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ENVIRONMENTAL STRESS AND THE LOSS OF UREA, SODIUM AND POTASSIUM IN THE SWEAT OF CAMELS (*Camelus dromedarius*), UNDER SEMI-ARID COASTAL CONDITIONS

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ABSTRACT

Sweating rate, Na, K and urea concentrations in sweat and serum, and sweat Na, K and urea output were determined in eight non-pregnant and non-lactating female dromedary camels fed at the maintenance level. Half of the animals were watered daily whereas the other half was intermittently watered once every seven days. There were two levels of protein intake, however 100% and 50% of their estimated maintenance requirements. 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. The present study was intended to investigate the effects of watering regimen, protein intake, housing environment and season on the potential losses of urea, sodium and potassium in the sweat of the dromedary camel.

The sweating rate in daily watered camels in summer was about 220 ml/m^2/h. The outdoor camels had significantly higher sweat rates than those kept indoors. Also, the sweating rate of camels in early and late summer was significantly higher than those in spring. The sweating rate of water deprived camels was significantly lower than that of the daily watered ones. The level of protein intake did not affect sweating rate. In water deprived camels both housed indoors and outdoors, sweating rate was high on the watering day, then decreased through the water deprivation cycle.

All urea, sodium and potassium excreted in sweat followed changes in sweating rate. Output increased in animals kept outdoors as compared to indoors, and in summer as compared to spring. In water deprived animals, on the other hand, sodium and potassium output decreased as the sweating rate decreased whereas urea output remained unchanged. The sweat-serum urea concentration ratio was always less than one. Camels may well be able to conserve some of the urea excreted in sweat as observed in the low vs. high protein intake groups in the present experiment especially when camels were water deprived. Sweat-serum concentration ratios ranged from 1 to 2 for sodium and 68 to 128 for potassium for the different environmental treatments. Therefore, the sweat output of K was much greater than that of sodium (sweat K/Na ranged from 2-4) even though its serum concentration was much less than Na. The increase in K/Na ratio may suggest the presence of Na^+ K^+ exchange in the duct of the sweat gland as in the distal tubule of the kidney.

Key words: Camel, potassium, sodium, stress, sweat, urea

Animals inhabiting hot arid environments lose heat principally by evaporating water through sweating, panting or both. Propensity of a species to use one mechanism or the other, e.g. sweating vs. panting, is a developmental characteristic of the particular species. Invariably it is aided by some other adaptive mechanism i.e. camel has ability to allow his core temperature to rise during the day and loosing heat passively during the cooler night (Schmidt-Nielsen *et al,* 1957).

Sweat contains varying amounts of electrolytes and water soluble metabolites of small molecules, e.g. urea (Macfarlane *et al,* 1963). Losses to the animal of these metabolites might be significant where conditions are conducive of heavy sweating, hence affecting the animals' acid-base balance and its nutritional status (Yagil, 1985; Wilson, 1989). Among these, besides the heat load, are the availability of water, shelter, amount and type of feeds, seasonal variations and others (Etzion and Yagil, 1986; Zeine-Filali *et al,* 1992; Ayoub and Saleh, 1998; Achaaban *et al,* 2000 and Souilem and Barhomi, 2009). Quantitative data are not yet available.

The present study was intended to investigate the effects of watering regimen, protein intake, housing environment and the season of the year on

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potential losses of urea, sodium and potassium in the sweat of the dromedary camel.

Materials and Methods

Animals and Management

Eight non-pregnant and non-lactating adult female dromedary camels were used in the experiment. Their live body weights averaged 502.2 kg. Half the animals were housed individually in floor pens inside a barn whereas the other half was kept outdoors, tied to individual mangers and exposed to direct solar radiation and other environmental elements.

In addition to housing effects, the animals were subjected to two experimental treatments, i.e. level of protein intake and daily vs. intermittent watering, once every seven days. The experiment was repeated 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 the digestion and nitrogen balance trial and one week for the study of animal adaptation.

