Milk production, fluid balance and temperature regulation in lactating camels *(Camelus dromedarius)*

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Abstract

The aims of this thesis were to identify good milking and watering routines for camels, and to better understand the physiological mechanisms that enable camels to produce milk during long periods of water deprivation. Milk production was increased by changing the number of milkings from one to four times per day in an on-farm study. Camels that calved in the long dry season had a higher lactation yield than those that calved in the wet season. Seven camels were subjected to four watering regimes, each 16 days long with 5 days of daily watering in between. The regimes were: water offered once every day (W1); offered on days 4, 8, 12 and 16 (W4); on days 8 and 16 (W8) or on day 16 (W16). Milk yield decreased after about 8 days of water deprivation, and changes in milk fat, lactose and protein concentrations remained small during W16. Contrary to widespread belief, dehydrated camels did not dilute their milk, instead milk and blood plasma osmolality increased in parallel. Camels saved water by storing heat during daytime allowing body temperature to increase, and dissipating the heat during the cool night. Afternoon body temperature was around 39.0°C in all treatments but fell by 3 to 6°C at night, with the lowest recorded values in severely dehydrated camels. Despite low morning body temperatures, camels sought shade to avoid evaporative water loss but after drinking, they spent more time in the sun. Water deprived camels are known to compensate the number of kilograms of body weight lost by drinking equivalent number of liters of water, and this has been assumed to indicate a full recovery. However, diminished food and salt intake, and sodium loss via urine and feces, are seldom considered. During dehydration, W16 camels increased plasma vasopressin levels, which decreased upon drinking, but aldosterone concentration increased to retain sodium and camels took more than two weeks to recover. Camels maintained milk production during 8 days of water deprivation, to improve milk production, more frequent watering is recommended in the dry season.

Keywords: aldosterone, camel, body weight, milk osmolality, blood plasma, temperature regulation, water deprivation, vasopressin.

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Dedication

To My father Ato Kebede Tafesse
Who passed away while I was a student at SLU

Contents

Appendix

This doctoral thesis is based on four papers listed hereunder, which will be referred to their Roman numerals in the text.

Paper I
Milk production performance of the one humped camel *(Camelus dromedarius)* under pastoral management in semi-arid eastern Ethiopia.
Bekele, T., M. Zeleke, and R.M.T. Baars
Livestock Production Science, 76 (2002) 37-44

Paper II
Milk production and feeding behavior in the camel *(Camelus dromedarius)* during four watering regimes.
Bekele, T., N. Lundeheim, and K. Dahlborn
Journal of Dairy Science, (2010), Accepted for publication

Paper III
Effects of water deprivation on body temperature and behavior in the lactating camel *(Camelus dromedaries)*.
Bekele, T., K. Olsson, and K. Dahlborn
Manuscript

Paper IV
Salt and water regulation in the lactating camel *(Camelus dromedarius)*.
Bekele, T., K. Olsson, and K. Dahlborn
Manuscript

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Abbreviations

AVP = Arginine vasopressin
BW = body weight
DM = dry matter
EDTA= Ethylene dioxide tetra acetic acid
h = hours
L = liter
LSmeans = least square means
Kg = kilogram
Min = minutes
PAC= plasma aldosterone concentration
PCV = packed cell volume
RIA= radioimmunoassay
RPM = rounds per minute
SEM= standard error of least square
SNF= Solid non fat
TPP= total plasma protein
TS = total solids
W1 = camels watered daily
W4 = camels watered every 4^{th}
W8 = camels watered evey 8^{th} day
W16 = camels watered after 16 days

1 Introduction

The livestock sector in Ethiopia contributes 12 and 33 % of the total and agricultural gross domestic product (GDP) respectively, and provides a livelihood for 65% of the population. The sector also accounts for 12-15% of total exports (Ayele et al., 2005). Livestock contributes to the Ethiopian economy by providing food, inputs for crop production and soil fertility management, raw material for industry and cash income, as well as promoting saving, fuel, social functions and employment.

There are about 19 million camels on the Earth, of which 17 million are dromedary (one-humped) and the remainder bactrian (two humped) (FAO, 2004). About 15 million (78.9%) are found in arid and semi-arid African lands, particularly in the horn of Africa, including Somalia, Sudan, Ethiopia, Kenya, Eritrea and Djibouti.

Figure 1. *Camel producing areas of Ethiopia.(red color)*

Camelus dromedarius is supremely adapted to arid and semi-arid regions. The camel thrives in these harsh environments thanks to its tolerance of high ambient temperatures, drought and disease, and by browsing a wide range of plant species not utilized by other livestock. An appreciation of the value of camels in desert areas of Africa may be gained by reviewing data from 1973, when a major drought killed 150,000 pastoralists and millions of their livestock. While 100% of their cattle died, only 20-30% of camels were lost. Thus, when natural disasters take their toll on other indigenous animals, camels survive (Gauthier-Pilters and Dagg, 1981).

Ethiopia has about 1.03 million camels (FAO 1993), of which about 70 % are found in the eastern lowlands (CSA, 1988). Pastoralists regularly move between neighboring countries, states and zones, taking their livestock in search of water and good grazing land. Hence estimation of livestock numbers should be treated with caution at the national level. The Ethiopian dromedaries are found in southern and northeastern arid and semiarid regions, such as Ogaden, Afar, and Borana. The Somali, Afar and Borana are the main ethnic groups involved in camel husbandry in Ethiopia (Figure 1).

The camel plays a significant role as a primary source of subsistence in the lowlands of the country. It lives in wide arid and semiarid areas, which are not suitable for crop production and less suitable for other livestock production. Therefore, in this part of the country the camel is superior to all other livestock in terms of food security. With continuing land degradation and rapidly growing human population, the camel's importance will increase.

Knowledge about the physiological adaptations that make camels highly adapted to these regions is still insufficient, even though researchers in camel producing areas have been aware of this deficiency for some time. A clear understanding of the animal's physiological adjustments could improve the production of milk and meat. The information generated by studies in this thesis on different camel watering regimes is intended to improve milk productivity and may also provide a springboard for further field and on station investigations.

