Journal of Applied Veterinary Sciences, 8 (1): 57-64 (January, 2023)
ISSN: Online: 2090-3308, Print: 1687-4072
Journal homepage : https://javs.journals.ekb.eg

Unique Physiological and Behavioural Adaptive Features of The One-Humped Camel (*Camelus dromedarius*) to Arid Environments

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ABSTRACT

The dromedary camel is mainly found in the tropics of Africa, the Middle East, and the Indian sub-content, where it is of great importance to nomadic and rural communities to provide high-quality animal protein in the form of milk and meat and as a means of transportation. In the Arabian Gulf region, the camel gained popularity and importance recently as a racing animal. The camel is well adapted to harsh environments characterized by inadequate water and vegetation, high ambient temperature, and rough terrain. Camels are working animals suited to their desert habitat and are a vital means of transport for humans and cargo, especially for rural farmers. There are three surviving species of camel. Camels originated in North America and eventually spread across Beringia to Asia. They survived in the Old World, and eventually, humans domesticated them and spread them globally. However, the literature on the physiological parameters of the camel is scanty. This review aims to provide a general overview of the physiological features of the camel and an update on the available studies of physiological and behavioural features of the camel and the effects of thermal environmental conditions on some physiological responses.

Review Article:
DOI:https://dx.doi.org/10.21608/javs.2022.168375.1184

Received :12 October, 2022.
Accepted :01 Decemer, 2022.
Published in January, 2023.

Keywords: Adaptation, Arid environmental, One-humped Camels, Physiological features.

J. Appl. Vet. Sci., 8(1): 57-64.

INTRODUCTION

One of the most significant domesticated animals in the world's arid and semi-arid regions is the dromedary (one-humped) camel (*Camelus dromedarius*) (**Yagil, 1974; Mohammed, 2010; Bernard, 2013**). It can survive in tough climate conditions compared to many other species in the same area (**Mohammed, 2008**). Camels can travel 30 km/day carrying burdens up to 200 kg to far-off locations (**Khan, 2003**). Compared to traditional motorized forms of transportation, they are more affordable for small farmers and nomads (**Khan *et al*., 2003**). Camels can withstand temperatures that would be fatal to many other animals **(Ouajd and Kamel, 2009**). They can walk for 5-7 days with little or no food and lose a quarter of their body weight without any impairment in normal functions (**Ouajd and Kamel, 2009)**.

Camels are also raised in North Africa for their milk, which is more nutritious than cow's milk. There are between 29 and 36 mg/L of vitamin C in camel milk, which is three times more than in cow milk and 1.5 times more in humans (**Khan *et al*., 2003; Montes, 2003**). They are being utilized more often to transport domestic products, firewood, and agricultural supplies. In addition to being used for racing, camels are also used for plows, wagons, and other agricultural tools (**Singh, 1992**). Understanding an animal's health status is essential for its well-being and effective management (**Barnett and Hemsworth, 1990; Hanjra, 1994; Hall *et al*., 1998; Champak *et al*., 2002**). Compared to 8 to 10% of bovine, dromedaries' relative draught power (work output) exerted was roughly 19% of live weight, and the average working speed for camels is 0.95 m/s (**Mohammed *et al*., 2007**).

It has been hypothesized that the camel's capacity to use special biochemical and biomechanical pathways enables it to perform amazing feats of endurance under harsh climatic circumstances (**Khan *et al*., 2003; Montes, 2003**). Stress, such as severe temperatures, hampered animal performance, which can also result in major physiological changes in animals **(Yousef *et al*., 1989; Kataria *et al*., 2010**). Reactive oxygen species are produced by a range of stresses experienced by livestock. These species can alter normal behavior and development, resulting in performance losses (**Nazifi *et al*., 2009**). This review aims to highlight from the literature some of the physiological adaptive mechanisms of the one-humped camel in arid environments.

