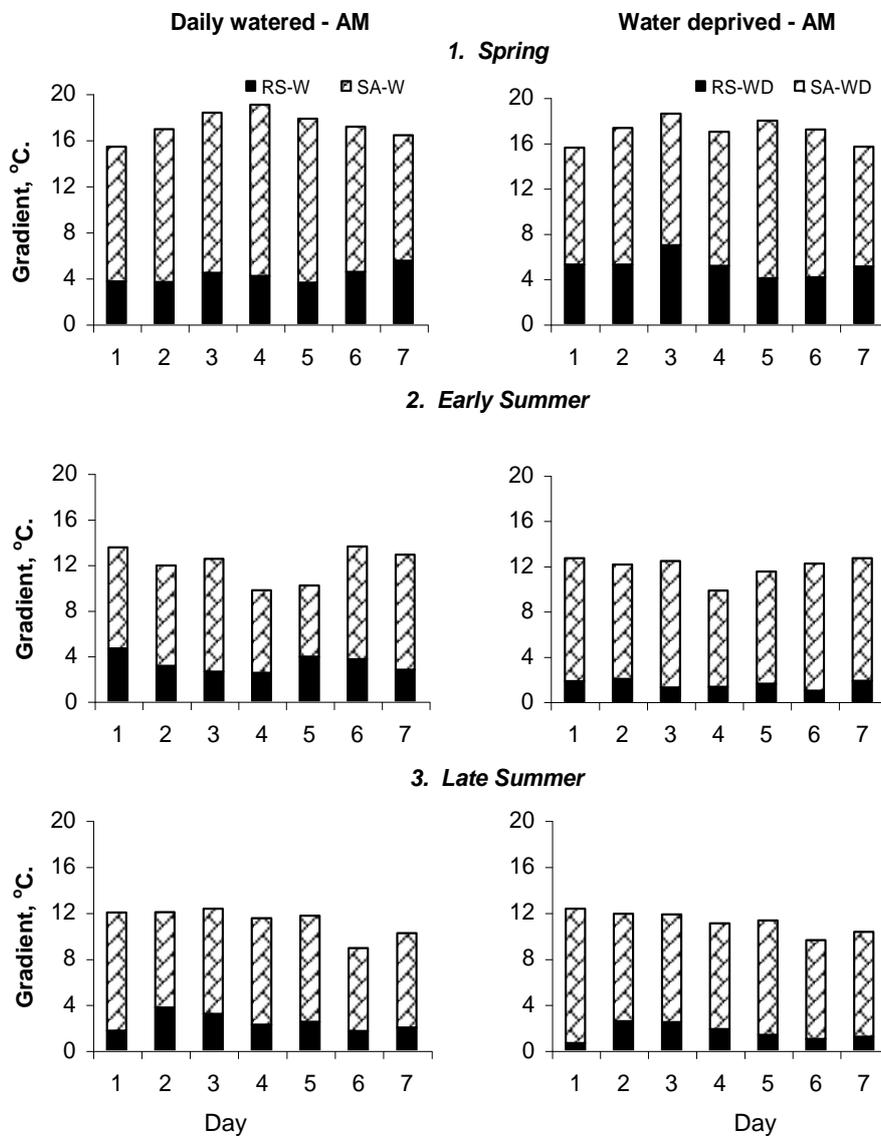


Figure 5: Morning (AM) Rectal-Skin (RS) and Skin-Air (SA) temperature gradients of daily watered (W) and water deprived (WD) camels during different seasons. (note: RS+SA gradients= Total Core-Ambient temperature gradient).