2 Background

2.1 Feeding and watering management

The camel's habitat is characterized by lack of water and high temperatures. There is a considerable seasonal variation in the availability of the amount and variety of forage. Pastoralists are well aware of the need for efficient utilization of their grazing land. Ogaden camels are fed both by browsing on low bushes, shrubs and trees and by grazing on grasses. Camels are long-range browsers, and cover large distances to meet their nutritional requirements. In the Errer valley, according to Kebebew (1999), camels consume mainly *Acacia brevispica, Opuntia vulgaris, Dickrostachys cinaria, Gadaba longifolia, Commiphora africina, Grewia bicolor, Rhynchosia velutina, Cordia somalenensis* and *Mourura crassififolia*. These species constitute the majority of the diet in most seasons. During dry, unfavorable conditions camels survive on drought tolerant and succulent plant species such as *Opuntia vulgaris*.

Camel watering is a laborious activity usually conducted jointly by a number of herders, especially when using well water. Water sources in the Ogaden camel area include wells, ponds and rivers (Abebe, 1991), whereas in the Jijiga area, they are mainly creeks, rivers and wells. In the Shinille area, intermittent rivers and riverbeds are the most important sources. Watering frequency depends on the availability of water sources, season and the capacity of the herders to pay money to the privately owned wells or ponds. Ogaden camels are watered every 10-15 days if a water source is nearby, however they can survive up to 30 days without being watered if no water source is nearby (Abebe, 1991). During the rainy season camels may not drink water for 1-2 months because the moisture of the plants is sufficient to meet their water requirement. Abebe (1991) reported that Ogaden camels can consume up to 200 liters of water after they have been deprived of water for long periods.

2.2 Milk yield

Camels were domesticated for the purpose of milk production (Epstein, 1971). They produce more milk for longer periods during drought than any other domestic animal adapted to arid habitats, and this is of great importance to pastoralists and agro-pastoralists.

The female camel has a four-quarter udder; one teat per quarter and two strip canals per teat. In the Errer valley and other parts of eastern Ethiopia, the milk let-down of camels is usually stimulated by a suckling calf and is of short duration. Therefore, the calf is quickly removed and the camel milked by two milkers on both sides of the animal simultaneously. There are a number of scientific reports concerning the milk yield of camels in nomadic areas of the world. The potential for high milk production exists, but there is a lack of organized research. According to Knoess (1976), average or poor quality Afar camels kept on irrigated Alfalfa pasture produced 2847 kg of milk during 14 months of lactation. According to Wilson (1984), milk production of the camel varies from 800-3600 kg during 9-18 months of lactation.

Milk production by camels kept in Eastern Africa has been reported as 5-6 L/day (Hussien, 1989), 10-15 kg/day (Knoess, 1980; Yagil, 1982), 12-20 L/day, (FAO, 1993), 8-10 kg/day (Abebe, 1991), 5 kg/day (Gedlu, 1996), 7.5 L/day (Kebebew, 1998), 4.5 kg/day (Tezera, 1998) and 1.5-3.1 L/day in eastern Ethiopia (Zeleke and Bekele 2001). Although there are discrepancies in reported milk yields, researchers and herdsmen agree that camels continue to lactate during dry seasons, and that camel milk is often the only nourishment available to humans during droughts. Camel breeds with very high milk production potentials are suspected to exist, but this has not yet been addressed by animal scientists.

The aim of pastoral dairy management is an animal with extended lactation, able to rear a calf without losing too much body condition and then conceive again (Hashi, 1988). Sustained milk output rather than high yield is far more important. The length of lactation in camels can be up to 18 months.

2.3 Milk Composition

A study of Ethiopian camels reported the % fat, SNF, protein, lactose, ash and water as 5.5, 8.9, 4.5, 3.4, 0.9 and 85.6%, respectively (Knoess 1976). Yagil and Etzion (1980a), reported the milk composition of camels with ample provision of water as 4.3, 14.3, 4.6, 4.6, 0.6, 1.01 and 85.7%, fat, SNF, protein, lactose, density, ash and water respectively. The same authors reported milk composition in dehydrated animals as 1.1, 8.8, 2.5, 2.9, 0.35, 0.96 and 91.2% in fat, SNF, protein, lactose, density, ash and water respectively. It was claimed that, when camels are exposed to seasonal water shortage, there is a change in the water content of the milk to provide fluid to the calf (Yagil, 1982).

Studies in the Errer valley (Kebebew 1998) report camel milk fat content as, protein, total solids, SNF, and casein 4.2 ± 1, 3.0 ± 0.6, 12.8 ± 1.6, 8.7 ± 1.6 and 2.4 ± 0.5% respectively. Although variation between camel individuals in fat quantity was found, values were well within the range reported by studies in other countries. The mean milk composition for Bedouin camels has been reported as 2.79, 4.81, 3.39, 0.77, 11.5% protein, lactose, fat, ash, and DM, respectively (Guliye, et al., 2000). Based on 82 reports, average camel milk composition could be summarized as 3.82 ± 1.08, 3.35 ± 0,62, 4.46 ± 1.03, 12.47 ± 1.53 and 0.79 ± 0.09, for fat matter, total protein, lactose, DM and ash, respectively (Konuspayeva, et al., 2009).

Camel milk has a higher level of Vitamin C than other animals, and the concentration of vitamins B1 and B12 are equal or higher than those of *e.g.* Afar sheep in Ethiopia (Knoess, 1979). The high level of vitamin C is especially important for the nomadic pastoralists, for whom fruits and vegetables are a rarity.

2.4 Growth and body weight changes in camel

The main constraints to improvement of productivity of dromedar herds are low daily body weight gain and high calf mortality (Ismail, 1990). In other domesticated animals, decreased nutritional intake markedly decreases growth of calves and delays the onset of puberty (Formigoni, et al., 1996). Compared with other domesticated animals, however, the camel has a slow growth rate (Wilson, 1984). Simpkin, (1985) reported that camels between the age of 1 to 3 years grow better than camels aged 3-4 years. Early growth is dependent on the amount of milk left for the calf. In pastoralist areas, the major production goal is milk used both for the family and for sale, thus there is always competition between the pastoralist and the calf.

The intrinsic growth capacity of individual animals is mainly governed by genetics, but proper management and nutrition are also important (Iqbal and Khan, 2001). Average monthly growth rates of camel calves are reported to range between 21.6 to 25.9 kg, but high ambient temperature combined with restricted milk feeding can slow this rate (Zekele and Bekele, 2001). In Sudanese camel calves, Bakheit et al (2009) found that camels managed and raised under semi-intensive and traditional systems did not differ in birth weight. These camels were followed for 18 months of growth, and the overall mean daily weight gain of calves under semi-intensive management (535 ± 9.83 g) differed significantly from the traditional system (317 ± 5.46 g).

