

Anatomical and physiological properties of the dromedary: A potential sustainability alternative and a vital asset in the era of climate change



Nasr Eddine Kebir^a | Naima Berber^b | Meriem Rabia Zahzeh^a

^aLaboratory of Molecular Microbiology, Proteomics and Health, Djillali Liabes University of Sidi Bel Abbes, Algeria.

^bLaboratory of Biotoxicology, Pharmacognosy, and Biological Valorization of Plants, Department of Biology University Dr. Moulay Tahar of Saida, Algeria.

Abstract The one-humped camel (*Camelus dromedarius*), commonly referred to as the Arabian camel, is primarily found in North Africa, tropical Africa, the Middle East, and the Indian subcontinent. The dromedary camel is of immense economic, social, and ecological value to nomadic and rural communities, offering high-quality animal protein through milk and meat and serving as a vital means of transportation. In some places, camels are also expected to enhance local tourism, providing much-needed financial support to the local economy. Owing to their unique qualities, camels are essential for maintaining desert ecosystems, setting them apart from other domestic livestock. The adaptations of dromedaries are tailored for survival in harsh environments with limited water and food, extreme heat, and rugged terrain. These adaptations include specialized skin, eyes, nostrils, lips, large bodies, long legs, and wide foot pads. Additionally, the biological, physiological, and biochemical traits of camels and their behavioral adaptations contribute to their resilience in desert conditions. These adaptations include water conservation, unique blood properties, thermoregulation, and efficient digestion and metabolism. Furthermore, the feeding, drinking, thermal, and reproductive behaviors of camels significantly support survival in deserts. The anatomical and physiological characteristics of the dromedary make it the ideal animal to meet the needs of users globally, especially amid climate change, where global warming, water scarcity, and scarce pastures are common. Therefore, camels are crucial for stabilizing the food supply in arid desert regions, nourishing their keepers, and serving as vital contributors to food security and sovereignty within desert ecosystems.

Keywords: dromedary camel, functional anatomy physiology, dehydration, adaptation, environment

1. Introduction

The dromedary (*Camelus dromedarius*), also called the Arabian camel or one-humped camel, was domesticated approximately 5,000 years ago (3,000 years B.C.) in the Arabian Peninsula. The term "dromedary" is derived from the late Latin word "dromedarius," which traces back to the Greek word "dromas" (δρομάς), meaning "runner" or "running." The Greek term "dromas kamelos" (δρομάς κάμηλος) translates to "running camel," specifically referring to the dromedary camel owing to its notable speed and endurance. This etymology reflects the dromedary's historical and cultural significance as a swift and reliable mode of transportation across deserts (Easton, 1897; Ali et al., 2019; Faye, 2022).

The domestication of Arabian and Bactrian camels occurred around the beginning of the third millennium BCE, approximately 5000 years after cattle and 2000 years after donkeys. This process occurred in their native regions among pastoral communities on the arid edges of early civilizations: for Arabian camels in the coastal areas of the Arabian Peninsula and Bactrian camels in southwestern Central Asia. The taming of camels was likely facilitated by

their docile nature and their utility in desert environments. Unlike other domesticated animals, in these arid regions, camel milk and wool collection began nearly simultaneously, with their use burdensome (Sala, 2017; Peters & von den Driesch, 1997).

Camels (*Camelus dromedarius*) are vital for sustaining livelihoods in lowland regions, offering multifaceted benefits to pastoralist communities. These benefits encompass asset accumulation, insurance against unforeseen events, and providing essential resources such as milk, meat, fur, and leather. Furthermore, camels serve as draft animals, undertaking tasks from transporting people to carrying loads, thereby contributing to income generation. Recently, the significance of camels has extended to international trade, where they play a key role in generating export revenue through the sale of live animals and carcasses (Ahmad et al., 2010; Faye, 2014; Faye, & Bengoumi, 2018)

Camels thrive in extensive arid and semiarid areas that are unsuitable for crop production and less suitable for other livestock. In these regions, camels outperform all other livestock terms of food security. Given the ongoing



land degradation and the rapidly growing human population, the importance of camels is increasing (Yagil, 1985; Kay & Wilson, 1991; Farah, 1996).

The camel (*Camelus dromedarius*) is remarkably adaptable to endure the extremely harsh climatic conditions of deserts, allowing it to inhabit areas where few other animals can survive. This makes them a more economical option than traditional motorized transport for small-scale farmers and nomads. Camels are capable of traveling up to 50 kilometers per day while carrying loads of up to 200 kilograms to remote areas. This species can withstand high temperatures that are typically lethal to other animals and can travel four to seven days without drinking minimal or no food, losing up to a quarter of its body weight without impairing its normal functions. These physiological and anatomical adaptations enable camels to thrive in environments characterized by scarce water and poor food resources (Oujad, & Kamel, 2009; Amsidder et al., 2021; Herbison & George, 2024).