Animals were weighed periodically every two weeks before morning feeding and watering. Feeds were offered in the morning as per treatments detailed below. Refusals if any were collected 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 intermittently, once every seven 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 kept unsheltered outdoors.

The camels were fed at the maintenance level as per maintenance requirements determined locally, being 2.15 g DCP and 26.8 g TDN per $kg^{0.73}$ (Farid *et al,* 1990; Farid, 1995). Ingredients used to formulate the rations included a commercial concentrate mixture and corn grains, and rice straw was the roughage. All animals received 100% of their estimated energy requirements for maintenance. There were two levels of protein intake, however, 100% and 50% of their estimated digestible protein requirements for maintenance.

Climatic data

The experiment was carried out at a site some 35 km south-west the city of Alexandria and about 20 km from the Mediterranean Sea shore. The following climatic elements were measured using standard equipments: 24-hour minimum (minT) and maximum (maxT) temperatures, and dry-bulb ambient temperatures (AT) and relative humidity (RH) at 7:00 AM and 2:00 PM Egypt standard time, EST = GMT+2. Table 1 summarises the main climatic elements observed during the three experimental periods. They were typical of conditions prevailing in arid desert areas close to seashores. Both climatic and animal data were recorded for a full water deprivation cycle, i.e. seven days.

Sweating rate

The sweating rate was measured by the calcium chloride capsule technique as described by Ferguson and Dowling (1955). The capsules were applied to clipped patches of skin on the mid-side of the animal and held there for a specific period of time, usually 30 minutes. The gain in weight of the capsule along with the surface area it covered were used to calculate the sweating rate which was expressed in ml water/ m^2/hr.

Sweat electrolytes and urea

After a clipped area on the mid-side of the animal has been wash-cleaned and dried, it was exposed to open air for two hours. Thereafter, a metal ring of known surface area and with a lip was applied to the skin and the inside area was washed with two portions of distilled water, 10 ml each, and allowed to drain into a 25 ml volumetric flask and the volume was adjusted to the mark and kept frozen. These samples were used for the determination of sodium, potassium and urea in sweat. Sodium and potassium were determined using standard flame-photometric

Table 1. Average climatic data during the different experimental periods.

Housing	Season	Tmin	Tmax	Ambient (Ta)		Humidity %	
		(°C)	(°C)	am	pm	am	pm
Indoors	Sp	16.79	24.21	19.79	23.21	72.03	58.57
	ES	23.29	31.43	25.57	30.64	69.21	45.84
	LS	24.14	31.34	25.36	30.71	78.17	59.83
Outdoors	Sp	16.64	28.00	20.57	23.93	70.90	53.72
	ES	24.43	35.02	25.57	33.71	69.35	36.21
	LS	24.07	36.47	26.07	34.36	75.15	43.94

SP = spring period, (1-7 May), ES = early summer period (20-26 June) and LS = late summer period (4 –10 Aug).

procedures. Urea was determined by the diacetyl-monoxime colorimetric procedure as described by Evans (1968). Results were then expressed in mg/m^2/hr to indicate rates of output, or loss, of these elements in sweat.

Serum electrolytes and urea

Jugular blood samples were withdrawn at 2:00 PM, at the same time of sweat collection, and were allowed to clot. Serum was collected after centrifugation in a clinical centrifuge and saved frozen for pending analysis of sodium, potassium and urea. Analytical procedures were those applied for sweat.

Statistical procedures

Factorial analysis of variance was performed using the GLM model of the NCSS statistical package (Hintze, 2006). F-test was performed for the four main effects and the 2-way interactions. Higher interactions were included in the error term. Multiple range comparison tests were applied to the means of the main effects as described in the NCSS package.

Results

Free water intake

On watering days, water deprived camels drank five times as much as the average intake of their daily watered mates. However, when intake was expressed as the daily average through the 7-day water deprivation cycle, it was significantly (P<0.01) less than the daily watered ones, 50.2 vs. 71.8 ml/day/$kg^{0.82}$ (Table 2). Daily averages were calculated for both daily watered and water deprived camels to facilitate the evaluation of the main effects of the housing environment, protein intake and season.