A study in Egypt with 24-month old camels showed that animals that received supplement gained 950 g/day whereas those that did not gained 886 g/day, although this difference was not statistically significant (Mohamed, 2007). Another study conducted in Niger over four years found that camel calves born during the wet season or at the beginning of the dry season were 10% heavier and grew 10% faster than those born in the hot dry season (Pacholek et al. 2000). This illustrates the importance of ample milk supply and availability of browsing during the wet season. Females were heavier than males at birth, but when the chest girth was 0.9 m the opposite was true (Pacholek et al,. 2000). Live weight at birth was 32.73 ± 3.63 kg for females and 30.59 ± 3.71 kg for males, but at 0.9 m girth it was 168.8 ± 2.9 kg for females and 174.0 kg for males. Megersa et al (2008) recorded an increase in annual herd growth rate of 5.7% in 2003 and 14.9% in 2004.

2.5 Thermoregulation

Body temperature is regulated mainly by nervous feed-back mechanisms from the periphery to the hypothalamic region of the brain, and the hypothalamus itself has neurons which respond to differences in temperature (McKinley et al., 2008).

Homeothermic animals continuously balance heat loss and heat production to maintain a near constant body temperature. The camel is not a strictly homoeothermic animal however because its body temperature varies according to alterations in ambient temperature (Schmidt-Nielsen, 1964).

The ability of camels to elevate body temperature when ambient temperature increases, store the heat inside the body, and dissipate it when it becomes cooler is an important adaptation for minimizing water loss through evaporative cooling. With increasing dehydration, the difference between morning and afternoon temperatures increases, as Schmidt-Nielsen et al (1967) elegantly illustrated. Later studies confirmed that a similar difference between day and night rectal temperature exists in several desert-adapted wild ruminants (Taylor, 1970).

A fully hydrated camel starts sweating at 36.5 °C, but 6 days of dehydration raises that threshold to 38.0 °C and, if dehydrated for 8 days or more, camels do not sweat even at higher temperatures. Additionally, the camel reduces water loss in feces and urine. By contrast, goats use both sweating and panting for evaporative cooling (Robertshaw and Zine Filali, 2004). Ethiopian Somali goats, studied at the same station in Errer Valley as the camels in this thesis, had a diurnal variation in rectal temperature of 3.5°C. The difference was similar when the goats were watered daily or water deprived for four days (Mengistu, 2007).

2.6 Efficient use of water and importance of sodium ions

Mammals must maintain a balance between input and output of water and sodium ions to keep the extracellular fluid volume within narrow limits. This homeostatic control of fluid balance depends on the regulation of release of antidiuretic hormone (vasopressin) from the neurohypophysis which prevents losses of water via the urine, and on an efficient thirst mechanism. When no drinking water is available, the animals become dehydrated, the solute concentration of the body fluid increases and both intracellular and extracellular fluid volumes are reduced (Anderson, 1971).

Hormonal and neural factors also act jointly to maintain salt balance. If animals do not obtain enough sodium from their food, the sodium concentration of the body fluids decreases and, due to osmotic action, the extracellular fluid volume including the blood volume decreases. This is sensed by cells in the kidneys. These cells produce renin, which starts a series of reactions leading to secretion of the sodium-retaining hormone aldosterone from the adrenal cortex (Andersson, 1971). In addition, sodium depletion in many species also gives rise to specific sodium appetite which provides a motivation to seek and ingest salt (Denton, 1982).

Tropical animals adapted to marginal desert lands are subjected to constant seasonal water shortage, but they have developed several survival mechanisms such as increasing core body temperature, storing water in the rumen and adjusting their behavior to minimize the loss of the water (Schmidt-Nielsen et al., 1956; Macfarlane et al., 1963). The Ethiopian Somali goat, which lives in the same region as camels, allows the rectal temperature to fluctuate, can store water in the rumen, and can choose shade or sun depending on hydration status (Mengistu, et al., 2007).

According to Shkolnik et al. (1980), camels can tolerate up to 25%, cattle up to 18%, and black Bedouin goats more than 40 % loss in body weight. Over a period of 15-21 days without drinking, camels lose more than one third of their body weight (Macfarlane, et al., 1971, Schmidt-Nielsen, 1964, Yagil, 1985). Macfarlane et al. (1963) suggested that the majority of body weight lost during dehydration is from the gastro-intestinal tract.

Milk production demands extra water (Dahlborn, 1987b). In the wet season in arid areas, camels depend entirely on the moisture found in grazing and browsing materials and are not watered at all by pastoralists. In the dry season, experienced herdsmen water lactating camels every 7-15 days to avoid a diminished milk production. This shows the importance of regular watering for lactating camels (personal observation).

2.7 Behavior

Physiological adaptation is one of the important mechanisms that allow camels to survive in the harsh environment of the desert, but behavioral adjustments are equally vital to survival and reproduction. Camels are generally good-tempered and patient animals. Arid and semiarid areas have high ambient temperatures and cold night temperatures which, in most cases, are not hospitable to either humans and animals. Animals adapted to these areas show an interesting behavior when the temperature is very high during the day time. On very hot days, one humped camels form closely packed groups, reducing the impact of heat reflected from the ground.

In a study with four suckling female camels that were observed for 600 min/day, animals spent 464 min (77.3%) grazing and 135 min (25.5%) resting. After the camels returned to their enclosure for the night, they spent 573 min (68.1%) on rumination and the remaining time resting (Khorchani et al. 1992). In an another study conducted in Thai regions of Pakistan

(Khan et al., 1998), the time spent by camels on grazing, rumination, idling and resting/sleeping was recorded at 37.4, 31.7, 26.5, 4.4 percent of a 24 hr period respectively.

3 Aims

The aims of this study were to produce knowledge about the milk production potential, and the physiological responses of lactating camels to periods of water deprivation.

Specific aims:

- To investigate the lactation characteristics of camels in selected herds managed by pastoralists
- To investigate the effects of different water restriction periods on milk yield and composition
- To investigate changes in blood plasma osmolality and total plasma protein during normal conditions and water and salt deprivation
- To investigate changes in plasma vasopressin, aldosterone and cortisol during normal conditions and water and salt deprivation
- To clarify contradictory results on the ability of camels to dilute milk during dehydration

To follow changes in blood plasma during recovery after water and salt deprivation.

4 Materials and Methods

4.1 Study area and experiment facilities

The Ethiopian dromedary is found in the south-eastern and north eastern arid as well as semiarid regions, such as Ogaden, Afar and Borana. The Somali, Afar and Borana are the main ethnic groups involved in camel husbandry in the country. These groups live in wide arid and semiarid areas that are unsuitable for crop production and less suitable for other livestock production (Figure 1). Therefore, in this part of the country the camel provides food security that is superior to all other types of livestock.