Water conservation

The ability of an animal to avoid (or minimize) water loss contributes to its capacity for heat tolerance. For instance, compared to sheep (62 to 127 mL/kg/d) and goats (76-196 mL/kg/d), camels have a lower water turnover rate (38 to 76 mL/kg/d) (**Ouajd and Kamel, 2009**). The camel will adjust to hot, dry conditions by concentrating pee, producing less urine, sweating less, raising body temperature, and "storing" CO_2 and glucose in the blood (**Yagil *et al.*, 1974; Schroter *et al*., 1989; Mohammed, 2008**). When faced with high ambient temperatures and limited water supply, other big desert animals (such as sheep and goats) employ comparable coping mechanisms, but the manifestation of these mechanisms seems to be more pronounced in the camel. (**Dahlborn *et al*., 1989; Robertshaw and Zine-Filali, 1995**).

The disparity in the literature is most likely caused by variations in the research locations' environmental circumstances**. Elkhawad** (**1992**) reported that camels could go up to 14 days without water. However, **Schmidt-Nielsen** (**1997**) and **Oujad and Kamel** (**1998**) asserted that they could only go six to eight days. The highest water loss that many animals can sustain is around 10 to 12%. However, camels can withstand water loss up to 30% (**Elkhawad, 1992**). Other species, such as Australian Merinos, can similarly lose up to 30% of body weight, but it is unlikely that they would last more than one or two days in temperatures above 41 degrees Celsius with no shade, whereas a camel would endure the same conditions for 15 days (**Manefield and Tinson, 1996**).

Animals need to rehydrate after being without water for a while to survive. As it rehydrates, a camel may consume more than one-third of its body weight **(Schmidt-Nielsen, 1997) and Yagil *et al*., (1974)** recorded a water intake of 200 L in 3 minutes, and **Irwin, (2010)** reported a water intake of 110 L in 10 minutes. Rehydrating at these levels would cause overhydration and maybe death in other species. The camel can accomplish this because it can retain enormous volumes of water in its digestive tract for up to 24 hours to prevent a quick depletion of blood **(Willmer *et al*., 2006).** By producing highly osmolar urine, the camel's kidneys contribute significantly to water conservation. The kidney is distinguished by a long Henle loop and a well-developed medulla (medulla/cortical ratio is around 4/1) (**Oujad and Kamel, (2009).** In contrast to the Bedouin goat's urine concentration of 2200 mOsm and a dehydrated Bos taurus cow's maximal pee concentration of roughly 1160 mOsm, the kidney has a great capacity for water absorption and the ability to expel exceptionally concentrated urine (3200 mOsm) **(Gaughan, 2011).** The camel has a bi-phasic airflow pattern, which means that the flow rates through the nasal turbinates during inspiration and expiration are identical (**Schroter *et al*., 1989**). Additionally, the bi-phasic breathing rhythm conserves water (**Schmidt-Nielsen *et al*., 1981**)

Body temperature regulation

Animals need to improve evaporative heat loss in hot environments to maintain their body temperatures below harmful levels (**Schoter *et al*., 1989**). The body temperature of a thoroughly hydrated camel ranges from 36 to 38 ^{o}C during the day. However, when dehydrated and exposed to a hot environment, body temperature can change by 6 to 7 degrees Celsius, from about 34 to 41 degrees (**Fazil, 1977; Wilson, 1989; Schmidt-Nielsen, 1997; Ali *et al.*, 2012**). Although not to the same degree as the camel, other animals also allow their body temperatures to rise. Bos taurus cattle, for example, will experience a 2 to 4 ^{o}C difference in body temperature when exposed to hot temperatures (**Gaughan *et al*., 2010; Mader *et al*., 2010**). Because it enables significant heat to be retained during the day and released at night (via radiation) without using water, the increase in body temperature of camels subjected to high heat loads is beneficial, especially after a 2 ^{o}C fall below the typical minimum (**Schmidt-Nielsen, 1997;Grigg *et al*., 2009**).