Camels kept outdoors consumed 24% more water (P<0.05), whereas the level of protein intake did not affect free water intake (P>0.05). Free water intake was least during the spring season, increasing significantly (P<0.01) during early summer and more so during late summer. Average free water intake during late summer was 167% of that recorded during the spring.

Sweating rate

The sweating rate of water deprived camels was significantly (P<0.05) lower than that of the daily watered ones, 131.2 vs. 161.3 ml/m^2/hr (Table 2). Housing the camels outdoors increased their sweating rate significantly (P<0.01) as compared to their sheltered mates housed indoors. The level of protein intake did not affect sweating rate whereas seasonal effect was significant (P<0.05). Camels produced more sweat during the summer than during spring. On average, sweating rate was similar in both daily watered and water deprived camels housed indoors and their seasonal changes were similar. Camels housed outdoors produced more sweat as indicated above. In water deprived camels, both housed indoors and outdoors, sweating rate was high on watering days, first day of the water deprivation cycle, decreasing steadily in the fourth and seventh days.

Urea output in sweat

Serum urea concentration, mg/100 ml, was measured four hours after feeding, i.e. less than two hours before sweat measurements were taken. It significantly (P<0.01) increased in the water deprived camels, 30.2 vs. 19.4 mg/100 ml (Table 3). Housing

Table 2. Effects of watering regime, housing environment, protein intake and season of the year on free water intake and sweating rate in dromedary camels.

Items	Watering	Environment		Protein intake		Season of year			Water means
	Treat.	Indoors	Out	High	Low	Spring	E. Sum.	L. Sum.	
Free water intake, ml/day/$kg^{0.82}$	Daily	61.82	81.87	71.78	71.72	49.94	72.43	93.17	71.85[a]
	WD	46.97	53.44	49.45	50.96	41.06	51.00	58.55	50.20[b]
	Means	54.40[b]	67.66[a]	60.71[a]	61.34[a]	45.50[b]	61.72[a]	75.86[a]	
	SEM + F-test	2.945*		2.945 N.S.		3.607**			2.945**
Sweating rate, ml/m^2/hr	Daily	126.2	196.4	153.3	169.3	91.02	222.0	170.8	161.3[a]
	WD	119.4	142.9	125.9	136.4	79.18	154.3	160.0	131.2[b]
	Means	122.8[b]	169.4[a]	139.6[a]	152.9[a]	85.10[b]	188.2[a]	165.4[a]	
	SEM + F-test	8.37**		8.37 N.S.		10.25*			8.37*

a-b. means of a main effect with different superscripts were significantly (P<0.05) different.

*=P<0.05, **=P<0.01 and NS=P>0.05 (non-significant).

Table 3. Effects of watering regime, housing environment, protein intake and season of the year on urea concentrations in serum and sweat and output in sweat.

Items	Watering Treat.	Environment		Protein intake		Season of year			Water means
		Indoors	Out	High	Low	Spring	E. Sum.	L. Sum.	
Serum Urea oncentration mg/100ml	Daily	19.23	19.60	25.1	13.73	18.75	16.40	23.10	19.42[b]
	WD	29.07	31.37	35.85	24.58	24.70	28.95	37.00	30.22[a]
	Means	24.15[a]	25.48[a]	30.47[a]	19.16[b]	21.72[b]	22.67[b]	30.05[a]	
	SEM + F-test	1.396 N.S.		1.396 **		1.710*			1.396**
Sweat Urea oncentration mg/100ml	Daily	12.22	18.52	15.14	15.60	13.52	11.19	21.41	15.73[a]
	WD	19.51	18.81	24.78	13.53	15.08	13.67	28.73	19.16[a]
	Means	15.86[a]	18.66[a]	19.96[a]	14.50[a]	14.30[ab]	12.43[b]	25.07[a]	
	SEM + F-test	2.603 N.S.		2.603 N.S.		3.188*			2.603 N.S
Sweat Urea output mg/ m^2/hr	Daily	15.77	34.89	25.45	25.21	11.58	28.01	36.41	25.33[a]
	WD	23.48	28.09	33.62	17.94	10.93	21.29	45.13	25.78[a]
	Means	19.62[a]	31.49[a]	29.54[a]	21.57[a]	11.25[b]	24.64[ab]	40.77[a]	
	SEM + F-test	3.892 N.S.		3.892 N.S.		4.767*			3.892 N.S.