The dromedary camel is a crucial livestock species that is particularly prevalent in arid regions. It has been selectively bred for its extraordinary ability to endure prolonged periods of thirst and hunger, making it invaluable in some of the most inhospitable environments (Kay & Wilson, 1991). The ability of camels to survive in these harsh environments, coupled with their endurance during prolonged droughts and their capacity to convert limited desert resources into milk and meat in regions where the climate negatively impacts the performance of other livestock, makes them highly important to pastoralists (Farah, 1996; Harek et al., 2022).

Camels possess unique mechanisms that enable them to withstand extended periods of water deprivation and high heat loads, especially when water is not readily available, and to survive on scarce or low-quality feed resources. These adaptations include homeostatic mechanisms that allow them to survive, produce, and reproduce in harsh desert environments characterized by seasonal water shortages, high ambient temperatures, and other environmental stresses (Gebreyohanes & Assen, 2017; Harek et al., 2022).

Dromedary camels thrive in environments characterized by low-nutrient pastoral resources and arid ecosystems. They face extreme heat and solar radiation during the day and relatively cold nights in their desert habitats (Schwartz et al., 1992). This species's remarkable adaptation highlights the traits necessary for survival in scorching regions. Owing to arid conditions, the plants consumed by camels are primarily xerophytes, which have small, wax-covered, often spiny leaves rich in lignin. To process such vegetation, specialized chewing, salivation, and swallowing mechanisms have been developed for camels. These adaptations include tough, mobile lips and a unique tongue capable of picking small leaves from desert plants (Schwartz et al., 1992; Gebreyohanes & Assen, 2017; Almansour et al., 2024).

The dromedary oral cavity is lined with compound keratinized epithelium covering loose, dense fibrous connective tissue. Their cheeks are lined with thick papillae, and they possess sharp teeth, a muscular esophagus, and efficient salivary glands. These anatomical features enable camels to consume xerophytes, which require substantial amounts of saliva for lubrication, and grasses that other animals in the same arid environments cannot eat (Almansour et al., 2024).

Camels also exhibit physiological adaptations such as low water turnover rates, fluid shifts between compartments to maintain plasma volume, reduced urine and saliva production, increased concentrations of urine and saliva, a reduced metabolic rate, selective brain cooling, and heterothermy. These mechanisms are crucial for their survival in harsh desert conditions (Schmidt-Nielsen, 1997; Jessen, 2001).

Camels possess a sophisticated salivary gland system comprising three pairs of major salivary glands and several minor ones. Adult camels can produce up to 150 liter of saliva daily, which is significantly greater than that of other ruminants, such as cattle (≥ 100 liters) and sheep (≥ 10 liters) (Al Razaiki et al., 2023). In a dehydrated camel, there is a significant reduction in all digestive secretions, particularly salivary secretion, which can decrease to 16 liters per day (Oujad, & Kamel, 2009).

Camel saliva is crucial for moistening and swallowing ingested food, maintaining oral hygiene, regulating the gastrointestinal tract, assisting in digestion, and supporting overall body water homeostasis. Furthermore, the saliva of camels is capable of buffering the stomach because of its high bicarbonate content (Al Razaiki et al., 2023; Almansour et al., 2024).

In addition, camel saliva is rich in electrolytes, proteins, and enzymes that provide antimicrobial and antifungal properties, thereby protecting the digestive system from harmful pathogens. These enzymatic activities also increase the utilization of a diet that is typically dry, low in nutritional value and contains poorly absorbable components, which is characteristic of desert conditions (Almansour et al., 2024).

2. Classification of Family Camelidae

To provide a clearer understanding of the organism in question, a simplified classification is presented to differentiate it from other species within the Camelidae family. The Camelidae family is divided into two main subfamilies: Camelinae (Old World Camelids) and Laminae (New World Camelids). Old World camelids include two domesticated species: the one-humped dromedary camel (*Camelus dromedarius*) and the two-humped Bactrian camel (*Camelus bactrianus*). These species are considered large camelids and are found in different regions globally. The dromedary camel primarily inhabits the hot climates of the Middle East and Africa, whereas the Bactrian camel is native to the colder regions of Central Asia and China (Kadwell et al. 2001; Wheeler, 2012; 2001; Hoter et al., 2019).