The Errer valley is located in Babile district in the eastern Oromia regional state. The Oromo and Somali camel herders that live here rely mainly on livestock production with camel as the dominant animal. Haramaya University has established a camel research center in the Errer valley to undertake on station experiments (Figure 2). The valley lies in the transitional zone between the intensively cropped areas of the northern highlands and the Jijiga plain and lies at an altitude of 1300 m to 1600 above sea level. The vegetation of the area is diversified according to geological and edaphic conditions, with *acacia* and *cacti* as the predominate vegetation types. The typical climatic condition of the area is, according to Tamire (1986), semi-arid with rainfall ranging from 400 mm to 500 mm, although the lower part of the valley receives less than 400 mm. The rainfall pattern is weekly bi-modal with two peaks, one in March to April and the other in July to mid-October, and relatively little in May to June. The long dry season is from mid-October to the end of February.

4.2 Errer valley research station

The camel research station in the Errer valley occupies 3 ha surrounded by barbed wire to separate camels from animals in the nearby village as well as from wild intruders. The Haramaya University camel herd is located in a village within 3 minutes walk of the station. Several researchers use the station for studies as well as for teaching. Between experiments, camels are managed together with the pastoralists' herd. Inside the fence is a paddock (24 m x 30 m) with 8 poles on one side designated for each camel used in the current experiment. At night camels are kept in a pen (6 m x 6 m) and calves are kept together in a separate pen (3 m x 3 m). A small wooden office covered with corrugated iron was built inside the paddock and used by technicians and researchers during data collection. The camels were released from the paddock to graze and exercise during the 5 day interval between the experiment periods.

Figure 2. Haramaya University Camel Research Station, Errer Valley, Ethiopia. Camels are standing tied to separate poles.

4.3 The field study (Paper I)

A field study on milk production performance was conducted in the Errer valley using the pastoralists' camels, based on their willingness to participate in the study. The animals used in the experiment were selected using purposive sampling. Nine households with a total of 101 camels were selected. An inventory of the herds was performed, and information on age, sex, parity, month of pregnancy and lactation month were recorded, and data files were opened to enter data each month. The pastoralists selected for this study were from the Somali ethnic group. The management of the camels in each household was largely similar (although it may have differed in certain respects), and their browsing and watering area was the same.

The feeding management was based on the natural browsing and grazing vegetation in the surrounding area and all the camels regardless of sex and age were managed together. They were watered only during the dry season on a weekly base, whereas during the wet seasons they were mainly dependant on the moisture present on the browsing and grazing vegetation. Camels were supplied with salt once a month by their owners. The pastoralists were given salt and health care services as incentives for participating in the study.

4.4 Milking procedure

The milking procedure was the same in the field study (Paper I) and in the experimental study (Papers II, III, IV).

In all the households selected for the field study, the calf was allowed to start suckling to elicit the milk let-down reflex (Figure 3). After a few seconds the calf was moved aside and the camel was milked by two men standing on opposite sides of the animal (cover picture). The milk volume was immediately measured using a graduated cylinder. The milking was done in the morning, late morning, evening and late evening for experiment I. Sixty- one lactations were followed and 2386 samples were analyzed.

Figure 3. Suckling camel before milking.

4.5 The experimental studies on station (papers II, III, and IV)

Eight lactating camels at different lactation stages and ages were selected. Three of the camels were part of the Haramaya university herd managed by pastoralists and the remainder were purchased for the study from Babile livestock market.

Before the start of the adaptation period, the camels were clinically examined by a veterinarian for any physical or clinical abnormalities. Fecal samples were collected and both qualitative and quantitative examinations were done. All the camels were infested with strongyle eggs and were treated with anti-helminthics. Ticks were also found on the camels and all animals were sprayed with acaricide against ticks and other ectoparasites prevalent in the area. Blood samples were collected, thick and thin blood films were prepared and, after fixation and staining with Giemsa, checked for possible trypanosomiasis. All camels tested negative for trypanosomes, which are prevalent in the Errer valley.

After all the camels had been found healthy and fit for the experiment they were given ten days to adapt to the experimental procedures. The purchased camels were unaccustomed to concentrate feeding, in contrast to those from the University herd. The camels were offered hay *ad libitum*, supplemented with 6 kg of concentrate distributed three times per day. For composition of the hay and concentrates, see Paper II.

During the adaptation period, all persons involved were informed about procedures, responsibilities, measurements and registration of data. All measurements were done by the researchers and the same trained technicians throughout the experiment.

A Latin square design was used with the following treatments: W1- watering of camels every day, W4- watering of camels every four days, W8- watering of camels every eight days and W16- watering of camels after sixteen days. The experiment period for each treatment group was sixteen days with five days rest before the beginning of the next trial. For the order of treatments in individual camels, see Table 2, Paper II.

The principal time schedule for the experiment was as follows (for details see papers II, III, and IV):

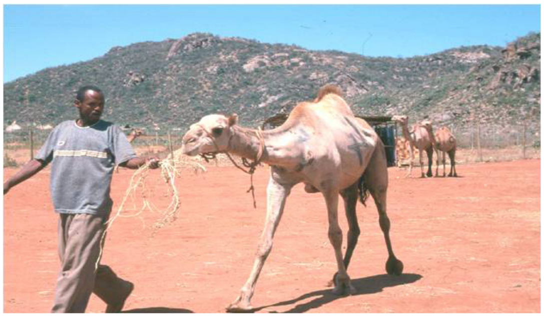
0700 - 0900 h tied up, fed hay and concentrate, milked
0900 - 1200 h released to move freely in the paddock
1200 – 1300 h h, tied up, fed hay and concentrate
1300–1315 h allowed to drink offered water, thereafter, released to walk freely in the pen
1700-1900 h tied up, fed hay and concentrate, milked

After each period the camels were watered daily during 5 days and were allowed outside the paddock, but kept within the fence.

4.6 Data collection (Papers II, III, IV)

The milking procedure was the same as for the field study, but milking was only performed morning and afternoon. The volume was measured in graduated cylinders and a well-mixed sample was taken at each milking from each camel. Camels were weighed daily at noon using a digital scale (Figure 4).