a-b. means of a main effect with different superscrips were significantly (P<0.05) different.

*=P<0.05, **=P<0.01 and NS=P>0.05 (non-significant).

the animals indoors or outdoors did not affect serum urea concentration whereas the level of protein intake had a significant effect (P<0.01) and serum urea concentration decreased as the level of protein intake was restricted. Seasonal effect was also significant (P<0.05). Serum urea concentration was low in the spring and highest in late summer.

During the 7-day water deprivation cycle changes in serum urea concentration were relatively small. It tended to decrease as water deprivation progressed in spring but increased in early and late summer in camels housed indoors. In those housed outdoors it increased in the spring as water deprivation progressed but was practically unchanged in summer.

The concentration of urea in sweat, mg/100 ml, on the other hand, was significantly (P<0.05) affected only by the season of the year (Table 3). It tended to increase slightly in camels housed outdoors in the summer and when fed the higher level of protein. Noteworthy, in all cases the concentration of urea in sweat was less than that in blood serum. During the water deprivation cycle it was practically stable and not different from the daily watered mates in spring and early summer. Only in late summer it increased when compared to the concentration in the daily watered camels and as water deprivation progressed.

The output of urea in sweat, often neglected even though it may be of importance to the nutritional status of the animal, is presented in Table 3. It was similar in both daily watered and water deprived camels, 25 mg/m^2/hr. However, it increased 60.4% in camels housed outdoors, decreased 36.0% in camels fed the lower level of protein and increased 262.4% (P<0.05) during late summer as compared to spring, 11.25 vs. 40.77 mg/m^2/hr. The lack of statistical significance (P>0.05) is due to the large individual variation as observed in the magnitude of SEM (Table 3) and should not overshadow the biological significance of the results.

During the water deprivation cycle there was no effect on the rate of urea output in sweat from day-one to day-seven except in early summer where it tended to decrease as water deprivation progressed. As this effect was absent in spring and late summer, it is believed that mild water deprivation does not affect the rate of urea output in sweat and its ramifications on the animal's nitrogen metabolism.

Sodium output in sweat

Serum sodium concentration was significantly (P<0.01) affected by the environment (Table 4). The camels housed indoors had 14.5% higher serum sodium levels than those kept outdoors (478.0 vs. 410.3 mg/100 ml). However, the sweat sodium concentration did not differ significantly (P>0.05) between indoors and outdoors camels. Meanwhile, the direct exposure to the sun and other environmental factors increased (P<0.05) the rate

of sweat sodium output in camels kept outdoors by 29.5%. This paralleled the 37.8% increase in the sweating rate of the outdoor camels.

The sweat sodium concentration was higher than that of the serum in both indoor and outdoor camels (about 1.3 and 1.5 times, respectively). Indoors, sweat sodium concentration was 613.4 mg/100 ml whereas in serum it was only 478.0 mg/100 ml, a ratio of 1.28. Similarly, in the outdoor camels corresponding values were 627.6 and 410.3 mg/100 ml, respectively, a ratio of 1.5. The same was observed when comparing daily watered and water deprived camels. Sweat sodium concentration was higher 1.38 times than the serum sodium concentration. Sweat and serum sodium concentrations were 636.5 and 461.3 mg/100 ml, respectively, in the daily watered and water deprived camels. Corresponding values in the water deprived camels were 604.4 and 426.7 mg/100 ml. This indicates that the camels were able to maintain the ratio of sodium concentrations in the sweat and serum (sweat Na/serum Na) practically constant so as to achieve homeostasis.