New World camelids consist of four main species located in South America, commonly referred to as small camelids. Two of these species, the llama (*Lama glama*) and the alpaca (*Vicugna pacos*), have been domesticated, whereas the other two, the guanaco (*Lama guanicoe*) and

the vicuña (*Vicugna vicugna*), remain wild. . A diagrammatic classification and geographical map of the camelidae family members shown in Figure 1. (Kadwell et al., 2001; Wheeler, 2012; Hoter et al., 2019).

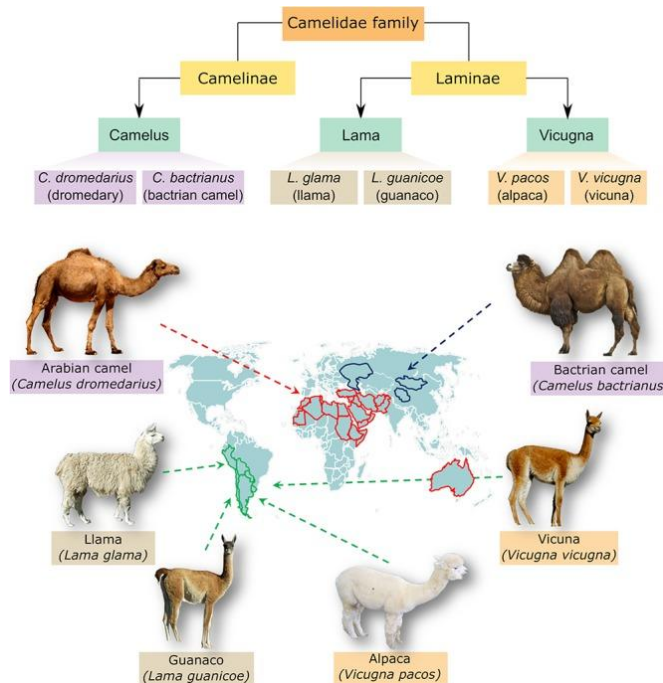


Figure 1 Classification and distribution of camel species. The upper panel demonstrates the genera and species belonging to Camelidae family. These include three genera, Camelus, Lama, and Vicugna, which comprise include large camel species such as Arabian camels (one humped camel) and Bactrian camels (two humped camels), as well as small camelids such as llama, alpaca, guanaco and vicuña. Camelus ferus, which is a double humped wild Bactrian camel, is not shown for simplicity. The lower panel shows a visual distribution map of different species within the Camelidae family.

3. Functional Physiological and Anatomical Adaptations

3.1. Functional anatomical adaptations

The remarkable anatomical and physiological adaptations of the dromedary camel have enabled it to thrive in extremely harsh climates. The head and neck region of camels possesses several unique features that are crucial for their survival in arid environments. The elongated neck of camel not only aids in reaching vegetation that is otherwise inaccessible but also helps in dissipating heat, an essential function in the extreme temperatures of desert habitats. The head is characterized by a narrow, elongated structure that minimizes exposure to the sun, whereas large, expressive eyes with long eyelashes protect against sand and intense sunlight. Nostrils can close to keep out blowing sand, and the lips are tough and prehensile, adapted to browsing thorny plants typical of their environment (Figure 2) (Bornstein & Younan, 2013; Adakole et al., 2023).

Furthermore, camels have a specialized oral anatomy that includes thick, leathery tongues and robust teeth adapted to chew rough, fibrous plant material. The internal structure of the mouth, with a keratinized epithelium and prominent papillae, facilitates the processing of such coarse

vegetation. These anatomical adaptations are complemented by physiological mechanisms such as the ability to conserve water and regulate body temperature effectively (Bornstein, 1990; Allouch, 2016).

The camel brain region has evolved to support its remarkable adaptability to harsh desert environments. One of the key features is the presence of an efficient thermoregulation system within the brain, which helps camels manage the extreme temperatures of their habitats. This system includes a mirabile rete, a complex network of blood vessels that cools the blood before it reaches the brain, thus protecting it from overheating (Bouâouda et al., 2014).

Moreover, the camel brain is adapted to regulate body functions under stress, such as dehydration. The hypothalamus plays a crucial role in maintaining water and electrolyte balance, enabling the camel to withstand prolonged periods without water. Additionally, the pituitary gland in camels is highly responsive to osmotic pressure changes and secretes hormones such as vasopressin to conserve water (Ali et al., 2023).