Respiratory rate was counted by flank movements three times a day at 0700, 1200 and 1700 hrs, and the rectal temperature was measured with a digital thermometer (Paper III). Camels were watered according to their watering regime, and the amount of water drunk was recorded (Paper IV). Blood samples were taken from the jugular vein after cleaning the puncture site with alcohol on days 1, 4, 8, 12 and 16 in each period, always before watering. The blood was collected in pre-chilled 5 ml Li-heparin venoject tubes with vacutainers. For hormone analysis, 10 ml of blood was collected into tubes containing K_3-EDTA.



Step 1

Step 2

Step 3

Figure 4. Body weight measurement of camels (steps 1-3).

4.7 Handling of blood and milk samples

Samples were transported in a box with ice clamps to the Anatomy and Physiology laboratory, Haramaya University campus. Capillary tubes were used to determine the PCV of blood. The blood was centrifuged at + 4 °C (2000 rpm/min) for five minutes and the plasma transferred to two tubes; one containing Li-heparin was used to determine the osmolality immediately and the other was stored at - 20 °C. All plasma from the K_3-EDTA-tube was stored immediately at - 20 °C .

Analyses of plasma sodium and potassium were done by flame photometry, and total plasma protein concentration was determined with a refractometer (for details, see Paper IV). The analyses of vasopressin, aldosterone, and cortisol were done with commercial radioimmunoassay kits after validation in camel plasma (for details, see paper IV)

4.8 Behavior

In paper II, the feeding behavior of each camel was recorded every 5 min from 0700 to 1200 h and from 1300 to 1800 h. The measurements were performed only on days 11 and 15 in each period, *i.e.*, the days when the camels were most dehydrated before watering on day 12 and 16, respectively.

In paper III, behavior was recorded by the same observer on Days 3, 4, 7, 8, 11, 12, 15 and 16 in every period. Behavioral data were collected during twelve direct spot observation sessions every 30 minutes, six in the morning starting at 0930 h and finishing at 1200 h, and six in the afternoon starting at 1400 h and finishing at 1630 h. At each session the activity of the camels (walking, standing, or lying down) was recorded on a score sheet. It was noted if the camel was in the feeding areas, partly in shade or at other places in the paddock (Paper III). Partly in shade was defined as: a camel being close enough to the storage shed to have part of its body in shade, or putting its head and neck into the opening of the shed (Figure 5).

Figure 5. Camel seeking shade in the storage shed. The number on the side was for identification during behavioral studies.

5 Results

5.1 Milk production and composition in camels kept by pastoralists

Milk production in the pastorally managed camels was influenced by a number of factors such as parity, season of calving, calf death and household size (Paper I). The overall mean daily milk offtake of camels was 4.14 ± 0.04 kg/day. During the first three months of lactation the mean daily milk offtake was 4.19 ± 0.07 L, between 3 - 6 months it was 4.86 ± 0.07 L, but during the remaining period of lactation a decline in milk offtake was observed. The milk offtake was based on watering camels every week by pastoralists, and no watering days during the wet season. The number of milkings per day was important for total milk yield. The milk offtake was 6.77 ± 0.15 kg/day in camels milked four times a day, 4.70 ± 0.05 kg/day in those milked three times a day and 3.67 ± 0.08 kg/day in those milked twice a day.

The duration of lactation varied between 7-18 months, with an average of around 12 months (353 ± 14 days). The lactation days showed variation based on the parity of the camels. The longest time was obtained for parity 6 (406 ± 6 days) and the shortest for parity seven and eight (291 ± 90 days). The mean lactation offtake was 1422 ± 7 kg with highest for parity five (1694 ± 19 kg) and the lowest for parity 7 and 8 (703 ± 175 kg). Camels that lost their calf produced on average 3.75 ± 0.09 kg/day and those with their calf produced 4.22 ± 0.04 kg/day. The milk offtake was lower from camels without a calf (1188 ± 146 kg), than from those with a calf (1492 ± 81 kg). Shorter duration of lactation (330 ± 16 days) was recorded for camels that lost their calf compared to camels with a surviving calf (352 ± 18 days).

The milk offtake was also compared among the nine participating households. One household produced a milk offtake of 6.01 ± 0.13 kg/day compared to the other households that had an offtake in the range of 3.17 ± 0.13 to 4.68 ± 0.14 kg/day. The mean monthly milk offtake was 4.46 ± 0.13 kg/day in April compared to 3.31 ± 0.14 kg/day in February. In most wet months the yield was higher than in dryer months.

5.2 Milk production and composition in the experimental camels

In camels watered daily, initial milk yield was 2.0 ± 0.7 L and increased to 2.5 ± 1.2 L on day 16. In camels watered every four days, initial milk yield was 2.1 ± 0.6 L and was 1.9 ± 0.7 L on day 16 (Paper II). In camels watered every eight days, initial milk yield did not differ from the other watering regimes (2.3 ± 0.9 L declining to 1.8 ± 0.9 L on day 8). When the camels were deprived of water during sixteen days, yield fell significantly from 2.2 ± 0.7 L initially to 1.3 ± 0.7 L on day 16.

In camels watered every day, every four days and every eight days percentage fat content did not change, but in camels watered after sixteen days of dehydration, the fat yield tended to decline. The protein yield and percentage content showed no marked difference among the days of dehydration in camels watered every day, every four days, and every eight days, whereas in camels watered after sixteen days of dehydration there was a decline in protein yield from day eight, but the change was significant only from day 12 onwards.

Compared to W1, W4 and W8 the level of lactose in W16 was low, and the difference was significant at day 12. However, for the other treatment groups there were no significant changes during the days of dehydration. The total solids increased for camels watered daily (W1) but for camels dehydrated for sixteen days (W16) it fell to its lowest level at day 12. There was also a difference between watering regimes W1 and W8 at day 7, but this disappeared after watering on day 8. The differences observed between W1 and W4 were not statistically significant.

5.2.1 Feeding behavior

Camels watered daily (W1) spent more of their time feeding on hay and concentrate than camels subjected to dehydration for 8 (W8) and 16 (W16) days. Time spent feeding on hay was similar for camels on W1 and W4, respectively, but these treatments differed in the time spent on concentrates.

Time feeding on hay and concentrate for camels on W4 was comparable with W8, but was significantly shorter on W16. When camels were dehydrated for sixteen days they spent significantly less time on rumination and the time for feeding in the last two days of dehydration compared with all other treatments,.

On checking the protocols after the experiments were finished some further, interesting details became apparent. It was noted that camels spent most time at the hay in the mornings when ambient temperature was low and the shortest time between 1300 - 1530 h when the ambient temperature was at its peak. On watering days, however, camels fed between 1300 – 1530 h. One camel stopped eating completely on the 12th day during W16 and was therefore offered water. It recovered completely and thereafter participated in the other three treatments. As dehydration became prolonged, camels became more passive and tried to seek shade (see also paper III).