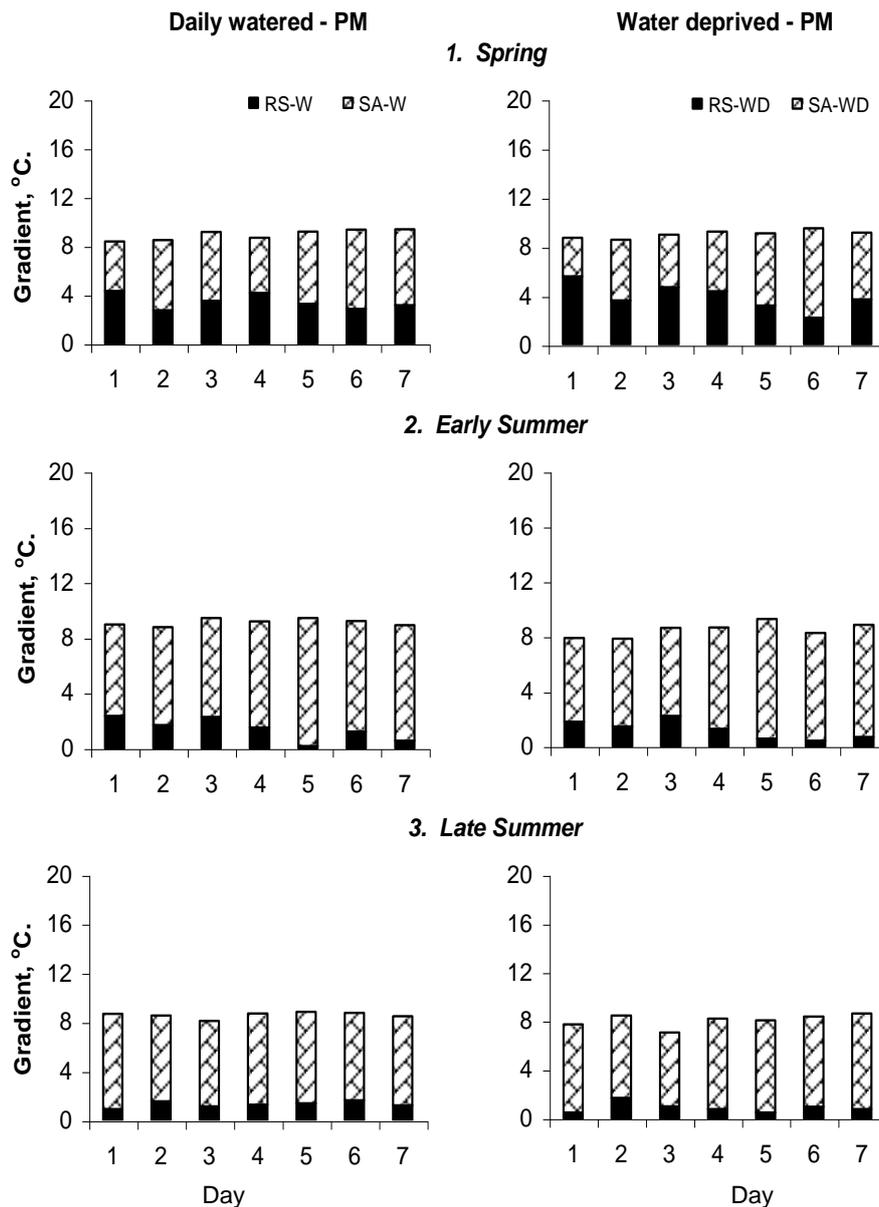


Fig. 6: Afternoon (PM) Rectal-Skin (RS) and Skin-Air (SA) temperature gradients of daily watered (W) and water deprived (WD) camels during different seasons.

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

In the afternoon for example, R/S gradient was less 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 was observed.

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 ±0.24	3.9 ^a ±0.26	4.3 ^b ±0.44	3.3 ^b ±0.34	2.4 ^b ±0.37	3.3 ^a ±0.13
	W.D.	3.0 ^b ±0.97	2.5 ^b ±0.24	5.3 ^a ±0.48	1.5 ^b ±0.30	1.5 ^b ±0.48	2.8 ^b ±0.14
	Overall means	2.9 ^a ±0.12	3.2 ^a ±0.15	4.8 ^a ±0.41	2.4 ^b ±0.23	1.9 ^b ±0.35	
2:00 pm	W	2.2 ^a ±0.28	1.9 ^a ±0.29	3.3 ^a ±1.07	1.4 ^a ±0.51	1.4 ^a ±0.65	2.1 ^a ±0.11
	W.D.	2.2 ^a ±0.25	1.9 ^a ±0.28	3.8 ^a ±1.05	1.3 ^a ±0.49	1.0 ^a ±0.67	2.0 ^a ±0.12
	Overall means	2.2 ^a ±0.22	1.9 ^a ±0.23	3.5 ^a ±1.05	1.4 ^a ±0.46	1.2 ^a ±0.63	

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 ±0.32	9.4 ^b ±0.34	13.0 ^a ±0.58	8.7 ^c ±0.44	8.9 ^c ±0.49	10.2 ^b ±0.17
	W.D.	11.0 ^a ±0.25	10.3 ^{ab} ±0.32	11.8 ^b ±0.63	10.4 ^b ±0.40	9.7 ^{bc} ±0.63	10.6 ^a ±0.19
	Overall Means	11.0 ^a ±0.16	9.8 ^b ±0.20	12.4 ^a ±0.54	9.6 ^b ±0.30	9.3 ^b ±0.40	
2:00 pm	W	6.8 ^a ±0.27	6.9 ^a ±0.27	5.6 ^a ±1.04	7.7 ^a ±0.49	7.2 ^a ±0.63	6.8 ^a ±0.10
	W.D.	6.3 ^a ±0.24	6.7 ^a ±0.27	5.2 ^a ±1.02	7.3 ^a ±0.47	7.1 ^a ±0.65	6.5 ^a ±0.11
	Overall Means	6.6 ^a ±0.20	6.8 ^a ±0.22	5.4 ^a ±0.10	7.5 ^a ±0.45	7.2 ^a ±0.61	

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

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 was not different 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 minimizing the heat gain from the environment.