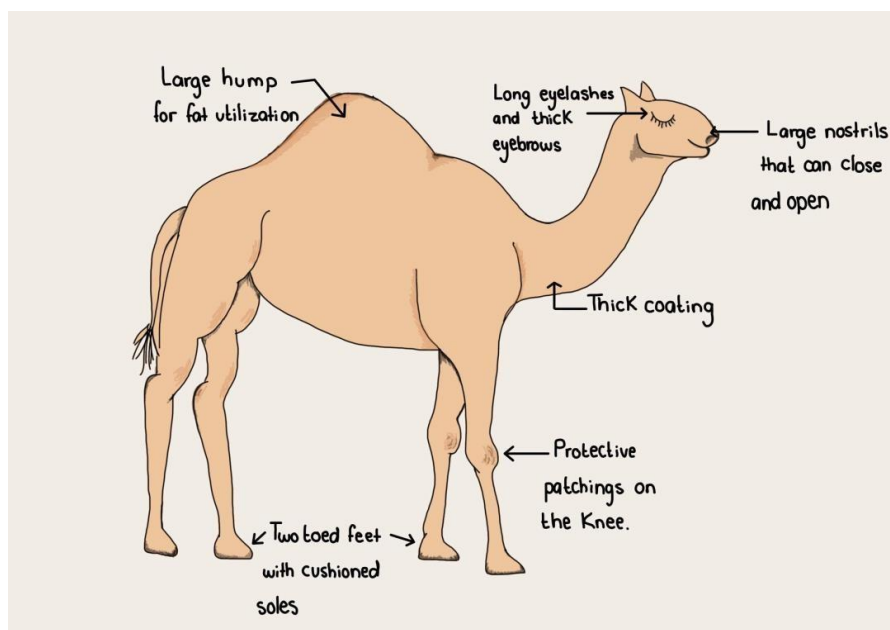


Figure 2 Features of the camel that aid in temperature regulation.

The dromedary camel (*Camelus dromedarius*) has a distinctive upper lip divided into two mobile parts by a fissure that is continuous with the lateral nose wing. The lower lip is more pointed and features an apparent chin. Both lips are covered with hairy skin and tactile hairs. Anatomically, the lips consist of three zones: cutaneous, transitional, and mucosal. The cutaneous zone has an outer epidermis and deeper dermis embedded with sweat and sebaceous glands, along with tactile hair roots. The transitional area lacks sweat glands and hair roots and is covered by thin skin. The mucosal zone includes the mucosa, submucosa, and muscularis, where the mucosa has a compound squamous epithelium; the submucosa contains connective tissue rich in blood vessels and labial glands; and the muscularis is composed of skeletal muscle fibers (Fath El-Bab et al., 2017; Almansour et al., 2024).

The one-humped camel has a mobile, elongated tongue approximately 40 cm long and is attached to the hyoid bone, consisting mainly of obliquely arranged skeletal muscle fibers. The tongue is covered by filiform, fungiform, and circumvallate papillae. The tongue is highly innervated with numerous ganglia and nerve fibers, and the surface of the tongue is covered with cornified compound squamous epithelium. The lingual lamina propria is narrow and continuous with the muscular mucosa of the submucosa. The dorsal epithelium has filiform, fungiform, and circumvallate papillae, with thick connective tissue bundles along the ventral surface. Filiform papillae, conical in shape, are scattered mainly on the dorsum and lateral edges, whereas fungiform papillae and taste pores are observed on the anterior surface. Circumvallate papillae are restricted to the posterior portion of the tongue (Mohamed et al., 2018; Almansour et al., 2024).

Another significant aspect is the camel's enhanced olfactory system, which is vital for locating water sources and recognizing other camels. The olfactory bulbs camels

are well developed, indicating a reliance on smell for survival in the desert (Bornstein & Younan, 2013; Li et al., 2018).

The thoracic region of the camel, encompassing the heart, lungs, and sternum, exhibits several unique adaptations that support its survival in extreme desert conditions. The camel's heart is robust, with a strong muscular structure that enables efficient blood circulation even during dehydration. Its lungs are highly efficient, facilitating effective gas exchange in hot and arid environments. The sternum is elongated and robust, providing structural support and protection to vital organs within the thoracic cavity Schmidt-Nielsen, 1997; Alsafy et al., 2023).

Camels exhibit several unique adaptations to cope with the extreme heat of desert environments. The thick coats provide insulation against the intense heat radiated from desert sand. During summer, the coat becomes lighter in color, which reflects sunlight and helps prevent sunburn (Gebreyohanes & Assen, 2017). Additionally, camels have a specialized structure called the pedestal, a pad of thick tissue over the sternum. When lying down, this pedestal, along with other padded contact points, elevates the body above the hot ground, allowing cooling air to circulate underneath (Fesseha, & Desta, 2020).