5.3 Thermoregulation (Paper III)

The lowest mean environmental temperature was 19.6 °C measured at 0700 h and the highest was 33.1 °C measured at 1200 h. During all treatments, the camels' rectal temperature showed a regular diurnal pattern with low values in the morning and high values in the late afternoon.

5.3.1 Rectal temperature.

The mean morning rectal temperature during daily watering was 35.6 ± 0.2 °C, which was significantly higher than in all dehydration treatments, with a minimum of 35.0 ± 0.2 °C, in W16. At noon, the rectal temperature in W16 had increased to 37.3 ± 0.1 °C, but this was still significantly lower than the 37.8 ± 0.1 °C registered in daily watered camels. At 1700 h, mean rectal temperature was 38.8 ± 0.1 or 38.7 ± 0.1 °C. The lowest morning temperature registered was 32.7°C, and the mean afternoon temperature did not differ significantly between treatments.

The lowest rectal temperature registered during the experiment was 32.7 °C and the highest was 40.0 °C. The mean temperature variation was 3.2 °C in camels watered daily and 3.8 °C in those dehydrated for 16 days. A difference of between 5-6°C between morning and evening occurred at several occasions in individual camels.

5.3.2 Respiratory rate.

The respiratory rate showed a diurnal pattern similar to that of rectal temperature, but peak levels were reached at noon. The mean morning respiratory rate was 6.0 ± 0.2 breaths/min inW1, W4, and W8, but in W16 it decreased from 6.5 ± 0.2 breaths/min during the first 8 days to 5.1 ± 0.2 breaths/min ($P < 0.001$) during days 9 – 16.

5.3.3 Behavior

Camels spent their time at different places in the paddock between meal times. In all treatments camels had at least part of the body in shade on more occasions in the morning than in the afternoon, and this was accentuated on days when they drank at noon. The difference was most apparent on day 16 when all camels had access to water at noon and then spent the afternoon in the sun.

Hay was freely available on the ground in the middle of the paddock and hanging on the poles (Figure 4). There was no shade in these parts of the paddock and camels spent most of their time at one of these places when they were not seeking shade. Camels spent the majority of their time standing, with no significant difference between treatments (Figure 5). They lay down significantly more often during the afternoon than during the morning in W1 ($P < 0.001$) and W16 ($P < 0.001$) and during the afternoon more in W1 than in W4 ($P < 0.05$) and W8 ($P < 0.001$). Camels walked significantly more often in W8 than in W1 ($P < 0.05$).

5.3.4 Concentrate intake

As the duration of water deprivation increased, camels ate smaller amounts of concentrates. During the first week of each treatment they consumed an average of 5.3 ± 0.4 kg in W1, which was significantly more than in the other treatments, 4.2 ± 0.4 kg in W4 ($P < 0.01$), 3.3 ± 0.4 kg in W8 and 3.8 ± 0.4 kg in W16 (both, $P < 0.001$). During the second week, consumption did not differ significantly from the first week within treatments , but during W16 camels consumed only 1.6 ± 0.4 kg.

5.4 Salt- and water regulation

5.4.1 Water intake.

In W1, with access to water once daily, camels drank on average 17 ± 5 L/day. In W4 the water deficit was compensated by drinking 47 ± 5, 49 ± 5, 46 ± 5, and 53 ± 5 L on the four days when water was available. In W8, they drank 72 ± 5 L on day 8 and 72 ± 5 L on day 16. In W16, after 16 days without water, they drank 88 ± 5 L. The total water intake was 254 ± 25 L in W1, 195 ± 16 L in W4, 140 ± 12 L in W8 and 88 ± 5 L in W16.

5.4.2 Body weight changes.

In W1 body weight increased from 436 ± 16 to 465 ± 16 kg from day 1 to day 16. In W4 the camels initially weighed 461 ± 16 kg and lost on average 27, 21, 16, and 16 kg during each 4 days of water deprivation, each time replenished by drinking. In W8, camels weighed 463 ± 16 kg on day 1, decreased by 56 kg to day 8 and weighed 412 ± 16 kg on day 16. In W16, camels weighed 459 ± 16 kg on day 1 and decreased to 368 ± 17 kg after 16 days without drinking water, corresponding to a total body weight loss of 20 %.

5.4.3 Plasma osmolality, sodium and potassium concentrations.

The initial plasma osmolality of W1 camels was 314 ± 2 mosm/kg. In W4, plasma osmolality increased from 313 ± 2 to 327 ± 2 mosm/kg after 4 days without water and reached similar levels after each 4 day period. In W8, plasma osmolality increased from 318 ± 2 on day 1 to 338 ± 2 mosm/kg on day 8, decreased after watering then increased again to 337 ± 2 on day 16. In W16, plasma osmolality was 318 ± 2 on day 1, 327 ± 2 on day 4, 338 ± 2 on day 8, 343 ± 2 on day 12, and 346 ± 2 mosm/kg on day 16. Plasma sodium concentration showed a similar pattern to that of plasma osmolality.

5.4.4 Total plasma protein concentration.

Mean total plasma protein concentration (TPP) was 67 ± 2 g/L in W1 and 68 ± 2 g/L in W4, which was significantly lower than W8 and W16 (72 ± 2 g/L). TPP increased significantly during the first 8 days of water deprivation in W8 and W16. In W16, TPP increased from 66 ± 2 g/L on day 1, to 74 ± 2 g/L on day 8 and to 76 ± 2 g/L on day 16.

5.4.5 Plasma concentrations of vasopressin and cortisol.

The average plasma concentration of vasopressin was below 0.6 pmol/L (*i.e.*, the minimal detectable value) on the first day in all treatments, and remained low in W1. During dehydration days it increased significantly and the highest level recorded in W4 was 1.84 ± 0.39 pmol/L on day 12. After 16 days without water, plasma vasopressin concentration had increased to 2.87 ± 0.42 pmol/L (W16).

The mean plasma cortisol concentration was below 45 nmol/l in all treatments with no difference within or between treatments.

5.4.6 Plasma aldosterone concentration and recovery after 16 days of water deprivation.

On day 1, plasma aldosterone concentration was 1862 ± 406 pmol/L in W1 compared to 760 ± 406, 267 ± 406, and 208 ± 406 pmol/L in treatments W4, W8, and W16 respectively. This result prompted a further analysis of the data which revealed that, before the start of W1, five of the camels had had 16 days of water deprivation (the W16 treatment), whereas for the other two camels, water regime W1 was their very first experiment.

