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Dromedary camel and its adaptation mechanisms to desert environment: A review

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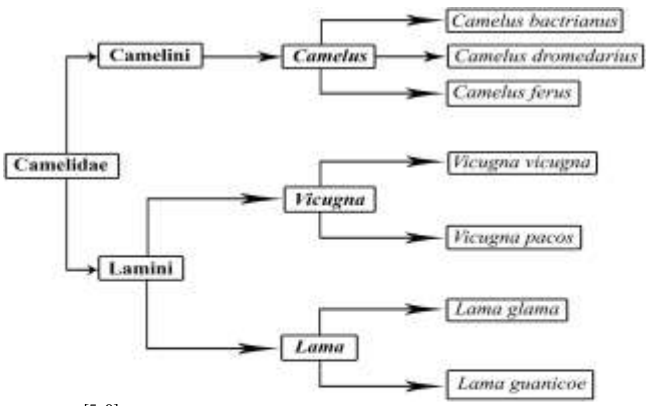
Abstract
Camel is a multi-purpose animal that is the only source of food and transport for people in arid and semiarid areas and used for centuries in different parts of the world especially in Asia and Africa. Camels including Dromedary camels are desert animals that can withstand harsh environmental conditions by different adaption mechanisms that help them to survive successfully in dry and arid climates where there is a shortage of water and high environmental temperature. For survival in the desert environment, camels have physiological, anatomical and behavioural adaptation mechanisms. Water conservation ability, the unique features of blood, thermoregulation, and efficient digestion and metabolism are among the physiological adaptations. Anatomically the nature of skin coat, eye, ear, hump, poll gland, nostril and lips, large body size and long height and large foot pads contribute to their survival. Moreover, the feeding, drinking, thermal and sexual behaviour of camels also plays a major role in succeeding in their existence in the desert environment. Despite their great contribution to the livelihood of many pastoralists in different parts of the world in which other animals face difficulties, camels are the most neglected domestic animals by the scientific community.

Keywords: adaptation, desert, dromedary camel

1. Introduction

Camel is one of the oldest animals domesticates as documented in ancient history and the name is derived from the Latin (*Camelus*) and Greek (*Kamélos*) languages [1, 2]. Camels contribute hugely to human survival in less agroecological parts of African, Asian and Arabian deserts. They have been used for transportation, as a source of food and for protection for a very long time. Nowadays, they are hugely important in many parts of the arid world as sustainable livestock species [3].

Camels are members of the Camelidae family. Camelidae probably appeared in North America around 35 million years ago during the Eocene period [4]. There are two major types; small and large camels, which are further subdivided into *Camelus*, *Lama*, and *Vicugna* genera. Even though there is no universal defined classification, the most widely accepted classification of camels is described in Figure 1 [5]. They are generally differentiated based on color, function, and habitat. Camel breeds have roughly the same shape but diverge in body conformation, size, and color [6]. Large camelids include two domestic species: *Camelus dromedarius*, the single-humped camel, and *Camelus bactrianus*, the two-humped camel. The dromedary camels are also known as Arabian camels and are most prevalent in the hot and arid region between the east of Asia to the northern part of Africa. The dromedary camel was first domesticated around five thousand or six thousand years ago in the Arabian region [7, 8].



***Source*:** [5, 9]

Fig 1: Classification of camels.

Bactrian camels are found in cold regions and deserts of central Asia. Small camelids include the llama and the alpaca which are restricted to South America. A less widely present and reported form of large camelids is the Tartary camel (*C. bactrianus ferus*) which are found in the remote areas of Mongolia and China. These wild Bactrian camels are considered the lone survivors of Old-World Camels. Their total number reported in 2012 was 730-880. This species is facing a population size reduction of at least 80% within the next 45-50 years [3, 9, 10].