The effect of season is summarised in Table 4. It is apparent that serum and sweat sodium concentrations were affected significantly (P<0.01). Whereas serum concentration was greater in late summer than in spring and early summer, the sweat concentration was greater in spring than in early and late summer. However, the rate of sweat sodium output increased about 50% in late summer as compared to spring. This increase was more pronounced in the daily watered camels. These changes were not statistically significant (P>0.05), however. It was also noted that as the sweating rate increased the sweat sodium output increased as well while the sweat sodium concentration decreased.

Although the effect of water deprivation on serum and sweat sodium concentration and its output rate in sweat were not significant it was of interest to examine their changes during the water deprivation cycle. Irrespective of the housing environment, indoors or outdoors, camels lost more sodium in sweat on the watering day and it then decreased as water deprivation progressed. The rate of sodium output in sweat of the camels housed indoors decreased by 56% during the first four days of the cycle then remained stable up to the 7th day. In the outdoor camels corresponding relative decrease values were 28% and 12%, respectively, with an average decrease rate of 5.7% per day throughout the cycle.

The serum sodium concentration also decreased as water deprivation progressed and as sweating rate decreased measured on the 4th and 7th days of the cycle in early and late summer. However, in spring serum and sweat sodium concentrations increased as water deprivation progressed. These changes were however, not statistically significant (P>0.05).

The level of dietary protein intake did not significantly affect serum and sweat sodium concentrations or its rate of output in sweat (Table 4).

Table 4. Effects of watering regime, housing environment, protein intake and season of the year on sodium concentrations in serum and sweat and output in sweat.

Items	Watering Treat.	Environment		Protein intake		Season of year			Water means
		Indoors	Out	High	Low	Spring	E. Sum.	L. Sum.	
Serum Urea concentration mg/100ml	Daily	515.8	406.7	427.5	433.6	415.0	416.3	552.8	461.3[a]
	WD	439.5	413.9	495.0	419.8	408.4	378.7	492.7	426.7[a]
	Means	478.0[a]	410.3[b]	430.6[a]	457.4[a]	411.7[b]	397.5[b]	522.8[a]	
	SEM + F-test	13.01**		13.01 N.S.		15.93***			13.01 N.S.
Sweat Urea concentration mg/100ml	Daily	653.2	619.9	657.8	615.3	719.4	413.0	777.2	636.6[a]
	WD	573.6	635.2	695.9	512.9	938.7	418.3	456.2	604.4[a]
	Means	613.4[a]	627.6[a]	676.8[a]	564.1[a]	829.1[a]	415.6[b]	616.7[ab]	
	SEM + F-test	47.18 N.S.		47.18 N.S.		57.79**			47.18 N.S.
Sweat Na output mg/m^2/hr	Daily	802.5	1098.7	933.0	968.2	639.7	872.7	1339	950.6[a]
	WD	632.0	759.2	762.5	638.7	732.5	637.0	717.2	695.6[a]
	Means	717.2[a]	928.9[a]	847.7[a]	798.4[a]	686.1[a]	754.9[a]	1028[a]	
	SEM + F-test	86.30 N.S.		86.30 N.S.		105.70 N.S.			86.30 N.S.

a-b. means of a main effect with different superscrips were significantly (P<0.05) different.

*=P<0.05, **=P<0.01 and NS=P>0.05 (non-significant).

Potassium output in sweat

The serum potassium concentration (Table 5) was not affected significantly by the housing environment, indoors vs. outdoors, and it amounted to 18.24 and 16.94 mg/100 ml, respectively. However, the sweat potassium concentration and its output rate in sweat were significantly (P<0.05) affected by the housing environment. While the sweat potassium concentration of the indoor camels was relatively low it increased 75% in the outdoor camels exposed to the complex climatic elements, 1238 vs. 2163 mg/100 ml, respectively. The sweating rate of the same animals increased 140% when housed outdoors (Table 2).