Additionally, when body temperature rises, there is less of a temperature difference between the camel and its surroundings, which reduces the need for water (**Schmidt-Nielsen, 1997**). According to **Grigg *et al*.,** (**2009**), a 750 kg male camel can store around 3.9 kJ/kg of heat for every 1^{o}C increase in body temperature. Consequently, a drop in body temperature from 36 ^{o}C to 34 ^{o}C enables much higher heat storage. The ability to maintain a normal brain temperature is essential for life during times of intense heat. A carotid rete, found near the base of the brain in many animals, including camels, enables specific brain cooling. A network of tiny veins that drain blood from the nasal cavity come into touch with the carotid rete, a section of the carotid artery separated into many arterioles posterior to the brain. As a result of cooling the brain, the animal can withstand higher temperatures. Heat is transmitted from the warmer arterial blood to the cooler venous blood, cooled by respiratory evaporation in the nasal cavity (**Elkhawad, 1992**). The camel's breathing rate gradually increases as its body temperature rises from 35 to 41°C (about 70 to 80 breaths per minute) (**Schroter *et al*., 1989; Schmidt-Nielsen, 1997**). Contrarily, heat-stressed *Bos taurus* cattle may breathe more than 150 times per minute. Heat-stressed camels with higher respiration experienced brain cooling (compared to body temperature; brain temperature was around 1.5°C lower) (**Schroter *et al*., 1989**).

In particular, reproductive behavior and function in mammals, as well as the phasic and tonic release of hormones, oestrus, and in some cases, gonadal size, are regulated by the circadian and seasonal rhythms of the hypothalamus, specifically the suprachiasmatic nucleus (**Pando and Sassone-Corsi, 2001; Buijis *et al*., 2003**). The suprachiasmatic nucleus appears to be sensitive to variations in environmental temperature, with certain cells responding more to cold than to heat, but photoperiodic variation may also play a significant role (**Burgoon and Bailant, 2001; Marai *et al*., 2006**). The camel's core body temperature rises slightly when subjected to heat stress because they expel more heat into the environment to maintain a normal body temperature (**Al-Haidary, 2005**). The primary routes for heat loss in camels are evaporative heat loss from the skin and respiratory system. However, a prolonged water shortage may impair an animal's capacity to expel heat, which might raise body temperature and cause hyperthermia (**Al-Haidary, 2006**).

The camel lies down on the ground early in the morning before warming up and tucks both the fore and rear limbs beneath it to decrease contact with the ground. This reduces heat absorption from the soil to its body (**McKnight, 1969**). When there is no shade, camels, especially dehydrated ones, sit down facing the sun. As the earth revolves over the day, it will gradually change positions to maintain itself in line with the sun. Camels also cluster together in the heat, oriented to the sun, to reduce the area exposed to radiation (**McKnight, 1969**). The behaviour of the camel to urinate on its legs contributes to some evaporative cooling.

Circulatory System

The heart rate of a camel averages 50 beats per minute. Its blood volume is 93 ml/kg, and its blood pressure varies from 76 to 115 mmHg (**Ouajd and Kamel, 2009**). These values are greater than other domestic ruminants (**Montes, 2003**). Camel's blood is a key component of the body's defenses against heat and dryness. About 50% of leucocytes are formed up of neutrophils, whereas lymphocytes predominate in the blood of other ruminants **(Ouajd and Kamel, 2009**). However, according to **AL-Busadah** (**2007**), lymphocytes predominate among the camel's leucocytes. The erythrocytes have a large transferring surface and are ovoid-shaped, tiny, and somewhat thin. The ability to change size in response to the animal's hydration level allows the erythrocytes to continue circulating in the presence of increased blood viscosity (**Mohammed and Hussein, 1999**). The erythrocyte span of life is around 150 days in cases of dehydration, representing energy and water economy in connection to erythrocyte destruction. Changes in erythrocyte size and shape follow rapid rehydration and occur within 4 hours (**Ouajd and Kamel, 2009**). Compared to other domestic ruminants, the haemoglobin content ranges from 13 to 16 g/100 ml, which is significantly higher. The camel's hemoglobin is known to have a stronger affinity for oxygen due to an increase in the amount of charged amino acid residues on the hemoglobin, which increases the hemoglobin's hydrophilicity and resistance to osmotic dehydration (**Ouajd and Kamel, 2009, Hogin, 2000**). The camel can lose its body water without compromising its blood viscosity. The camel’s blood plays a principal role in adaptive mechanisms to high heat load and dehydration (**Ouajd and Kamel, 2009**). Blood composition and volume remain relatively constant and haemoglobin functions remain normal (**Willmer *et al*., 2006**). The erythrocytes of the camel are oval-shaped and non-nucleated, which resist osmotic variation without rupturing; these cells can swell to twice their initial volume following rehydration (**Irwin, 2010; Adah *et al*., 2016**).