The camel coat, which is more hairy than wooly, creates a buffer zone that insulates the body from the surrounding environment. Coat thickness changes through growth and shedding to adapt to different seasonal conditions (Gebreyohanes & Assen, 2017). Unlike heavily furred animals, camels sweat directly from the skin surface rather than from the tips of their hair. This direct skin evaporation draws latent heat of vaporization directly from the skin, cooling the body more efficiently and conserving energy (Bouâouda et al., 2014; Abdalla, 2020; Alvira-Iraizoz et al., 2021).

The musculoskeletal system of the camel is adapted to withstand long journeys across harsh terrains. The feet are broad and padded, reducing the risk of sinking into the sand and providing stability. The knee joints are particularly strong, allowing the camel to kneel and rise easily, an essential function for loading and unloading cargo. The back is arched and sturdy and capable of bearing heavy loads for extended periods, whereas the hump stores fat, which can be metabolized into water and energy during times of scarcity (Yagil, 1985).

In their abdominal region, camels lack a gallbladder and cystic duct, which aids in the efficient digestion of coarse desert vegetation. Their kidneys are highly specialized, are able to concentrate urine to conserve water, and they can endure significant dehydration without impairing kidney function. (Bornstein & Younan, 2013). The absence of a gall bladder reduces the risk of gallstones, which can be detrimental in environments where water and medical care are limited (Schmidt-Nielsen, 1997).

Camels have a unique adaptation in their abdominal region, lacking a gall bladder and cystic duct, aiding in the efficient digestion of coarse desert vegetation. This absence also minimizes the risk of gallstones, which can be particularly harmful in environments with limited water and medical resources (Schmidt-Nielsen, 1997). Additionally, camels excrete liver-metabolized toxins directly into the duodenum without storage, further increasing their survival under harsh conditions (Longo-Hammouda & Mouats, 2008; Ahmed & Abdalla, 2018; Ali et al., 2020; Boukerrou, et al., 2023).

The heart of a mature dromedary camel features a unique osseous structure known as the os cordis, along with

cartilaginous elements called cartilago cordis. Typically, the camel's heart contains a single, large, and elongated bone embedded within the heart wall, providing attachment and support for the cardiac muscles. The amount of calcified cartilage and the development of these bony structures in the camel heart increase with age, indicating an adaptation to the mechanical stress and high pressure exerted in the atrioventricular plane and aortic ring during systole. Notably, among all mammals, camels have the largest atrioventricular node, measuring approximately mm (Balah et al., 2014; Soliman, 2015; El-Gendy et al., 2023).

The stomach of a camel is specifically adapted to its diet and challenging living conditions, comprising three compartments instead of the four found in true ruminants. The largest compartment, the rumen (C1), has a substantial capacity for holding ingested food and features a unique lining with both glandular and nonglandular regions (Lechner-Doll et al., 2014). The Reticulum (C2), which is smaller and closely linked to the rumen, is lined with a honeycomb-like structure that assists in fermenting ingested plant material and facilitates the regurgitation process for chewing. It also helps in sorting larger particles from smaller ones, sending the larger particles back to the rumen for further fermentation (Kutzler & Wood, 2006). The third compartment, the omasum (C3), is elongated and similar to the true stomach of monogastric animals, playing a crucial role in the absorption of water and nutrients and the digestion of proteins. Its mucosal lining has numerous folds that significantly increase the surface area for absorption (Allouch, 2016; Qureshi et al., 2020).

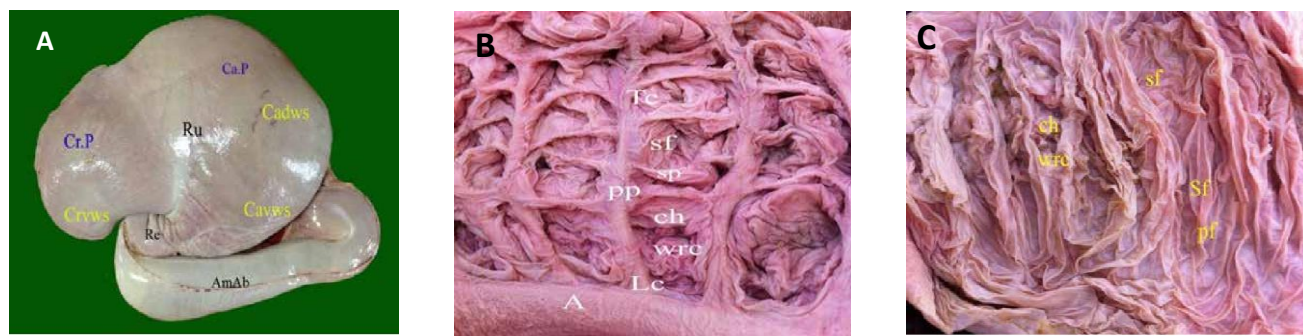


Figure 3 A: Left view of the camel stomach showing 3 compartments and the water sac. B: Internal view of the camel stomach showing the cranioventral water sac (Crws). C: Internal view of the camel stomach showing the sac of the caudodorsal water.