The serum potassium levels of the daily watered and water deprived camels were practically the same. However, the sweat potassium concentration and its output rate in sweat were significantly (P<0.05) affected by water deprivation. The water deprived camels had lower had lower sweat concentration and output rate than their daily watered mates, less 39% and 42%, respectively.

The serum potassium concentration and its output rate in sweat differed significantly (P<0.05) during the different seasons. While the highest serum levels of potassium were observed in the spring, the highest output rates were in the late summer. The trend of sweat potassium concentrations, high in spring than in summer, was similar to the trend of serum concentrations. The effect of level of protein intake was not significant (P>0.05) either on potassium levels in serum and sweat or on its output rate in sweat (Table 5).

It is of interest to examine the trends of change of the serum and sweat potassium concentrations and its output rate during the 7-day water deprivation cycle. Irrespective of the housing environment, indoors or outdoors, camels lost more potassium in sweat on watering days, then it decreased as water deprivation progressed. The rate of potassium loss in sweat of the camels kept indoors decreased 37.4% between day-1 and day-4 of the cycle and 23.2% between day-4 and day-7, with an average of 8.7% daily throughout the cycle. In camels kept outdoors, corresponding values were 25.0% and 18.4%, with an average of 6.3% daily throughout the cycle.

The changes of sweat potassium concentrations during the 7-day water deprivation cycle differed in spring and early summer from that observed during late summer. In spring and early summer it decreased gradually throughout the cycle, but in late summer it increased as water deprivation progressed. Observed changes of serum potassium concentration were relatively small and not conclusive. The effect of water deprivation was not statistically significant (P>0.05).

Discussion

The dehydrated camel utilises many adaptive mechanisms to conserve water. Camels have large daily fluctuations in body temperature between day and night (adaptive heterothermy) (Schmidt-Nielsen *et al*, 1957) which minimises the need for water to dissipate heat. Another adaptive mechanism to conserve water is selective brain cooling (adaptive

Table 5. Effects of watering regime, housing environment, protein intake and season of the year on potassium concentrations in serum and sweat and output in sweat.

Items	Watering Treat.	Environment		Protein intake		Season of year			Water means
		Indoors	Out	High	Low	Spring	E. Sum.	L. Sum.	
Serum K concentration mg/100ml	Daily	18.21	16.62	17.67	17.17	20.0	15.81	16.44	17.42[a]
	WD	18.28	17.25	17.58	17.94	20.52	15.65	17.12	17.76[a]
	Means	18.24[a]	16.94[a]	17.62[a]	17.55[a]	20.26[a]	15.73[b]	16.78[ab]	
	SEM + F-test	0.901 N.S.		0.901 N.S.		1.103*			0.901 N.S.
Sweat K concentration mg/100ml	Daily	1735	2494	2167	2062	3000	1185	2158	2114[a]
	WD	740.6	1832	1409	1164	1199	859.1	1801	1286[b]
	Means	1238[b]	2163[a]	1788[a]	1613[a]	2099[a]	1022[a]	1980[a]	
	SEM + F-test	225.2*		255.2 N.S.		312.6 N.S.			255.2*
Sweat K output mg/m^2/hr	Daily	2012	4116	2993	3135	2641	2754	3797	3064[a]
	WD	824.7	2705	1868	1661	947.5	1382	2965	1765[b]
	Means	1418[b]	3411[a]	2430[a]	2398[a]	1794[b]	2068[ab]	3381[a]	
	SEM + F-test	315.3*		315.3 N.S.		386.2*			315.3*

a-b. means of a main effect with different superscrips were significantly (P<0.05) different.