When the camel is dehydrated, the erythrocytes have a longer lifespan than other animals, which is another distinctive quality. Erythrocytes from hydrated camels have a lifespan of 90 to 120 days (**Yagil., 1974; Ouajd and Kamel, 2009**). Erythrocyte life duration increased to 150 days when camels were chronically dehydrated throughout the summer (40 °C mean during the day; 20 °C at night) (**Ouajd and Kamel, 2009**). At 0.9%, 0.7%, and 0.5% NaCl concentrations, erythrocyte osmotic fragility in camels has been observed to exhibit very minimal hemolysis (**Adah *et al*., 2016**). This is because erythrocytes from camels may swell up to 240% of their usual size without bursting, but erythrocytes from other species can only swell up to 150% before hemolysis begins (**Montes, 2003**). It is clear that, camel erythrocytes are exceptionally resistant to hemolysis (**Khan *et al*., 2003**).

Gastric Digestion

Comparatively speaking to real ruminants, the pre-stomach of the camel has just three divisions (**Khan *et al*., 2003**). A highly active microflora, greater microbial digestion, and a more capable aptitude for food mixing than cattle are the causes of the considerable digestive capacity (**Selim *et al*., 1999**). The stomach and intestines absorb water relatively slowly, giving equilibration time without experiencing significant osmotic issues (**Ouajd and Kamel, 2009**). During times of water shortage, the ability for food mixing and sluggish water absorption both contribute to water saving (**Selim *et al.*, 1999**),

Lipid Metabolism

The dromedary's capacity to survive food scarcity correlates with its capacity to utilize body fat reserves during starvation and store fats during favorable conditions. The dromedary has poor ketogenesis under all conditions, and its plasma concentrations of 3-hydroxybutyrate and acetoacetate are lower than those of sheep by 33 and 4, respectively (**Chilliard *et al.*, 1998**). Hypothyroidism causes dehydrated dromedaries to have higher cholesterol levels (**Nazifi *et al.*, 1999**). Liver lipids in dehydrated dromedaries drop from 13.5% to 2.5%, showing a significant mobilization of hepatic lipids. However, triglyceride and free fatty acid contents are constant (**Nazifi *et al.*, 1999**). Phospholipids and very few triglycerides make up the lipids in the camel's hump. The hump's size prevents the accumulation and distribution of fatty tissue in other body areas, notably the distribution of fat beneath the skin, which promotes heat removal via the skin (**Yagil, 1985**).

Glucose Metabolism

The energy metabolism of camels differs significantly from that of ruminants. The dromedary has a normal glycemia of around 5 mmol/l, which is explained by its rapid rate of gluconeogenesis and extremely low insulin level (**Yagil, 1985**). When enough water is available, as is the diabetes case just after a water shortage, glucose urine clearance is accompanied by significant water losses. To limit water loss, a dehydrated camel maintains hyperglycemia and almost little glycosuria (**Yagil, 1985; Chilliard *et al.*, 1998**).