Camels including the Dromedary camel, have several unique traits that enable them to

Survive and live in remote areas, high mountains and arid lands. They can withstand thirst and hunger for long periods in the most inhospitable ecological conditions since camel is anatomical, behavioral and physiologically equipped with adaptive homeostatic mechanisms enabling it to survive in a harsh environment, produce and reproduce, and to support human life in such arid zones [11, 12]. Under very hot conditions, the dromedary camel (*Camelus dromedarius*) may drink only every 8 to 10 days and lose up to 30 % of its body weight through dehydration [13].

Moreover, Genetic studies of the camel have elucidated the role of several genes that enable them to adapt to desert conditions. Importantly, several studies have uncovered the beneficial property of camel products in the treatment of various diseases [14-16]. The camel number and distribution vary from region to region. While the human population living in deserts has substantially decreased, the trend of nurturing camels in the desert is increasing at the global level. The camel population was estimated to be 27 million in 2014 according to the Food and Agriculture Organization (FAO). Interestingly, the annual growth rate of camel is higher than sheep, cattle, and horses [17, 18].

According to FAO statistics, the camel population is increasing with a yearly growth of 2.1%. The proportion of camels in the Domestic Herbivorous Biomass (DHB) was 1.1% in 1961 and this has increased to 1.5% in 2014 [19]. Previously, camels were associated with nomadic communities. However, they are now an important part of modern life in arid regions [13].

Most of the world's camel population (> 80%) is found in Africa with 60% in the Horn of Africa. Camel population was estimated at Kenya 1.3, Chad 1.6, Mauritania 1.7, Niger 1.9., Ethiopia 3.1, Sudan 4.5 and Somalia 7.1 million camels [20]. The camel population ranges from 120,000 to 998,000 in countries such as Turkmenistan, Egypt, Kazakhstan, Afghanistan, Tunisia, Oman, Saudi Arabia, Nigeria, China, Mongolia, Algeria, Eritrea, India, United Arab Emirates, Yemen, and Mali [19]. According to Faye *et al*. 2012, the growth rate of camel in different countries and listed the countries with increasing and declining growth rates. They concluded that a decline in camel growth rate is due to a reduction in arid land devoted to camel rearing and a lack of universal selection programs for choosing the best breeds [17].

Dromedary Camels have diverse roles in the livelihood of the pastoralists, including the building of assets, insurance against unexpected events, transportation of goods, food supply and income generation. Nowadays, camels also start to play an important role in the export revenue of the countries in both live animal and carcass export [5, 19, 21]. Camels are superior to all other livestock in terms of food security since they are well adapted to arid and semiarid areas, which are not suitable for crop production and less suitable for other livestock production. With continuing land degradation and a rapidly growing human population, the camel's importance is increasing [22]. Hence, this is to enlighten the cope up mechanisms of dromedary camel to desert environment for improved production and productivity.

2. Adaptations of Dromedry Camel to the Desert Environment

Dromedary camels are hardy desert animal are famous for their exceptional tolerance of heat and deprivation of water or feed in an arid climate. This is as a result of distinctive anatomical, behavioral and physiological adaptations that help them to live and survive under the hostile desert environment for long period without feed and water ([3, 22, 23].

2.1. Physiological Adaptations

The camel possesses inimitable characteristic s which enable them to survive in extreme desert conditions [9].

2.1.1. Water conservation

Desert adapted camels have evolved physiological adaptations that reduce the amount of water lost or can tolerate significant amounts of water loss [12, 24]. Where green forage is available in mild climates, the camel may go several months without drinking. During the winter and cold seasons of the year, camels can go without water for months. They do not even drink when offered water. Under very hot conditions, it may drink only every eight to ten days and lose up to 30 percent of its body weight through dehydration [25, 26].