*=P<0.05, **=P<0.01 and NS=P>0.05 (non-significant).

heterothermy) mechanism (Schroter *et al,* 1989; Dahlborn *et al,* 1987; El-Khawad, 1992). A decline in metabolism (Yagil *et al,* 1978) also reduces heat production and respiratory water loss. Water (and urea) recycling from/to the rumen (Farid *et al,* 1979; Yagil, 1985; Souilem and Barhomi, 2009) reduces sweat and urine water losses.

One aspect that has received little attention so far is the losses in sweat of essential metabolites such as electrolytes and urea, and possible mechanisms regulating its magnitude. The present investigation addressed this subject, although it was qualitative in nature. The effects of heat stress, water deprivation, season of the year and dietary protein intake were evaluated. Aspects of heat tolerance under these conditions were reported in El-Zeiny (2010).

Sweating rate

Most mammals employ either panting or sweating, or both, as their means of evaporative heat loss to varying degrees (Robertshaw and Finch, 1984). The camel is predominantly a sweating species and respiratory water loss contributes approximately 3% of total evaporative water loss (Schroter *et al,* 1989). The evaporative loss is the largest component of water loss and minimally represents about 50 to 60 per cent of the total water loss in summer (Schmidt-Nielsen, 1964; El-Zeiny, 1986 and Robertshaw and Zeine-Filali, 1995). This fact ultimately points to the considerable activity of the sweat glands of the camel which is in accordance the histological findings that the sweat glands of the camel are of intermediate nature between that of the eccrine and apocrine glands (Dowling and Nay, 1962; Lee and Schmidt-Nielsen, 1962 and El-Zeiny, 1986).

In the present work, the sweating rate of camels was about 220 ml/m^2/h in daily watered camels in summer. These results are in agreement with those reported by other workers (Schmidt-Nielsen *et al,* 1957; Macfarlane *et al,* 1963; El Zeiny, 1986 and Zeine Filali *et al,* 1992), who reported rates between of 230 and 280 ml/m^2/h.

Housing environment and time of the year were significant ($P < 0.05$) sources of variations affecting the sweating rate. The outdoor camels had significantly higher sweat rates than those kept indoors. Also the sweating rate of camels in early and late summer was significantly higher ($P< 0.05$) than those in the spring. These results could be explained on the basis that when camels are exposed to solar radiation, the main heat load is sensed by the irradiated skin, and sweating rate is correlated with skin temperature (Zeine-Filali, 1987).

Moreover, water deprivation was also found to be a statistically significant source of variation affecting sweating rate. When camels were dehydrated, the threshold for the onset of sweating is raised and the maximum sweat rate is either reduced or totally abolished (Schmidt Nielsen *et al,* 1957; Bianca, 1965 and Zeini Filali, 1987). Meanwhile, the respiration rate decreased by 30-40% and sweating rate dropped to 20 % in dehydrated camel in summer (Deepti-Khanna *et al,* 2000).

In summer, water deprivation resulted in increased plasma osmolarity (Siebert and Macfarlane, 1975), and decreased plasma volume (Zeine-Filali *et al,* 1992). The osmoresceptors activate the production of the antidiuretic hormone arginine-vasopressine, AVP (Ben Goumi *et al,* 1993). This hormone helps conserve water. As water deprivation progressed the sweat rate is decreased. This decrease may be due to the increase in the plasma osmolality through the days of water deprivation. Moreover, the sweat reduction or suppression during dehydration could be the result of reduction in normal gland stimulation and not loss of sensitivity at the glandular level. Sweat glands remain functional even during dehydration (Zeine Filali *et al,* 1992).

Another mechanism may be attributed to the high water-holding capacity substances, mucopolysacharides, abundant in the sweat gland of camels (El-Zeiny, 1986; Ghanem *et al,* 1999), which constitute a physical means of reducing the rate of water seepage and loss by evaporative cooling, and/or due to selective brain cooling which is enhanced under conditions of water deficit (Jessen, 1998 and Dahlborn *et al,* 1987).