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 \pm SEM)

Time of day	Water	Housing		Season			Overall means (Water)
		indoors	outdoors	spring	E-summer	L-summer	
7:00 am	W	13.7 ^{ab}	13.3 ^{ab}	17.3 ^a	12.0 ^b	11.3 ^b	13.5 ^a
		± 0.33	± 0.35	± 0.60	± 0.46	± 0.51	± 0.17
	W.D.	14.0 ^a	12.8 ^b	17.1 ^a	11.9 ^b	11.2 ^b	13.4 ^a
		± 0.26	± 0.33	± 0.65	± 0.41	± 0.65	± 0.19
Overall Means	13.9 ^a	13.1 ^b	17.2 ^a	12.0 ^b	11.2 ^b		
		± 0.17	± 0.21	± 0.56	± 0.31	± 0.48	
2:00 pm	W	9.0 ^a	8.8 ^a	8.9 ^a	9.2 ^a	8.6 ^a	8.9 ^a
		± 0.23	± 0.24	± 0.88	± 0.42	± 0.53	± 0.87
	W.D.	8.5 ^a	8.6 ^a	9.0 ^a	8.5 ^a	8.1 ^a	8.6 ^a
		± 0.20	± 0.23	± 0.86	± 0.40	± 0.55	± 0.10
Overall Means	8.8 ^a	8.7 ^a	9.0 ^a	8.8 ^a	8.4 ^a		
		± 0.18	± 0.19	± 0.86	± 0.38	± 0.51	

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

DISCUSSION

Thermo-regulatory mechanisms

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 been also found that animals use it at rest under moderate heat load (Baker, 1979). Also, 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 $\leq 3.9^{\circ}\text{C}$ cooler than the rest of the body (Taylor, 1972). Moreover, Mitchell *et al.* (2002) hypothesized 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. Also, days of water deprivation had significant effects 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 skin temperature of camels was more sensitive than rectal temperature to the climatic conditions throughout seasons, especially direct solar radiation, as T_a , 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, however. 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 behaved differently in such a way that the 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 fell after dawn, even though the ambient heat load was increasing, 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 during water deprivation the increased plasma osmolarity and reduced plasma volume (Zine Filali *et al.* 1992) are factors that the mechanisms for suppression of evaporative heat loss depend on as reported by (Mack and Nadel 1996). Superimposed on that mechanism is the attenuation of the thermoregulatory drive on evaporative heat loss brought about by 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 may explain why most of the water deprived animals have lower sweating rates and use fluctuating cutaneous evaporation depending on their extent of hydration, This is consonant with other results from the literature on camels and other ungulates (Taylor 1969, 1970a, 1970b, Schmidt-Nielsen *et al.* 1957, Deepti-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 depress 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 center whose sensitivity to thermal stimulation could be lowered (Bianca 1965). Such delay is asserted by (Zeine Filali *et al.* 1992) who concluded that injection of adrenaline into water deprived camels would initiate sweating in all regions suggesting that there is a reduction 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 role of body fluids and metabolic factors

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. This result is 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 hypovolemia, 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). For the first two days of water deprivation the need for maintaining blood volume was not felt (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). Haemodilution on the fourth day of water deprivation was also found in the outdoor water deprived camels by (Assad *et al.*, 1997) suggesting a shift of water between compartments and to the circulatory system. It was also reported that camels could face 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 from the rumen (Macfarlane *et al.*, 1963, Hoppe *et al.*, 1975, Farid *et al.*, 1979, Zine Fillali and Show 2004) and also from the intracellular fluid compartment (Achaaban *et al.*, 2002).

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 due, at least in part, to reduced feed intake and a lower metabolic rate to minimize 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).

Conclusion

The greater ability of the camel to survive in hot environments with its harsh conditions is not explained simply and only by diurnal variations and the pm-am amplitude of its rectal temperature. Rather, the way the water deprived camels can regulate its rectal and skin temperature in the morning and in the afternoon by several thermoregulatory mechanisms are dependant for the most part on adjusting skin temperature and temperature gradients as explained above. Meanwhile, body fluids and its regulating mechanisms, the metabolic status and behavioral adaptations/adjustments all play significant roles as well.