Nitrogen Metabolism

Given that the majority of the food that camels in dry regions may eat only includes a small proportion of soluble nitrogen, the dromedary's larger capacity for recycling endogenous nitrogen is advantageous (**Emmanuel, 1976)**. In contrast to ruminants, which can only recycle 10–30% of blood nitrogen, the camel can recycle up to 90% of it (**Jouany, 2000**). Camel nitrogen recycling is increased by a diet deficient in protein or dehydration (**Gihad *et al.*, 1989**). Dehydration significantly impacts urea metabolism, as does a rise in uremia (**Ouajd and Kamel, 2009**). In contrast to other animals, the dromedary has a particularly distinctive kidney anatomical structure that inhibits significant urea removal in the urine (**Mahmud *et al.*, 1984**). The kidney is distinguished by a lengthy Henle loop and a well-developed medulla (the ratio of the medulla to the cortex is around 4 to 1). (**Oujad and Kamel, 2009**). In contrast to the Bedouin goat, which has urine with a concentration of about 2200 mOsm, and a dehydrated Bos taurus cow, which has a maximum urine concentration of about 1160 mOsm, the kidney has a unique capacity for water reabsorption and an ability to eliminate very concentrated urine (3200 mOsm) (**Oujad and Kamel, 2009**).

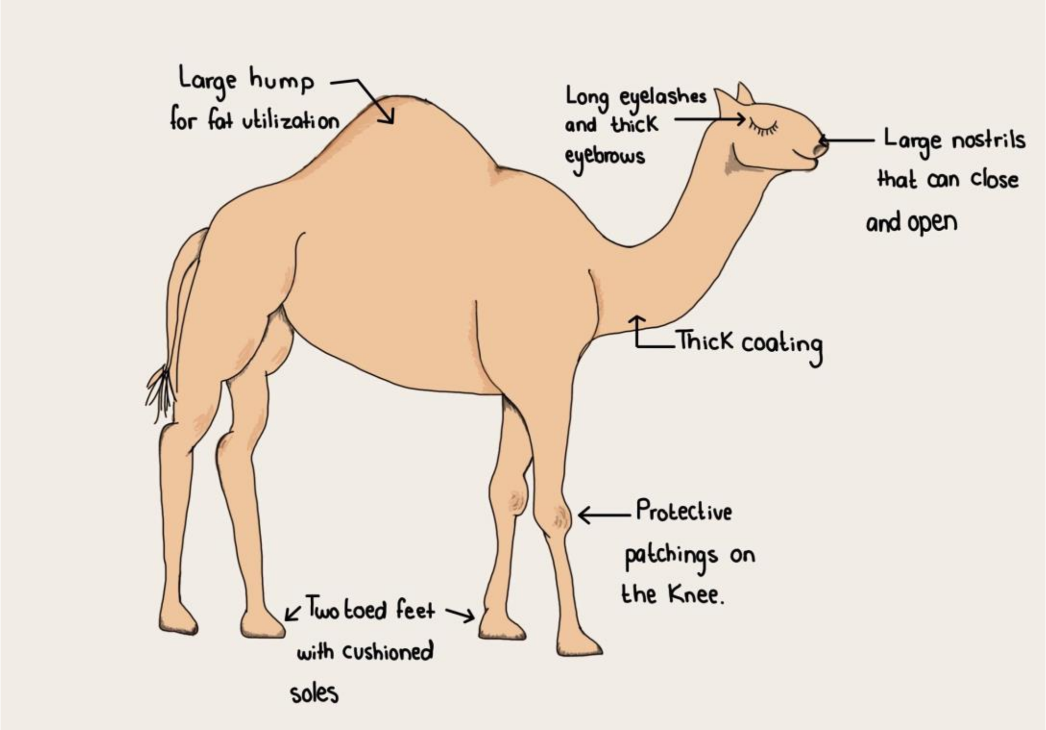
The dromedary appears to experience substantial urea production during dehydration. Dehydration appears to cause the dromedary to produce a lot of urea. The urea uses the osmotic action to draw water from other media into the plasma (**Emmanuel, 1976**). So, by restricting urea excretion in the urine, camels are particularly well suited to low-nitrogen diets. As a result, urea supplements in the diet may be harmful. The camel can withstand a low-nutrient diet better than other ruminants due to its good nitrogen recycling, slow transit, and foregut flora, which helps to improve the resources-to-production ratio (**Jouany, 2000**).