The digestive and urinary tracts are well specialized in water conservation. Cattle lose 20 to 40 litres of fluid daily through feces, whereas camels lose only 1.3 litters. This is one of the primary methods for resisting water deprivation in the desert. Fluid is absorbed in the end part of the intestines, where the small fecal balls are produced [2, 13]. The rumen helps maintain water balance in two ways. First, the rumen of hydrated ungulates and the foregut of camels contain a large volume of water, approximately equal to 20% of body weight, and may defense ungulates against short term water deprivation. During the first few days of dehydration, fluid contained in the rumen is used to maintain the water balance of blood and body tissues and represents a large portion (50-70%) of the water lost during dehydration. Second, after dehydration in some species, the rumen plays a role in the prevention of hemolysis and osmotic tissue shock during rapid rehydration [26].

The camel's kidneys play a major role in the process of conserving water through increasing the osmolarity of urine. The kidney is characterized by a long loop of Henle, and a well-developed medulla (the ratio medulla: cortex is about 4:1) [27]. During dehydration, the kidneys reduce water losses both by decreasing the glomerular filtration rate and by increasing the tubular reabsorption of water. Anti-diuretic hormone (ADH) is important in regulating the volume of urine excreted and its concentration. ADH is produced in the hypothalamus and is released into the bloodstream in response to increased blood osmolarity. Larger release of ADH leads to a fast-renal response that causes increased reabsorption of water. This leads to a smaller volume of more concentrated urine being excreted [25, 26, 28, 29].

Table 1: Glomerular filtration rate in dromedary in comparison with sheep and goat.

Species	Glomerular filtration rate
Dromedary	0.5 – 1 ml/kg/min
Sheep	1.2 ml/kg/min
Goat	4.0 ml/kg/min

***Source*:** [29, 30].

A dehydrated camel urinates only drops of concentrated urine being shown by white stripes of salt crystals on the hind legs and tail. This concentrated urine not only serves to

conserve water, but also allows camels to drink water which is more concentrated than seawater (above 3% NaCl), and to eat salty plants (halophytes) that would otherwise be toxic. The body of camels can tolerate loss of water over 30% of body weight whereas most mammals die if they lose half of this value [31, 32].
Also, their ability to regulate their body temperature from 34.5-40.7°C conserves a lot of water, when most needed [33]. Rehydration following a period of water deprivation is important for animal survival. A camel may drink more than one-third of its body weight as it rehydrates. In terms of actual water intake, Irwin, [32] reported 110 litters in 10 minutes. In other animals, rehydration at these levels would lead to overhydration and possibly death. The camel can do this as large amounts of water can be stored for up to 24 hours in the gut to avoid a rapid dilution of the blood [34].

Table 2: Water turnover in a dromedary and other ruminants.

Species	Water turn over ml/Kg/day	% Corpora water
Dromedary Camel	38-76	72
Sheep	62-127	60
Goat	76-196	65
Zebu	63-178	65
Buffalo	108-203	66

***Source*:** [32].

2.1.2. Unique features of blood
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 [32]. The oval red blood cells in dromedary camels can easily flow quicker in a dehydrated state of the animal as compared to the round-shaped red blood cells in other mammals. These red blood cells are also enormously expansible. Because of the shorter and less saturated fatty acid chains that they identified, the dromedary red cell membranes are more fluid than those of human red cells and perhaps this explains the remarkable stretching ability in camels. The ellipsoid shape of camel erythrocytes is very stable and that the cytoskeleton differs from that of human red cells and they may expand with distilled water to 400% before they rupture [12, 35].
Another unique feature of the erythrocytes is their long-life span when the camel is dehydrated. The life span of the erythrocytes of hydrated camels is 90 to 120 days. When camels are chronically dehydrated during summer (40°C mean during the day; 20°C mean at night) the life span of erythrocytes extends to 150 days. Erythrocyte turnover is water and energy expensive. Therefore, extending the life span of erythrocytes reduces energy and water expenditure [27, 28].