The highest RT amplitude (pm-am) measured between 7:00 am and 2:00 pm in the present study was only about 2°C. These results are in agreement with Kawashti (1968) and El Hassanien (1989) working on camels in the north-western coastal zone of Egypt. 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.

It is noteworthy to stress the fact that the present experiment was different from other experiments cited above in that the water deprived camels were adapted to cyclic water deprivation and the control camels were a separate group, and measurements were taken concurrently. Other experiments, on the other hand, relied on measurements taken during acute dehydration followed by sudden rehydration.

In further experiments, longer cycles of water deprivation might prove beneficial and concurrent measurements of body fluid changes and determination of key stress-related hormones in blood would be needed. Further studies would also need to consider the course of long-term

adaptation to dehydration, a situation imitating natural conditions prevailing in arid zones.

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بعض مظاهر التنظيم الحراري في الإبل العطشى تحت ظروف الصحراء شبه الجافة في الساحل الشمالي الغربي في مصر

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تم تقييم تأثير الإجهاد الحراري بسبب ظروف البيئة المحيطة والعطش وفصل السنة من خلال متابعة التغيرات في درجة حرارة المستقيم والجلد ، ومدى الاختلاف بين درجات الحرارة صباحاً ومساءً والفرق بين درجة حرارة المستقيم والجلد ودرجة حرارة البيئة المحيطة ، وذلك في ثمان من نوق الإبل وحيدة السنام غير الحوامل وغير المرضعات ، كان نصفها يشرب كل يوم والنصف الآخر يشرب كل سبعة أيام. أيضاً نصف الحيوانات كانت داخل حظيرة مسقوفة أما النصف الآخر فكان دون مأوى ومعرض للشمس والظروف الجوية المختلفة ليلاً ونهاراً ، كانت النوق تعطى علائق توفر المستوى الحافظ من التغذية . كررت معاملات التجربة ثلاث مرات في الفترة من إبريل إلى أغسطس لتمثل فصول الربيع وبداية الصيف وآخر الصيف . سجلت كل من القياسات الخاصة بالمناخ وشملت درجة حرارة الجو ، الرطوبة النسبية ، ودليل إجهاد الحرارة والرطوبة، والقياسات الخاصة بالحيوانات وشملت درجات حرارة الجلد والمستقيم في الساعة السابعة صباحاً والثانية مساءً خلال دورة التعطيش الكاملة في سبعة أيام متتالية .

أظهرت النتائج أن البيئة المحيطة بالحيوان أثرت تأثيراً معنوياً على درجات حرارة الجلد والمستقيم في الصباح ، كما أثرت على مدى التغيير فيهما من الصباح إلى المساء . وكذلك على الفرق بين كل منهما وبين درجة حرارة الجو. أيضاً أثر التعطيش على درجة حرارة المستقيم في الصباح والمساءً تأثيراً معنوياً وصباحاً فقط على درجة حرارة الجلد التي تأثرت أيضاً بفصل السنة. كما أن أيام التعطيش كان لها تأثيراً معنوياً في الصباح والمساءً على جميع القياسات قيد البحث.

بدا واضحاً من النتائج التي توصلت إليها الدراسة أن درجة حرارة المستقيم في الإبل المعطشه والمعرضة للظروف البيئية نهاراً وليلاً كانت دائماً أقل من مثيلاتها التي كانت تشرب يومياً تحت نفس الظروف . كما كان أكبر متوسط في مدى الاختلاف في درجة حرارة المستقيم بين الصباح والمساءً في الحيوانات المعطشه والمعرضة للظروف البيئية مقارنة بمثيلاتها داخل الحظيرة . وعلى عكس ذلك كانت درجة حرارة جلد الحيوانات المعطشه والمعرضة للظروف البيئية غالباً أعلى منها في الحيوانات التي كانت تشرب يومياً تحت نفس الظروف . ففي الصباح كانت أعلى بحوالي 0,8 درجة مئوية . وبدا جلياً قدرة الإبل على المحافظة على فرق ثابت تقريباً بين درجة حرارة المستقيم ودرجة حرارة الجو من خلال تغيرات طفيفة في الفرق بين درجة حرارة المستقيم والجلد والفرق بين درجة حرارة الجلد والجو . لذلك فإن درجة حرارة الجلد تحدد إلى درجة كبيرة درجة حرارة الجسم في الإبل . ساعد على ذلك أن درجة حرارة البيئة المحيطة كانت على الدوام أقل من درجة حرارة المستقيم والجلد.