Effects of Thermal Environmental Conditions and Heat Syndrome

Heat syndrome is a range of disorders brought on by exposure to extremely high ambient temperatures. The ambient temperature, relative humidity, thermal radiation, and windspeed have all been found to have a negative impact on animal health and performance (**Bianca, 1979; Ayo *et al.*, 2008**). Temperature is the primary environmental factor influencing how domestic animals' bodies work. Camels frequently experience heat stress in the desert regions where they are most prevalent (**Vathana, 2002**). Other environmental parameters become more significant when the temperature rises over the comfortable level, including humidity, solar radiation, and wind speed (**Minka and Ayo, 2007; Ayo *et al.*, 2008**). Direct sun radiation and solar radiation reflected off clouds or the ground can significantly raise an animal's thermal burden (**Ayo *et al.*, 2008**). As long as the air temperature is lower than the skin temperature, air motions aid in heat loss by evaporation, conduction, or convection (**Minka and Ayo, 2007**). High ambient temperature activates defense and resiliency systems, including homeothermy, to restore the body's homeostasis (**Scott, 1981**). As a result, changes in body temperature, respiration rate, and heart rate have been used to evaluate how the camel reacts physiologically to environmental stress (**Finch *et al.*, 1982; Ayo *et al.*, 2002**).

When camels are exposed to high external temperatures for an extended period, the peripheral thermal receptors are stimulated, sending nerve signals that reduce hunger to the hypothalamus's appetite center. As a result, the amount of substrate available for enzymatic processes, hormone synthesis, and heat generation decreases, lowering the thermal burden (**Habbeb *et al.*, 1992**). The generation of hormone-releasing factors from the hypothalamus is suppressed by increased heat exposure (**Marai *et al.*, 2006**). The metabolic pathways become slower, severely impairing the body's ability to use protein. Due to a reduction in apparent digestibility, synthesis of volatile fatty acids, foregut pH, and electrolyte concentration in gastrointestinal fluid as well as a deficiency in energy sources, hormones, and enzymes, this occurs (**Habeeb *et al*., 2002**). Under these conditions, protein synthesis cannot counteract protein catabolism, leading to a negative nitrogen balance (**Chandrasena *et al.,* 1979; Marai *et al*., 2006**).

The production of camels may be hampered by continuous exposure to extremely high ambient temperatures, which cause many drastic changes in the animals' physiological and biological processes, including a reduction in feed intake and utilization, disturbances in the metabolism of water, protein, energy, and mineral balances, enzymatic reactions, hormonal secretions, and blood metabolites. Production and reproduction performance is harmed due to these changes (**Marai *et al*., 2006**). The neuroendocrine system, especially the hypothalamic-pituitary-adrenal system, hypothalamic-pituitary-adrenal stress (**Burgoon and Bailant, 2001; Pando and Sassone–Corsi, 2001**). Due to the release of glucocorticoids and catecholamines, the humoral response is suppressed and the cell-mediated response is inhibited (**Ayo *et al*., 1999; Speer *et al*., 2001**).



Features of the camel that aid in temperature regulation

CONCLUSION

The camel is known for its ability to withstand extreme environmental conditions associated with the world's arid regions and employs unique physiological, behavioural, and biochemical features to adapt to conditions. However, prolonged extreme high temperatures and unfavourable environmental conditions will have deleterious effects on all physiological systems of the camel and limit its ability to withstand conditions of the arid environment. Good management practices such as providing comfortable housing, good veterinary care such as antioxidant supplementation, and improved welfare practices such as providing high-quality feed and water are recommended to help camels withstand extreme environmental conditions better.

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How to cite this article:

Adakole S. Adah , Joseph O. Ayo and Deborah A. Adah, 2023. Unique Physiological and Behavioural Adaptive Features of The One-Humped Camel (*Camelus dromedarius*) to Arid Environments. Journal of Applied Veterinary Sciences, 8 (1): 57– 64.

DOI: **https://dx.doi.org/10.21608/javs.2022.168375.1184**