2.1.3. Thermoregulation
Body temperature regulation
A fully hydrated camel has a daily body temperature range of 36 to 38°C. However, when dehydrated and exposed to high environmental heat load body temperature may fluctuate by 6 to 7°C, from approximately 34 to 41°C [2]. Other animals also allow body temperature to increase but not to the same extent. For example, *Bos Taurus* cattle will have a 2 to 4°C variation in body temperature when exposed to hot conditions [36, 37]. The increase in body temperature of camels exposed to high heat load, especially following a 2°C reduction below the normal minimum, is advantageous because it allows a considerable amount of heat to be stored during the day and dissipated at night (by radiation) without the expenditure of water [38].

Selective brain cooling
Selective brain cooling has been assumed as a mechanism for animals to maintain brain temperature below thermal critical values when body temperature increases the camel can resist intensely high body temperatures without damaging its brain [26, 39, 40]. The camel has a bi-phasic airflow pattern; the inspiratory and expiratory flow rates through the nasal turbinates are similar. The bi-phasic breathing pattern also reduces water use [2]. Camels, like most other animals, need to maintain a constant brain temperature. However, this is very difficult considering they live in an extremely hot environment. moreover, camels have a "rete mirabile", it is a complex of arteries and veins lying very close to each other which utilizes counter-current blood flow to cool the blood flowing to the brain. This helps camels to maintain a stable brain temperature, essential for survival [2, 25].
Under normal conditions (A), the cool venous blood, after having passed over the nasal cavity, travels via a general circulation. However, when temperatures increase in the body (B) the nasal and the angular veins (1 and 2) become wider while the facial vein (3) is constricted. When this situation occurs, the cool venous blood can only go in one direction through the ophthalmic veins to the cavernous sinus which then cools the arterial blood through heat exchange in the carotid artery [9, 40, 41].

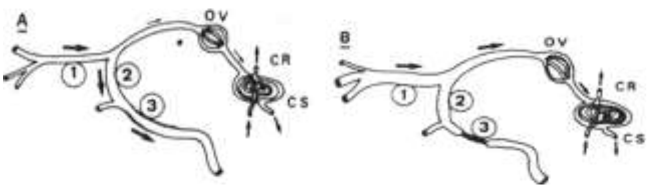


Fig 1: Superficial vein of the camel head under normal conditions (A) and hot conditions (B) [40].

2.1.4. Digestion and metabolism
Gastric digestion
The pre-stomachs of the camel are characterized by the presence of only three compartments in comparison with true ruminants. The great digestive capacity of cellulose by camels is due to a specific and differentiated motility, a very active microflora and better microbial digestion and more significant food mixing in pre-stomachs. Water is absorbed very slowly from the stomach and intestines allowing time for equilibration without severe osmotic problems [9, 12].

Lipid metabolism
The well-known capacity of the dromedary to resist thirst and lack of food is related to remarkable adaptive mechanisms, including the mobilization of the body reserves of lipids (fatty tissue) during malnutrition and the storage of fat during favourable periods [22, 23]. In dehydrated dromedaries, liver lipids decrease from 13 to 2.5%, indicating a strong mobilization of hepatic lipids. On the contrary, concentrations of triglycerides and free fatty acids remain unchanged. However; severe water deprivation during 14 days would induce lipolysis revealed by the increase in concentrations of triglycerides, free fatty acids, phospholipids and cholesterol [27].

Glaycidic metabolism

The camel's energy metabolism differs in particular from that of ruminants. The dromedary presents a normal glycemia of about5 mmol/l, a value fully similar to that of monogastric species [28, 41]. After a 10 days water deprivation, the glycemia increases from 20 to 80% without glucosuria [39, 42]. The glucose urinary elimination is accompanied by enormous water losses like in diabetes cases. Thus, a dehydrated camel reduces moisture losses by maintaining a high glycemic and practically null glucosuria. The hypo-insulinemia would allow the camel to maintain a low basal metabolism by decreasing glucose use [27].