4. Physiological Adaptations

The camel possesses inimitable characteristics that enable it to survive in extreme desert conditions.

5. Water Conservation Mechanisms

In extreme heat, camels may drink only every eight to ten days and can lose up to 30% of their body weight due to dehydration, which is fatal for other farm animals and humans (Gaughan, 2011). Unlike cattle, which lose 20 to 40 liters of fluid daily through excrement, camels lose only 1.3

liters. The digestive tract and kidneys of camels are critical for resisting water scarcity (Gaughan, 2011). The rumen, which holds approximately 20% of the body weight in water, helps maintain the water balance during short-term deprivation. During dehydration, fluids from the rumen support blood and tissue water balance, accounting for 50–70% of the water lost. Upon rehydration, the rumen



prevents hemolysis and osmotic shock (Bekele et al., 2013; Akinmoladun et al., 2019; Fesseha, & Desta, 2020; Kandeel, et al., 2022).

The camel stomach and intestines absorb water slowly, allowing equilibration without significant osmotic issues. This slow absorption rate is beneficial during water scarcity, as it aids in water conservation. Additionally, camels have efficient lipid metabolism, which is crucial for survival during food shortages. Making food thoroughly and slowly absorb water helps camels maintain hydration and nutrient balance under harsh conditions (Lechner-Doll et al., 1995; Franklin, 2011; Bekele et al., 2013; Dittmann et al., 2015).

Camel kidneys are exceptionally designed for water conservation and electrolyte balance, particularly sodium and chloride ions, which are vital for hydration in desert environments without affecting renal function (Bornstein & Younan, 2013). The renal cortex and medulla are highly specialized and contain many nephrons, notably long-looped Henle nephrons, which are much longer than those found in cattle. These long loops are essential for concentrating urine and reducing its volume. Furthermore, the medullary pyramids possess a well-developed high-concentration gradient, and the renal papillae extend deeply into the renal pelvis, enhancing water reabsorption. This adaptation allows camels to efficiently reduce water loss and excrete urea even with limited water intake (Yagil, 1985). It also enables them to consume saltwater, which is more concentrated than seawater (above 3% NaCl), and to feed on salty, toxic plants known as halophytes (Laudadio et al., 2009; Franklin, 2011; Fesseha, & Desta, 2020).

A dehydrated camel's urine is so concentrated that it leaves white salt crystal stripes on its hind legs and tail. Camels exhibit a lower water turnover rate (38 to 76 mL/kg/day) than do sheep (62 to 127 mL/kg/day) and goats (76 to 196 mL/kg/day) (Oujad, & Kamel, 2009; Fesseha, & Desta, 2020).

Camels possess unique physiological traits that enable them to endure extreme environmental stressors. Moreover, camels can tolerate salt levels that are up to eight times greater than those of other closely related mammals without experiencing hypertension. Under such conditions, there is typically a reduced binding affinity for oxygen molecules due to the stress of dehydration and high temperatures. Notably, camel hemoglobin is more hydrophilic and contains more charged amino acid residues than the hemoglobin of other mammals, which aids in maintaining oxygen transport even under extreme dehydration (Ali & Vijayan, 2022).

6. Distinctive Characteristics of the Blood

The erythrocytes of camels are oval-shaped and nonnucleated, enabling them to resist osmotic variations without rupturing. These cells can expand to twice their original volume upon rehydration, a unique adaptation that allows camels to endure dehydration and then quickly rehydrate without damage (Ali et al., 2019). Compared with

round red blood cells, the oval shape of camel erythrocytes also facilitates quicker blood flow in a dehydrated state in mammals. This adaptability is attributed to the fluidity of the red cell membranes, which is greater due to the shorter and less saturated fatty acid chains in camel cells (Pesen, et al., 2023). The ellipsoid shape of erythrocytes is notably stable, allowing them to expand significantly before rupturing, which is advantageous in harsh desert environments. 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 involves water and is energy-intensive. Therefore, extending the life span of erythrocytes reduces energy and water expenditure (Oujad, & Kamel, 2009; Gaughan, 2011).