The camels drank 88 ± 5 L of water, corresponding to their body weight loss of 91 kg during W16, and the five day interval before the next experiment started was believed to be sufficient for recovery. However, it took more than two weeks for the camels to regain their body weight.

The mean salt intake was 27.8 ± 2.6 g/day in W1, 23.1 ± 2.6 g/day in W4, 17.1 ± 2.6 g/day in W8 and 14.4 ± 2.6 g/day during W16. This assumes that the salt was well mixed with the concentrate. Thus, the salt intake in W16 was only half of that recorded for W1.

6 Discussion

In this thesis, milk production of camels in the Errer valley, eastern Ethiopia was studied under natural conditions in the field (Paper I) and under experimental conditions at a research station in the same area (Papers II, III, and IV). The aim was to investigate the camels' physiological responses that enable them to sustain milk production during severe and prolonged dehydration.

6.1 Are camels good dairy animals in the Errer valley?

Milk production was the primary reason for the domestication of camels as farm animals in the arid and semi arid regions of the world (Epstein, 1971). The milk production characteristics of camels under traditional management by pastoralists in both dry and wet seasons were addressed in paper I.

Sixty one camels were studied for more than two years. Mean milk offtake of the camels was 4.14 ± 0.04 kg/day with a mean lactation length of 353 ± 14 days, resulting in a mean total offtake of 1422 ± 74 kg/lactation. A similar milk yield has been reported from a study in the United Arab Emirates (Wernery, 2004), based on 16 camels with a daily milk offtake of 4.8 kg/day. Khalil et al. (2007) report a daily yield of 3.04 kg for Saudi camels with a lactation yield of 1436 kg and a lactation period of 282 days. In Somalia, daily yield varies between 3-10 kg/day during the 12-18 month lactation (Farah et al., 2007). The highest offtake in the cited study was 13.75 kg/day in one camel in its thirteenth week of lactation, whereas most camels had a peak offtake of 5kg/day. In the same area, indigenous zebu cattle produce less than 2 kg/day. In most studies camels are also suckled by their calves and this amount is seldom reported.

In arid and semi arid lands where severe, prolonged and recurrent draughts decimate populations of cattle, sheep and goats, the camel is the only species that survives and continues to produce milk (Wernery 2006). The global milk productivity of camel is five times lower than cattle, but in its arid habitats, milk production of camels is higher than cattle (Wernery, 2006). In a study using Afar camels kept on alfalfa from irrigated pasture in north-eastern Ethiopia, Knoess (1979) found a lactation period of 14 months with a total yield of 2847 kg of milk. This illustrates that, if the feeding management of camels were improved, they could potentially provide milk for longer periods and achieve higher yields.

Milking frequency influenced milk yield (Paper I). Milking four times per day resulted in an average yield of 6.77 ± 0.15 kg/day compared with 3.67 ± 0.03 kg/day from two daily milkings. It has been found that increased milking frequency can improve milk yield by 10-15% (Allen et al., 1986), and cows milked six times a day had higher milk yields than those milked twice a day (Svennersten-Sjaunja, et al., 2002).

Lactation was affected by parity. Lactation after the fourth pregnancy resulted in the highest mean milk yield of 4.98 ± 0.10 kg/day, and camels in parity five had the highest lactation offtake whereas the first lactation and lactation after the seventh and eighth calves gave the lowest (Paper 1). Similar results were reported by Simpkin (1998) and Kebebew and Baars (1998).

The lactation characteristics discussed above illustrate the importance of the camel as a dairy animal in the environments to which it is adapted. During the field study it emerged that a demand exists for identifying an optimal watering schedule for lactating camels that will maintain or improve milk production and save the time and effort of bringing the animals to a water source.

6.2 How can camels tolerate water deprivation longer than other ruminants and still produce milk?

If no water is available an animal's body starts to conserve it leading to an increase in plasma osmolality, the first indication of dehydration (Andersson, 1971). As soon as water was withheld, the osmolality and plasma sodium concentration increased in the experimental camels (Paper IV) in agreement with earlier studies (Siebert and Macfarlane, 1975, Ben Goumi, et al., 1993, Dahlborn et al. 1997, Ayoub and Saleh, 1998, Achaaban et al., 2000, Al-Haidary, 2005). The increased plasma osmolality stimulated the release of vasopressin, which facilitates reabsorption of water from the distal convoluted tubule and the collecting duct of the kidney. This retains water in the body, maintaining plasma volume.

Although water was conserved in the kidney, camels lost 20% of their body weight after 16 days of water deprivation. This contrasts with the 30% body weight loss reported previously in non lactating camels after 14 days of water deprivation (Ben Goumi et al., 1993, Macfarlane et al., 1971, Schmidt-Nielsen, 1964). Thus, even though climatic conditions varied between the studies, the results suggest that lactating camels used their water-saving mechanisms to maintain body weight more efficiently than nonlactating camels. This is supported by the fact that plasma volume decreased by only 10-15 % after 16 days of dehydration, compared with a 40 % decrease in nonlactating camels dehydrated for 14 days (Ben-Goumi et al., 1993). The only other dairy animal in which plasma volume is better maintained during lactation than non-lactation is the Bedouin goat (Maltz and Shkolnik, 1984, Olsson et al., 1983). This may be one explanation for the camel's ability to maintain milk production, since blood supply to the udder is necessary for milk synthesis.

A 40% of loss of body weight during dehydration in Bedouin goats has been reported (Shkolnik et al., 1980) and attributed to a decline in both food and water intake as the dehydration period progressed. Immediately after drinking, the goats' body weight was regained. Camels compensate lost body weight by drinking a corresponding amount of water, as observed in this thesis (Papers II and IV) and other studies (Schmidt-Nielsen et al., 1956; Siebert and Macfarlane, 1975). This has been interpreted as an important adaptation to life in arid and semiarid regions (Schmidt-Nielsen et al., 1956; Schmidt-Nielsen 1964). Most of the required water can be consumed in one draft since it can be stored in the forestomach (Shkolnik et al.,1980).

When given access to water after 16 days of water deprivation, camels drank 88 L, corresponding to a body weight loss of 91 kg. Although this was assumed to have compensated their water loss, the animals had become sodium deficient, and their plasma aldosterone concentration was high when analysed 6 days after rehydration (Paper IV), not declining until 8 days later. Aldosterone acts on the kidneys and gastro-intestinal tract to reabsorb sodium, but the hormone cannot affect sodium excretion via the milk. This could be another mechanism allowing camels to maintain milk secretion.