Nitrogen metabolism

The nitrogen recycling in Camelids increases in the case of lower proteins in the diet and/or dehydration. This great aptitude of urea recycling is due to very powerful mechanisms whose effectiveness does not deteriorate in the case of dehydration [43].

2.2. Anatomical Adaptation of Camel

2.2.1. Skin and hair coat

The skin of the camel is attached tightly to the underlying tissues and has short fine hairs (Weber) which help in thermoregulation. The camels' thick coats insulate them from the intense heat radiated from desert sand and during the summer the coat becomes lighter in color, reflecting light as well as helping to avoid sunburn. The coat of the camel is fairly sparse which allows sweat to evaporate at the surface of the skin. Dromedaries have a pad of thick tissue over the sternum called the pedestal. When the animal lies down, the pedestal and other small areas of padded contact points on with the ground their legs raise the body from the hot surface and allow cooling air to pass under the body (Simenew, 2014).

2.2.2. Eye, Nostril, Ear, Pol Gland, Hump and Lips

The eyes are large and prominent enable the camel to see in different directions and for long distances and they have long eyelashes that help to protect the eyes from the sun and the blowing sand. They have also a third, clear eyelid that protects their eyes from blowing sand [12]. The slit-like closable nostril protects against blowing sand and moistens air on its way to the lungs. When camel exhales, water vapor becomes trapped in their nostrils and is reabsorbed into the body to conserve water. Split upper lip assists feed selection and easy prehension during browsing and their mouths have a thick leathery lining, allowing them to chew thorny desert plants [24].

The ear contains small hairs to filter and warm the air entered the ears in a sandy environment. The poll gland is situated towards the top back of the neck behind the ears. It is more active under the condition of heat and fatigue than that at any other time except when the male is in a rut, so it acts as a modified sweat gland to help in the evaporation [44].

Hump is rounded mass or protuberance, such as a fleshy structure on the back of the camel. The hump composed of the adipose tissue which contains white fat. It acts as food (fat) storage which will be converted to energy and water in case of starvation in the desert [12].

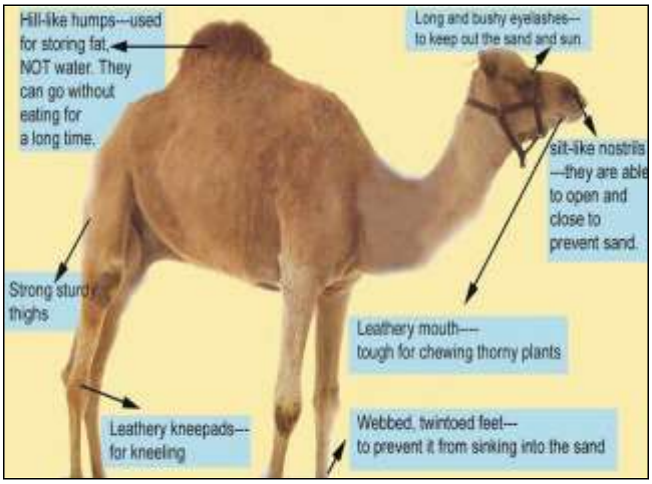
2.2.3. Large body size and height

The large size and height of the camel can be of some advantage in heat regulation. A large body mass heats up much more slowly than a smaller mass exposed to the sun. Body size is related to the metabolic rate. While their overall energy requirements are higher, large animals have lower mass-specific metabolic rates than do small animals; these low metabolic rates contribute comparatively less metabolic heat to the total thermal load [26].

The long legs and the large humps, containing adipose tissue, give camels a large skin surface to the body mass. The height above the ground is used to hold their body far from the hot sand and allows the desert winds free access to the body thus in some circumstances cooling it effectively [14]. It also enables the camels to browse high above the ground reaching 3.5 meters into the canopies of trees and bushes. This characteristic together with their preference to browse on many kinds of bushes makes them an excellent complement for multi-species herds in different kinds of rangelands, increasing the productivity of the land without really competing with other livestock [9, 41].