The circulatory system of camels is highly adapted to their desert habitat. The average heart rate is 50 beats per minute, and the blood volume is 93 ml/kg, with a blood pressure ranging from 76 to 115 mmHg, which is higher than that of other domestic ruminants (Alsafy et al., 2023).

These physiological parameters help camels maintain blood fluidity and circulation even when dehydrated. The hemoglobin content in camel blood is between 13 and 16 g/100 ml, which is higher than that in other domestic ruminants, and it has a stronger affinity for oxygen. This is due to increased charged amino acid residues in hemoglobin, increasing its hydrophilicity and resistance to osmotic dehydration (Elkhawad, 1992). The ability of camel erythrocytes to change in size in response to hydration levels allows them to maintain circulation despite increased blood viscosity during dehydration (Auer & Windberger, 2015; Kizhina et al., 2020).

7. Thermoregulation

Two essential mechanisms are implicated in heat tolerance: adaptive heterothermy and selective brain cooling.

A fully hydrated camel has a diurnal body temperature range of 36 to 38°C. However, when dehydrated and exposed to high environmental heat loads, the body temperature may fluctuate from approximately 34°C to 41°C. Other animals also allow their body temperature to increase but not to the same extent. Camels exhibit numerous physiological and behavioral traits that enable them to withstand the extreme heat of desert environments. One such adaptation is "adaptive heterothermy," a mechanism allowing camels to vary their body temperature between 34°C and 42°C (approximately 70 to 80 breaths per minute). This fluctuation helps minimize sweating and prevents water loss through evaporation. Other animals also allow their body temperature to increase but not to the same extent. Furthermore, camels tend to gather together to cool, leveraging their lower body temperatures relative to the surrounding air. When lying down, the sternum of a camel assumes a "plate-shaped" conformation, enhancing air

circulation and cooling. (Bouâouda et al., 2014; Kizhina et al., 2020).

8. Adaptive Body Temperature Regulation

Camels utilize adaptive heterothermy to manage their body temperature effectively. This technique limits perspiration, with sweating occurring only when the body temperature reaches 42°C. In hydrated camels, daily temperature fluctuations are minor, at approximately 2°C. However, in dehydrated camels, the temperature can vary as much as 7°C to further reduce water loss through evaporation. This mechanism allows camels to store approximately 2,900 kcal of heat, which is equivalent to saving 5 liter of water (McKinley, 2016; Oujad, & Kamel, 2009).

9. Thermal Storage and Dissipation

Camels' ability to increase their body temperature in response to high heat loads, particularly following a 2°C reduction below the normal minimum, is beneficial. This capacity enables substantial heat storage during the day and its dissipation at night via radiation without expending water. As the body temperature increases, the temperature gradient between the camel and the environment decreases, further conserving water. The stored heat for a 750 kg male camel, for each 1°C increase in body temperature, is approximately 3.9 kJ/kg. Thus, reducing body temperature from 36°C to 34°C significantly enhances heat storage capacity (Macfarlane et al., 1963; Elkhawad, 1992; Gebreyohanes & Assen, 2017).

10. Camel Brain-Specific Cooling

Camels possess a specialized brain cooling system that protects their brains during extreme heat. This system allows camels to survive temperatures that would otherwise be lethal for their sensitive brains. Many animals, including camels, have a carotid rete located at the base of the brain, enabling selective brain cooling. This network of tiny veins, which drain blood from the nasal cavity, contacts the carotid artery—an area of the carotid artery divided into small blood vessels near the brain. This arrangement facilitates heat transfer from warmer arterial blood to cooler venous blood, which has been cooled by respiratory evaporation in the nasal passages. As a result, the blood entering the brain is approximately 3.98°C cooler than the core body temperature, a critical adaptation for brain protection during high heat loads (Elkhawad, 1992; Schmidt-Nielsen, 1997; Strauss et al., 2017; Hong et al., 2022).

Under normal conditions, cool venous blood from the nasal cavity travels via the general circulation. However, when body temperatures rise, the nasal and angular veins expand while the facial vein constricts. This causes cool venous blood to flow through the ophthalmic veins to the cavernous sinus, where it cools the arterial blood through heat exchange in the carotid artery. This mechanism ensures that the brain remains protected from excessive

heat, thereby supporting the ability of camels to function in extremely desert climates (Windberger et al., 2018; Mota-Rojas et al., 2021).