6.3 Do camels dilute milk during dehydration?

It is a widespread belief that camels dilute their milk during water deprivation (FAO, 1993) and that this represents an adaptation to the harsh environment. However, this seems to be a misinterpretation of the changes in milk composition during water deprivation.

Milk osmolality increased in parallel with blood plasma osmolality in the current study (Paper IV), supporting a previous report on camels by Dahlborn et al. (1997). In Bedouin goats, milk yield fell by 35% of its initial value as milk osmolality and fat and protein concentrations increased during four days of water deprivation (Maltz and Shkolnik, 1984). Similarly, Ethiopian Somali goats increased milk and plasma osmolality and reduced milk yield during water deprivation (Mengistu, et al., 2007). Reduced milk production has also been reported in goats with 50% and 25% water restriction (Alamer, 2009). Therefore, it appears that desert-adapted ruminants respond in the same manner as other ruminants subjected to water deprivation, such as cows (Little and Shaw, 1978) and goats living in temperate zones (Dahlborn, 1987a).

In the studies on camels by Yagil and Etzion, (1980a,b), milk and plasma osmolalities were not measured, but the authors found decreased total solid content, fat, protein and lactate concentrations, and consequently a higher water percentage. This has been interpreted as milk dilution. However, when discussing water balance, the term 'dilution' is used if a body fluid has an osmolality lower than that of blood plasma, which never occurs in dehydrated animals.

6.4 How do camels save water for milk production?

Animals adapted to hot deserts regulate their body temperature over a much wider range than animals living in temperate zones. In camels the body temperature increases during the day, rising to even higher levels during dehydration (Schmidt-Nielsen et al., 1967). Passively allowing body temperature to increase by solar warming then fall during the night saves both energy and water, and can be observed in several desert-adaptive wild ruminants (Taylor, 1970).

If the body temperature rises too high, animals mobilize evaporative cooling by sweating and panting. However, as they become dehydrated, these evaporative cooling mechanisms are inhibited so that fluid loss from the body is reduced (Baker, 1989). Thus, increased osmolality signaling water deficit in the body affects another homeostatic mechanism, that of temperature regulation. These conflicting processes are coordinated by the hypothalamus (McKinley et al., 2008) and it appears that retaining water and electrolytes takes priority over temperature regulation. Indirect evidence suggests that the camel's coordinating center is in the hypothalamus, as in other species (Robershaw and Zine-Fiali, 1995).

The afternoon rectal temperature did not increase with degree of dehydration in lactating camels (Paper III), unlike the nonlactating camels studied by Schmidt-Nielsen et al., (1967). However, morning temperature was lower and therefore the difference between day and night also increased in lactating camels. During the last eight days of the 16 day dehydration treatment, morning respiratory rate was lower than during any other period of the experiment. Metabolic rate may also have decreased at this time, as has been observed in non-lactating camels during dehydration (Schmidt-Nielsen et al., 1967), since food intake had decreased.

Although they had a low morning rectal temperature, camels sought the shade (Paper III). Low morning rectal temperature and seeking shade meant that the increase in rectal temperature during the day was slowed, and at noon it was still lower in dehydrated camels than in camels watered daily. A similar behavior was observed in lactating goats kept at the same station as the camels in this study. The goats were released on pasture during daytime and sought shade in the bushes. Despite this, the goat's rectal temperature increased to 41°C in the afternoon, with only a slightly higher afternoon rectal temperature in dehydrated animals compared to those watered daily (Mengistu et al., 2007). As in the camels, the goats' temperature fell during the night. The camels in this study therefore saved water and sodium by every available mechanism (Papers II, II, and IV) and were still able to produce milk after 16 days of water deprivation.

6.5 What watering frequency is best for both welfare and milk production in camels?

This study has demonstrated that the camel's milk production is affected during severe water deprivation and that this is a gradual process. Camels are adapted to harsh environments where water and food shortages are common. This study suggests that, for high milk production, camels need to drink water often enough to maintain their blood circulation, plasma volume, and mammary blood flow. Optimization could mean the survival of a calf and generation of cash income for pastoralists and agro pastoralists in Eastern Ethiopia. It is hoped that the results of this study can be a springboard for further field studies on the best way to water camels.

Conclusions

Camels under traditional pastoral management produce more milk than other types of domestic animal reared in the same environment. This study has demonstrated a great potential for the camel as a dairy animal in its natural environment.

Camels eat enough browsing materials during wet seasons to produce more milk than with repeated watering during the dry season, without needing to be taken to a watering spot. Thus, although watering is not necessary during the wet season, camels need to be watered every four to seven days during the dry season.

During 16 days of dehydration, milk production decreased after seven days, but camels continued to produce milk for the calf and for the pastoralists.

In water-deprived camels, milk osmolality increased and was positively correlated with plasma osmolality. This confirms that milk is always iso-osmotic to the plasma. Dehydrated camels did not dilute their milk.

During dehydration, lactating camels saved water by avoiding the sun, a low respiratory rate, low rectal temperature in the morning which increased slowly during the day minimizing evaporative water loss and by mobilizing vasopressin, which retained water in the body.

Camels responded to dehydration in a similar manner to other ruminants, but it took camels 16 days to reach a degree of dehydration that occurred after only four days in goats.

Camels need to be watered before blood plasma volume decreases and mammary blood flow is disturbed.

Water deprivation may involve sodium deprivation. Therefore drinking the equivalent amount of water to the body weight loss does not necessarily mean the animal has recovered. Although salt deficiency mobilizes aldosterone, it may take much longer to replenish salt than water.

Scope for future work

Investigations on water and salt balance and effects on calf growth and productivity of camels can be an area of future interest

Severe dehydration in the lactating camels leads to a delayed recovery in sodium balance and as a consequence plasma aldosterone levels remain elevated for a long time. Further investigation on how to rehydrate camels after they are water deprived can be a priority area of future work.

Based on the outcome of this study it could be recommended that camels kept on dry food in a hot environment should be watered at least once in a week to maintain the milk quality and quantity. Further scrutinizing this recommendation under traditional pastoral management and also under hot and desert areas of eastern Ethiopia may be field of future research.

The potential of camels as dairy animal was demonstrated in this study. Camels under different management as well as controlled environmental condition are required to be evaluated and approach should also be made towards identification of breeds and types of camels which may be considered superior for camel dairying.

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