Sweat urea losses

Present results also indicated that all urea, sodium and potassium excreted in sweat followed changes in sweating rate. Output increased in animals kept outdoors as compared to indoors, and in summer as compared to spring. In water deprived animals, on the other hand, Na and K output decreased as the sweating rate decreased whereas urea output remained unchanged.

It is known that sweat urea is derived from blood urea (Slegers, 1966), but there is a lack of association between sweat and serum urea concentrations. The present results indicated a significant increase in serum urea concentration

in the water deprived camels, which may be due to the decrease in body water content and plasma volume (Macfarlane *et al,* 1962, Ben Goumi *et al,* 1993, Igbokwe, 1997 and Abdelatif *et al,* 2010). The urea appears to play a significant role during dehydration, by the osmotic effect; urea attracts the water of other media towards the plasma. Therefore, the metabolism of urea is strongly influenced by dehydration. The present results were in agreement with those of (Ben Goumi *et al,*1993; Ayoub and Saleh, 1998; Kataria *et al,* 2002) on camels.

In humans, sweat urea concentration is greater than serum concentration. In camels, the present study showed that the sweat-serum urea ratio was always less than "one." The final sweat concentration depends upon the rate at which it is secreted in the coil of the sweat gland and by subsequent ductal modification (excretion or absorption). Therefore, it is influenced by the sweating rate because ductal modification is a function of the flow rate (Taylor *et al,* 1994). Thus, the sweat-serum urea ratio in camels (less than "one") possibly indicates net reabsorption in the duct of the sweat gland. That is in man, sweat is a means for urea excretion whereas the camels can conserve some of the urea excreted in sweat as observed in the difference between high and low protein intake groups in the present experiment when the camels were water deprived. If so, the sweat glands in the camels play a role in urea conservation possibly similar to that of the kidney (Farid *et al,* 1979) especially under adverse physiological and nutritional conditions.

Sweat sodium and potassium losses

In the present study, the sweat to serum concentration ratios of sodium and potassium were persistently greater than "one", indicating net secretion in the secretory coil of the sweat glands. The effects of the environmental elements were much more pronounced in the case of potassium. Sweat to serum concentration ratios ranged from 1.2 to 2.0 for sodium and 68 to 128 for potassium for the different experimental treatments. Therefore, the sweat output of potassium was much greater than that of sodium even though its serum concentration was much less than sodium. There are suggestions (Grand *et al,* 1967; Sato and Dobson, 1970a) that aldosterone may play a role modifying excretion and reabsorption of sodium and potassium in the duct of the sweat gland. This warrants further experimentations. The decrease in sweat Na/K ratio suggests the presence of Na^+ - K^+ exchange in the duct as in the distal tubule of the kidney (Sato *et al,* 1971).

The presence of Na^+, K^+ and ATPase has been demonstrated in both duct and secretary coil (Sato and Dobson, 1970b; Sato *et al,* 1971; Gibbs *et al,* 1967). Aldosterone also reduces sweat rate (Dobson and Selgers, 1971; Grandchamp *et al,* 1968). There are, however, several reports of both reduction in sweat rate and increase in sodium concentration after administration of ADH (Fasciolo *et al,* 1969; Quatrale and Spier, 1970; Slegers and Van Hot-Grootenboer, 1971).

Changes in sodium and potassium output in response to housing environment and season of the year, and water deprivation, paralleled that of the sweating rate. They all increased in camels housed outdoors as compared to indoors, in summer as compared to spring, and decreased in the water deprived camels. Maximum output of sodium and potassium were in the order of 1.0 and 3.4 $g/m^2/hr$ as observed in late summer. Although the camels' maintenance requirements of sodium and potassium are not known yet, it is believed that the sweat losses may not be significant under the present experimental conditions. Losses may be significant under more adverse conditions such as in pack camels in the hot Sahara desert. Water deprivation may counter-balance the adverse environmental effects enabling the camel to conserve electrolytes.

Further studies on the physiology of the sweat glands of camels and the role of neural and endocrine factors in the control of sweating and electrolytes homeostasis are areas for further investigations.

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