11. Digestion and Metabolism

11.1. Digestive processes and metabolic functions

Camels exhibit a highly efficient digestive process, allowing them to thrive on the limited and often tough vegetation available in desert environments. Unlike true ruminants, camels have a stomach with only three compartments, which contributes to their distinctive digestive efficiency. They prefer halophyte plants and selectively consume foliage, which is efficiently processed owing to their unique anatomical and physiological adaptations (Kay & Wilson, 1991; Ali et al., 2020; Li et al., 2024).

The digestive efficiency of camels is enhanced by their unique anatomical structure, which includes a larger glandular area that secretes mucus, aiding in effective food digestion. This distinctive feature enables better microbial activity and food mixing, leading to superior cellulose digestion compared with that of other ruminants. The presence of highly active microflora in the prestomach further facilitates this process (Li et al., 2024).

11.2. Glucidic metabolism

Compared with other ruminants, camels (*Camelus dromedarius*) exhibit unique energy metabolism. The camel normally maintains a blood glucose level of approximately 5 mmol/L, akin to that of monogastric species. Remarkably, after 10 days of water deprivation, the camel's blood glucose can increase by 20% to 80% without causing glucosuria. This adaptation helps prevent significant water loss through the urine, which is critical for survival in arid conditions. The ability of camels to maintain high blood glucose levels without glucosuria during dehydration is facilitated by hypoinsulinemia, which reduces glucose utilization and helps maintain a low basal metabolic rate (Mohamed, 2008; Oujad, & Kamel, 2009).

11.3. Lipid metabolism

During periods of severe water deprivation lasting up to 14 days, the dromedary camel exhibits remarkable adaptive mechanisms that enable survival during prolonged thirst and food scarcity. (Abdel-Rahman et al., 2020)

One key mechanism is lipolysis, as evidenced by elevated levels of triglycerides, free fatty acids, phospholipids, and cholesterol. This process is essential for energy production and maintaining physiological functions under extreme dehydration. Notably, during dehydration, the lipid content in the liver of dromedaries decreases significantly from 13% to 2.5%, indicating substantial mobilization of hepatic lipids. Despite this mobilization, the levels of triglycerides and free fatty acids generally remain stable (Yagil, 1985; Asadi et al., 2009; Ali et al., 2020; Fesseha, & Desta, 2020).

11.4. Nitrogen metabolism

Nitrogen metabolism in camels is highly efficient, particularly under conditions of low dietary protein intake and dehydration. Camels have an exceptional ability to recycle urea, which is critical for conserving nitrogen and water. This recycling mechanism remains effective even

12. Conclusion

The Arabian camel, or dromedary, has long been esteemed for its utility in desert transportation and its provision of leather, wool, meat, and milk. Despite enduring persistent droughts, food shortages, and extreme temperatures, these animals can reproduce and function normally without any physiological impairment, highlighting their importance from both scientific and economic viewpoints.

The ability of dromedaries to thrive in harsh desert environments is a test of their extraordinary biological and physiological adaptations. These adaptations allow camels to maintain reproductive efficiency and performance, unlike other species that struggle under similar conditions. Camels excel at conserving water, tolerating water loss of up to 30% of their body weight, and can go without water for more than ten days without a decrease in appetite. They can also modulate their body temperature to conserve energy, and their feet are specially adapted for desert terrain. These unique characteristics make camels ideal candidates for addressing the challenges posed by climate change, meteorological disruptions, and economic instability,

Ethical Considerations

This review emphasizes the significant role of dromedaries in enhancing food security and supporting local economies in areas at risk from climate change. Their distinctive anatomical and physiological features, like water retention

Conflicts of Interest

The authors declare no conflicts of interest.

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during dehydration, allowing camels to adapt to environments where water and protein sources are scarce. The effectiveness of these mechanisms ensures that camels can maintain their nitrogen balance and avoid the detrimental effects of protein deficiency (Faye & Bengoumi, 2018; Faye, 2022).

especially in impoverished and disadvantaged regions where water and resources are scarce.

Understanding the unique anatomical and physiological features of camels is vital for researchers and breeders to maximize these benefits, providing crucial socioeconomic solutions. Additionally, camels are environmentally friendly, and innovative breeding methods should be developed to increase their ability to produce milk and meat in environments where other animals cannot thrive. As a result, camels have emerged as a symbol of resilience and hope for sustainable breeding in a rapidly changing world, where global warming affects everyone. In the face of escalating climate challenges, the dromedary's enduring capabilities offer a beacon of stability and promise, underscoring its indispensable role in fostering sustainable development and economic resilience across the globe.

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and temperature regulation, make them vital for survival in extreme environments. The review also highlights the ethical necessity of using dromedaries sustainably, acknowledging their crucial role in adapting to climate challenges and promoting community welfare.

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