2.2.4. Large foot pad

Their large broad 'elastic' pads with two-finger nail-like toenails on the front are also important structures to easily walk on the desert sand which is not possible for other ungulates to walk on tips of hoof covered toes. The advantage of this broad leathery pad in camels is to disperse their weight in a wider surface area and their feet don't sink in the loose sandy soil [43].



***Source*:** [12].

Fig 2: Different anatomical adaptations in camel

2.3. Behavioral Adaptation of Camel

2.3.1. Feeding and drinking behavior camel

The camel selects only a few leaves from each plant and ingests the foliage parts. It prefers halophytes plants. It can take in a very large amount of water at one occasion for compensating previous fluid loss and it can move for a long distance in the desert to seek water [14, 27]. Camels are very versatile and opportunistic feeders, they accept a wide range of browse species that are often avoided by other species, but also some grasses. Foraging camels normally spread over a large area thus minimizing pressure on a particular area [45].

The camel has a preference for feeding at night, in the early morning or late evening or when the sky is clouded or just before and just after sunset. At very hot times camels tend to avoid feeding around midday. Under restricted herding conditions where camels are confined at night, behavior cannot be described as natural since nutritional requirements have to be met in a shortened period and rumination and rest take place for the most part during the hours of darkness. If the camel is allowed to feed at night, it settles on the ground early in the morning before the sun has warmed the ground, thus reducing heat absorption by conduction from the earth to its body [9, 35].

2.3.2. Thermal behavior of camel

The camel avoids sitting in the sun if possible, otherwise, it faces the sun and does not expose all the body. In the recumbent position, the camel raises its sternum to ensure a "plate-like" shape and this allows air circulation. Standing or sitting, the camel gradually keeps shifting its position throughout the day to keep in line with the sun, thus reducing the area subject to direct radiation. When herded in groups and allowed to rest, camels invariably cluster together if conditions are hot, which again reduces the total area subject to radiation. Sheep also adopt this strategy under hot conditions, but unlike sheep which cluster with their heads central to the unit, camels prefer to orient (as they do as individuals) to the sun and move position as the earth rotates (Muhammad, 2010).

***Source*:** [35]

Fig 2: Behavioral adaptation mechanism of dromedary camels facing the sun to reduce exposure of their body

2.3.3. Sexual behavior

The camel's reproduction is characterized by a seasonal activity that is typically timed to ensure that parturition occurs at a favourable time of year to maximize offspring survival. During the sexual seasons, the male is very aggressive and presents some characteristic signs like the extrusion of the soft palate and becomes very vocal. Occipital glands (neck glands) become active and secrete a brownish liquid during sexual activity. Copulation induced ovulation occurs in the down position over a relatively long period that is 10 to 15 minutes [45, 46].

3. Conclusion and Recommendations

Camels have an important role in the lives of human beings, especially in arid regions, due to their multipurpose role and unique ability to adapt to harsh conditions. Dromedary camels adapted to desert areas can survive and reproduce despite extreme temperatures and limited water availability using a variety of physiological, anatomical and behavioral mechanisms to either avoid or tolerate environmental conditions that can result in heat stress and dehydration. Camel production has several comparative advantages over other domestic animals within the camel's optimal environmental limits. Apart from different adaptation mechanisms for desert survival, camels are environmentally friendly animals. Therefore, new and improved methods of camel raising must be initiated that will enable man to utilize the natural ability of the camel to produce milk and meat where other animals cannot produce or produce only with difficulty. In conclusion, the proper use and protection of Dromedary camels should be adapted since they have several adaptation mechanisms that allow them to live successfully in desert conditions. Furthermore, sustaining camel health is crucial since the livelihood of most desert peoples in the world relies on camels and their products including their milk and meat. Much care should have to be given to Dromedary Camels since they have been used for transporting heavy loads of goods for a long period of time across the desert without food and water.

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